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IMPROVED METHODS FOR THE PRODUCTION OF TITANIUM ALLOY EXTRUSIONS

JOHN J. CHRISTIANA

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METALLURGICAL PROCESSING BRANCH
MANUFACTURING TECHNOLOGY DIVISION
A.F. MATERIALS LABORATORY
RESEARCH & TECHNOLOGY DIVISION
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, (OHIO)

RTD TR 63-7-556

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John J. Christiana

Republic Aviation Corporation
Manufacturing Research

Contract: AF33(600)34098
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Metallurgical Processing Branch
Manufacturing Technology Division
A. F. Materials Laboratory
Research & Technology Division
United States Air Force
Wright-Patterson Air Force Base, Ohio

ABSTRACT - SUMMARY
Final Technical Engineering Report

IMPROVED METHODS FOR THE PRODUCTION OF TITANIUM ALLOY EXTRUSIONS

John J. Christiana

Republic Aviation Corporation

A process has been developed to produce long, thin aircraft structural shapes in high-strength titanium alloys by a combination of hot extrusion and warm drawing.

A variety of structural shapes such as angles, channels, zees, hats and tees were extruded in the following titanium alloys: Ti-155A, MS 821, Ti-7Al-4Mo, Ti-4Al-3Mo-1V, and Ti-6Al-4V.

Extrusion of 1/16 inch cross sectional thickness shapes of 20 ft. length can be accomplished by the utilization of split ceramic coated dies and a composite glass-wool/granular-glass die pad. A ceramic coating thickness of .010"-.020" is recommended on the entrance and land of the die to act as a thermal barrier and prevent die wash. Split Peerless A tungster steel dies are reusable but must be recoated with ceramic after each extrusion. The billets were preheated to 1800°F in an argon atmosphere with protection glass on the billet surface during heating. The temperature of the tooling was 900°F for the die, 900°F for the container, and 400°F for the dummy block.

The straightening process developed consists of a combination of stretch and punch straightening. The extrusions were resistance heated to 1100°F with current passing directly through the jaws, stretch straightened 3% and punch straightened to remove bow while still warm.

Warm drawing of the extrusion can be successfully accomplished by preheating the lengths to 1050°F in an electric furnace and drawing at 24 feet per minute. Warm drawing is employed to improve dimensional tolerances and surface finish. In addition, warm drawing can be employed to produce thin shapes beyond the present limits of the extrusion process (1/16 inch) by reducing the thickness in successive draw reductions of approximately 10% per pass. Drawn tee shapes in cross section thicknesses of .090", .080", .075", .063" and .040" were produced. Split tungsten carbide draw dies, shimmed to accommodate the various draw sizes, have proven to be an economical and attractive method for drawing the thin shapes. Positive gripping of the extrusion points was accomplished with Hufford Universal jaw grips. The lubricant system developed consists of a Granodraw T conversion coating, lime dip coat, Alpha Molykote 196X overcoat, and Fiske 604 grease applied at the die.

Typical structural "T" shapes for the RB-70 weapons system were produced in Ti-6Al-4V to prove the process. A workable process was demonstrated to produce RB-70 shape 64E15 by extruding to 3/32 inch and warm drawing in two passes to 0.080 inches. It was proved feasible to produce 0.043" "T" shapes by extruding to 1/16" and warm drawing in five passes to 0.043". However, a high degree of material loss was experienced and present technology cannot be considered suitable for a production process for 0.043" shapes

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FOREWORD

This Final Technical Engineering Report covers the work performed under Contract AF33(600)34098 from 1 January 1957 to 31 October 1963. The manuscript was released by the author on 29 November 1963 for publication as a RTD Technical Report

This Contract with Republic Aviation Corporation, Farmingdale, Long Island, New York, was initiated under the Research & Technology Division Project 7-556, "Improved Methods for the Production of Titanium Alloy Extrusions." It was administered under the direction of Mr. T. S. Felker, Metallurgical Processing Branch (MATB), Manufacturing Technology Division, AF Materials Laboratory, Research and Technology Division, Wright-Patterson Air Force Base, Ohio.

This report, identified as RAC 2571, was prepared by Mr. J. J. Christiana of the Manufacturing Research Department of Republic Aviation Corporation who was the project engineer. Former project engineers of this program were Mr. M. Levine and Mr. G. Pfanner. The work performed at the various companies was under the direction of the following personnel:

Babcock and Wilcox - Mr. J. Barrett
Titanium Metals Corporation - Mr. H. Palmer
Allegheny Ludlum Steel Corporation - Mr. E. Emmerich
Battelle Memorial Institute - Mr. A. Sabroff
United States Steel Corporation - Mr. D. McBride
H. M. Harper Company - Mr. J. Stevenson
Comptoir Industrial D'Etirage & Profilage DeMetaux - Mr. R. Hubert

The primary objective of the Air Force Manufacturing Methods Program is to develop on a timely basis manufacturing processes, techniques and equipment for use in economical production of USAF materials and components. This program encompasses the following technical areas:

Rolled Sheets, Forgings, Extrusions, Castings, Fiber and Powder Metallurgy Component Fabrication, Joining, Forming, Materials Removal
Fuels, Lubricants, Ceramics, Graphites, Non-metallic Structural Materials Solid State Devices, Passive Devices, Thermionic Devices.

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional Manufacturing Methods development required on this or other subjects will be appreciated.

* * * * * * * * * * * * * * * * *

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER

Melvin E. Fields

MELVIN E. FIELDS, Colonel, USAF
Chief, Manufacturing Technology Division
AF Materials Laboratory

ACKNOWLEDGEMENT

The development program was conducted by Republic Aviation's Manufacturing Research Department personnel under the supervision of R. W. Hussa, Assistant Chief Manufacturing Research Engineer.

The following are especially acknowledged for their major contributions to the program:

T. Felker,	Research and Technology Division, WPAFB
G. Pfanner,	Republic Aviation Corporation
D. Edgecomb,	Babcock and Wilcox Company
E. Bohanek,	Titanium Metals Corporation of America

Mr. Bohanek wrote certain sections of this report dealing with warm drawing. Many others have made significant contributions in technical suggestions and report preparation. Although it is impossible to include all, the efforts of the following are recognized.

Republic Aviation

M. Levine
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U. S. Steel

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H. M. Harper

E. Harness

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J. Rice

Battelle

T. Byrer

Cefilac

J. Buffet

The patience of Miss Jane Hunter in typing this voluminous report is particularly appreciated.

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I - INTRODUCTION

Present military aircraft designs normally utilize large percentages of extruded sections. The reasons for the extensive use of extrusions are:

1. The extrusion process is the most practical and economical method for producing the many structural shapes required by the airframe industry.
2. The extrusion process permits design flexibility unequaled by other methods of working a metal.

The ultimate objective of this program was to create usable titanium extrusions in common sections for use by the aircraft designer for random structural application. To further define this objective, the extrusions had to have small gage straightness and twist tolerances. In addition, they had to have the proper thickness ratio to prevent any weight penalties. They also had to make maximum use of the material and contain no inherent defects due to the conversion process. The attainment of the ultimate objective dictated a research and development program of a rather large scope.

The development program was originally scheduled in five parts to produce titanium alloy structural shapes in three size categories. The extrusion development for the first and second category shapes (Figures 1 and 2) was completed in Parts II and III of the program. The double tee shape (Figure 3) originally selected for extrusion development in Part IV, was replaced with thinner tee shapes (Figure 4) which were produced by a combination of extrusion and subsequent drawing. Such thinner shapes represented design requirements in advanced airframe structures. The scope of the program was further increased by the addition of Parts V to produce a typical RB-70 titanium alloy shape and Part VI to develop heat treatment procedures for full length titanium alloy extrusions. Part VI was subsequently deleted. The program parts are listed below as originally scheduled and as revised.

Original Program	Revised Program
Part I Determination of Shapes and Materials	
Part II Extrusion of First Category Shapes (Fig. 1)	
Part III Extrusion of Second Category Shapes (Fig. 2)	
Deleted Part IV Extrusion of Third Category Shape (Fig. 3)	Part IV Extrusion and Drawing of Third Category Shapes (Figure 4)
Part V Final Report	Part V Extrusion and Drawing of Typical RB-70 Shape (Fig. 5)
	Deleted Part VI Heat Treatment Development

II - CONCLUSIONS

A. Product

1. A workable process was demonstrated to produce a typical RB-70 titanium "T" shape (64E15) by a combination of extrusion and warm drawing processes.

In the final extrusion trial, eight of the eight nominal 3/32" thickness 64E15 extrusions were considered suitable for warm drawing, indicating a development of satisfactory die design, billet heating practices, lubrication and straightening techniques for the extruded lengths.

In the Part V warm drawing trials, eight of eight extrusions were successfully drawn two passes to 0. 080 in. thickness in 20 foot lengths, indicating a development of satisfactory die design, lubrication and drawing practices, straightening techniques, and anneal and heat treat cycles for the drawn lengths. The eight 20 foot lengths consisted of six extrusions from the final extrusion trail and two extrusions that were drawn earlier.

2. It was found feasible to produce 0. 043 in. titanium "T" shapes by extruding to nominal 0. 065 in. thickness and warm drawing in five passes to 0. 043 in. (RB-70 shape 64E12 modified). However, a high degree of material loss was experienced and present technology cannot be considered suitable for a production process. The longest drawn finished length was approximately 15 feet.

3. Tolerances of ± 0. 005 in. of nominal size on thickness dimensions was demonstrated to be within the capability of the developed process for both 0. 080 in. and 0. 043 in. "T" shapes.

4. Edge machining was demonstrated as being a feasible method of finishing the edges of the "T" to finished print tolerances of ± 0. 005 in. The alternative of warm drawing the edges produces severe metal losses due to column failure.

5. Aircraft requirements for straightness tolerances was demonstrated to be within the capability of the developed process for both 0. 080 in. and 0. 043 in. "T" shapes. The straightness requirements were 0. 010 in. per foot straightness; 1/2° per foot, 3° max. twist; and ± 1/2° angle.

6. The process did not meet the target surface finish goal of 100 u in. RMS for the 0. 043 in. shapes. The average surface finish for these shapes was 115 u in RMS. The failure to meet the 100 u in RMS surface finish can be traced to longitudinal striations in the extruded shape caused by pickup on the extrusion die. This appears to be the major problem area in titanium extrusion of thin shapes. Scoring due to die wash and/or coating failure and laminations due to improper flow were eliminated.

Surface finish requirements were met for the 0. 080 in. shapes which had an average surface finish of 80 u in. RMS.

7. It was demonstrated that the process produced extrusions which met aircraft requirements for minimum mechanical properties and internal microstructure after solution treatment and aging. The minimum room temperature tensile property requirements for the Ti-6Al-4V alloy "T" shape were 160.0 ksi ultimate, 150.0 ksi yield (0.2% offset) and 6.0% elongation (2 inches). The minimum elevated temperature tensile properties were 110.0 ksi ultimate and 90.0 ksi yield (0.2% offset). (700°F)

B. Extrusion

1. Billet Preparation

a. Smooth polished billet surfaces are necessary to eliminate billet surface markings being carried into the extruded surface. Forged billet material results in an extrusion surface with less oxygen contamination than cast billet material.

b. A slightly tapered billet nose configuration assists in obtaining smooth flow.

c. Sprayed glass coatings for billet protection during heating are more adherent than dip coatings.

d. Sprayed protective glass coatings must be applied on a warm billet and predried to obtain maximum protection.

e. Billet heat soak time should be kept to a minimum to avoid deterioration of the billet coating. The billet should be kept at temperature only long enough to insure sufficient heat soak and avoid a sticker. For the 4" diameter billets in this program, 1 hour at 1800°F proved to be optimum.

2. Die Design

a. Modified flat face dies were superior to conical shaped dies in obtaining good metal and glass flow. The conical dies did not retain sufficient glass at the die face for proper lubrication throughout 20 foot lengths. Modified flat face dies with 20° entry angles and 1/4" land were employed with good results on this program.

b. Peerless A tungsten steel dies were satisfactory for extruding 1/8" and larger shapes. The high tungsten steel dies proved superior to other steels evaluated on this program.

c. For extrusion of 1/16" shapes, ceramic coated, segmented dies are required. A minimum coating thickness of .010" is necessary. Meticulous care must be maintained in the application of the coating to insure an adherent coating. The ceramic must be applied by spraying perpendicular to the surface. A finish machining operation is required on the ceramic to obtain accurate orifice dimensions.

d. The tooling arrangement utilizing a tapered seal between the conical die holder and container is an attractive technique of locking segmented dies together in compression without the necessity of shrink fitting the die segments in the die holder.

3. Lubrication

a. A relatively high viscosity die glass improves die fill at the start of extrusion.

b. Glass in fiber form has more favorable melting characteristics than granular glass for providing lubrication at the start of extrusion. Provision of an orifice in glass wool pads is required to prevent stickers resulting from glass blockage of the die orifice.

c. Granular die pad glasses give better die fill and surface finish when used in the -30 + 100 mesh size range than in the -325 mesh range.

d. Hot tooling is required to obtain good lubrication practice.

C. Straightening

1. Effective straightening can be realized by a combination of stretch straightening 3% at 1100°F and punch straightening to remove bow and camber while the shape is still warm (over 300°F).

2. The decrease in shape dimensions with extrusion elongation is sufficient to necessitate increasing the die orifice dimensions to anticipate the decrease.

3. Air operated collets with diamond shaped teeth of 1/16" pitch nitrided .015" to Rc 67 are suitable to securely hold the extrusions without slippage.

4. Use of insulated jaws as electrodes assures uniform electrical contact, produces a straightened extrusion near the grips and saves at least 1 foot of cropping per extrusion by avoiding local hot spots from clamping the electrodes.

D. Warm Drawing

1. Pointing and Lubrication

a. The pointing procedure of grinding the fillet radii and chem milling the points was satisfactory for pointing 0.080" shapes. Improved techniques should be developed for pointing 0.040" shapes.

b. The lubricant system of Granodraw T conversion coat, lime dip coat, Molykote 196X overcoat and Fiske 604 performed best of the lubricants investigated during this program.

2. Die Design

a. Split dies are attractive for warm drawing in that one set of dies can accommodate a complete drawing reduction and in addition can be used for several dimensional sizes of a specific configuration.

b. Tungsten carbide dies are suitable for warm drawing titanium shapes. No wear or wash of the dies resulted during the course of the program.

c. The tungsten carbide blocks must be tightly wedged in the die case. A small amount of movement of the blocks will result in cracking of the die blocks.

d. The dies must be preheated to prevent heat checking of the carbide blocks.

3. Gripping

a. Jaw teeth must be nitrided to high hardnesses (Rc 67) to avoid gross deformation of the teeth.

b. A diamond pattern of 1/16" pitch is more efficient than 1/8" pitch in gripping into the titanium surface.

c. Gripper jaws with individually operated air cylinders for each jaw insert were not satisfactory in gripping and holding the extrusion throughout the draw cycle.

d. The Hufford Universal Gripper Jaw which is an air operated wedge shaped chuck was successfully employed to grip the shapes.

4. Heating

a. Induction heating was found unsuitable for heating the extrusions prior to warm drawing. Further development would be required to make this technique attractive.

b. The practice of resistance heating the extrusions to temperature and placing in a holding furnace was found to be entirely satisfactory for heating the thin shapes prior to warm drawing.

III - PROCESS DEVELOPMENT

A. PHASE I - DETERMINATION OF SHAPES AND MATERIALS

1. Survey of Airframe Manufacturers

a Agenda

The survey included Boeing Airplane Company, Seattle, Washington; North American Aviation, Incorporated, Inglewood, California; Douglas Aircraft Company, Santa Monica, California; Northrop Aircraft, Incorporated, Hawthorne, California; Lockheed Aircraft Corporation, Burbank, California; Convair, Div. of General Dynamics Corporation, San Diego, California; Change-Vought Aircraft, Incorporated, Dallas, Texas; McDonnell Aircraft Corporation, St. Louis, Missouri; and Republic Aviation Corporation, Farmingdale, New York

All meetings were conducted according to an agenda that was sent in advance of the visit. This lead time enabled the interested groups to review and prepare drawings and reports for the conference. The agenda covered is shown below:

1) Operational Specifications

Determination of the environmental requirements of extruded elements such as temperature, duty service at temperature and strengths.

2) Alloy Recommendations

Determination of applicability of available titanium alloys to the aircraft industry's use in the extruded form (the heat treatable alloys as well as the non-heat treatable alloys were under consideration in the study).

3) Shapes and Size

Selection of six sections for evaluation; three sections to be of a configuration capable of being confined in a 1 1/2" circle, two sections to be confined in a 1 1/2"-3" circle, and one section to be confined in a 3"-4" circle.

4) Tolerance and Finish

Tolerance and finish were discussed not only from the standpoint of what was desirable, but also the maximum values that were acceptable without excess in-plant processing.

5) Evaluation Program

Determination of type and scope of tests required to satisfy conformance to operational specifications.

b Summary of Airframe Manufacturers' Requirements

The airframe manufacturers requirements are summarized below:

(1) Target mechanical properties
Room temperature U. T. S. 180,000 psi
800°F stability at 70,000 psi load for 500 hours
Creep 0.5% max. after exposure at 800°F stability conditions

(2) The dimensional tolerances shall be equal to the present aluminum extrusion tolerances

(3) Surface finish shall be 125 RMS maximum and entirely free from oxygen contamination

(4) Most useful shapes are angles, tees and channels in lengths of 20 feet.

2. Alloy Survey

After receiving the requirements and recommendations of the airframe manufacturers as to mechanical properties needed in the titanium extrusions, a survey of the metal producers was made to determine if these properties were obtainable using alloys that were presently available for release in billet and large diameter round form. Discussion was limited to those alloys that were sufficiently tested and evaluated in the wrought form for room and elevated temperature properties to provide a datum line for comparison with extruded properties. This accumulated data also served to establish the capabilities of the alloy and thereby eliminate alloy development work which is beyond the scope and cost estimates of the extrusion program.

Titanium Metals Corporation of America, Rem-Cru Titanium Incorporated, Malloy-Sharon Titanium Corporation and Republic Steel Corporation research laboratories were visited and the alloy selection problem discussed with their alloy designers and research staffs. The data is summarized below:

a. Titanium Metals Corporation of America, Henderson, Nevada

TMCA recommended Ti 155A as an alloy that could be heat treated for properties similar to the requirements. Nominal composition 5% Al, 1.2% Mo, 1.4% Cr, 1.4% Fe and beta transus 1830 ±15°F.

b. Rem-Cru Titanium, Incorporated, Midland, Pennsylvania

After reviewing the room temperature and elevated temperature requirements, the Rem-Cru staff proposed the use of C-135A Mo with a nominal composition of 7.0% Al - 4.0% Mo.

c. Mallory-Sharon Titanium Corporation, Niles, Ohio

The Mallory-Sharon alloy that appears best suited for this program is MS821 containing 8% Al, 2% Cb, 1% Ta with a beta transus temperature of 1920°F. This alloy has been developed for weldability and is age hardenable.

d. Republic Steel Corporation, Massillon, Ohio

RS 140 is a Republic Steel titanium alloy with properties very similar to those outlined by the airframe manufacturers. Nominal composition 5% Al, 2.75% Cr, 1.25% Fe.

3. Selection of Shapes and Sizes

Since no titanium extrusion existed that even remotely correlated to available aluminum extrusions, and the immediate prospects of one becoming available were not good, no airframe manufacturer had any specific needs. Rather, the needs were for very special extruded shapes for special applications where the use of titanium is almost mandatory. It was not the intention of this program to create such a specialized product, but rather produce something of almost universal usefulness. Upon thorough study of the designers problems, certain conclusions were reached, however, and these conclusions were sufficient to establish the product shape criteria. Using the basic design factors such as optimum thickness ratios, common sections, general size requirements, etc., as the basis for decision, the following conclusions were reached:

a Sections inscribed within a 1 1/2" circle can tolerate a maximum gage thickness of .094" and a lesser thickness of .065" is desirable for many applications. Sections of this size are most usable in lengths 10-15'.

b Sections inscribed in a 3" circle can tolerate a maximum gage thickness of .125" and a lesser thickness of .100" is desirable for many applications. Sections of this size are most usable in lengths of 15-18'.

c Sections inscribed in a 4 1/2" circle can tolerate a maximum gage thickness of .200" and a lesser thickness of .180" is desirable for many applications. Sections of this size are most usable in lengths of 20'-25'.

d In general, the smaller the section size the more simple the section. The converse is not universally true since many large simple shapes are required, but the more complex sections occur in the large sizes. Based on the above conclusions, it was recommended that the sections shown in Figures 1-4 be extruded during Parts II, III, and IV of the program.

4. Selection of Alloys

The alloys selected were:

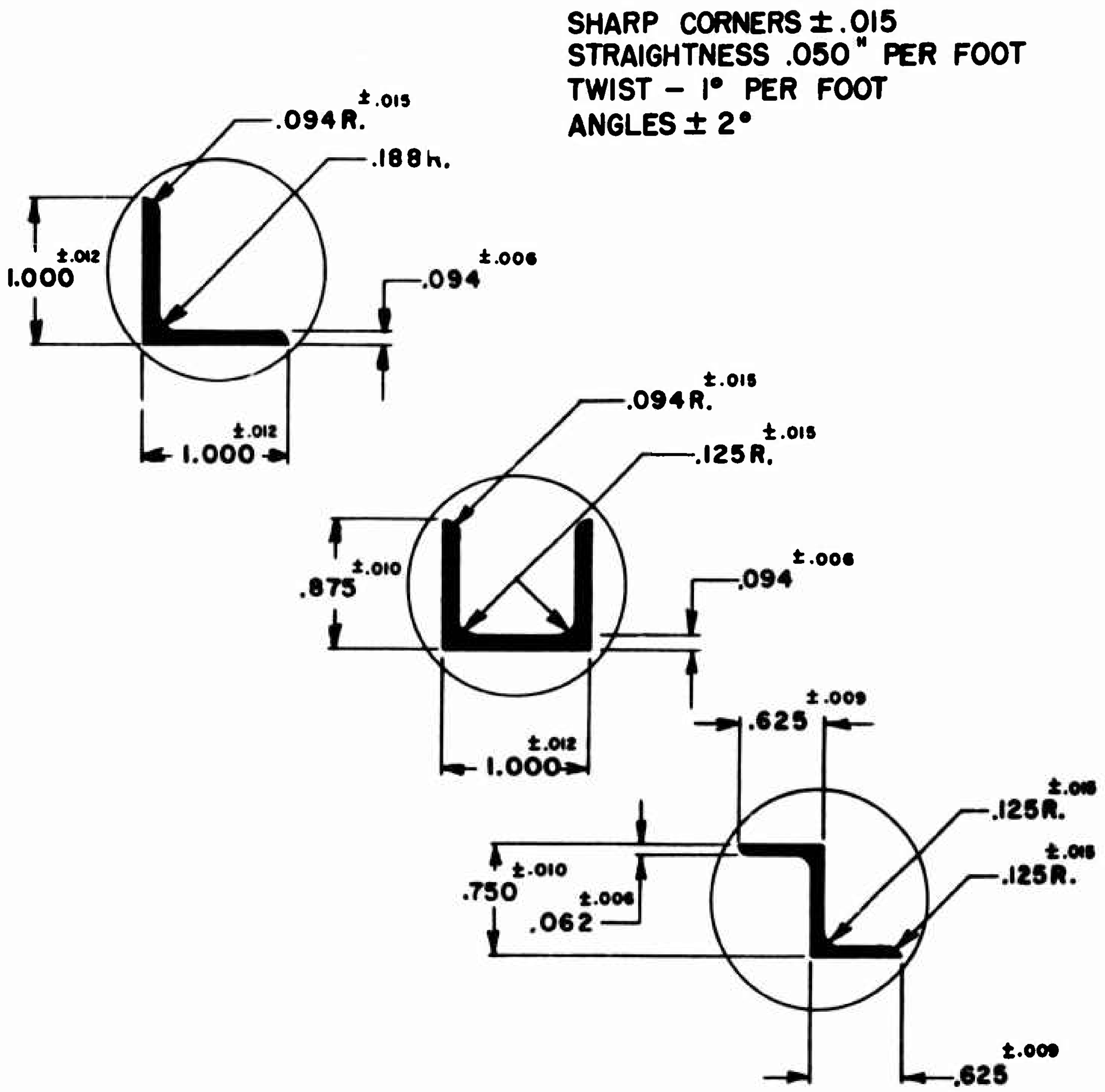
1.	C-135A Mo	7% Al-4% Mo.
2.	MS-821	8% Al - 2% Cb - 1% Ta
3.	Ti-155A	5% Al - 1.4% Fe - 1.4% Cr. - 1.2% Mo

5. Selection of Extruders

Per the contractual statement of work, three extruders were required for Part II of the contract.

The following extruders were selected as sub-contractors to produce the indicated sections and alloys:

Extruder	Section	Alloys
Babcock and Wilcox	Angle	C-135 A Mo and MS 821
U. S. Steel	Channel	Ti 155A and C-135A Mo
H. M. Harper	Zee	MS 821 and Ti-155A

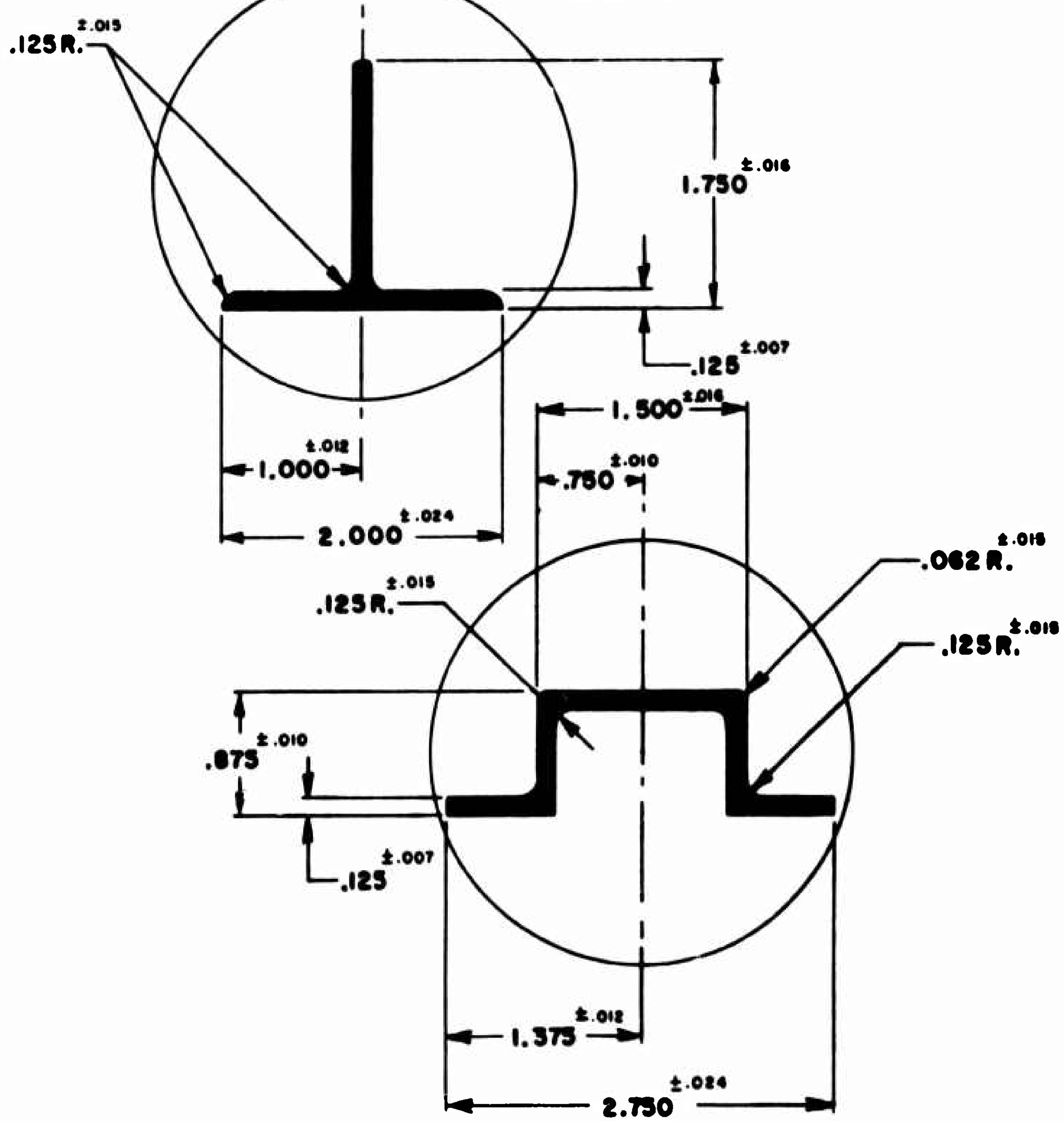


SHARP CORNERS ±.015
STRAIGHTNESS .050" PER FOOT
TWIST - 1° PER FOOT
ANGLES ± 2°

SHAPES SELECTED FOR EXTRUSION METHOD DEVELOPMENT
PART II

FIGURE 1

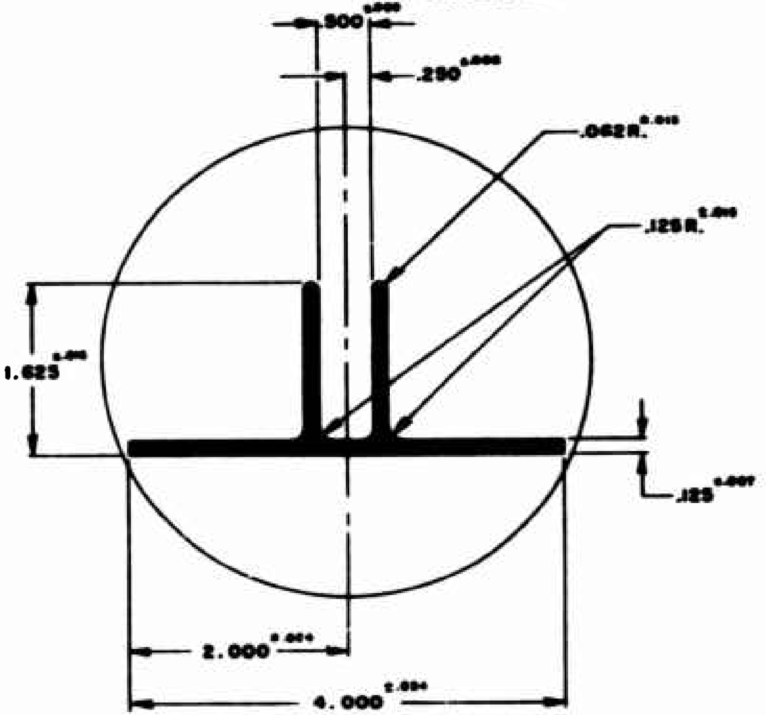
SHARP CORNERS .015 RAD. MAX.
STRAIGHTNESS .0125" PER FOOT
TWIST 1/2° PER FOOT, MAX. 5°
ANGLES ± 2°



SHAPES SELECTED FOR EXTRUSION
METHOD DEVELOPMENT
PART III

FIGURE 2

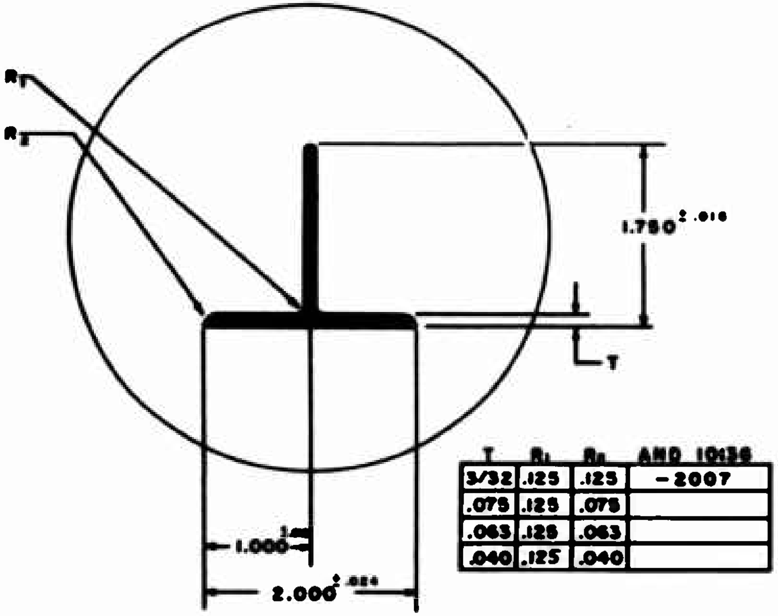
SHARP CORNERS ± .015
STRAIGHTNESS .0125" PER FOOT
TWIST 1/4° PER FOOT, MAX. 3°
ANGLES ± 2°



SHAPE SELECTED FOR EXTRUSION METHOD DEVELOPMENT PART IV

FIGURE 3

SHARP CORNERS .005 RAD. MAX.
STRAIGHTNESS 0.0063" PER FOOT
TWIST 1/4° PER FOOT, MAX. 2 1/2°
ANGLES ±1°



T	R_1	R_2	AND 10136
3/32	.125	.125	-2007
.075	.125	.075	
.063	.125	.063	
.040	.125	.040	

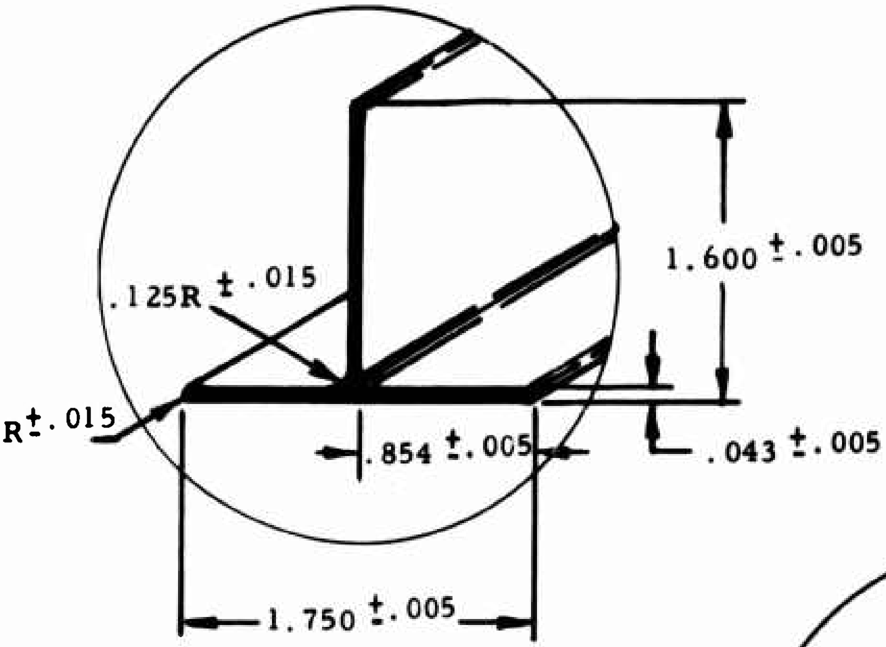
SHAPE SELECTED FOR EXTRUSION METHOD DEVELOPMENT PART IV (REVISED)

FIGURE 4

STRAIGHTNESS .010" PER FOOT

TWIST 1/2° PER FOOT, MAX. 3°

ANGLES ± 1/2°



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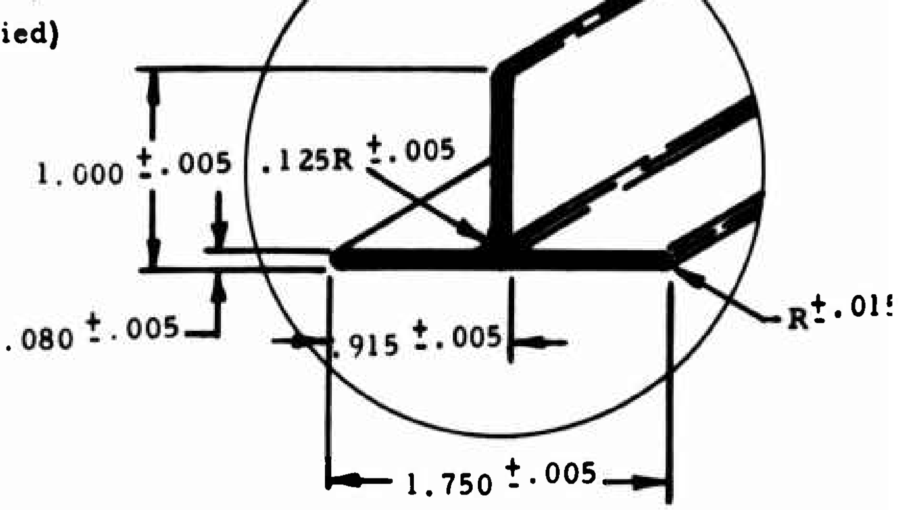

NAA NO. 64E15

SHAPES SELECTED FOR FABRICATION AS TYPICAL
RB-70 AIRCRAFT TITANIUM ALLOY EXTRUSIONS

PART V

FIGURE 5

B. PART II - EXTRUSION OF FIRST CATEGORY SHAPES

1. Extrusion, Straightening and Heat Treat Development at Babcock and Wilcox Company.

a) Extrusion Development

The extrusion program consisted of eight trials conducted on eight different occasions. The work performed on each date was designated as a separate test group.

1) Extrusion Facilities

The extrusion press is a 2500 ton Loewy-Hydropress capable of operating at the fast extrusion speeds necessary in steel and titanium extrusion. The extrusion press was equipped with a 4 3/16" container and 4 1/16" diameter hardened steel stem for all the extrusion trials. The 180,000 psi stress limitation in the steel stem required that the press extrusion force be limited to about 1,000 tons.

2) Extrusion Trials

Extrusion trials were performed on both of the titanium alloys involved, namely, C135 AMo and MS 821. The extrusion trials can be divided roughly into three categories: (1) Extrusion of Round Bars, (2) Extrusion of Angles using a Drilled Billet, and (3) Extrusion of Angles using a Solid Billet. The results of seventy-six (76) extrusions, forty-five (45) of C135 AMo alloy, eighteen (18) of MS 821 alloy and thirteen (13) of AISI 4340, are summarized below. The extrusion data is listed in the Appendix. The extruded product from test group #2 is shown in Figure 6.

1. All titanium alloy billets were heated in an electric furnace with an argon atmosphere. The billets were coated with a glass frit before they were charged to the furnace. This method was used to obtain a uniformly heated billet with a scale-free surface.

2. Both glass lubricants and grease and graphite lubricants were investigated. Glass lubrication resulted in better surfaces and die life. The major problem with grease and graphite was maintaining sufficient lubrication over the full length of the extrusion. Fine mesh glass gave a better surface to the extrusion, but was more prone to die orifice plugging than regular mesh glass.

3. Two die designs were tried. First, a special die and mandrel were used in conjunction with a drilled billet to produce three angles in one extrusion (See Figure 7). The other die design (Figure 8) was a multi-hole die, again used to produce three angles simultaneously. These die designs were used to lower the extrusion ratio from that encountered with a single port die. The extrusion ratio for the die and mandrel was 22:1 and for the multi-hole die was 25:1. The multi-hole die appeared

to be more promising because of three shortcomings of the die and mandrel practice. These were (1) complications in manufacture of toolage; (2) loss in extrusion yield because of drilled billets; and (3) failure of the billet surface during the collapse of the billet to conform to the mandrel shape prior to extrusion. Flat dies with 20° inlet angle produced better results than dies with 30° inlet angles.

4. Shell cast dies of two standard die steels, a chromium-nickel steel and a 12% tungsten hot work steel were employed. The 12% tungsten hot work steel gave evidence of better die life and improved extruded surfaces than the chromium-nickel die steel. The dies were heat treated to Rc 40-46.

5. Both scalping and full lubrication* extrusion techniques were examined. To avoid division of effort between two different practices, it was decided to thoroughly explore the scalping techniques during this phase of the program.

6. It was established that the temperature of the tooling was critical. For the scalping method, a container preheated to 400°F was better than a hot (1000°F) container. The colder container chills the billet skin and retards flow which is essential for the scalping method. Hot (800° - 1000°F) dies and die holders are advantageous for glass extrusion since the hot die will fuze the glass and minimize die clogging.

b) Straightening Development

Straightening trials were conducted in a 150 ton Loewy hydropress stretcher and detwister. This press had 40" head travel for stretching and could straighten 40 foot lengths. The press was normally used for the straightening of heavy shapes. Limiting the machine tension to the low pressures required for the small angle extrusions was difficult, although in most cases the limiting tension was determined by the slip of the gripping jaws.

The current for resistance heating was supplied by a tube welding transformer. The voltage setting used for each extrusion was determined by the length of extrusion between the electrodes. The voltage settings were selected to maintain the desired temperature (approximately 1100°F) with continuous current, although it was occasionally necessary to shut the current off momentarily to prevent overheating.

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* Full lubrication is the standard method of extrusion whereby the lubricated billet skin moves out of the container during extrusion to become the extrusion surface. Billet scalping is accomplished by pushing an undersize dummy block through the billet during extrusion and leaving a roughly concentric can, formed of the billet skin, in the container. This requires somewhat higher extrusion force than the full lubrication technique but presents the cleanest possible material to the die during extrusion. In order to retard the flow of the billet skin and thereby achieve the scalping effect, the glass used to lubricate the billet should be a higher melting glass than that used for the glass pad. Figure 9 shows the scalp obtained on the extrusion discard.

Considerable difficulty was experienced in straightening and detwisting the 3/32" x 1" titanium alloy angle extrusions. During initial trials, the principle difficulty stemmed from the slipping of the extrusions through the stretch press jaws which made it impossible to keep the extrusions in the yield condition as required for complete straightening. Additional problems resulted from local non-uniform resistance heating due to small electrode contact and occasionally due to extrusion cross section variation.

Improvement in the gripping problem was obtained with insulated jaws fitted with hard replaceable file inserts at the areas of contact with the angle extrusion. It was not possible to avoid slipping entirely, however, since the tapered jaw holders require tension to wedge the file teeth into the extrusion, and the slipping which occurs during the initial tension application dulls the file teeth and thereby permits further slip against the hard titanium surface when the tension is later increased.

Temperature measurements were made with optical and surface contact pyrometers. At higher temperatures fairly accurate measurements were obtained with the optical pyrometer, but the surface contact pyrometer proved unsatisfactory for measurements in the 1000°F to 1300°F range so that Tempilsticks were used to measure the lower temperatures.

After straightening, the extrusions were sandblasted. This was accomplished in a large enclosed room by an operator wearing a respirator who walked along the angles and sandblasted them at table height.

c) Heat Treatment Study and Mechanical Property Testing

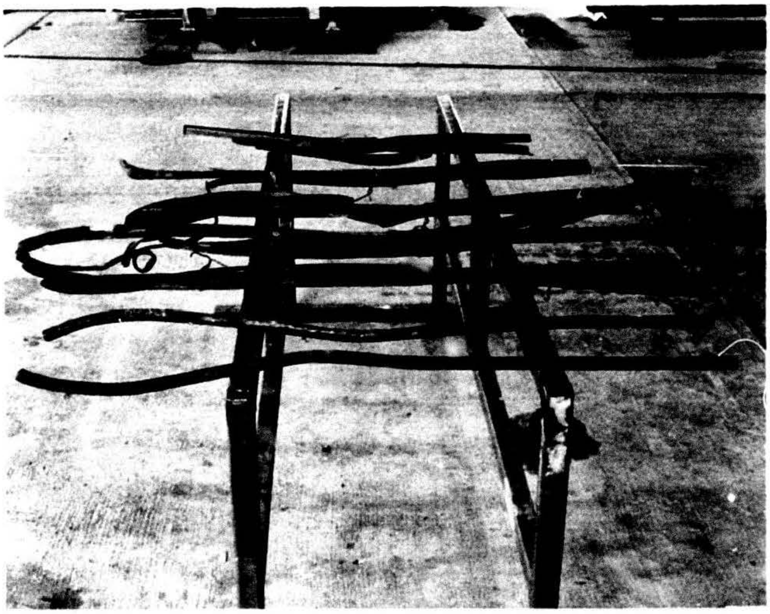
Mechanical property data obtained during the initial phases of the program proved to be erratic. Room temperature strength and ductility varied over a broad range with some attendant brittle fractures. Examination of these brittle fractures showed them to initiate from the surfaces which contained varying amounts of surface contamination. Subsequent evaluation revealed that brittle behavior was exhibited only when the extrusions were re-heated into the solution temperature range during heat treatment or straightening. Therefore, this brittle behavior was attributed to surface contamination formed during the high temperature exposure in air.

To eliminate the effect of surface contamination, tensile specimens were prepared by surface grinding the as-extruded and heat treated surfaces from the specimens. Tensile results were obtained on as-extruded, as-straightened, and heat treated samples. The as straightened samples were obtained from angles which had been solution treated at 1600°F by resistance heating for a few seconds to two minutes followed by a water quench. The angles were then straightened at approximately 1100 to 1200°F.

The heat treated samples included those heat treated after straightening in the Babcock and Wilcox Laboratory and some which were heat treated at the Metlab Company in Philadelphia prior to straightening at Babcock & Wilcox. In all cases the solution treating temperature was 1650°F. The aging treatment varied from 1050°F to 1200°F for various time intervals. The heat treatment done at the Metlab Company was accomplished in a propane fired, vertical furnace. A protective atmosphere of helium gas was employed during the heating cycle. The heat treatment conducted at Babcock and Wilcox was accomplished in a laboratory muffle furnace with no protective atmosphere.

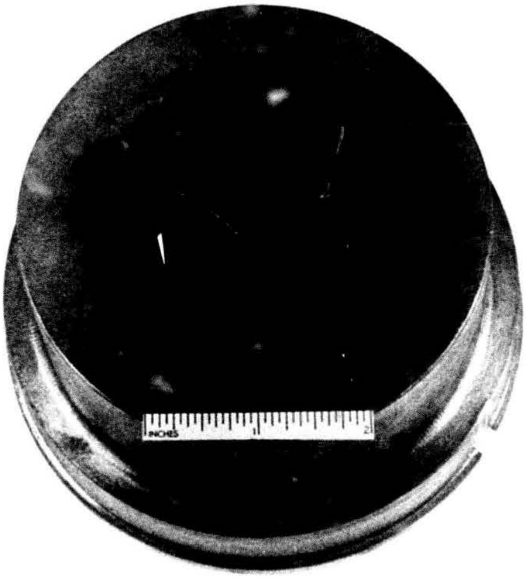
The most significant conclusion indicated by the heat treatment study and mechanical property testing was that in none of the conditions was it possible to obtain the objective mechanical properties for C135 AMo titanium alloy of 180,000 psi room temperature ultimate strength with 8% elongation. Secondly, improvement upon the as extruded properties was not obtained by heat treatment. The lack of heat treatment response was a function of the extrusion process employed in Part II since the heat treatment capability of the 7Al 4Mo billets prior to extrusion was determined in the initial testing of the program to be 190,000 psi ultimate strength with 8% elongation.

Metallographic examination of the extruded product indicated that the majority of extrusions took place at or above the beta transus.



Extruded Product of Test Group No. 2
at Babcock & Wilcox

Figure 6



Mandrel and Die Used for Extrusion
of 3 Angles with a Drilled Billet

Figure 7

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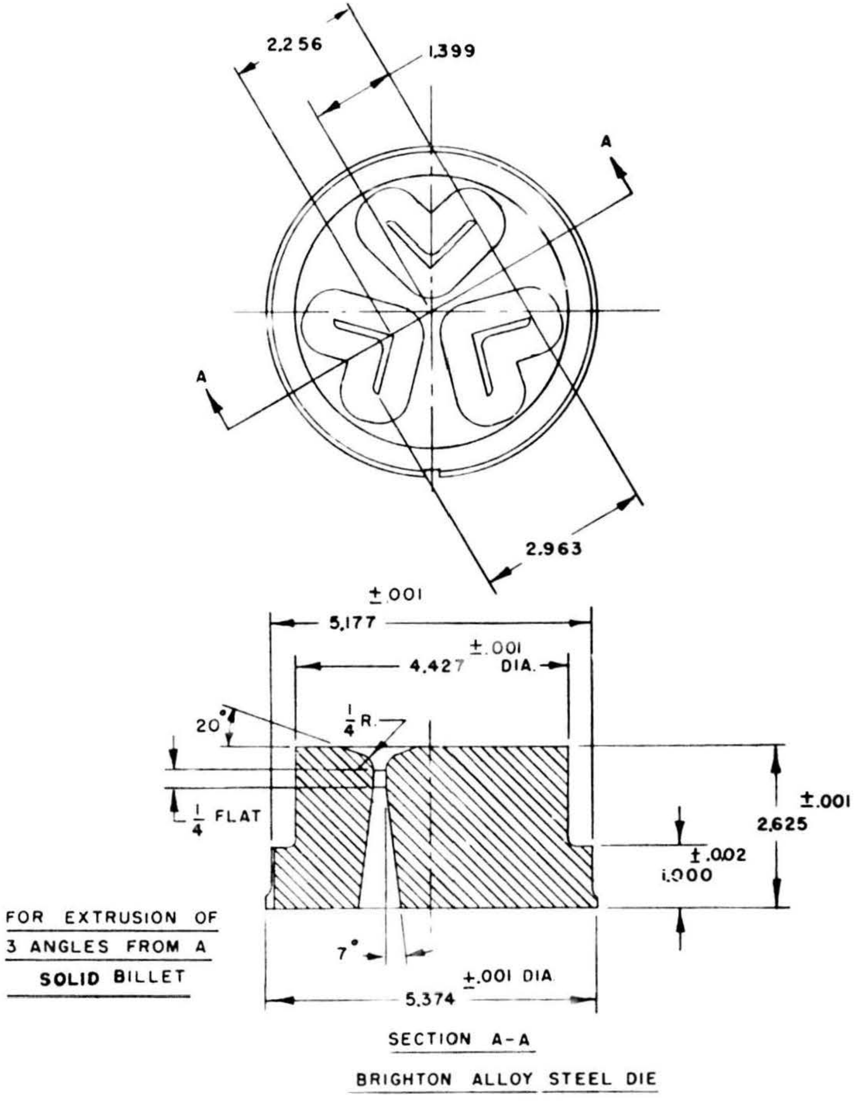
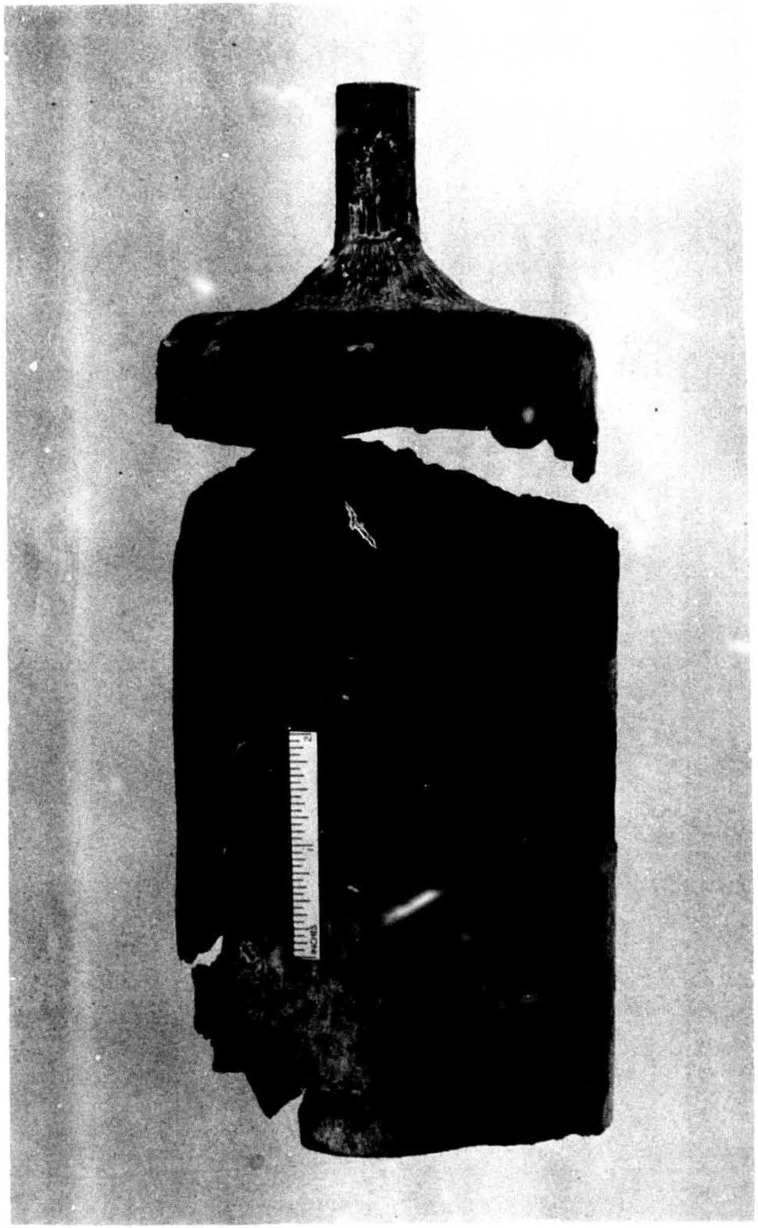


Multi-Port Extrusion Die
For Angle Shape

FIGURE 8



Typical Scalp and Extrusion Butt in the Scalping
Technique

FIGURE 9

605288

2. Extrusion, Straightening and Heat Treat Development at United States Steel Corporation

a. Extrusion Development

(1) Extrusion Facilities

The press tools for adapting the 2,500 ton extrusion press at the Gary Plant of the National Tube Division for extrusion of the small channel section from 2-3/4" diameter billets consisted of the following:

(a) Extrusion Press Liner - 2-7/8 inch inside diameter (extrusion ratio 27:1) - SAE 4340 steel heat treated to 300/350 BHN.

(b) Hollow Mandrel Holder - SAE 4340 steel heat treated to 390/440 BHN

(c) Stem - Halcomb 218 steel heat treated to 390/440 BHN.

(d) Dummy Blocks - Halcomb 218 steel heat treated to 390/440 BHN.

(e) Die Holder - Halcomb 218 steel heat treated to 390/440 BHN.

(f) Bolster - SAE 4340 steel heat treated to 360/419 BHN.

(g) Guide Barrel - mild steel.

The extrusion tools were designed for a maximum press force of 500 tons. This is the extrusion force resulting from the maximum allowable stress of 180,000 psi in the 2-7/8 inch diameter Halcomb stem. The tools, in general, performed satisfactorily during the extrusion trials. Two methods for heating the extrusion billets were used: (1) an electrically heated muffle furnace with argon protective atmosphere and (2) a container of molten glass heated by immersing the container in a high temperature salt pot.

(2) Extrusion Trials

Six extrusion trials were conducted at the Gary Plant. The data sheets for the trials are included in the Appendix.

The trials included pushes with grease and glass lubrication of flat face and modified flat face dies machined from 5 chrome steel and cast from 11% tungsten steel. The flat face die design is shown in Figure 10.

Due to inadequate lubrication, it was not possible to develop an extrusion method capable of producing long (15-20 feet) extrusions with 125 RMS surface throughout and within the dimensional tolerances required. A section from the front end of a typical channel extrusion is shown in Figure 11.

Specific conclusions concerning the important extrusion variables are presented below.

Billet Heating and Transfer

Heating the titanium alloy billets under a protective atmosphere of argon in a closed container immersed in a molten salt bath provided good temperature control, temperature uniformity, and protection from surface contamination. Manual transfer of the small billets from the heating container to the press chamber was satisfactory when relatively few extrusions are to be made, but the billet transfer should be automated for commercial production runs.

Die Material

Dies shell-cast from steel containing about 0.40% carbon, 2% chromium, 0.35% vanadium, and 11.5% tungsten heat treated to a hardness of about 50 Rockwell C are resistant to wear, and therefore maintained uniform cross sectional dimensions in the extruded product. The required uniformity of cross sectional dimensions were not maintained when extrusion dies made from steel containing 0.20% carbon, 1.5% chromium, 1% nickel, 1% cobalt (about 20 R_c) or steel containing 0.40% carbon, 1.05% silicon, 5.0% chromium, 0.35% vanadium, and 1.35% molybdenum (50 R_c) were used for the extrusion dies.

Die Design

Conical dies had no noticeable advantage over flat-face dies when glass lubrication was used during the extrusion; laminar flow being obtained with both die types. A disadvantage of conical dies with glass lubrication, apparent during the last trial, was the loss of much of the glass pad with the first foot of extrusion. When grease-base lubrication was used, shear-type flow occurred with both conical and flat face die types, but the shear cone formed was somewhat less pronounced with a conical die contour

Lubrication

No lubrication system was developed that provided the required surface finish on the extrusions beyond about six feet of extruded length. Of the lubricants studied, the best front end surface was obtained with Fisk No. 604, but Corning 3KB glass gave better results in the sense that the surface of the extrusions remained somewhat smoother at the back end than when Corning No. 575 glass, Corning No. 9771 glass, Fisk No. 601 grease, or Fisk No. 604 grease were used. The protective film of glass obtained from a wetting of the extrusion from the glass pad reservoir that is typical of steel extrusion was not obtained with any of the glass compounds used during the program.

Extrusion Ratio

The extrusion ratio of 27 to 1 used throughout the program appeared to be suitable for the extrusion of the small channel section in 15 to 20 foot lengths. Variations in extrusion ratio were not studied in the program.

b. Straightening Development

Experiments were made at the Gary Plant of the National Tube Division to establish a suitable practice for hot straightening and detwisting the channel sections and for commercial heat treatment of the sections in conjunction with the straightening operation.

The stretch straightening and detwisting equipment at the Gary Plant of the National Tube Division consists of a Loewy 100-ton capacity, horizontal stretch-straightening and detwisting machine. The essential parts of this machine are (1) a heavy cast iron bed, (2) a fixed rotatable head at one end, and (3) a movable hydraulically powered, non-rotating head. In operation, the ends of the bar to be straightened are clamped in the two heads of the machine, the fixed head is rotated to effect detwisting, and tensile force sufficient to produce slight plastic yielding throughout the bar is applied to effect straightening. Special jaws for gripping the small channel section in the heads of the stretch-straightener were constructed.

An Alnor "Pyrocon" contact-thermocouple pyrometer with a temperature range 0 to 1200°F was used to indicate the 900 to 1000°F straightening temperature and a Leeds & Northrop optical pyrometer was used to indicate the 1600 to 1700°F solution temperature. The longer channels (12 to 15 feet) were resistance heated using the 45-volt tap of the main salt-bath transformer and the shorter channels were heated using the 33-volt tap. The temperature of the channels was controlled by switching the current in the transformer primary off when the channel reached a temperature 50°F above the desired temperature and switching it on at 50°F below the desired temperature. The controlling switch was located at the straightening press and was connected to operate a relay to furnish current to the primary coils of the transformer.

Initial trials indicated that the C135A Mo extrusion could be water quenched from 1600°F solution temperatures while held taut in the stretch-straightener without distorting during quenching. However, when the Ti-155A extrusions were similarly processed, considerable bow resulted and subsequent Ti-155A extrusions were therefore permitted to air cool and considerable improvement in straightness was obtained.

Gripping pressure was provided by an air cylinder, but during tension in the yield range, this pressure was not sufficient and the additional wedging action of the jaws in the jaw holder during tension was required.

It should be noted that, whereas many of the channels were straightened and detwisted satisfactorily, several were bowed slightly more than desired and several had localized sections with excessive twist that could not be rectified on the equipment used in this trial.

c. Heat Treatment Study and Mechanical Property Testing

Following the straightening and solution annealing treatment, all the channels were aged at 1200°F in a commercial roller hearth furnace. To insure uniform aging of these small sections, they were inserted into 7-inch OD by 1/2-inch wall carbon steel tubes during the aging treatment in the gas-fired roller hearth furnace.

Three of the Ti-155A and one of the C135 AMo channels were selected for product evaluation at the Applied Research Laboratory of United States Steel. In addition, a channel section that had been extruded at the National Tube Division, Gary Plant, and heat treated in a vertical quench furnace with helium atmosphere at the Met Lab Company, Philadelphia, Pa., was also selected for evaluation.

The mechanical property evaluation consisted of room temperature tension tests, elevated temperature tension tests, and creep and stress rupture tests. In addition, the metallographic characteristics of the product were determined and documented.

From the results of the evaluation, the following conclusions can be drawn:

(a) Tensile strengths in the range 170,000 to 180,000 psi were obtained in both Ti-155A and the C135 AMo titanium alloy channels heat treated by the practices described in the previous section. However, as indicated by tensile elongation, only the C135 AMo alloy exhibited ductility within the desired range.

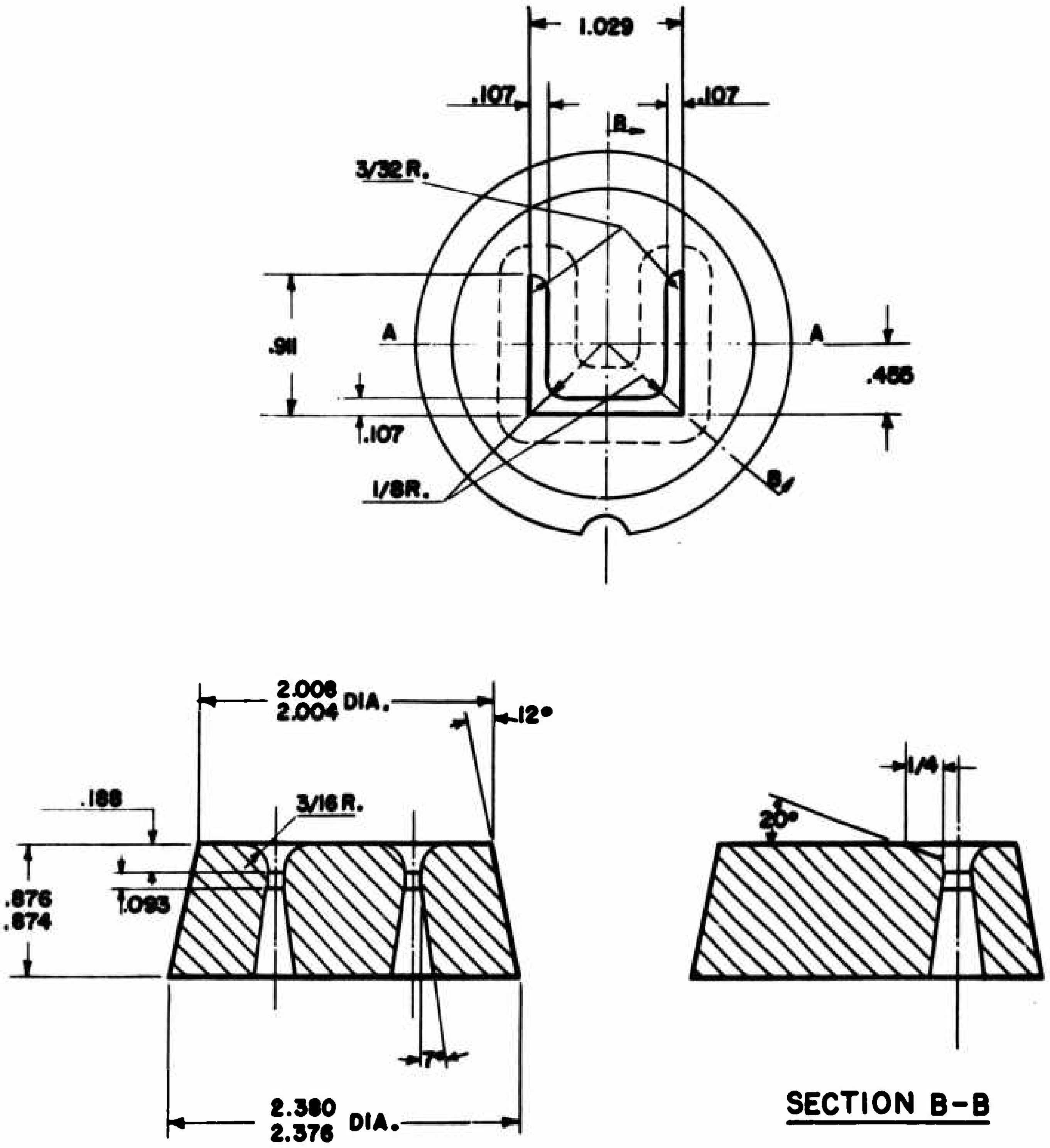
(b) Both Ti-155A and C135 AMo channels are more notch sensitive at room temperature than at 800°F in sharply notched specimens.

(c) The fully processed channels of both alloys exhibited 800°F tensile strengths of about 70 percent of their room temperature tensile strengths and yield strengths of about 60 percent of their room temperature yield strengths.

(d) The creep strengths of the commercially processed channels were about the same as those of laboratory heat treated samples of the two alloys. The C135 AMo titanium alloy channel exhibited the desired creep of less than 0.5 percent in 500 hours when tested at 800°F and 70,000 psi stress. The Ti-155A channels exhibited about five times the desired creep under these test conditions.

(e) Both the Ti-155A and the C135 AMo channels withstood 1,000 hours at 800°F under a stress equal to one-third the room temperature tensile strength in stress rupture tests. However, the Ti-155A alloy extended six times as much as the C135 AMo alloy in this test. In 800°F stress-rupture tests with a stress of two-thirds room temperature tensile strength, the C135 AMo alloy had a life of 24 hours, whereas the Ti-155A alloy failed in 0.2 hours.

(f) Stability test results indicated that the tensile and yield strengths of the titanium alloy channels were not affected by heating for times as long as 1,000 hours while stressed at one-third the room temperature tensile strength, but that the ductility of the alloys was markedly reduced by heating highly stressed specimens for only 20 hours.



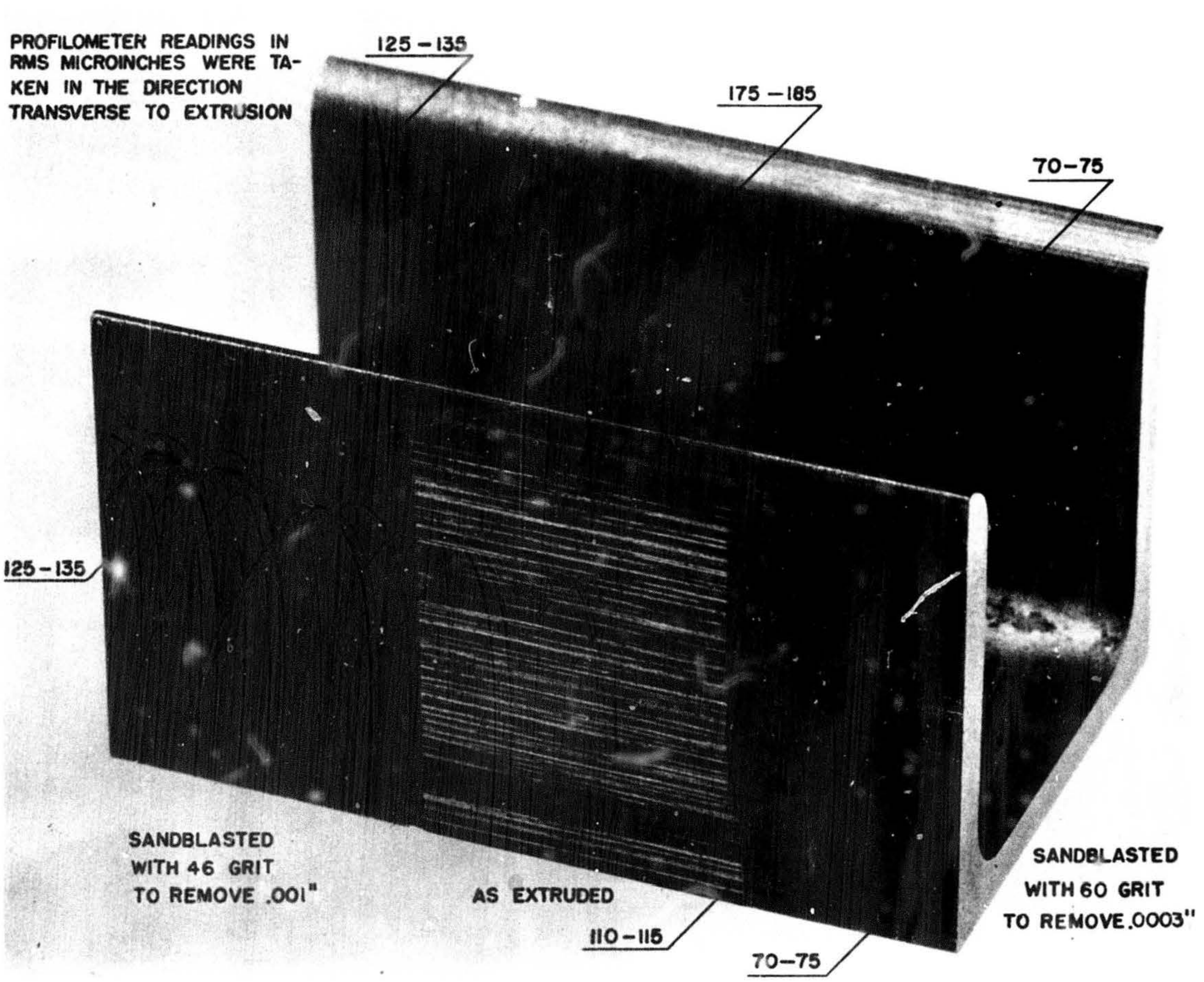
SECTION B-B

SECTION A-A

FLAT FACE EXTRUSION DIE

PART II CHANNEL

FIGURE 10



Surface Finish of Channel Extrusion
Push No. 34 at U. S. Steel

FIGURE 11

605298

3. Extrusion Development at H. M. Harper Company

a. Extrusion Facilities

The extrusion press was a Loewy Hydropress four-column horizontal press of 1650-ton capacity. The press was a high-speed water type capable of ram speeds from 1/4 inch per second to 6 inch per second fully variable and controllable at any speed between the limits.

The press tools to adapt the 1650-ton extrusion press to extrusion of the zee section from 3-7/8 inch diameter billets consisted of the following:

(1) Extrusion Press Liner - 4-inch inside diameter (extrusion ratio 102:1) Ajax Ti steel heat treated to 429/461 BHN.

(2) Stem - Ajax Ti steel heat treated to 445/475 BHN

(3) Dummy Blocks - Ajax Ti steel heat treated to 415/429 BHN.

(4) Backer - Ajax Ti steel heat treated to 401/429 BHN.

(5) Die Holder - Ajax Ti steel heat treated to 429/461 BHN.

(6) Bolster - Ajax Ti steel heat treated to 401/425 BHN.

Billet heating for all the extrusion trials was accomplished in an induction heating setup with three magnathermic vertical 60-cycle induction coil billet heaters. The heater pedestal was modified to permit heating the 3-7/8 inch diameter x 4 inch billets in the standard 5-5/16 inch heating coil. It was determined that by delaying (cycling) the heating rate, a billet could be heated rapidly to an even temperature throughout. The rapid heating possible in the induction heater minimized the possibility of billet surface contamination. After heating, the billet rolled down to the extrusion press and was placed into the container with a hand cradle in an average transfer time of seventeen seconds.

b. Extrusion Trials

Five extrusion trials were held at H. M. Harper Company. A total of fifty-five extrusion pushes were made consisting of thirteen pushes of 4140 steel, thirty-eight of Ti-155A titanium alloy and four of MS 821 titanium alloy. The trial data sheets are included in the Appendix.

The trials indicated that extrusion of the difficult zee section was possible at a 102:1 extrusion ratio, but good surfaces and the desired dimensional tolerances were not obtained due to die wear.

Glass, grease and graphite lubrication were investigated as well as extrusion in 5/8 inch wall thickness low carbon steel tubes which was unsuccessful.

The following die materials and designs were used during the extrusion trials:

Cast Dies

M2 or HMH 72 - .70% C. 4% Cr 2% V 5% Mo 6% W R_c50-52
Star "J" 2.5% C. 41% Co. 32% Cr 17% W

Machined Dies

Crucible Halcomb 218	.40% C. 5% 1.35% Mo. .35% V. R_c50-52
Crucible Peerless "A" Carpenter TK	.28% C. 3.25% Cr 9% W. .25% V

Insert Dies

Aluminum oxide insert with a HMH 72 shell cast shroud.
Chrome carbide insert with a Halcomb 218 shroud.
Zirconium carbide insert with a HMH 72 shell cast shroud.

Design 1

A 25° conical face die, entry radii 3/8-inch, bearing length of 1/4-inch and a 7° back relief 1/8-inch long.

Design 2

A 25° conical face die, entry radii 3/8-inch, 25° angle to bearing, bearing length of 1/16-inch, and 7° back relief 1/16-inch long.

Design 3

Flat faced die with entry radii of 3/8-inch with 1/4-inch bearing length, and 7° back relief about 3/4-inch long.

The three methods of extrusion used during the trials were:

Standard

The billet was brought to the die with the stem under extrusion press prefill pressure and upset. High pressure was then applied. A delay of 1-2 seconds occurred before extrusion.

Throttle

The press speed was throttled by means of a manual valve. This in turn caused a delay of 3-6 seconds before high pressure could be applied.

Impact

High pressure was applied to the billet as the stem made contact. There was no delay. The results obtained with the use of the impact extrusion method indicated that the glass lubricant was not given time to fuse and thereby shield the die from the billet heat to avoid die deformation.

c. Conclusions

The extrusion objectives of surface finish and dimensional uniformity for the zee section were not approached. Lengths of 25 feet were produced but die washout was excessive. The thickness was held within the .062 ± .006 tolerance for some parts of the cross section for the entire length on the best extrusion (Push No. 19) but the die wash originating in the fillet areas tapered into much of the .062 areas.

The specific conclusions that could be drawn from the extrusion techniques employed during the trials are presented below for each of the extrusion variables.

(1) Billet Heating

Billet heating was not a problem during the trials. Billets heated in the 60-cycle billet heater were uniform in temperature and did not have a surface oxidation determined to be harmful in extrusion.

(2) Die Materials

The die materials used during the trials did not seem to have the properties necessary to withstand extrusion under the prevailing conditions. The metal dies had several deficiencies. The most serious of these was their lack of resistance to the combination of hot glass and hot titanium during the extrusion of such a thin section.

The ceramic and carbide materials failed due to their extreme brittleness under tension type stresses. The designs used during the trials allowed this type stress since the insert was not confined sufficiently in the die shroud.

(3) Die Design

The design of an extrusion die for titanium extrusion using glass lubrication must be one that permits proper lubrication and eases the flow of the metal during extrusion. The conical type die eased the flow, but did not retain glass for proper lubrication. This was because the glass had a tendency to flow at a faster rate than the metal.

The proper design for grease-type lubrication could not be determined since the high extrusion temperature volatilized the grease, thus leaving only graphite for lubrication.

Of the three basic die designs that were used, design no. 2 with large open double angle conical entry was the least satisfactory, although the press force was reduced with that design. The design does not have sufficient die mass at the bearing area to carry away the heat of the passing titanium alloy. As a result, the bearing area washed considerably.

(4) Lubrication

Glass lubrication was the most promising type used. Complete coverage of the extrusion with glass was achieved on most pushes. However, the glass was not uniformly thick on the extrusion. Where the glass was thin, pickup and resulting scratching occurred. Where glass was thick, the lines formed on the billet face were carried through the die and appeared as sharp lines on the extrusion.

The defect called pickup was probably a reaction product from a reaction between titanium, glass and/or the die. Examination under polarized light indicated that the material called pickup was crystalline in nature. The glass as used for lubrication was not crystalline under polarized light. Some hard particles that could be produced from a glass, titanium and die reaction are Al_2O_3 - aluminum oxide; SiO_2 - silica; TiO_2 - titanium dioxide; TiC - titanium carbide; and combinations of these. All of the above materials are hard at extrusion temperatures.

To overcome the variation of thick and thin glass on the extrusion, a glass slurry coating was used on a conical die (Push No. 22). This procedure was not successful because the glass was consumed by the first few feet of the extrusion.

(5) Die Temperature

The die temperature variable was not completely investigated. Temperatures as high as could be used without excessive tool wear were maintained. These temperatures were 400°F to 1200°F. This was in line with general extrusion practice.

(6) Extrusion Ratio

The extrusion ratio necessary to extrude the section from a four-inch diameter container was the greatest deterrent to achieving success in this program.

The high extrusion ratio necessitated the use of high billet temperatures which in turn caused other problems such as surface contamination and excessive die wear.

4. Manufacturing Evaluation at Republic Aviation Corporation

a. Resistance Heating Experiment

Purpose

The resistance heating experiment was conducted to determine the heating characteristics of various voltage and temperature ranges in the resistance heating of a titanium alloy structural length, and to determine the degree of temperature differentials in the cross section at the range of temperatures. This information can be used as a guide in the consideration of hot stretch straightening or heat treatment of the extruded lengths. A 4Al-4 Mn titanium alloy extruded length 5' long and machined to 3/32" x 1" x 1" was used for the resistance heating tests.

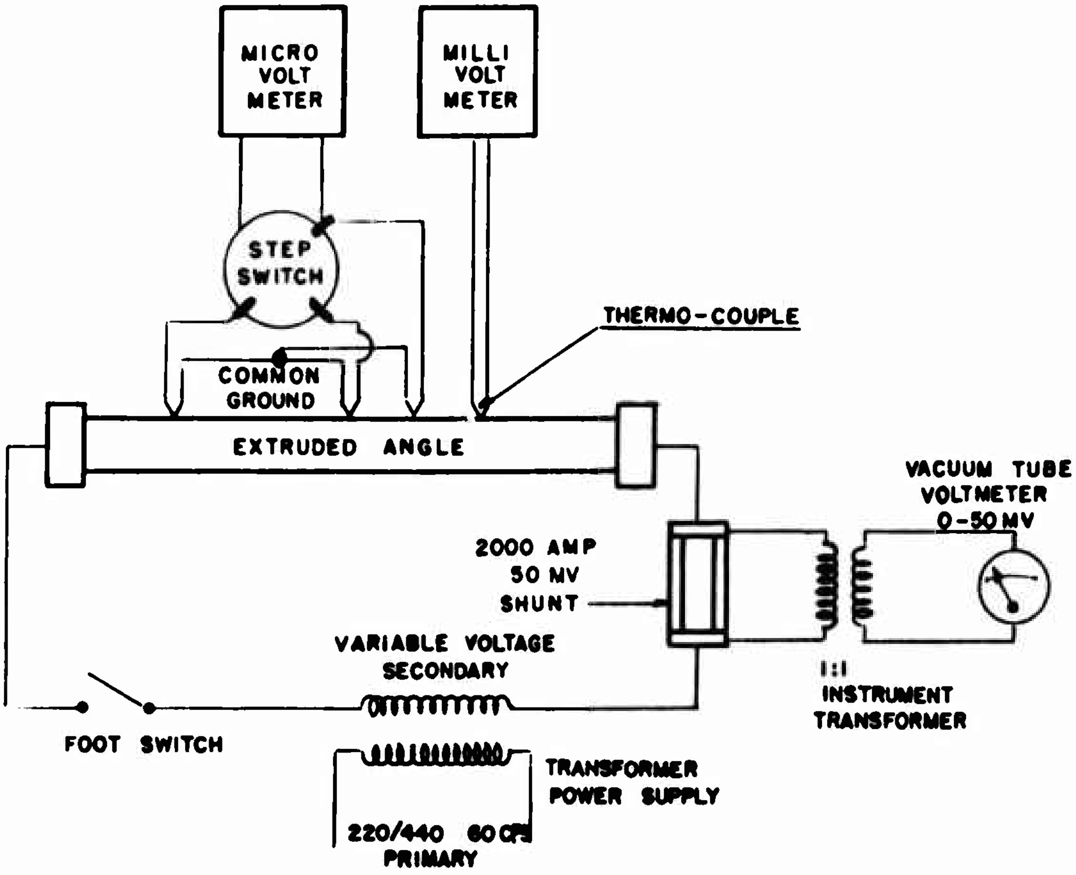
Conclusions

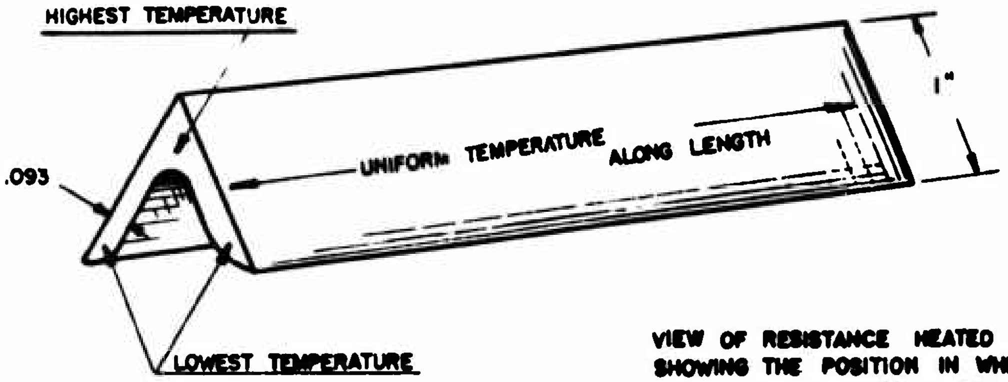
Less time was required to reach the maximum temperature at higher voltages. For example, at 22 volts the maximum temperature, 1795°F, was reached in 80 seconds and at 9.4 volts the maximum temperature, 935°F was reached in 170 seconds. This was a result of the temperature exponential radiation heat loss which was a much larger factor at the higher temperatures and abruptly halted the rate of heating at the higher temperatures.

The data plotted in Figure 12 shows the rate of heating at voltage ranges of 9.4 to 22 volts and the maximum temperature these voltages produced in the 5 foot angle used for the test. The current required to reach the maximum temperatures at the range of AC transformer voltage settings was plotted in Figure 13.

The equipment and power requirements for other extruded shapes and alloys in various lengths can be approximated by correcting for the difference in resistivity of the alloys, cross section area, and length by means of Ohms Law and the equation $R = \rho\frac{l}{A}$ where R = resistance, ρ = resistivity, l = length and A = cross section area. This is possible since the maximum temperature attainable for the voltages plotted are determined by the equilibrium between the heat equivalent of the KVA input and the conductive and radiant heat losses. Since the ratio of surface perimeter to surface area in structural extrusions are roughly similar, approximately equal maximum temperatures will be realized in resistance heating all titanium alloy extruded lengths provided that the KVA inputs per square inch of cross section per foot of length are equal. Transformer power requirements for resistance heating various titanium alloy extruded lengths to temperatures in the range of 935° to 1795° are shown in Table 1.

Variations in temperature in the resistance heated length occurred at points in the cross section of the angle. The corner and fillet area was consistently at a higher temperature than the outer portions of the legs. This can be attributed to the concentration of the mass of the cross section in the sharp corner and fillet area which reduces radiation losses, and to the relatively greater exposure of the legs. The temperature differential varied from 20°F at 1000°F to a differential of 100°F at 1800°F. This differential in temperature was consistent throughout the length, and no temperature gradients existed along the extruded length except at the ends in the zone 1" to 2" from the electrodes where heat is conducted to the electrodes.





VIEW OF RESISTANCE HEATED ANGLE SHOWING THE POSITION IN WHICH THE ANGLE WAS CLAMPED DURING HEATING.

Equipment

100 KVA Transformer, single phase, 60 cycle, 220/440 volt connected to deliver secondary output in a range of 7 to 22 volts.

Millivoltmeter to determine temperature.

Microvoltmeter to determine temperature variations through the cross section and along the length of the angle.

Vacuum tube voltmeter to record voltage drop across shunt.

Procedure

A pair of clamps machined to fit the angle around its entire surface were used as electrodes. The clamps were spaced 5 feet apart on the angle and then fastened. The transformer leads were screwed to the angles to complete the setup. The titanium angle was heated by passing current through the angle at 6 voltage settings of the transformer. The angle was continuously heated at each voltage setting and the temperature was recorded at 10 second intervals until the maximum temperature was reached. The current flow during each test was determined from the voltage drop across a 2, 000 amp shunt connected in series with the angle being heated. The voltage drop remained quite constant during the heating with a variation of 5% from minimum to maximum readings. This can be attributed to the relatively constant resistivity of the 4Al-4Mn alloy which ranges from 150 to 170 to 150 x 10^{-6} ohm cm in the 200° to 1000° to 1800°F temperature range. Maximum readings were recorded for the voltage drop across the shunt for each of the heating tests. The voltage drop readings were measured with a vacuum tube voltmeter which was isolated from the heating circuit by an instrument transformer with a 1:1 ratio.

Chromel-Alumel thermocouple wires were welded to various cross section locations on the titanium angle by heliarc welding which permitted inserting the twisted wire into a tiny molten puddle of titanium. One pair of thermocouple wires was connected to the millivoltmeter so that the total temperature of the angle could be determined from the millivoltmeter readings. Other thermocouple wires were joined and connected to the microvoltmeter so that the potential difference at various parts of the cross section could be determined.

A step switch was used to permit rapid alternate readings of difference in potential between various points in the cross section and length of the extrusion Separate heating tests were conducted to determine the variation in temperature at various points in the cross section or along the length of the extrusion. Readings were taken immediately after the heating current was shut off to avoid distortion of the thermocouple readings due to voltage differentials along the extrusion length.

The data in Table 1 is presented to indicate the power requirements to heat extruded titanium alloy lengths to the indicated temperatures. The data for the 10, 15 and 20 foot lengths is calculated from the data recorded during the resistance heating tests of the 4Al-4Mn five foot extruded angle which was heated by a 100KVA transformer operating at 100% duty cycle for the indicated voltages.

Commercial transformer equipment is available for heating lengths to the lower temperatures, but specially designed equipment would be required for the power to heat to the higher temperatures. Another consideration in resistance heating heavy sections to high temperatures that will require investigation is the pertinent safety codes for the high currents required.

The data in the table is based on an average extrusion shape with a perimeter to cross section ratio of approximately 21:1 and an average resistivity of 160×10^{-6} ohm cm. Correction for a higher or lower resistivity can be made by raising or lowering the voltage required and KVA required in proportion.

b. Contamination Rate Study

Purpose

The surface contamination of titanium alloys at elevated temperatures for various time exposures is an important consideration during billet heating and during extrusion, hot straightening and heat treatment of the extruded lengths. The purpose of this study was to determine the rate of contamination during heating in open air and in the restricted air supply and circulation of an electric furnace

Conclusions

As indicated in the curve Depth of Contamination vs. Time of Exposure (Figure 14), the rate of contamination of Ti 155A alloy specimen resistance heated in free air was almost twice as rapid as the rate of contamination of a specimen heated in a muffle air furnace. These two heating conditions can be considered the upper and lower limits of contamination rate in heating without atmosphere. The estimated contamination depth for practical heating applications will approximate the depth of either of the test conditions or an in-between condition.

The maximum allowable contamination of .0025 for removal by chemical or mechanical finishing is plotted on the curve. This indicates that 1650°F is a safe temperature for heating periods of over 1 hour and 5 to 15 minute exposures at 1750°F are allowable. At higher temperatures, only short exposure of less than 1 to 3 minutes can be considered.

The rate of beta grain growth above the beta transus was instantaneously very rapid. At temperature of 1900 to 2250, large grains (25 and 30 microns respectively) were present after 1 minute heating. After 10 minutes, these grains grew to 50 to 55 microns respectively.

Equipment

For furnace heating - Tempco Electric Double Door Muffle Furnace 8 1/2 x 9 1/2 x 13 1/2 heating chamber

For resistance heating - 100 KVA Transformer, single phase, 60 cycle, 220/440 volts, connected to deliver secondary output at 7.3 volts with adjustable percentage heat control for resistance heating.

Bausch & Lomb MILS Metallograph

Procedure

The electric muffle furnace was brought to the test temperature and small specimens (approx. 1/16" x 1/4" x 5/8") of Ti 155A alloy were placed on a titanium platen in the furnace. It was estimated that the specimens reached the test temperature in approximately 10 seconds and were then held at the temperature for the time intervals plotted in the curves. Quenching was accomplished by a rapid transfer into a water can at the furnace door. The specimens were mounted, polished, etched with 10% HF-5% HNO_3 solution, examined metallographically and photographed. This preparation included removing 1/64" of material from the face of the specimens to be viewed. The structure viewed was longitudinal to the billet axis. Contamination depth was measured with a B&L micrometer eyepiece on the surface exposed to the air.

The resistance heating tests were conducted with Ti 155A specimens approximately 1/16" x 3/8" x 6" which were prepared from 2 3/4" round billet bars. The specimens reached the 1750° test temperature in 30 seconds and reached the 2050° test temperature in 20 seconds after the current was applied. Temperature measurement was made with a Chrom-Alumel thermocouple. By adjusting the heat control, the test temperature was maintained for the time intervals plotted in the curve. Quenching was accomplished by pouring water over the hot specimens. The specimens were then prepared and examined as described in the above paragraph.

c Stretch Wrapping Evaluation

Specimens, Equipment and Procedure

An evaluation of the stretch wrapping characteristics of the 7Al-4Mo titanium alloy angle extrusions which were produced by the best extrusion method (glass lubrication-hot tooling-scalping) developed during Part II of the program was conducted at Republic Aviation Corporation.

3/32" x 1" angles were received from Babcock and Wilcox in lengths that were straightened and solution treated with resistance heat and surface cleaned by grit blasting. The resulting surface finish was quite consistent throughout the lengths and was not essentially altered from the as-extruded condition. The 7Al-4Mo angle extrusions typically have an .0005" contaminated surface after the above treatment. Extrusions with smooth (100 microinch, RMS) and rough (250 microinch orange peel, little striation) surfaces were used for the evaluation.

The amount of material available for the evaluation was limited. Much of the extruded product was unsatisfactory due to incomplete section fillout during extrusion, and most of the best product had been used for mechanical property testing and heat treatment studies. Of the material available, it was possible to cut only eight lengths 58" long.

An 18" die diameter was selected as a fairly severe bend for a 3/32" x 1" angle structure, and the angles were wrapped to 180° during the operation. All the stretch wrapping was done on a Hufford A12 stretch press equipped with air operated collets to grasp the extrusions. The collets held the insulated jaws required to permit resistance heating of the extrusions without passing current through the machine bed. Jaw teeth were cut to a medium 21 pitch diamond knurl and hardened to Rockwell C-60. This is a finer knurl than is used for softer metals and has been found to be effective in grasping titanium without slipping or notching to failure at the jaws. A photograph of the equipment during stretch wrapping is shown in Figure 15.

Fitted electrodes were fastened to the angles at points just outside the stretch press jaws. Flexible cables were used to connect the electrodes to the output of a 1500 amp Hobart Motor Generator (variable voltage, 0-30 volts). During the trials the voltage required to heat the angles into the 1100-1200 range was approximately 9 to 11 volts.

The dies were heated into the range of 800 to 1200°F before the angles were brought into contact with the die. This heating was accomplished at the press with two acetylene torches. Twenty to thirty minutes were required to heat the die from room temperature to the operating range.

Stretch Wrapping Trails

A typical part formed during the evaluation is shown in Figure 16. The data is listed in Table 2.

The first two trials were conducted with rough and smooth extruded surfaces with a 1100° die and a 4-ton wrapping force. Both angles failed before wrapping had progressed more than 10°. The failure was attributed to localized strain at point of contact with the die due to the reluctance of the colder material outside the die to yield. In the balance of the trials, the angles were resistance heated to a uniform temperature throughout the angle before being brought into the die. Approximately one minute was required to bring the angle from room temperature to the operating range.

The first resistance heated trial, #3, produced a wrapped angle without failure. However, considerable difficulty was experienced in getting the compression leg to enter the die after about 90° of wrapping due to twist in the portion of the angle outside the die. This twist occurred due to an equalization of forces in the two angle legs outside the die. A large lower plate was substituted on the die to provide a 1" flange for entry. This considerably improved the entry problem, and subsequently it was found that higher wrapping forces also facilitate entry.

Trials #4, 5, 6 were conducted with continuous or intermittent resistance heating during the wrapping and stretching operations. This heating proved to be a problem since it was difficult to avoid overheating either at the die contact or in the portions of the angle outside the die as the overall electrical resistance dropped during the wrapping operation.

The most successful results were obtained in trials #7 and #8 by resistance heating the angles until wrapping was started. The higher wrapping forces (4 tons) used for trial 7 and 8 eliminated corrugation even though the compression leg clearance was excessive (9/64") due to die deformation.

Stretching into the yield range was not effectively realized before Push #7, and most of the trials showed almost no elongation in the unwrapped portions of the angle. The 4 ton forces used for stretching did not put the angles into yield. However, since the fracture point is so close to the yield point in titanium alloys, several failures had occurred. The stretch force was not increased until trial #7 since the number of angles available for evaluation was limited. An elongation of approximately 3% was obtained in the unwrapped portion of #7 and shrink was a minimum of 1 1/2 - 2% with approximately 10% stretch. After successfully yield stretching this angle, it was disappointing to find that the part radius still did not conform to the 9" die radius even after a 1/2 hour period at 1200 to 900°F. Subsequently, the die was reheated to 1300°F. At this higher temperature, the creep forming temperature of the 7Al-4Mo alloy was attained and the radius of part #7 conformed to the die radius (9 1/16" vs 9") after a short 3 minute low tension contact with the hot die.

A radiation pyrometer was available to record the temperature of the heated extrusion, but this method of temperature measurement was unsatisfactory since variations of temperature along the angle lengths could not be recorded and the angle target moved out of focus and position during the wrapping operation. Tempilstiks were found to be satisfactory for die and angle temperature measurements.

A die was machined to 18" diameter from SAE 1010 steel for the evaluation. Originally, the die contained only three screws to fasten together the upper plate, spacer and lower plate. The plates are 1" thick and the spacers are variable from 3/32 to 5/32". After the first three trials, it was determined that a flange portion added to the lower plate would reduce the tendency for the angle to twist before entering the die. To accomplish this, a new 20" diameter lower plate was substituted and a circumferential ring of screws was added to reduce deformation of the plates during the 1000°F operation. Examination of the upper and lower plates after the eight stretch wrapping trials showed that both had deformed approximately 1/16". This condition progressed during the trials, and the circumferential screws were not adequate to fasten the plates securely against the spacer ring to obtain a restricting flange space. However, the combination of high operation temperature and wrap force was sufficient to prevent corrugating the later trials. Typically, the compression edge increased about .005" while the tension leg of the angle reduced about .003" in thickness.

The die surfaces in contact with the angle were coated with a 1/64" layer of aluminum oxide ceramic spray as furnished by Metallizing Engineering Company. This coating was then sealed with brush coats of hydrolized ethyl silicate. The ceramic coating provided a hard forming surface and an electrical insulation between the die and angle to permit the resistance heating of the angle during wrapping without creating a short circuit through the die. The ceramic coating was an effective electrical insulation except at points of severe corrugation which created pressure points against the die thereby creating arc spots. Such arc spots were the center of local compression yielding. After Push #5, when the die was heated to 1200°F with acetylene torches, the ceramic coating began to peel off the steel die. This is attributable to the intense torch heat and localized heating, since the coating is normally adherent at much higher temperatures.

The limited evaluation performed indicated further work was required but permitted the following conclusions and recommendations:

1. Extruded 7Al-4Mo titanium extrusions can be successfully stretch wrapped to part configurations but higher temperatures are required for this high creep strength alloy than are required with other alpha beta titanium alloys in current use.

2. One part, #7 was successfully formed to the part configuration (Figure 16) by wrapping at 1100°F and creep forming at 1300°F.

3. Future stretch wrapping evaluation should include the following:

   (1) Hot die - no resistance heat

      a. Range of die temperatures
      b. Range of wrapping forces

   (2) Hot die - resistance heated part

      a. Locally, internally heated die to permit temperature increase into creep range after forming.
      b. Separate creep fixture if (a.) is not practical.

4. The 1" thick carbon steel dies cannot resist the 1200° forming temperatures without deformation. For future evaluations, the following should be considered:
    a. Hot work steel dies
    b. Thicker dies
    c. Locally, internally heated die with operating temperature confined to die circumference.

d. Joggling Evaluation

Introduction

A joggling evaluation was conducted with 7Al-4Mo titanium alloy angles which were extruded during Part II of the program. The objective of the evaluation was to determine the forming characteristics of these extrusions under various tool and part temperatures for tight, standard and open joggles.

The extruded material available for the evaluation varied considerably in surface finish. Most of the better material had been used for previous property testing. Some of the angles which were used for the joggling evaluation were cut from the straight ends of angle lengths which had previously been used in stretch wrapping. Since the overall leg dimensions (nominal 1.000") varied considerably, one leg of the angles was milled to .850" so that the joggle kick plate would bear uniformly in all tests.

The joggling was performed with a Model 2B joggle die manufactured by the Joggle Tool and Die Co. The die was equipped with heaters in the lower portion which permitted tool temperatures up to 600°F. The die inserts were interchangeable for various extrusion shapes and both joggle depth and joggle length are adjustable. The first tests with unhardened tool steel inserts normally used for aluminum forming showed such inserts were too soft for forming titanium alloy, whether heated or unheated. Hardened tool steel blocks were obtained with hot work die steel kick plate inserts. These proved satisfactory and showed no wear after 50 trials at room and elevated temperatures.

The initial testing at room temperature proved to be unsuccessful and resulted in severe cracks in all cases (see Figure 17). The remainder of the tests were conducted at temperatures from 500°F to 1300°F. Angles 4" long were heated in a small electric clam shell furnace for periods up to 3 minutes to reach the desired temperature. The angles were quickly removed with asbestos gloves and dropped into the die opening. While the operator clamped the extrusion with a hand lever, the temperature of the unclamped flange was read by a technician with a contact thermocouple pyrometer. No more than 5 seconds elapsed between removal from the furnace and the joggle press stroke, and parts were, therefore, formed at the temperatures recorded.

Results and Conclusions

Joggling Method

Extruded angle material was available for approximately 50 joggle trials. The first 10 attempts at joggling were done with both the angles and the die at room temperature. The severe cracking which invariably occurred is shown in Figure 17. Formability was greatly improved during the last 40 trials with heat, but the number of tests was not sufficient to conclusively indicate the best heating method or forming temperature.

The trial conditions and results with the heated tests are presented in Table 3. In the first series of tests, both die and angles were separately heated; in the second series, the angles were heated while clamped in the hot die; and in the third series, hot parts were formed in the room temperature die. Heating the parts in a hot die proved to be the least successful method and in four trials, all angles showed slight cracks. The results do not indicate a statistical choice between furnace heated parts in either the hot or cold die since in both methods, cracks were obtained in approximately 25% of the trials. However, heating both the die and the part would appear to be the most practical production method since more time is available to the press operator before excessive temperature drop occurs.

Joggling Temperature

The results are entirely inconclusive as far as a choice of joggle temperature is concerned. Both cracked and uncracked joggles were obtained at all temperatures from 500 to 1100°. No cracks were obtained in six trials over 1200°. Inspection of the cracked angles did not indicate that cracking resulted from extrusion defects. Some of the failures were in the form of very small multiple cracks which are associated with surface contamination. From the limited number of specimens available for testing, no definite conclusions could be drawn on either the cause of cracking or optimum temperature. The results indicated that heating to 500° markedly reduced the degree of cracking. Further testing would be required to determine whether best results would be obtained at a temperature between 500 and 1200° or whether joggling must be performed over 1200°F.

A typical joggle formed at elevated temperature is shown in Figure 17.

Joggle Dimensions

A joggle shim of .162" was used for all trials. This resulted in a finish joggle height varying from .105 to .150". The least variation occurred with furnace heated angles in a heated die. With this procedure, the finish joggle height varied from .130" to .150". The forming of tight joggles (7/16") transition appears to be a problem at temperatures under 1200°F. Longer (17/32") joggle transitions resulted in a lower percentage of cracked parts. Only three trials were conducted with the longest (5/8") transition and no conclusions can be drawn from such limited results, although it is felt that a long joggle transition is desirable.

e. Bend Testing Evaluation

Specimens, Equipment and Procedure

Bend tests were performed with specimens taken from 7Al-4Mo angle and channel extrusions to determine the minimum bend radius for this extruded titanium alloy.

3/4" longitudinal strips were cut from the angles and channels. The as-extruded surface of the specimens was not altered for the bend tests. All bends were made transverse to extrusion between beryllium copper V blocks mounted in a vise. Bend tests were made at room temperature, 800°F and 1000°F. For the high temperature tests, specimens were heated in air in an electric furnace for 10-15 minutes to reach the recorded temperature. The beryllium copper jaws were maintained at 800° - 900° by internal cartridge heaters for both 800° - 1000° bend specimens. Transfer from the furnace to the V blocks was accomplished with hand tongs in approximately 5 seconds. The gradual cooling as vise pressure was applied generally required 2 or 3 furnace reheatings of the specimen to maintain the temperature until the desired 90° bend was attained. The bent specimens were then examined for cracking without magnification.

Results

The results of the bend tests of 3/32" 7Al-4Mo extrusions are shown in Table 4.

It was not possible to bend specimens at room temperature without cracking at *6T radius, which was the largest radius available in the bend test tooling. Extruded material did not crack at radius up to 3T, at 800° and 1000°F. Heat treated and aged material required a 4T radius to avoid cracking at 800° and 1000°. The solution treated material was least ductile and required 5T at 800°F and 4T at 1000°F to avoid cracking.

f. Drilling Evaluation

Introduction

A drilling evaluation was conducted with 7Al-4Mo titanium alloy angle and channel extrusions to determine the drilling characteristics of the material. As extruded and heat treated extrusions in the Rockwell "C" hardness range of 37 to 40 were used in the evaluation. Drill sizes of #7 and #21 which represent typical small fastener hole sizes were tested with the higher included point angles typically used for harder materials. Drill life was measured in terms of the maximum number of holes which could be drilled into the 3/32"

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* T represents material thickness. 6T = 6 x 3/32 = 9/16 radius.

thick extrusions before either the drilling pressure or the drilling time doubled. Feed pressure was maintained by hand to obtain the highest cutting rate possible without excessively heating or breaking the drill. A table of the results of the evaluation is presented in Table 5. The table indicates the number of holes which resulted from standard twist drills of steel and carbide when these drills were tested with 3 surface speeds and several drill point modifications (Figure 18). The time required to drill the first hole for each set of conditions is an economically important factor and is tabled with the number of holes obtained so that both factors can be considered together.

Results and Conclusions

Drill Material

Carbide tipped drills with standard point configuration produced 25 to 30 holes as compared to 3 to 14 holes with the various grades of steel drills. This advantage with carbide did not occur in the type "D" reduced web point where the carbide tipped drill produced 50 holes as compared to 60-130 holes with steel drills. The results further indicated that carbide drills were not advantageous since longer drilling times were required due to the sensitivity of the carbide point to compressive forces which required lower feed pressures to avoid crumbling the drill edge. Therefore, since the carbide tipped drills did not result in a performance advantage under the best drill point conditions and since these drills cost considerably more than steel drills, they are not recommended for this application.

Cobalt steel and deep nitrided steel drills produced more holes than high-speed drills under comparable drill point conditions . This advantage varied from 10 to 100% depending upon drill speed and drill point. After the first sharpening nitrided drills produced less holes since grinding removes the nitrided case at the base of the drill, and reground nitrided drills can be considered equivalent to high-speed drills. In view of the performance advantage, cobalt and deep nitrided drills are particularly recommended, although high-speed steel drills are quite satisfactory. In this application, the additional cost of the cobalt steel drill will be more than offset by the greater number of holes produced during the life of the drill.

Drill Speeds

The results indicated that slower surface speed of 16 feet per minute produced more holes between sharpening than the higher surface speeds of 27 and 35 feet per minute. However, considerably longer drilling time is required per hole at the slower surface speed. For this type of application, 30 to 35 surface feet per minute with a feed rate of .002 to .004 inches per revolution are recommended since the reduced labor cost in shorter time per hole greatly exceeded the additional drill cost resulting from less holes between sharpening.

Drill Point

The most significant result of the drilling evaluation was the establishment of the drill point configuration as the major factor in determining drill productivity. The recommended Type "D" Reduced Web drill point produced approximately 100 holes between sharpenings as compared to approximately 10 holes for a standard point drill. The photographs and drill point descriptions in Figure 18 illustrate several drill point modifications that resulted in improvement over the Type A Standard Point.

The secondary clearance modification in the Split Point Type "B" drill resulted in a small improvement over the Standard Point due to the reduction in bearing work hardening and improved opportunity for cutting at the drill center.

The Type C Slash Point drill resulted in further improvement since the front edge grinding brings the center to a point to obtain minimum work hardening during drilling and the grinding also reduced the normal drill rake to 0° thereby strengthening the point cutting edge.

The Type D Reduced Web drill did not bring the drill center to a point and therefore can work harden the titanium to a greater degree than Type C. Type D, however, retains enough web to maintain a strong point for a greater number of holes than Type C where the sharper center breaks down sooner.

The Type E. Modified Split Point also has the advantage of reduced web but requires more drilling time than Type D.

TABLE 1

AC TRANSFORMER POWER REQUIREMENTS FOR RESISTANCE HEATING TITANIUM ALLOY EXTRUSION LENGTH

Max. Temp. °F	5' Length	10' Length	15' Length	Cross Section Area (sq. in.)	Current (amps) All L'gths	Rated KVA Reqd per ft. to Reach Max. Temp.
935	9.4	18.8	28.2	.1	215	4.04
				.2	430	8.08
				.3	645	12.12
				.4	860	16.16
				.5	1075	20.20
1265	14.6	29.2	43.8	.1	332	9.7
				.2	664	19.4
				.3	996	29.1
				.4	1338	38.8
				.5	1660	48.5
1410	16.0	32.0	48.0	.1	371	11.9
				.2	742	23.8
				.3	1113	35.7
				.4	1484	47.6
				.5	1855	59.5
1550	18.8	37.6	56.4	.1	441	16.6
				.2	883	33.2
				.3	1324	49.8
				.4	1766	66.4
				.5	2207	83.0
1730	21.0	42.0	63.0	.1	474	19.9
				.2	948	39.8
				.3	1422	59.7
				.4	1896	79.6
				.5	2370	99.5
1795	22.0	44.0	66.0	.1	516	22.7
				.2	1032	45.4
				.3	1548	68.1
				.4	2064	90.8
				.5	2580	113.5

TABLE 2

Stretch Wrapping Data - 7Al 4Mo Angle Extrusions

Stretch Wrap Trial Number	Extruded Surface Finish (1)	Die Temp. +0 -100°	Resistance Heated Angle Temp ±100 °	Wrap (2) Force, Tons	Stretch Force	Remarks
1	Rough	1100°	-	4	-	Failed at hot spot due to contact with die
2	Smooth	1100°	-	4	-	"
3	Smooth	800°	1100	2	4	Current on during wrapping and stretching. No flange on die. Part corrugated. Arc spot due to corrugation pressure.
4	Smooth	950°	1100°	2	4	Current on during wrapping, off during stretching. Some corrugation. Flange added to die.
5	Rough	1200°	1150°	2	-	Current on during wrapping. Failed at hot spot due to higher temperature of die.
6	Rough	800°	1150°	2	4	Intermittent current to maintain temp. in portion of angle not yet in contact with the die Failed due to resistance overheating outside wrapped portion during stretching.
7	Rough	1150°	1200°	4	8	Good result. Low % shrink.
8	Rough	1100•	1100°	4	10	Good result. High % shrink.

(1) Smooth - 75 to 125 microinches, RMS Rough - 250-350 microinches, RMS.

(2) Wrapping force recorded at start of operation. Gradually reduces to about half of original force during the wrapping operation.

TABLE 3

Joggling Data for 3/32" x .850" 7Al-4Mo Titanium Alloy Angles

Specimen No.	Die Temp. °F	Part Temp. °F	Joggle Shim	Transition Block Spacing	Finished Joggle Dimensions Height	Finished Joggle Dimensions Transition	Cracked
I Hot Die, Furnace Heated Parts, Variable Temperatures and Joggle Transition							
1	540	900	.162	.250	.134	5/8	No
2	540	900	.162	.250	.140	5/8	No
3	540	820	.162	.062	.149	7/16	Slight
4	550	1000	.162	.062	.149	7/16	Very Slight
5	550	1100	.162	.062	.142	7/16	Very Slight
6	550	1250	.162	.062	.155	7/16	No
7	550	1300	.162	.062	.148	7/16	No
8	550	1400	.162	.000	.150	5/16	No (side sheared)
9	560	1100	.162	.156	.148	17/32	No
10	560	820	.162	.156	.140	17/32	Slight
11	560	920	.162	.156	.141	17/32	No
12	560	760	.162	.156	.144	17/32	No
13	610	700	.162	.156	.130	17/32	No
14	610	750	.162	.156	.133	17/32	No
15	610	800	.162	.156	.136	17/32	No
II Part Heated While Clamped In Hot Die, Medium Joggle Transition							
16	610	500	.162	.156	.136	17/32	Yes
17	610	500	.162	.156	.139	17/32	Very Slight
18	610	500	.162	.156	.138	17/32	Yes
19	610	500	.162	.250	.124	5/8	Slight Cracks on Underside
III Unheated Die, Furnace Heated Parts, Medium Joggle Transition							
20	80	420	.162	.156	.132	17/32	Yes
21	"	500	"	"	.127	"	No
22	"	500	"	"	.105	"	No
23	"	520	"	"	.135	"	No
24	"	520	"	"	.113	"	Severe
25	"	520	"	"	.129	"	No
26	"	620	"	"	.137	"	No
27	"	630	"	"	.128	"	No
28	"	700	"	"	.130	"	No
29	"	720	"	"	.135	"	Yes
30	"	720	"	"	.120	"	No
31	"	930	"	"	.120	"	No
32	"	1000	"	"	.120	"	No
33	"	1030	"	"	.139	"	Yes
34	"	1060	"	"	.137	"	No
35	"	1100	"	"	.136	"	Yes
36	"	1200	"	"	.139	"	No
37	"	1200	"	"	.136	"	No
38	"	1200	"	"	.140	"	No
39	"	1300	"	"	.142	"	No

Part temperatures read with contact thermocouple pyrometer immediately before joggle press stroke.

Variable 1" angle extrusions machined to .850" to obtain uniform height dimension to conform with joggle kick insert height.

TABLE 4

Bend Test Results - 3/32" 7Al 4Mo Extrusions

Push Number and Treatment	Test Temp. °F.		Bend Radius			
		6T	5T	4T	3T	2T
48 B & W	R. T.	Shattered				
As Extruded	800		No Cracks	No Cracks	No Cracks	Cracked
	1000		No Cracks	No Cracks	No Cracks	Cracked
59E-B & W	R. T.	Shattered				
As Extruded	800		No Cracks	No Cracks	No Cracks	Cracked
	1000		No Cracks	No Cracks	No Cracks	Cracked
80E - B & W	R. T.	Shattered				
As Extruded	800		No Cracks	No Cracks	No Cracks	Cracked
	1000		No Cracks	No Cracks	No Cracks	Cracked
69 -U.S.Steel	R. T.	Shattered				
Heat Treated	800		No Cracks	No Cracks	No Cracks	Cracked
1650°F.-7Min/						
W.Q. + 1200°F.						
-30 Min./A. C.	1000		No Cracks	No Cracks	No Cracks	Cracked
71-U.S.Steel	R. T.	Shattered				
Heat Treated	800		No Cracks	No Cracks	Cracked	
Same As 69	1000		No Cracks	No Cracks	Cracked	
74-U.S.Steel	R. T.	Shattered				
Solution						
Treated Only	800		No Cracks	Cracked		
1650°F.-7Min./						
W.Q.	1000		No Cracks	No Cracks	Cracked	

All tests with 3/4" extrusions with as extruded surface. Bends made in direction transverse to extrusion.

TABLE 5

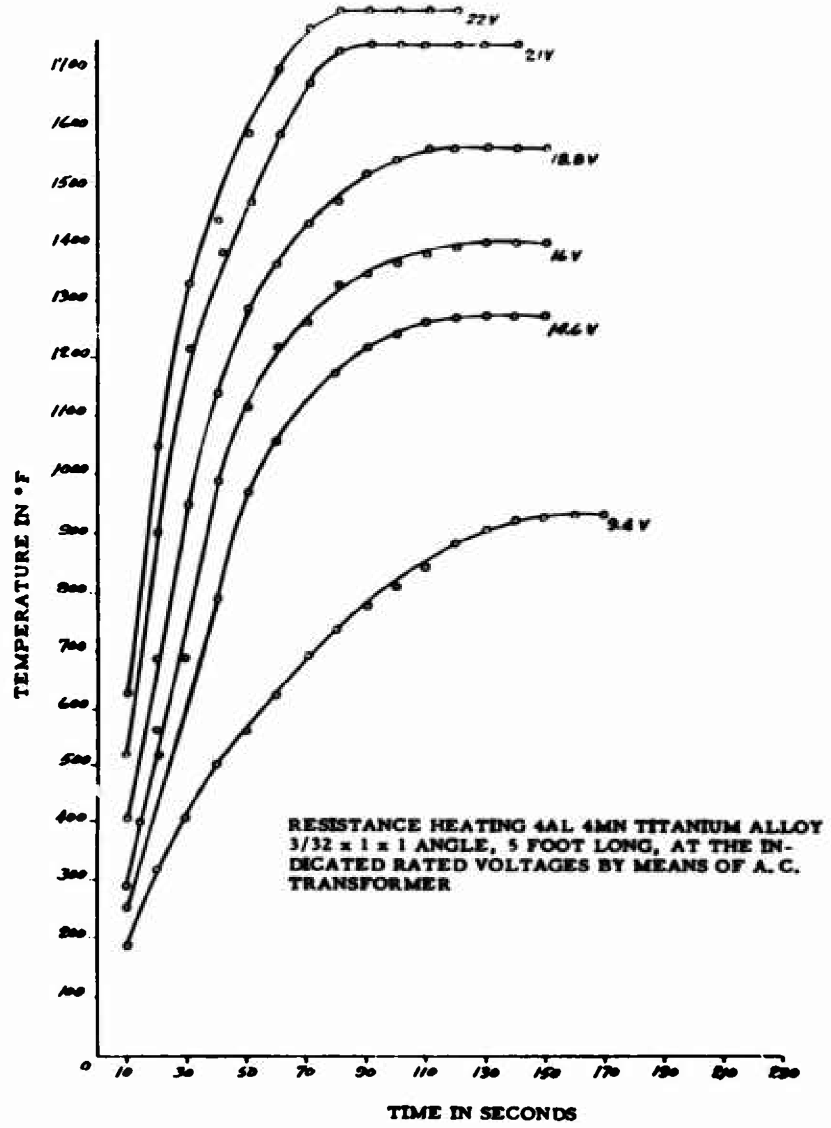
Results of Titanium Extrusion Drilling Evaluation of 37-40 Rockwell C 7Al 4 Mo Titanium Alloy Extrusions

Drill Surface Speed	A Standard Point		B Split Point		C Slash Point		D Reduced Web		E Modified Split Point	
ft. per min.	No. of Holes	Seconds per hole	No. of Holes	Seconds per hole	No. of Holes	Seconds per hole	No. of Holes	Seconds per hole	No. of Holes	Seconds per hole
Carbide Tipped - $4.00 each										
40	25	10					50	5		
30	30	12								
High-Speed Steel - $.50 each										
35	3	9	5	2	14	3	60	1		
27	6	15	8	3	20	4	80	1 1/2		
16	10	22	16	5	30	6	100	4		
Deep Nitrided - $.50 each										
35	5	9	25	2			100*	1	100*	2
27	10	15	25	3			100*	1 1/2	100*	2 1/2
Cobalt Steel - $2.00 each										
35	8	9	13	3	16	3	100	1		
27	11	15	11	3	27	4	100	1 1/2		
16	14	21	17	5	30	6	130	4		

The type "D" Reduced Web steel drills produced the best results both in number of holes per drill and in drilling time per hole. The deep nitrided and cobalt steel drills are particularly recommended.

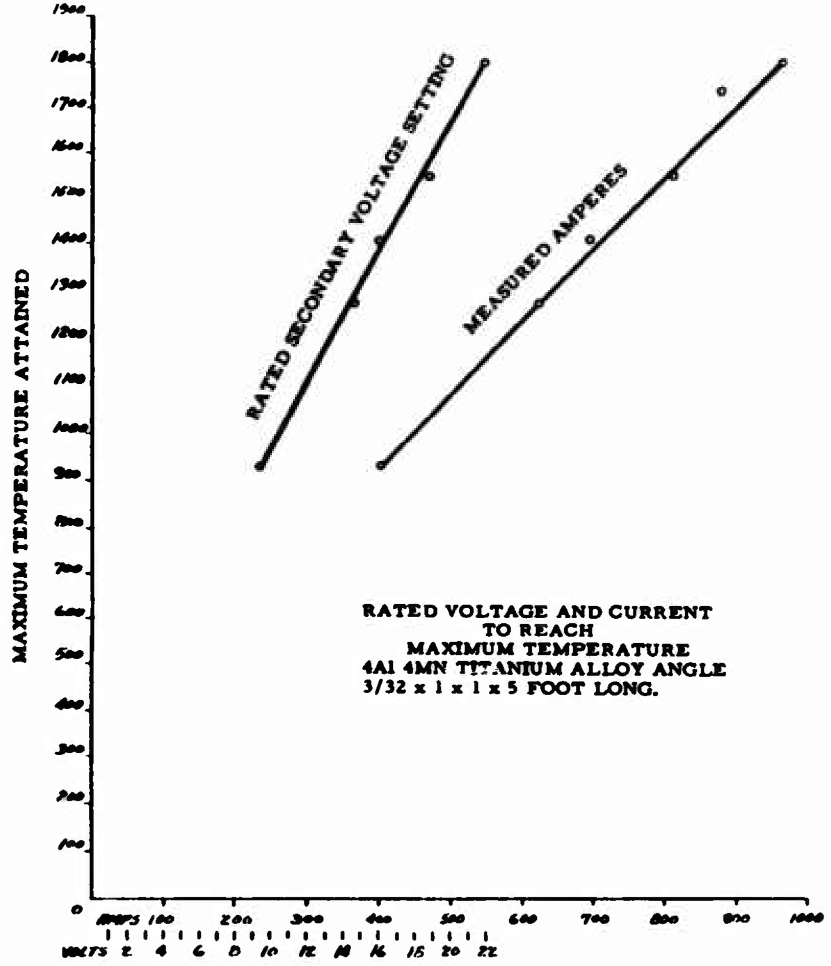
Drilling time is recorded for the first hole and represents time from contact to break-through.

* 60-80 after sharpening.



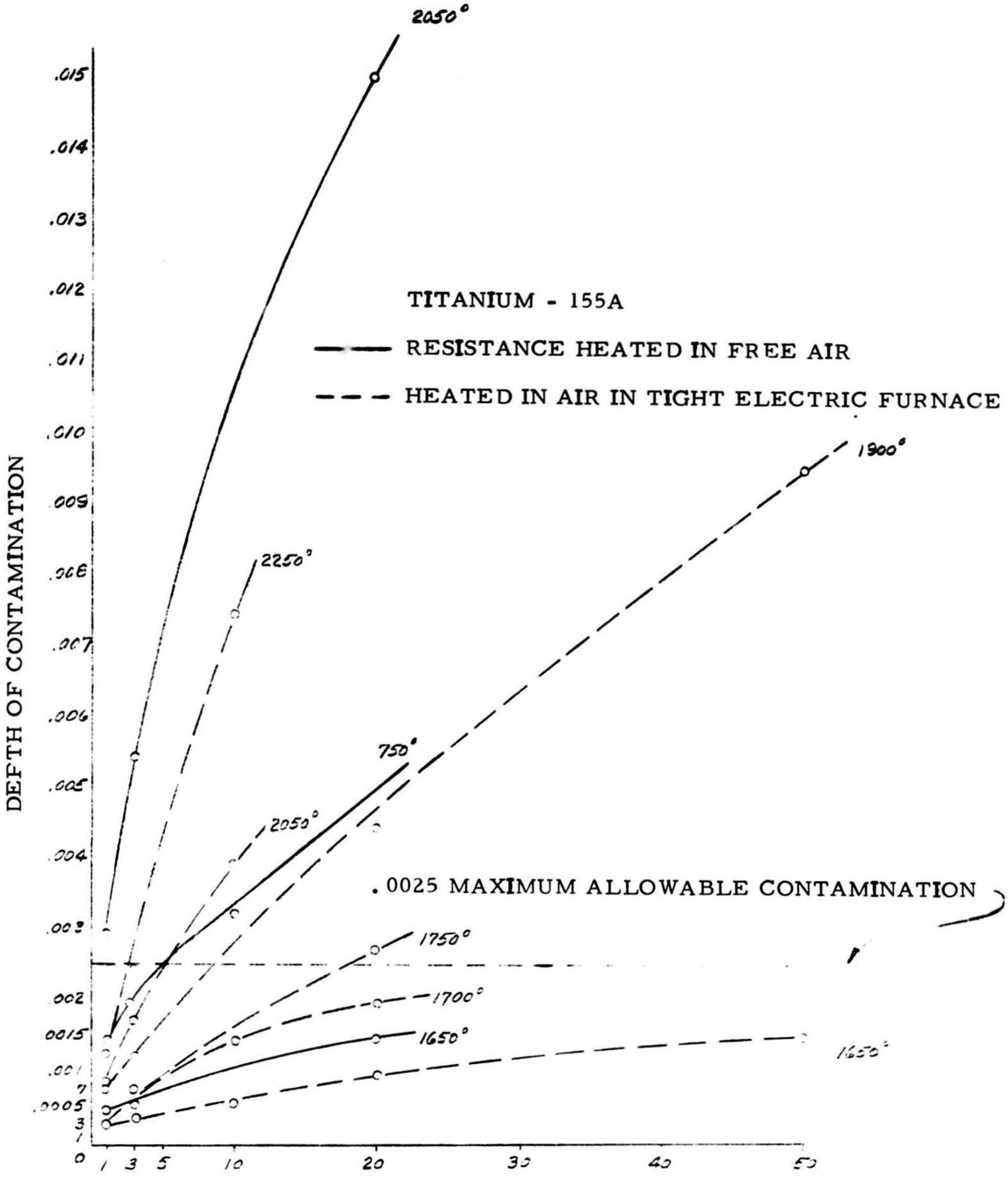
Rate of Resistance Heating at Various Voltage Settings for a Ti-4Al-4Mn Angle

FIGURE 12



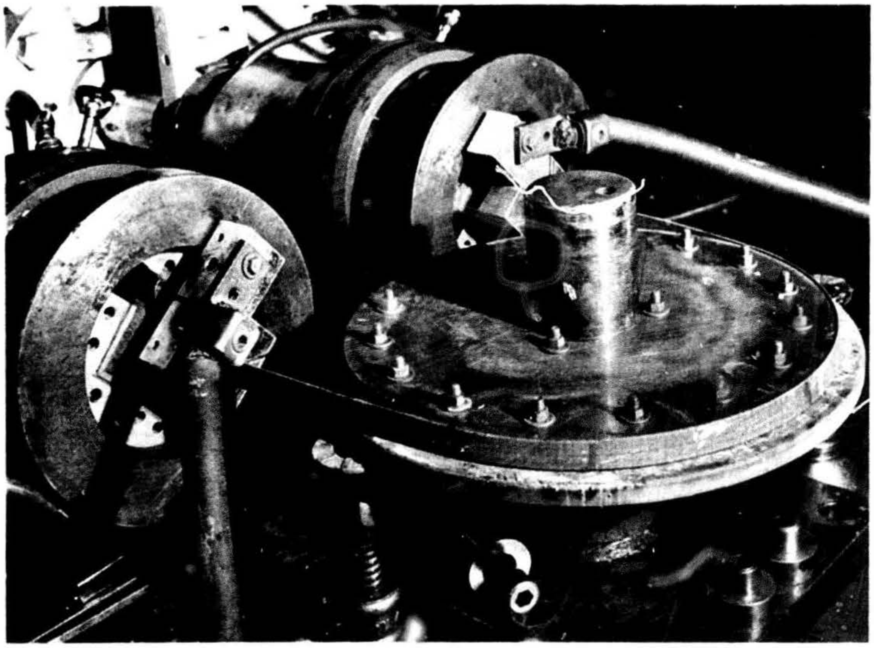
Rated Voltage and Current to Reach Maximum Temperature in a Ti-4Al-4Mn Angle

FIGURE 13



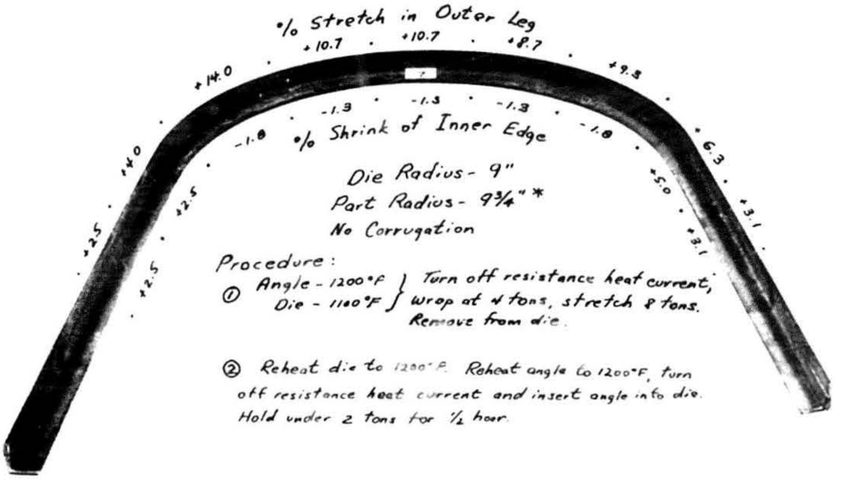
Depth of Contamination Versus Exposure Time in Heating of Ti-155A

FIGURE 14



Ti-7Al-4Mo Angle During Stretch Wrapping

FIGURE 15



Die Radius - 9"
Part Radius - 9¾" *
No Corrugation

Procedure:

① Angle - 1200°F, Die - 1100°F } Turn off resistance heat current; wrap at 4 tons, stretch 8 tons. Remove from die.

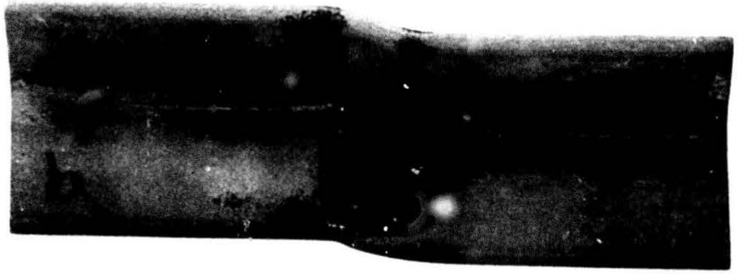
② Reheat die to 1200°F. Reheat angle to 1200°F, turn off resistance heat current and insert angle into die. Hold under 2 tons for ½ hour.

* Photograph shows angle after procedure ② which produced the 9¾" radius on the part. After procedure ③, consisting of holding the angle against a 1200°F die for 3 minutes under 1 ton pressure, the part radius remained within 1/16" of the die radius. Stretch and shrink were unchanged.

Stretch Wrapped Ti-7Al-4Mo Angle

FIGURE 16

605288



Inside surface of 7Al 4Mo angle joggled at 1100°F in a die heated to 560°F. The joggle is well formed without cracks.

Inside surface of 7Al 4Mo angle joggled at room temperature in an unheated die. Severe cracking resulted from all such trials.

Outside surface of above angle. The dark areas are due to surface discoloration in heating.

Outside surface of above angle.

Joggles in a Ti-7Al-4Mo Angle

FIGURE 17

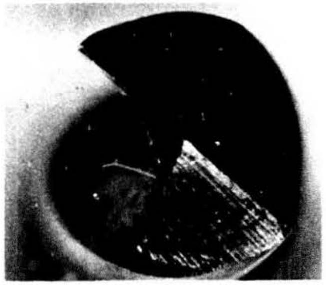
605 288

Type A - Used
Standard Point
130° Included Angle
10° Back Clearance
No web modifications
3 to 30 Holes

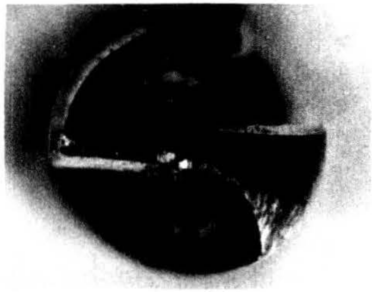
Type B - Used
Split Point
135° Included Angle
First clearance 10°
Second clearance at
45° to meet in center
No web modifications -
5 - 25 Holes

Type E - Not Used
Modified Split Point
150° Included Angle
Back Clearance 10°
Web reduced by grinding
second clearance at 45°
with sharp corner wheel.
- up to 100 Holes

Drills are shown as sharpened or after use. The range of holes obtained with the configuration in several drill materials is shown.



Type C - Not Used
Slash Point
150° Included Angle
10° Back Clearance
Modified to zero rake by
barely grinding outer edge
and meeting at center point.
No other web modifications.
14 - 30 Holes



Type D - Used
Reduced Web
150° Included Angle
10° Back Clearance
Modified to zero rake by substantial grinding of outer edge
and reduction of web to 1/2
original thickness.
60 - 130 Holes

Drill Point Configurations for Titanium Alloy Drilling
FIGURE 18

5 Heat Treatment Studies and Mechanical Property Testing

a. Specimen Testing

Extensive heat treatment studies and mechanical property testing was performed with both the Ti 155A titanium alloy and the C135 A Mo titanium alloy. Studies were conducted at U.S. Steel Corporation, Babcock and Wilcox Company, Crucible Steel Company and Republic Aviation Corporation. The objectives of the studies were to develop heat treat cycles which would give the following target properties:

1) Room temperature tensile ultimate strength of 180,000 psi with 8% minimum elongation

2) 800°F stability at 70,000 psi load for 500 hours

3) 0.5% creep after exposure to the 800°F stability conditions

Crucible Steel Company developed a heat treat cycle for C135 AMo with micro tensile specimens having a 0.6" gage length which met the ultimate tensile strength requirements of 180,000 psi with 8% elongation. The desired properties were achieved by both of the following processes:

	1	2
Extrusion:	1800°F	1750°F
Solution Heat Treat:	1800°F/ 1/2 hour water quench	1800°F/1/2 hr. water quench
Aging:	1200°F/4 hours air cool	1150°F/8 hours air cool

However, considerable testing at Babcock and Wilcox Company and Republic Aviation Corporation indicated that the target properties could not be obtained with the heat treat developed by Crucible Steel Company when a standard tensile specimen (2 inch gage) was used for the test.

The testing also revealed that no significant differences in properties between "as cast" and "forged" billet extrusions were indicated in heat treated material. "As-extruded" material with an "as cast" history had comparable tensile ultimate strength to the "forged" billet extrusions; however, the tensile yield strength of the "as cast" extrusion was slightly lower while ductility and modulus of elasticity was slightly higher. Typical extruded properties were 173,000 ultimate strength with 8% elongation and typical heat treated properties were 187,000 ultimate strength with 2.5% elongation. The microstructure of the extrusion produced from an "as cast" billet did not show any significant difference from that of the "forged'billet.

Metallographic analyses conducted at each of the four organizations listed above indicated that the majority of the extrisions produced using billet temperatures of 1800°F exceeded the beta transus. This rise in temperature of the billet during extrusion is attributed to internal friction generated in the billet. A typical photomicrograph is shown in Figure 52.

The presence of Widmanstattan alpha platelets (basketweave) within the prior beta grains outlined by an alpha network, indicate that the material has exceeded beta transus temperatures. The complete transformation of alpha to beta above the beta transus is time dependent. This would explain the presence of the primary alpha often seen after extruding (short time operation) at temperatures above the beta transus. The delineation of these alpha globules varies directly as the amount of time spent above the beta transus. Most of the 7Al-4Mo alloy billets extruded at 1650°F to 1810°F billet temperature contained 5 to 25 percent primary alpha. Mechanical property results show these type structures superior to those obtained when extruding at temperatures higher in the beta field. At these temperatures, no primary alpha remains and thus some beta embrittlement may occur.

b. Heat Treatment of full Length Sections

Heat treatment of full length extruded sections was conducted in an atmosphere controlled vertical furnace to test the process as a production method. The heat treating was conducted at Metlab Company. The lengths to be heat treated included three C135 A Mo channel extrusions and six 7Al-3Mo angle extrusions. Solution treatment was conducted at 1650°F for 10 minutes followed by a water quench. Aging was accomplished by reheating to 1200°F for one hour followed by an air cool. Temperature tolerance was set at ±10°F.

The heat treating equipment used consisted of a propane fired vertical furnace with an Inconel X retort and uniform heat zone of about 13 feet. This heat zone was divided into five sub-zones, each individually controlled by a Foxboro mechanical controller and facilities for recording temperatures at each zone with a Brown mechanical multipoint recorder. For protective atmosphere, helium out of a steel bottle was fed into a manifold equipped with a Selas flowmeter. During the purging operation, a flow of about 50 cubic ft/hr. was maintained. The retort was purged for about two hours, and then the first load of work was placed into the furnace and suspended from a spider with Inconel X pins. The work was split into two runs in order to be able to check out the method. For the first run, one channel and one angle were used. On this run, a blower inadvertently discontinued operation, thus decreasing the furnace temperature to 1425°F before a return to the required temperature could take place. Twenty-two minutes elapsed before 1650°F was again reached after which the work was held at temperature for 8 minutes. The subsequent water quench has handled well and took no more than one minute for the entire length to hit the water.

The furnace was then allowed to return to the equilibrium temperature of 1650°F and the second load consisting of two channels were admitted. No difficulties occurred during the run. The furnace dropped only 60 degrees which was corrected within eleven minutes. The work was then held at temperature for 10 minutes and quenched in water.

The aging treatment was performed with the same equipment at 1200°F ± 10° for 1 hour and was then allowed to air cool.

Straightened extrusions were not available at the time the vertical heat treatments were conducted. The angle and channel lengths were heat treated with the twist and distortion resulting from extrusion, and were stretch straightened after heat treatment. Due to the lack of straightness in the extrusions before heat treatment, it was not possible to establish how much additional distortion occurred during heating and quenching.

Mechanical property tests on specimens obtained from the production heat treated lengths indicated that all target properties could be achieved with the exception of room temperature elongation.

C. PART III EXTRUSION OF SECOND CATEGORY SHAPES

1. Extrusion and Straightening Development at Babcock and Wilcox Company

a. Extrusion Development

Objectives

The general objective of the Part III development program at Babcock and Wilcox was the establishment of extrusion and straightening processes for the production of the 1/8 inch Tee shape shown in Figure 2 .

The extrusion objectives of Part III were to provide an extruded product of 125 microinch RMS surface and dimensional uniformity throughout fifteen foot lengths. The desired mechanical properties of heat treated extrusions were (1) 180, 000 psi ultimate strength with 8% minimum elongation, (2) less than . 5% permanent deformation after 800° F, 70, 000 psi, 500 hour creep exposure, (3) stability after creep exposure as indicated by subsequent room temperature ductility.

Efforts to achieve the dimensional objectives included investigation of variables such as lubrication, die materials, billet temperature, billet length and tooling temperatures.

Extrusion Trials

Seven trials were held in Part III. A total of eighty-five extrusions were pushed including six 4340 steel billets, seven 18-8 stainless steel billets, ten Ti 6Al-4V titanium alloy billets and sixty-two Ti 7Al-4Mo titanium alloy billets. Initial extrusions of AISI 4340 and Croloy 18-8 were made to check the extrusion practice and new tooling for the tee shape

Considerable die breakage was experienced during the December 1st trial of Part III due to insufficient circumferential support during extrusion. This condition was corrected by reducing the outside diameter of the dies and incorporating the smaller dies into a thin conical die holder, Figure 19. The tapered fit between the die holder and container produced a compressive force on the die holder which is transmitted through the thin cone to support the die. The new design was completely effective in avoiding die breakage. A comparison of die dimensions before and after extrusion indicated that the compressive effect actually closed the orifice dimensions during extrusion.

After each push, dies and butts were examined in an effort to relate flow lines to extrusion scores and to determine whether the glass reservoir was adequate. Examination was made with glass caked to the butt and die and again after the glass was cleaned off. Extrusion butts and shapes revealing typical extrusion defects are shown in Figures 20-30.

The results of the trials are summarized below:

Results

(1) Cast billet material tends to tear along the leading edges of the extrusion during the initial breakthrough. The forged material does not. (See Figure 21).

(2) Uneven material flow during extrusion, due to uneven temperature distribution or lubrication, leads to partial scalping and results in laminations (See Figure 20)

(3) The can and cover used for heating and transporting the billets should be made of stainless steel to avoid contamination of the billet coating when the billets are removed from the can.

(4) Continuous glass lubrication for the entire length of extrusion protects the die and assists in preventing die wear.

(5) Longer heating time produced a streaky billet possibly due to excessive fluidity of the glass coating. This caused glass flow, thereby reducing glass protection in some areas In certain cases, the contamination appeared as small dark areas and caused surface imperfections on the billet surface and extruded section (See Figure 22). Figure 23 shows photomicrographs which identify the dark particles as separated portions of the billet skin. The particles appear as alpha phase from interstitial contamination during heating

(6) Softer glass die glass pads such as 318 material produced an irregular rough surface. It was felt that the 318 glass was not hard enough to iron the extruded metal as well as coat it at elevated temperatures. (See Figure 24).

(7) The die material was not too critical. There was little to choose from between the Peerless "A" and M-36 as long as lubrication was effective. The Inconel 713C dies were better in flat areas, but flowed readily in the fillet area at

high temperatures. Shell-mold cast, single orifice dies were satisfactory. Final orifice dimensioning was done by electric spark machining and consistent dimensions were obtained. Heating the dies to 900° F gave good results. Little or no die marking or deformation occurred in the orifice area under the best conditions. Such damage as did occur generally reduced the orifice size and was readily removed by a repeat spark finishing operation.

(8) The chromium plated container was generally good and reusable after the trials. There were two spots approximately 1-inch square that flaked off in areas where the die holder seated against the container. There was no container wear in the billet area except for some scratch lines in the upper portion of the container which was apparently due to dummy block eccentricity.

(9) A high container temperature appeared to be the controlling factor for proper continuous glass lubrication.

(10) The excess lubricant from the 1-inch thick die lubricant pads constricted the extrusion material approaching the die. This was clearly shown in the butts from Pushes 92 and 93 in Figure 25. The constricted "cross section" was less than the die orifice height and width and resulted in an incomplete "filling out" of these dimensions on the shape. Pads one-half inch thick eliminated the constriction effect and produced width and thickness fill-out.

(11) Die pads compacted of -40 fine mesh glass particles yielded shapes that were smaller and with more variation from front to back. The standard -14 mesh particles yielded shapes of more consistent dimensions.

(12) The scalping technique produced a smooth surface (60-125 RMS) without billet surface marks whereas the full lubrication technique produced a rougher (100-200 RMS) surface with billet surface marks. Under good heating and extrusion conditions such marks were so shallow that with a light grit blast, the typical herringbone pattern of the marks was removed. The effect of billet surface marks on the extruded surface is shown in Figures 26 and 27.

The full lubrication technique had the following advantages over the scalping technique:

(a) Lower extrusion pressures due to less sidewall friction. With the 7Al 4 Mo titanium alloy, the lower pressure permitted full lubrication extrusions of 20 feet whereas the scalping technique appeared limited to 12-15 feet with the particular shape and press tooling involved.

(b) Full lubrication offered a higher product yield since the billet skin was not rejected in the container as occurred in scalping.

It was felt that where surface finish is more of a consideration than maximum length, the scalping technique is preferred. Where maximum lengths are required, the full lubrication practice is preferred.

The extrusion trials which were conducted during the latter portion of Part III emphasized the full lubrication practice in an effort to meet the program objectives of 15-foot lengths.

b. Straightening Development

Effective hot stretch straightening was realized during Part III on a specially constructed stretch press modified with improved pneumatic operated grips which were insulated and served as the electrodes.

The straightness of the straightened shapes approached, but did not meet, the objectives of .012" per foot over the entire length.

The technique employed in straightening the shapes consisted of placing the extrusion in the gripper jaws and gripping the shape; resistance heating the length to temperature, detwisting and then stretching. After straightening the tension was released gradually. The air pressure holding the jaws closed was then released. Tension on the extrusion was continually released gradually until the extrusion started to bow in compression. This supplied the force necessary to release the jaws by forcing the jaws back into the wedge shaped chuck.

In an attempt to prevent the formation of the bow on the straightened extrusion, a bar was placed between the jaws when the extrusion was in the stretched position. Gradual release of tension would then result in the "jaw release bar" supplying the force necessary to slide the jaws so that they are in the opened position (see Figure 31)

However, several attempts with the "jaw release bar" resulted in bending of the bar or shearing of the bolts holding the stationary gripper head to the bed of the machine. Use of the "jaw release bar" was therefore discontinued. Attempts were also made to maintain straightness during cooling and eliminate the mushroom shape crown in the top of the tee shape by placing the extrusion in a restriction fixture upon removal from the stretch press. Steel rods were tack welded to the hinged cover of the fixture in an effort to produce an overbending effect to correct the crown shape in the top of the tee. The restriction fixture was unsuccessful, however, since the extrusions cooled sufficiently during transfer from the stretch press to the fixture to make straightening by this method impractical.

Results and conclusions of the Part III straightening trials are listed below:

1. The decrease in shape dimension with extrusion elongation was sufficient to necessitate increasing the die orifice dimensions to anticipate the decrease.

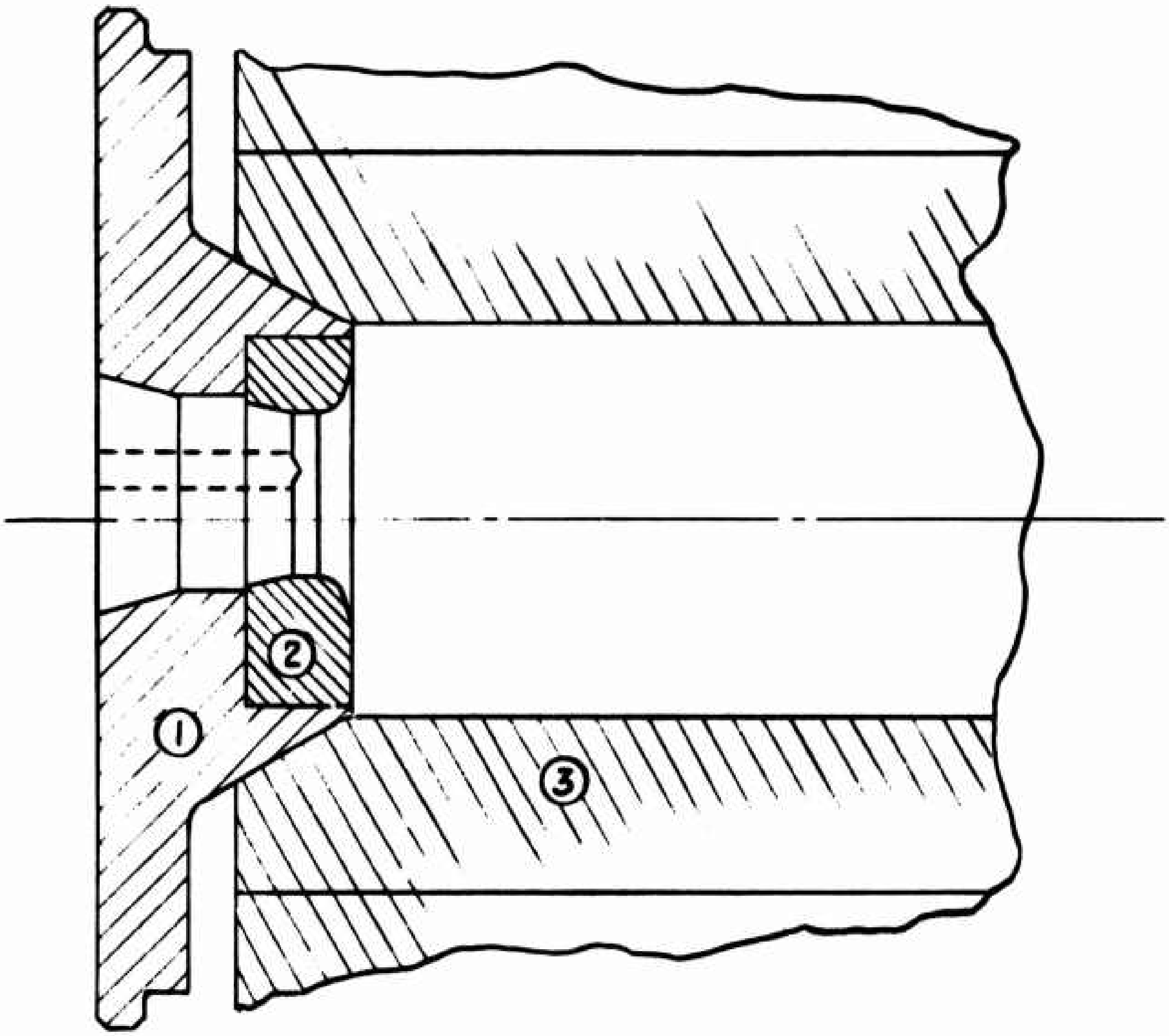
2. Air operated collets with diamond teeth of 1/16" pitch securely held the extrusions without slippage. The jaws should be clamped on a portion of the tee shape that is not severely distorted or twisted.

3. Use of insulated jaws as electrodes assures uniform electrical contact, produces a straighter extrusion near the grips and saves at least 1 foot of cropping per extrusion by avoiding local hot spots from clamping the electrodes.

It is necessary to check that all three jaws contact the tee shape uniformly. One extrusion was not uniformly clamped and a hot spot developed at the jaw. Reclamping eliminated the problem and the extrusion was straightened without failure.

4. Stretch straightening and detwisting at low elongations of 2-4% produced overall straighteness, but do not completely remove local twists. Higher elongations of 6% produce complete straightness and remove local twists completely. However, high elongations produced greater dimensional variation along the extrusion. Resistance heating with the tee shape in an upright position (as in the printed letter, T) produces a differential of 100-150° between the stem and the top of the tee. The stem does not become as hot since it is more exposed and the heat rising from the stem shields the top. Uniform heating throughout the section was obtained by clamping the tee extrusions in the reverse position so that the heat rising from the base shields the more exposed stem.

5. A very severe instance of high temperature, high stress corrosion was experienced in one 3" area near the middle of one of the extrusions. After straightening at 6% elongation, severe transverse cracks were apparent in parallel lines in the 3" area. The cracks corresponded exactly to tempilstik crayon markings which were used to determine temperature. Smaller cracks originating from tempilstik corrosion were also observed on another extrusion which was straightened. Use of tempilstiks to measure temperature was therefore discontinued.



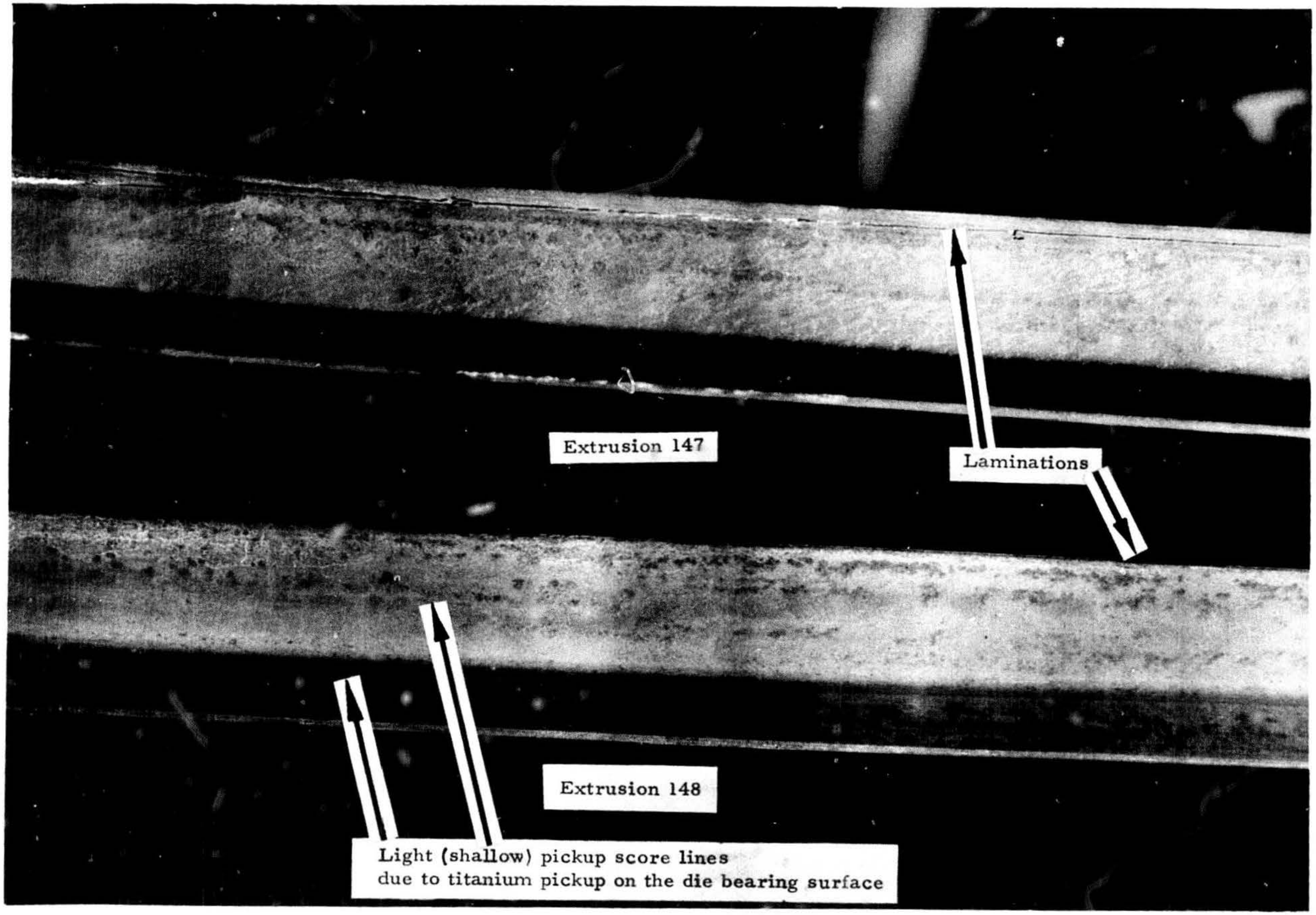
① DIE HOLDER

② DIE

③ CONTAINER

Tooling Arrangement Used During Part III Extrusion Trials. During Extrusion, the Conical Die Holder (1) is Wedged Into the Container Which Thereby Transmits a Compressive Force Which Supports the Die Circumferentially

FIGURE 19

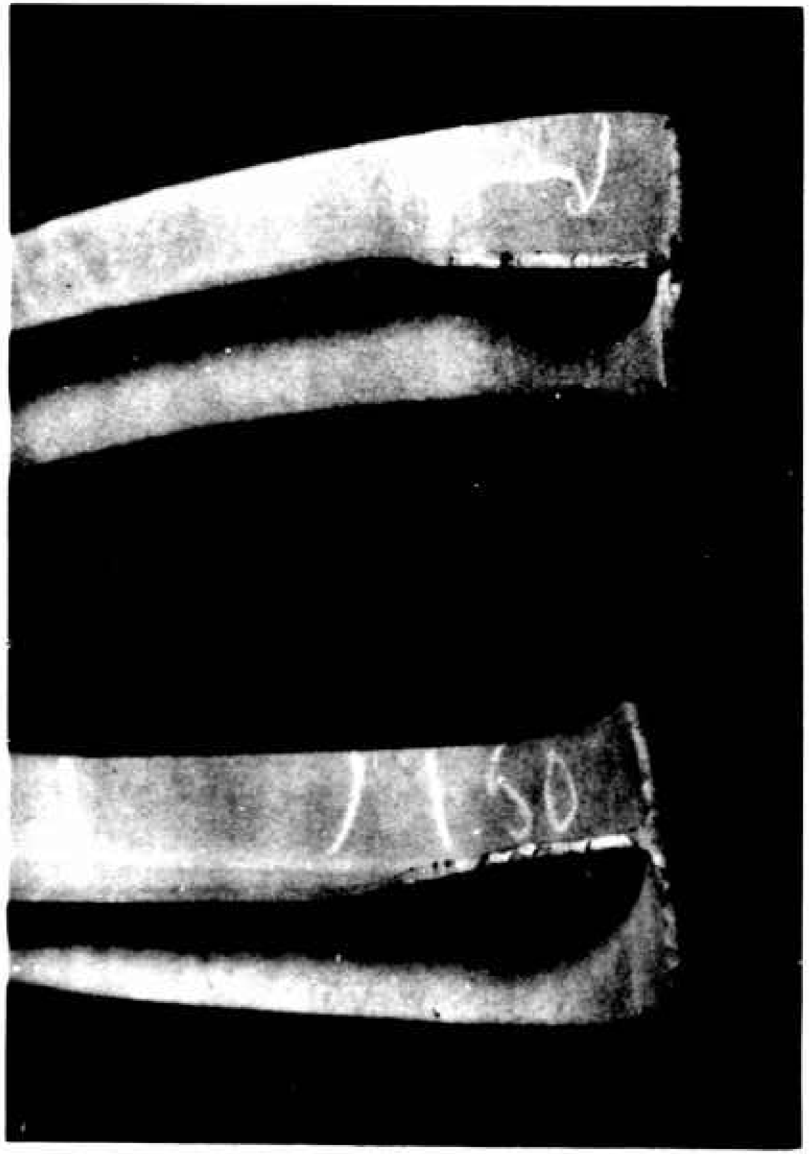


The laminations are extruded after an internal shearing of the billet metal has occurred. The shearing is due to the slower flow of the relatively cool billet surface as compared with faster flow of hotter interior billet metal.

ck End Laminations and Pickup Score Lines

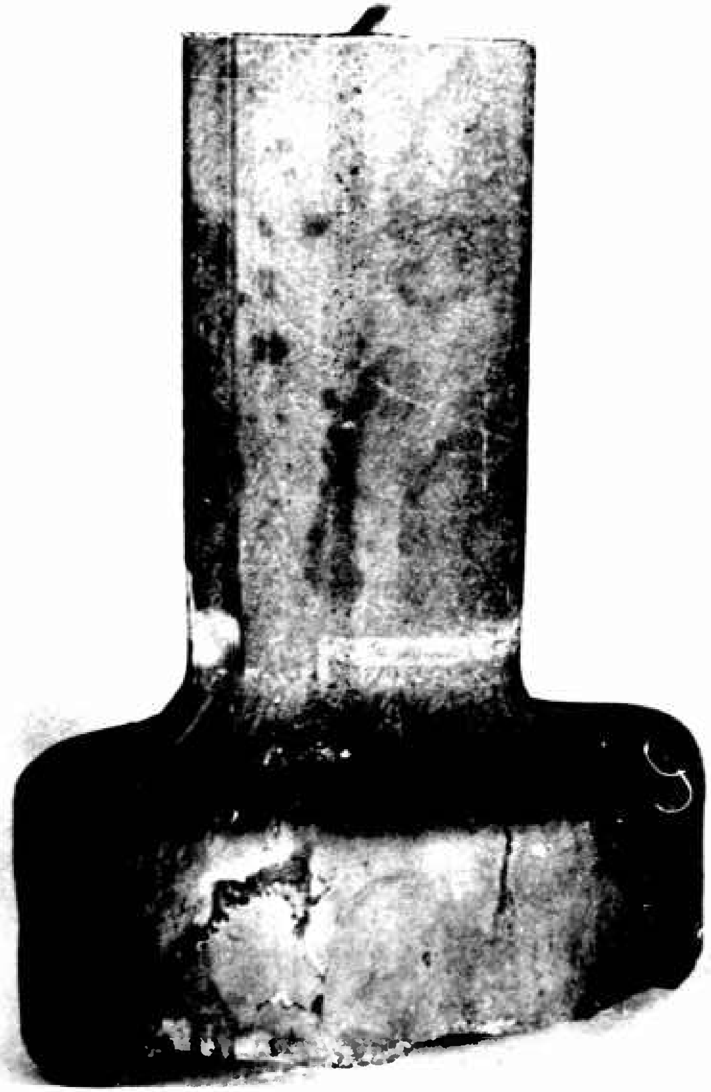
FIGURE 20

605288



Tears During Initial Break-Through on Extrusion of Cast Billet Material

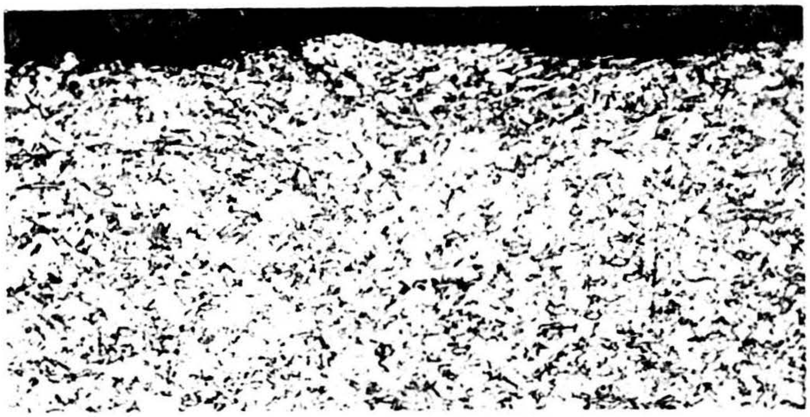
FIGURE 21



Discard of Push No. 168 Showing Regions of Black Areas on the Billet Surface Which Ultimately Result in Black Spots on the Extrusion Surface (See Fig. 23)

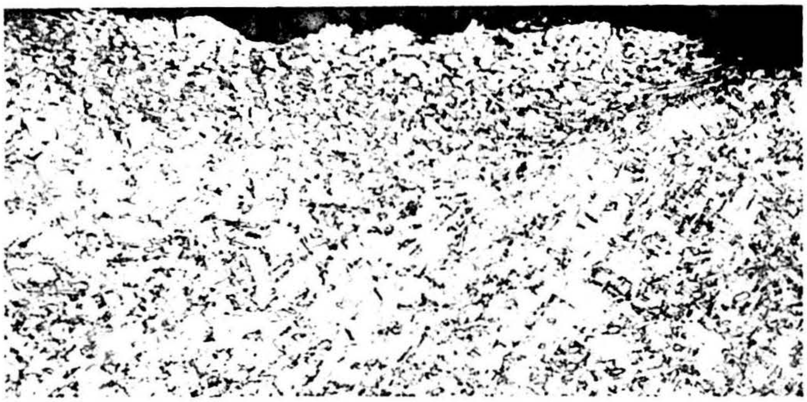
FIGURE 22

605 288



A. Extrusion 133 250X HNO_3 HF etch

"Smooth" type billet mark which appears dark in the glass film and is gray after deglassing.

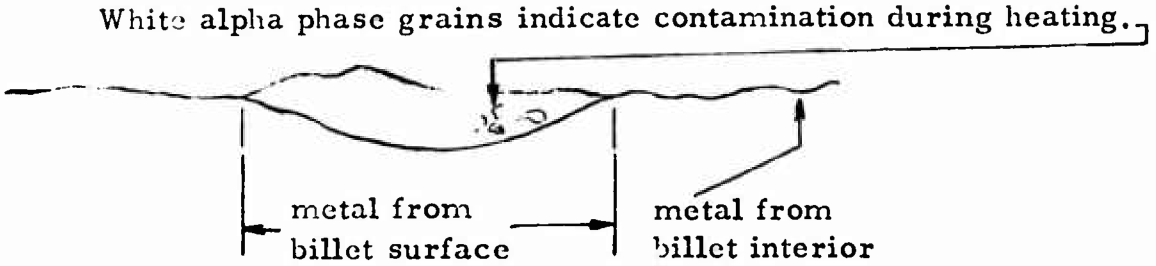


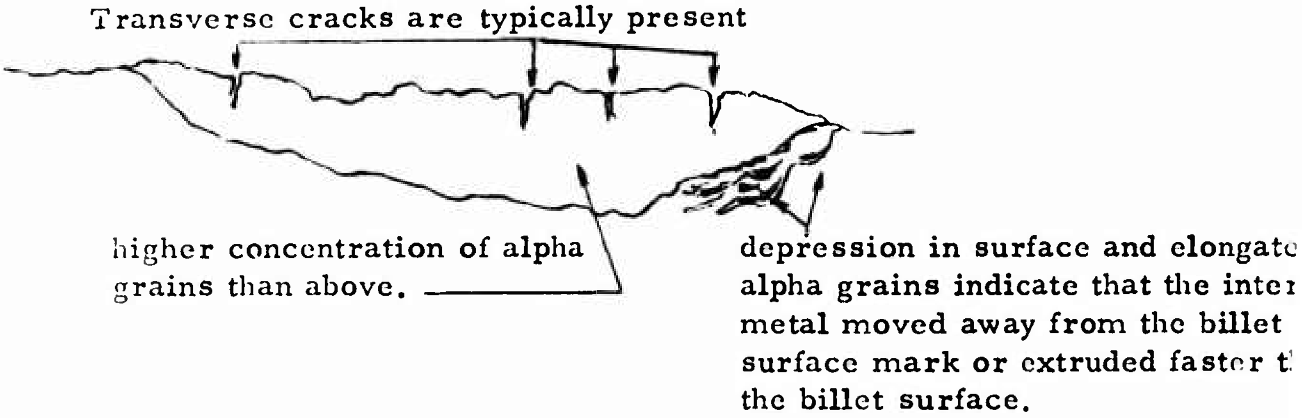
B Extrusion 133 250X HNO_3 HF etch

"Pebbly" type billet mark which appears dark in the glass film and is dark after deglassing.

C Extrusion 128 250X HNO_3 HF etch

Severe billet surface mark which appears to be an accumulation sheared from the extrusion.



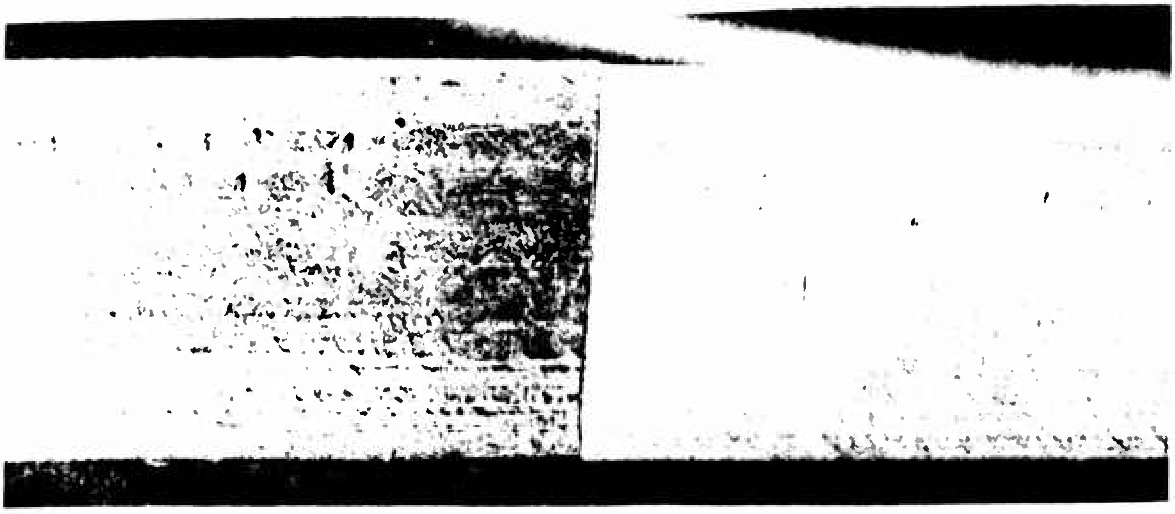


A and B are from the front end of 133 and C was taken near the back of 1

Micrographs showing Varying Degrees of Billet Surface Marks in the Extrusion Surface after Deglassing

Direction of Extrusion ⟶

FIGURE 23

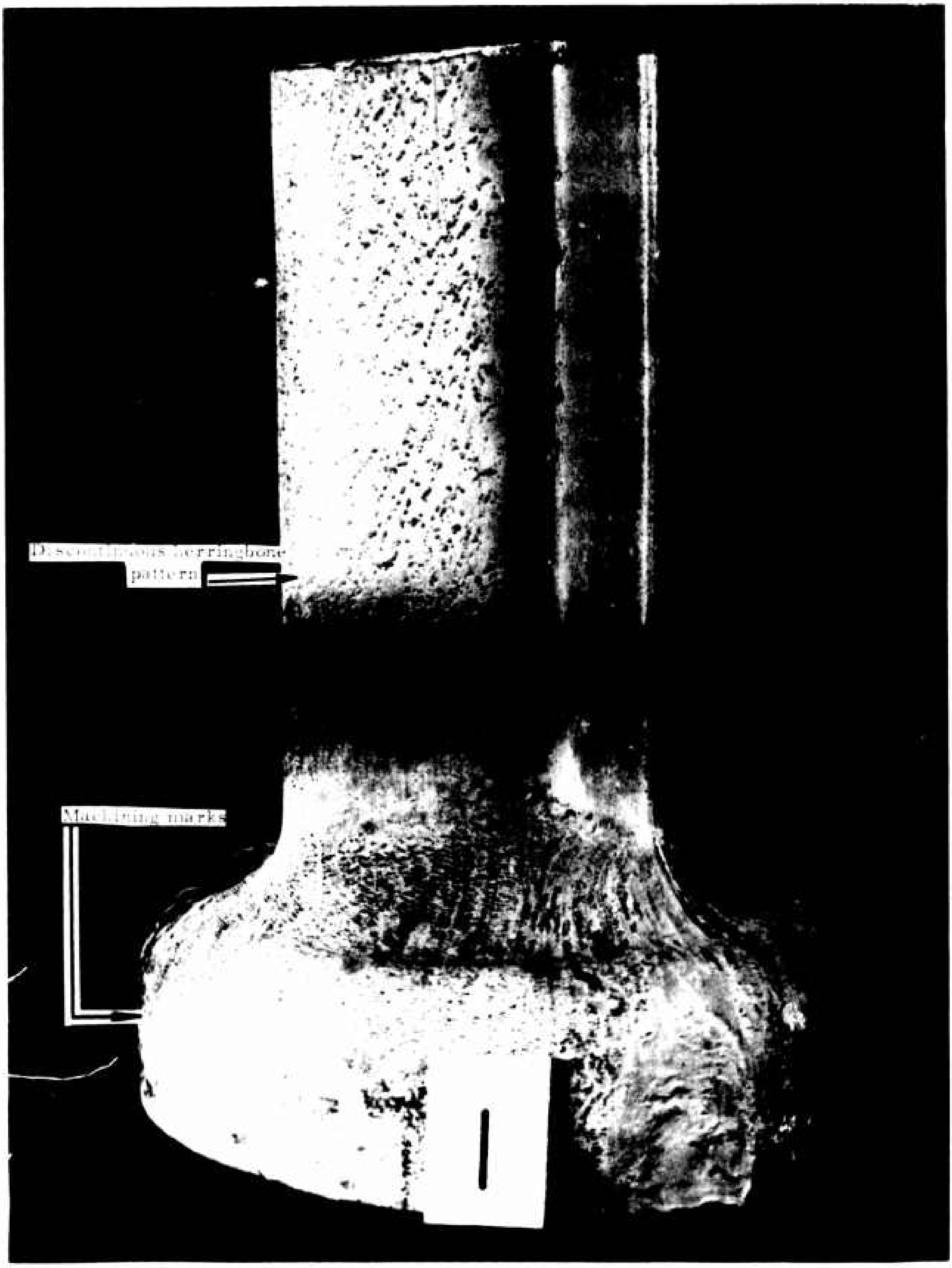


Extrusion 172, Showing the Rough Surface Resulting From Using the Soft (lower viscosity) 318 Glass as a Die Lubricant. Area Shown is Near the Shape Front-End.

FIGURE 24

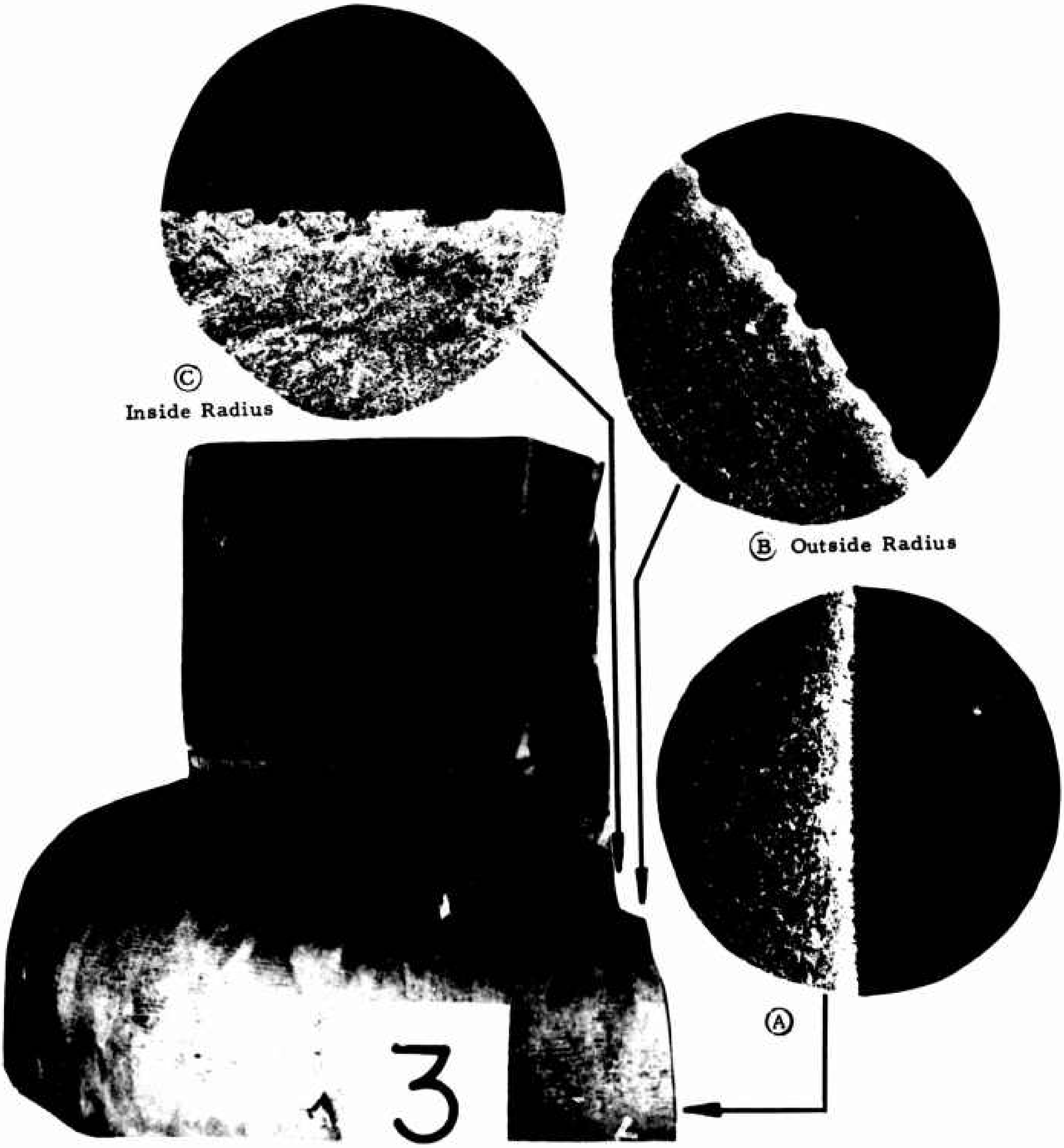
Photograph of Butt Ends from Extrusions 92 and 93. The wavy Condition of the Tee Stem and the Constricted Zones Between the Billet and the Extrusion Result from the Excess Lubricant in 1" Thick Glass Pads

FIGURE 25



Billet and Extrusion Discard - Push No. 177. Discontinuous Herringbone Pattern due to Billet Surface Machine Marks are Distinguishable on the Extrusion Surface.

FIGURE 26

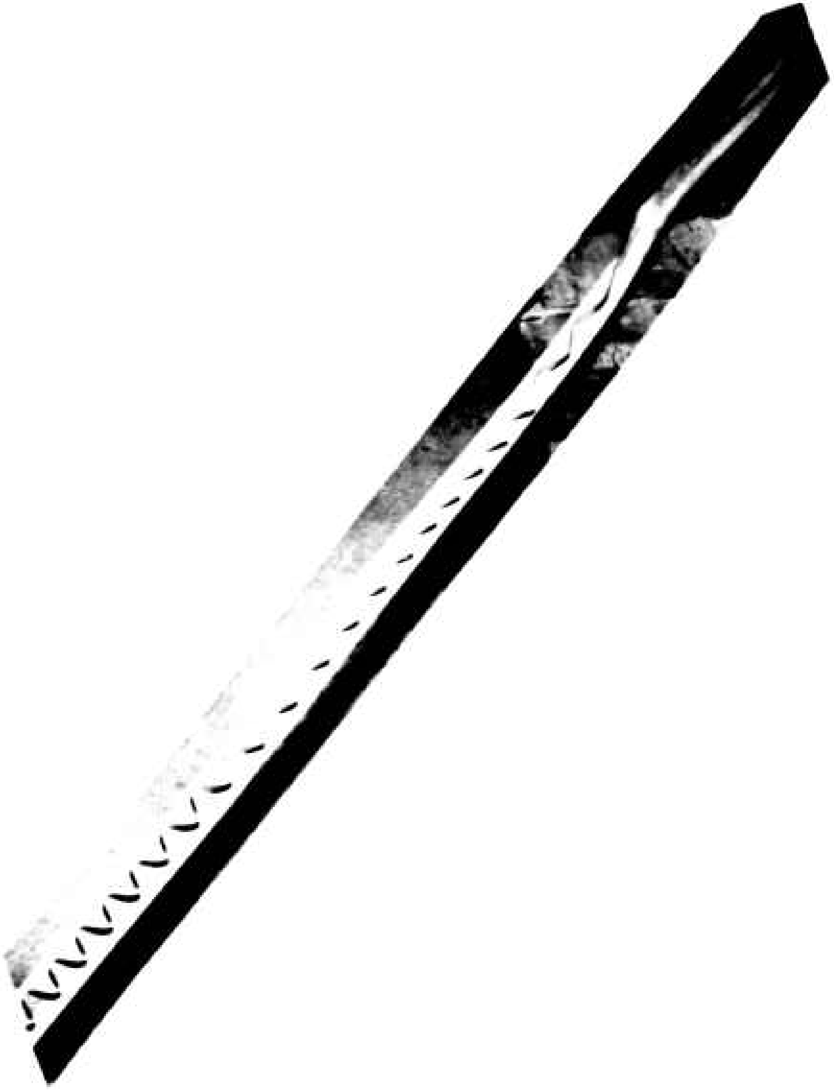


Micro Examination Shows Flow Effect on Billet Surface Machining Marks (50X mag.). Micrographs A, B&C trace the Growth of the Herringbone Pattern from the Closely Spaced Markings on the Upset Billet to the Widely Spaced Markings at the Inside Radius Area Approaching the Extrusion Die.

Billet Discard Push No. 184.

FIGURE 27

605285



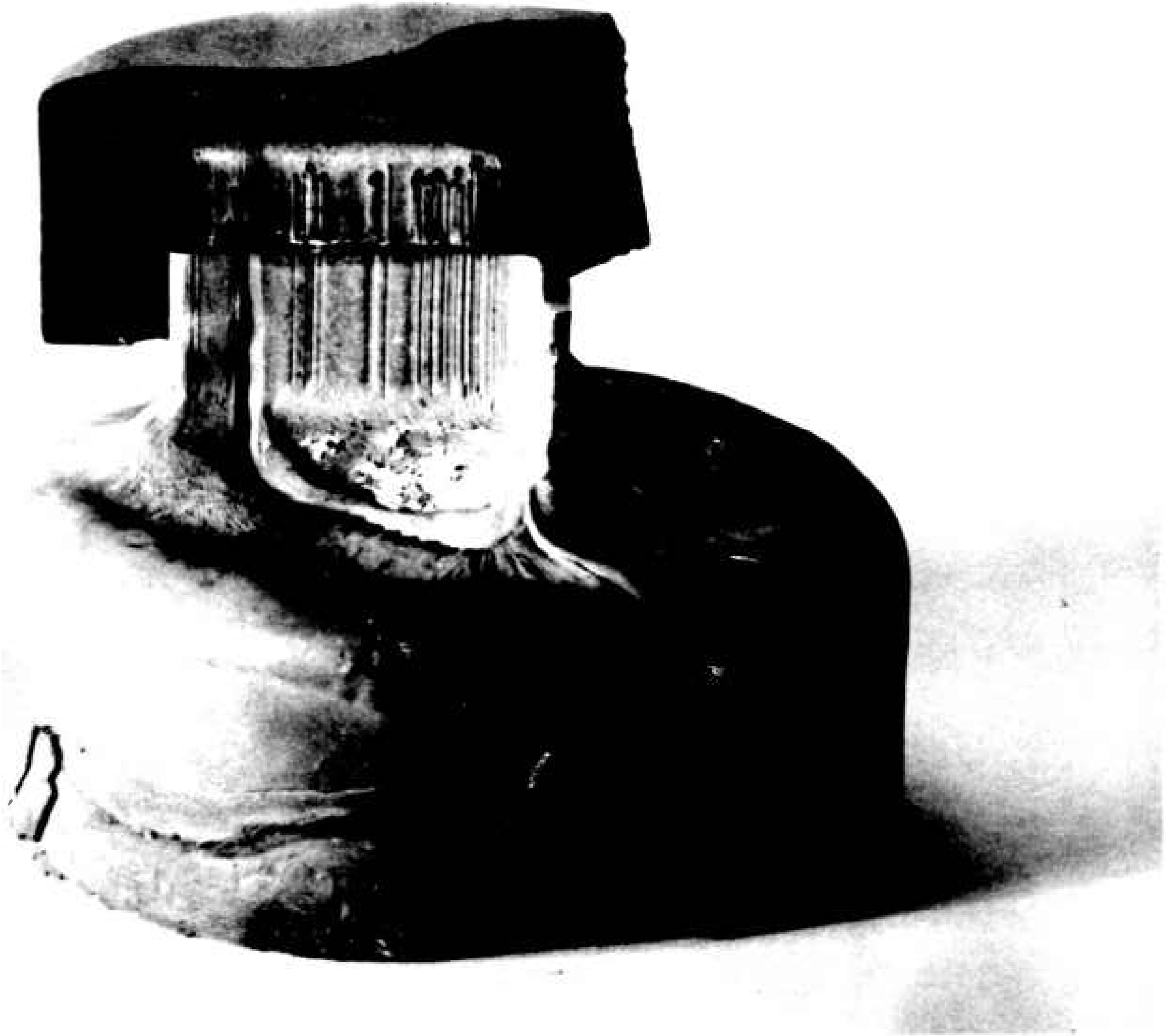
Extreme Waviness in the Tee Upright Resulting From an Excess of Material Being Extruded Through This Portion of the Die Orifice

FIGURE 28

View of Butt End of Extrusion #107 Showing Back End Suck-in Effect. This Effect Continues Through the Extrusion as a Seam Crack for approximately 1 foot.

FIGURE 29

605288

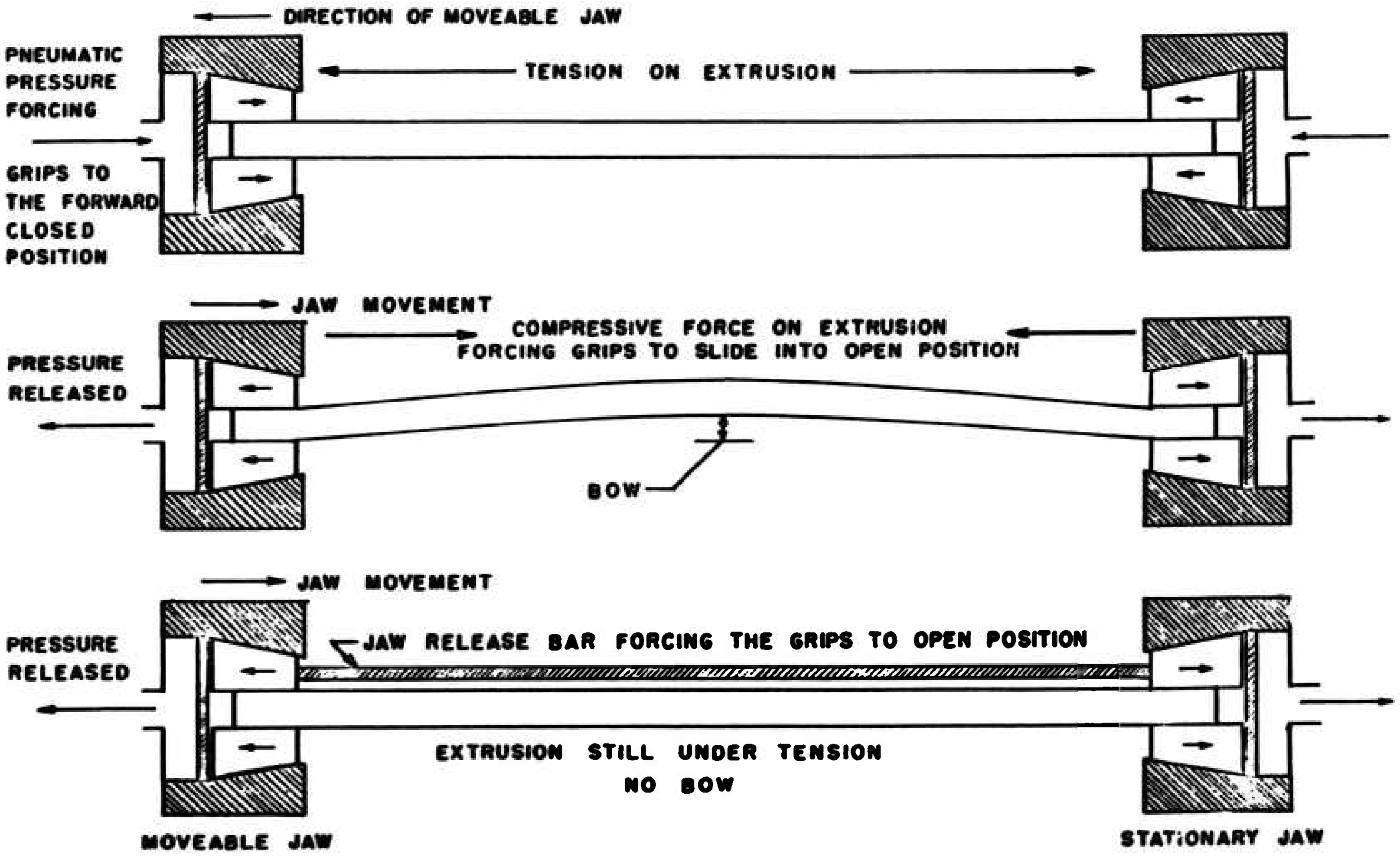


The die has been positioned on the discard so that the die pick-up and score lines match. This discard represents Push No. 166. The hard 3KB glass was used for die and billet lubrication and resulted in partial scalping and severe lamination of the billet

An Example of Extrusion Scoring Due to Die Pick-Up

FIGURE 30

602588



Function of "Jaw Release Bar" in Stretch Straightening

FIGURE 31

2. Extrusion Development at Comptoir Industriel D'Etirage and Profilage De Metaux

Introduction

An extrusion development trial was conducted in Persan, France, by Comptoir Industriel D'Etirage et Profilage de Metaus to determine the potential of their glass lubrication technique for the extrusion of airframe structural shapes. The trial was conducted on a 440 ton vertical press and consisted of four (4) pushes of 4340 steel and six (6) pushes of 6Al-4V. Excellent results were obtained with the three small shapes (angles, channels, and zees) (Figure 1) in 4340 steel and good results were obtained with 6Al-4V titanium alloy in the angle and channel shapes. The zee extrusion, 1/16" thickness at 40:1 ratio, exhibited severe dimensional deterioration from the front to the back of the lengths as a result of die washout.

Since Comptoir did not have previous experience with the 7Al-4Mo titanium alloy selected for Part III of the development program, it was determined that they would conduct exploratory extrusion trials with rounds and small shapes on their 440 ton experimental press before proceeding with the development of Part III shapes on the 1650 ton horizontal production press. The 1650 ton press was equipped with a 4.970" I. D. container.

Twelve (12) pushes were made with theTi 7Al-4Mo alloy on the 440 ton press. Ram speed on the 440 ton press was controlled to approximately 5" per second, and the die was lubricated by means of a glass pad. Billets were prepared from forged 7Al-4Mo titanium alloy to 2.36" diameter in 5 1/2" lengths. The billets were protected with a glass coating during heating to 1650-1750°F for heating times ranging from 40 to 65 minutes. Handling time to transfer the billets from the furnace to the extrusion press was very fast and was accomplished in 3 to 5 seconds.

In general, the 7Al-4Mo alloy extrusions produced during the trials were substantially poorer than the 6Al-4V extrusions produced earlier.

Several series of trials were then conducted at Persan with Ti 7Al-4Mo alloy billets in the following sequence:

Series "A"

Objective	Results
Extrude the Part III tee and hat shapes shown in Figure 2 in 15 to 20 foot lengths with 4 3/4" dia. billets in 1650 ton horizontal press.	A total of twelve (12) pushes were made consisting of (9) tees and (3) hats. Extrusions over 20 feet with uniformly acceptable surface finish but with varying degrees of pickup score lines were produced.

Series "B"

Objective	Results
Extrude small 2 3/8" dia. billets in the 440 ton vertical press into 3/32" x 1" angles to determine conditions which caused scoring obtained in "A" above.	A total of (16) pushes were made. Scores resulted from foreign particles or excess extrusion speed. Particles created localized pickup whereas extrusion speeds which did not permit formation of an adequate glass film resulted in catastrophic overall pickup. Pickup which was almost indiscernible on the die became aggravated in reuse of the die.

Series "C"

Objective	Results
Extrude the Part III tee and hat shapes in 15 to 20 foot lengths with 4 3/4" dia. billets in 1650 ton horizontal press. Extrusion conditions similar to "A" except for use of particle free glass grade found to extrude best in Series "B" trials.	Pickup scores were still present on all extrusions to at least the same degree as obtained in "A". Results were poorer than in "B". A likely reason for the poorer results was the inability to heat the 1650 ton container.

Nine additional billets were extruded into 1" x 1" x . 1" angles on the 440 ton press to investigate die pickup, but conclusive results could not be obtained.

3. Heat Treatment Study and Mechanical Property Testing

During Part III, a series of tests were conducted at Republic Aviation and Babcock and Wilcox to confirm the results obtained in a heat treatment study with C135 AMo titanium alloy extrusions at the Midland Research Laboratories of Crucible Steel. The Crucible work indicated that high (1800°F) solution temperatures with 1150-8 hour or 1200°F-4 hour aging, would produce the combined target properties of 180,000 with 8% elongation. Previous testing at Republic indicated that high solution temperatures result in brittle failures or elongations considerably below the 8% target and that 1650°F solution temperatures resulted in the best combination of tensile strength and elongation. It should be noted that this treatment was borderline and although the strength objectives were met, elongation of only 7% were typical.

A program was formed between Babcock & Wilcox, Crucible Steel and Republic Aviation to evaluate the heat treatment developed by Crucible Steel for 7Al 4Mo extrusions. The objectives of the program were:

1. To determine the consistency of the heat treatment.

2. To determine whether RAC and B&W practices would reproduce the Crucible results.

3. To determine whether standard tensile specimens would equal the Crucible results with sub-size specimens.

Tests were conducted with 7Al 4Mo titanium alloy rounds and angle extrusions produced by Comptoir during their exploratory extrusion trials at 1650°, 1700° and 1750°F extrusion temperatures.

When the Crucible heat treatment was employed with 1/4" round tensile specimens having 1" gage lengths, the target properties of 180,000 psi ultimate strength with 8% elongation were consistently obtained.

However, the 1/2" flat 2" gage length tensile specimens did not meet the target properties when heat treated with the optimum Crucible treatment. Strength levels were similar to those reported by Crucible but elongation in the standard size 2.0" gage length specimens tested at Republic Aviation ranged from 0 to 3% with most failures occurring where the specimen radius blends into the reduced area. Elongations of 8-9% were obtained with similarly heat treated .6" gage length microtensile specimens tested at Crucible and these failures occurred near mid-gage.

It was suspected that this discrepancy in elongation could be attributed to the large difference between the .6 and 2.0" gage lengths ince in titanium a large proportion of elongation is non-uniform. Microtensile specimens were prepared from the fractured 2.0" gage length specimens as indicated in the lower sketch in Figure 32. Since the standard specimens were prepared in a 7" overall length, it was possible to cut the microspecimens from the fractured specimens so that the new .6 gage length was entirely in the area previously under the grips. Because of inadequate section lengths, the microtensile specimens could not be made long enough to allow for clearance between the grips sufficient to permit attaching an extensometer. Therefore, stress-strain curves could not be obtained. However, the primary objective of the microtensile tests was to ascertain whether the high (8-9%) elongation obtained with 188,000 to 190,000 ultimate strength could be attributed to the difference in the gage length and the cross section proportions between the standard and the microtensile specimens. The results indicate that the typical elongation of the microtensile specimens is 6% with 190,000 psi ultimate strength as compared to a typical 2% elongation with 185,000 psi strength for the standard specimens.

The following explanations are offered for the variation in elongation obtained with round, flat micro and flat standard tensile specimens (Figure 32).

1. Standard quarter-inch round tensile bars of 185,000 psi strength levels exhibited typical elongation values of 8% over a one-inch gage length. Although the theoretical stress concentration factor across the fillet of the round specimen and through the transition area of the standard flat specimen were both equal to 1.122, the stress flow along the reduced area was more evenly distributed in the round bar. In the flat specimen, additional stress concentrations at the corners reduced the ductility available in the material.

2. Some of the increase in elongation obtained with microtensile specimens was attributed to the shorter gage length. The increase effect was typical in shorter gage length testing since the local necking near the fracture was more significant in overall elongation when divided by .6" than when divided by 2.0" gage length.

Additional testing was performed to compare properties of the Part III extrusions straightened at the 1000°-1100°F and 1400°-1500°F temperature range. Both the Ti 7Al 4Mo and Ti 6Al 4V titanium alloys were tested for:

a) short-time room and elevated temperature tensile properties

b) room temperature tensile properties of specimens exposed to 800°F for 500 hours

c) room temperature flexure fatigue strength

d) 800°F creep when exposed at 2/3 ultimate for 10 hours and 1/3 ultimate for 500 hours

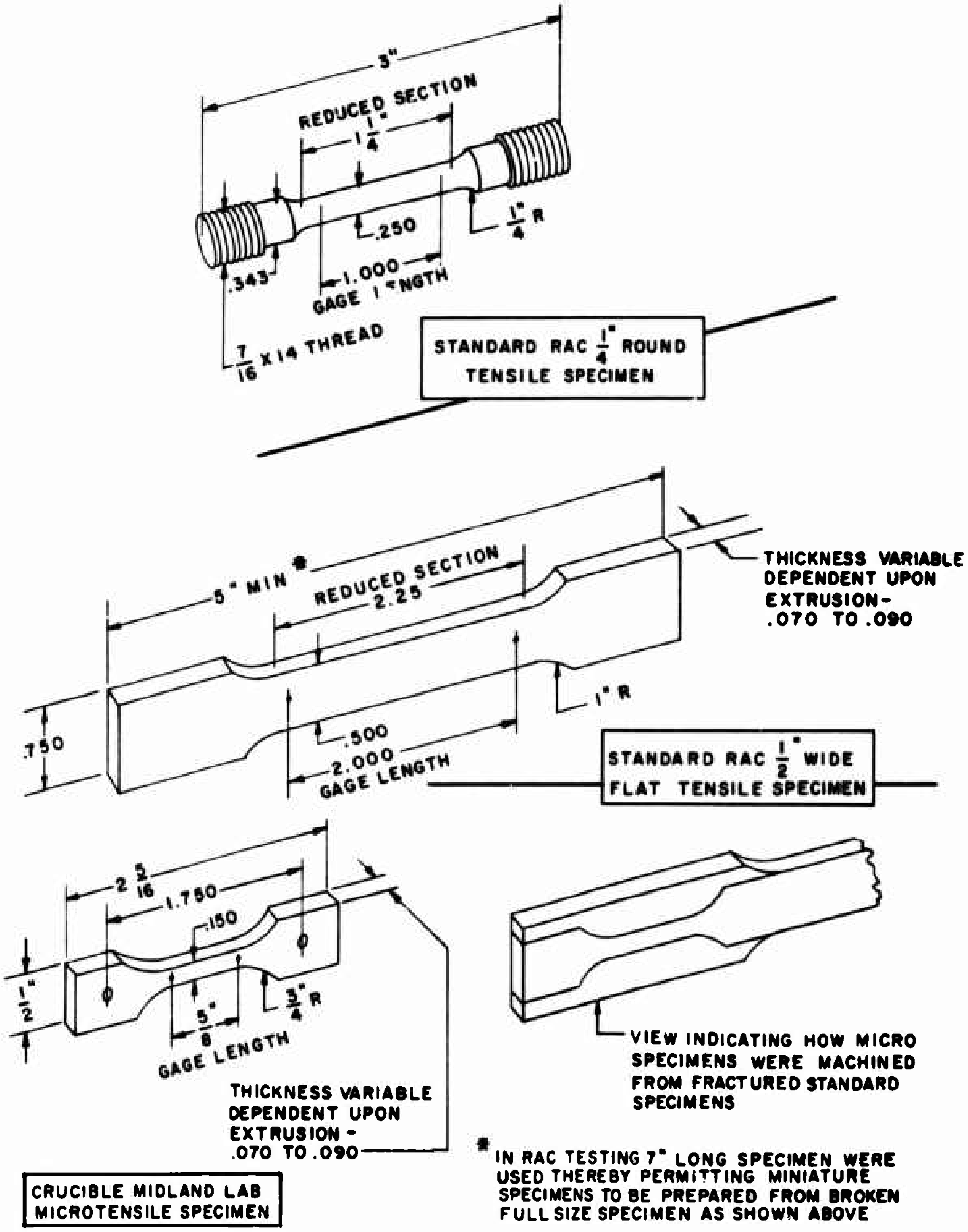
The flexture fatigue tests were conducted with specimens with severely mottled extrusion surface, lightly mottled extrusion surface and ground surface for comparison.

Test results indicated that room temperature tensile strengths before and after thermal exposure, and elevated temperature tensile strengths of both alloys were higher for material strengthened in the 1000°F range. Elongations for both alloys were higher for material straightened at 1500°F. Typical room temperature properties for 6Al 4V extrusions straightened at 1100°F were 152,000 psi ultimate strength with 6% elongation before exposure and 151,000 psi ultimate with 9.5% elongation after exposure to 800°F for 500 hours. For 6Al 4V extrusions straightened at 1500°F, typical properties were 148,000 psi ultimate with 8.5% elongation before thermal exposure and 147,000 psi ultimate with 8.5% elongation after thermal exposure.

The results suggested that intermediate straightening temperatures should be investigated. However, it was anticipated that the warm drawing operation after straightening would decrease the critical aspects of the straightening temperature regarding mechanical properties. With this as a consideration, the lowest possible straightening temperature was used in the Part IV work to minimize the occasional localized necking which occurred at the higher temperature range. Localized necking was undesirable since it presented non-uniform cross sections for the subsequent warm drawing operation.

Unstressed exposure at 800°F did not significantly alter tensile properties for material straightened at both temperatures. Flexure fatigue tests indicated a greater undesirable effect on fatigue life occurred as the degree of mottled surface became more severe.

The creep tests made at 1/3 stress level at 500-hours show that 7Al 4Mo extruded tee alloy had better high temperature properties than the 6Al 4V extruded alloy. Both alloys were well within the allowable tolerance of 0.5% maximum creep at 800°F.



Configurations of Specimens Used in Tensile Testing

FIGURE 32

D. PART IV - EXTRUSION AND DRAWING DEVELOPMENT OF THIRD CATEGORY SHAPE

1. Extrusion and Straightening Development and Billet Heating Trials at Babcock and Wilcox Company

a. Extrusion Development and Billet Heating Trails

The general objectives of the Part IV tee extrusion trials were to extrude 1/8" tee shaped sections to prove the extrusion process using the best extrusion practice developed under Part III and to develop new techniques for extruding thinner tee sections down to 1/16".

The extrusion of thinner tee shapes generated higher die heat due to the greater deformation work at the die. The die materials, therefore, had to be fabricated from higher heat resistant alloys or be thermally protected by the lubricant to remain below the plastic flow temperature of the die material.

In extrusions of tungsten at the Wright-Patterson Air Force Base Extrusion Facility, exceptionally good surface with practically no die erosion was obtained by steel dies coated with alumina at Republic Aviation. In view of the good results obtained with the tungsten extrusion trial, alumina coated dies were evaluated for extruding titanium shapes under 1/8".

The general procedure for coating the die surface was as follows:

(1) The die surface was degreased
(2) All areas to be coated were protected with a rubber base maskant.
(3) All exposed die areas were sandblasted to remove residue grease and handling contamination.
(4) An undercoat of molybdenum metal, .001 - .002 inches thick was applied with a Metco KD Gun
(5) Rokide A alumina rod ceramic composition was sprayed over the molybdenum undercoating.

(6) The rubber maskant was removed and final machining or hand grinding of the coating was employed to size the dies.

During Part IV, four (4) extrusion trials covering five (5) days were held

A total of sixty-nine (69) pushes were made consisting of seven (7) pushes of Ti-4Al-3Mo-1V, eight (8) pushes of Ti-6Al-4V, and fifty-four (54) pushes of Ti-7Al-4Mo.

The results of the extrusion trials and billet heating trials conducted during the same period are summarized below:

(1) High container temperatures (900°F - 1000°F) in combination with the glass lubricant of proper viscosity resulted in a uniform and continuous glass coverage on the extrusion surface.

(2) Longer heating time of the glass protected billet increased the depth of penetration of oxygen contamination in billet surface marks.

(3) Cast billets extruded without any difficulties and produced surfaces comparable to forged billets. Oxygen contamination was more severe with the cast structure.

(4) Extrusion of .092" thick tee shapes was realized using the best extrusion technique developed for 1/18" thick tee shapes, but scoring and die wear occurred about 12 feet from the front end of the 20 foot extrusion and ceramic coated dies were indicated for extrusions 3/32" and thinner.

(5) Continuous glass lubrication was realized with the 3KB-14 mesh glass ring/glass wool die lubricant pad. The glass ring provided a reserve of molten glass and also directed material flow by preventing shearing in the billet radius at the die approach area.

Provision of an orifice in the glass wool pads is required to prevent stickers from die blockage.

(6) Dishing of the billet nose had an advantage over the flat nose billets in terms of creating a greater reservoir of molten die glass available to the billet surface at the die opening and easing metal flow.

(7) The initial peak and average extrusion pressures for the .092" and .062" tee sections were comparable to the pressures experienced with the .125" tee extrusions.

(8) The initial peak and average extrusion pressures for the 45 and 60-minute billet heat soak time at 1800°F were comparable to the pressures experienced with longer heating times - 90 - 125 minutes.

(9) With respect to dies, the uncoated dies experienced wear, wash and hot creep deformation at extrusion ratios over 40:1, whereas with the ceramic coated dies, the die material remained undisturbed. The alumina coating was superior to chrome oxide coating. Mechanical damage to the land area coating during removal of the billet discard was obtained. Therefore, it could not be determined whether more than one push per coated die could be obtained.

(10) Micro-examination comparison of extruded surfaces indicated that oxygen stabilized alpha titanium contamination was minimized with decreased billet heat soak time at 1800°F. The optimum heating time ranged from 60-65 minutes.

(11) Good lubrication resulted from a double roll pass of the billet through the 318-14 mesh glass powder on the runout table to obtain a heavy coat.

(12) The use of the E-71 family of glasses for all extrusion locations resulted in poor lubrication properties and extrusion surface scoring as compared to the practice of using 85, 318, and 3KB glass compositions. However, a combination of the 85 billet coating with E-71 glass compositions (push Nos. 235 and 238) for O. D. and die lubrication resulted in the smoothest extruded surfaces of the Group 19 trial. This combination will be evaluated in the initial trials of Part V.

(13) Application of the glass coating for heating protection by dipping the billet into the slurry resulted in severe spalling of the coating when handled with tongs. This occurred in both the wet charge method and oven drying the coating prior to charging and handling of the billets. In contrast, the sprayed billet coating remained intact during the billet transfer procedure.

Examination of the glass coating immediately upon removal from the furnace at 1800°F showed a uniform, continuous, smooth fused glass coating for sprayed billets, as compared to non-uniform, porous glass coverage associated with the dip coated slurry.

Good results, in terms of smooth extrusion surfaces without contamination, were obtained when the billets were belt ground and polished smooth prior to glass spray coating which was applied at 300°F and then oven dried.

b. Straightening Development

Straightening procedures developed in Part III were employed to straighten the Part IV extrusions. The major contribution of the Part IV straightening work was the coupling of a punch straightening operation to the stretch straightening operation.

Punch straightening was performed on a 300 ton horizontal press and succeeded in reducing bow to 1/4" in a 20' section and eliminating camber. It is imperative that the extrusion is punch straightened while still warm to avoid imparting kinks to the extrusion. This requires close proximity of the punch press to the stretch press and demands haste in transporting the extrusions from the stretch press to the gag press.

2. Extrusion Development at Battelle Memorial Institute

Prior to embarking on a full scale extrusion program to produce the thin section tee extrusions at the Babcock and Wilcox production extrusion facility, pilot studies on glasses for heating and lubrication, and accompanying modifications in extrusion practice were conducted on the experimental extrusion facility at Battelle Memorial Institute.

Glass Studies

Initial efforts were directed towards evaluating protection and lubrication glasses. A study of the reactivity of a number of glasses with titanium indicated that the potassium borosilicate glass E-71 reacted least. However, its viscosity characteristics in the temperature range 1750 to 1850°F were such that it could not be used to serve simultaneously as a heating glass, container lubricant, and die lubricant. Therefore, a family of glasses based on E-71 were developed which had the following characteristics: (1) compatible with one another, (2) as inert to titanium as the base glass, and (3) permitted the selection of glasses for the various functions by having a range of viscosity.

Four glasses were developed with variations in both the SiO_2/B_2O_3 ratio and minor oxide additions for viscosity evaluation. The glasses were designated as E-71A, E-71B, E-71C and E-71D.

The glasses were smelted at 2200°F for 1 hour and water quenched. After drying, the glasses were ground to pass a 50-mesh screen.

For relative viscosity tests, cylindrical specimens 1/2-inch diameter by 1/2-inch long were compacted under 6 tons pressure. Each pellet weighed 3 grams.

One pellet of each glass composition was placed on a 16-gage stainless steel "setter" and heated for 2-1/2 minutes at 1750°F. The setter was then tipped at an angle of 110 degrees to allow the glass pellets to flow down the setter sheet. After 1 minute in this position, the setter was removed from the furnace and the length of flow of each pellet was determined as a measure of relative viscosity. Flow lengths for the various glasses were:

Glass	Length of Flow, inches
E-71A	2.084
E-71C	2.149
E-71 (Base)	2.334
E-71D	2.612
E-71B	2.783

These results gave the desired viscosity variations, namely, two more viscous and two more fluid than E-71.

The experimental glasses were crushed in a roll crusher, ball milled, and screened to provide material having particle-size limits of -80 mesh + 120 mesh for making glass pads. The sized glass was mixed with 5 weight percent liquid sodium silicate as a binder and compacted into pads 3 inches in diameter on a small press under a pressure of 2000 psi. Pads were dried in air at room temperature over night and then dried at 185°F over night.

Extrusion Facilities

Extrusion trials were conducted on a 700-ton vertical hydraulic press in the Battelle metalworking laboratory. This press was equipped for hot extrusion and has the following performance characteristics:

Main ram force	700 tons
Container sealing force	100 tons
Ram closing speed	1070 ipm
Ram pressing speed	80 ipm
Container size	3. 2 in. diameter x 14 in. bore
Maximum container temperature	1000°F
Stem size	3 in. diameter x 19 in.
Maximum billet length	10 inches
Maximum stem pressure	190,000 psi

Accessories are available for control and measurement of ram speed, container temperature, and pressure. The press is located over a readily accessible pit 15 feet deep.

A 30-kw, 3000-cycle induction heater having a controlled argon flow atmosphere heating chamber was used for heating the glass coated billets to 1800°F.

Extrusion Trials

A total of sixty-six (66) pushes were made with Ti 7Al-4Mo titanium alloy. The initial extrusion effort consisted of four (4) pushes to establish a reference condition from which modifications in the use of glass, heating practice, die design, could be evaluated. These trials were made with 0. 125 inch tees following as closely as possible the best practices evolved in the Babcock and Wilcox work.

Evaluation trials were then made on the 0. 094-inch tee following essentially the same practices, but with the experimental glasses. These trials were set up to ascertain the optimum glass-viscosity requirements for container and die lubrication consistent with the best billet coating practice for heating.

Subsequent trials were made with the .063 inch tee in an effort to optimize the use of the glasses for extrusion. Variables that were considered were: Glass pad thickness and form; Glass pad temperature; Die glass grain size.

Several pushes were made with alumina coated and uncoated dies to evaluate the alumina coating. Figures 33 and 34 show the condition of the two types of dies after extrusion.

Results

The results of the trials showed that with alumina-coated dies, the best combination of glasses on the basis of surface finish and dimensional uniformity was E-71A and glass wool for the die, E-71 or E-71B for the billet coating, and E-71B for container lubrication.

The effects of the glass variables on the performance of the glasses are summarized below for die glass E-71, E-71A and E-71B.

Glass grain sizes of 20, 100, and 325 mesh were evaluated using the open ring with 1 glass wool pad (Tests 40, 42, 43). Better die fill and overall glass coverage was obtained with the 20-mesh glass, but the best as extruded surface finish was obtained with the 100-mesh glass. It appeared that with 20-mesh and 100-mesh glass the glass particle flow during pad crushing at the outset of extrusion promoted die fill and resulted in better lubrication. The 325-mesh glass pad was very hard as compacted and little or no pad crushing occurred. Thus, melting of the glass particles did not appear to be as uniform with a hard, fine-mesh glass pad as with a more friable, coarse-mesh glass.

Both the pad shape and the conditions under which each pad shape was used had significant effects on extruded quality. The use of glass wool in addition to the die pad also proved to be an important factor in the overall lubricating process.

The use of a tapered ring at room temperature with 3 glass wool pads produced a good overall extruded section. The use of a shaped pad at room temperature without glass wool gave an inferior product. Heating of the shaped pad to 1000°F improved results somewhat.

Thus, on the basis of glass variables only, improvement in surface finish and dimensional accuracy were mainly the result of:

(1) The use of glass wool in combination with the compacted ground glass pads

(2) Preheating the compacted ground glass die pads

The advantage of the glass wool appeared to be in its melting characteristics in contact with the hot billet. The individual strands of glass fiber are much finer than the glass particles normally used in compacted pads. Melting of the fibers appeared to be more rapid than the ground glass, so that a film of molten glass was immediately available at the die, at the start of extrusion to supplement the glass applied as a coating for heating. As extrusion proceeds, the compacted pad begins to melt and supplies the glass for the remainder of the extrusion.

Preheating the ground glass pad to 1000°F appeared to have several advantages: (1) less time was required to melt the glass, (2) less heat was removed from the billet to melt the glass, and (3) no heat was removed from the die in contact with the glass. All of these factors contributed to achieving the conditions desirable at the billet-die interface for proper glass lubrication; namely, a film of completely molten glass with no solid glass particles.

Conclusions

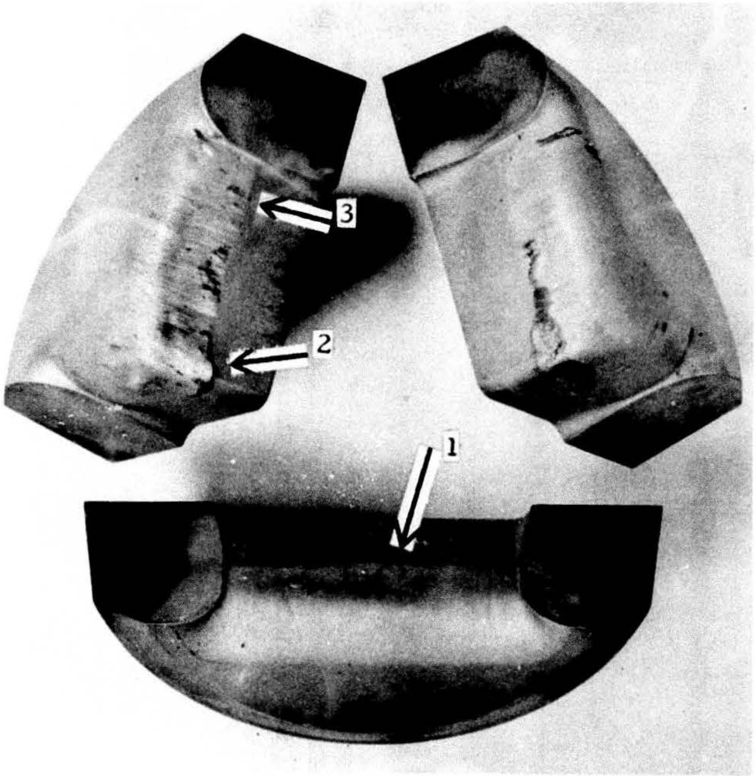
Several significant effects of glass variables on extrusion quality were observed in the trials and the following conclusions can be drawn:

1. A relatively high viscosity glass improved the die fill at the start of extrusion

2. Glass in fiber form had more favorable melting characteristics than granular glass for providing lubrication at the start of extrusion

3. Preheating compacted granular glass pads to the die temperature (1000°F) improved the lubricating performance of the glass

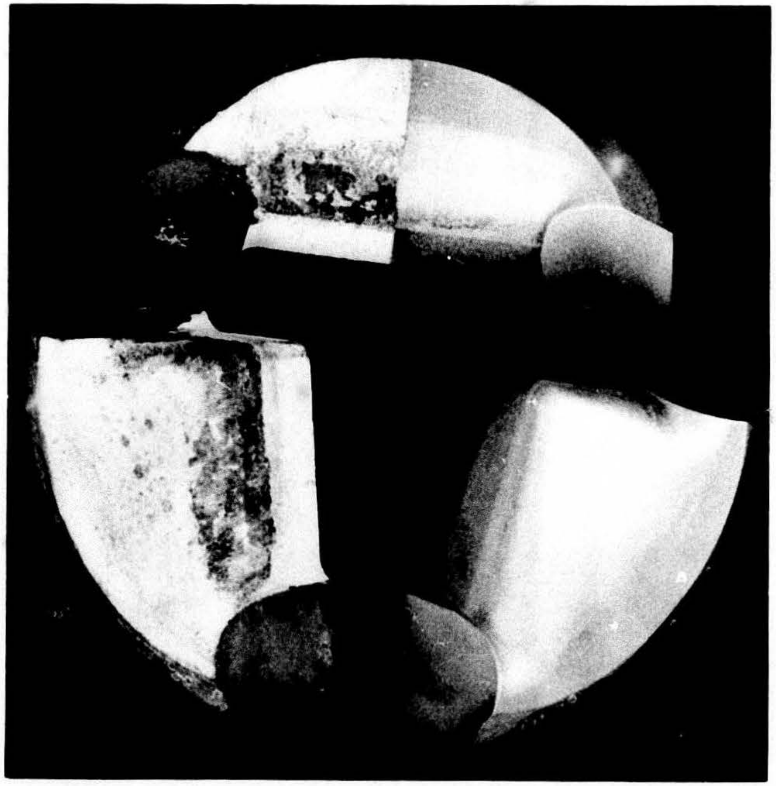
4. Granular die pad glasses give better die fill and surface finish when used in the -30 + 100-mesh size range than in the -325 mesh range.



(1) indicates die wear on land, (2) radius wash and (3) pick-up of metal particles on die land

An Uncoated 0. 063 inch Die After Extrusion

FIGURE 33



One-half of die vaporblasted to show condition of base metal

Condition of an 0. 063" Alumina-Coated Die After Two Consecutive Extrusions.

FIGURE 34

605-208

3. Warm Drawing Development at Allegheny Ludlum Steel Corporation

a. Introduction

The Titanium Metals Corporation of America was selected to conduct the warm drawing portion of the program. The work was performed at the Allegheny Ludlum Steel Corporation facilities. Because of the large amount of development work that was required for warm drawing equipment, it was decided to perform the initial development work with 1/8", 3/32" and 1/16" shapes prior to drawing the tee shapes to the target .043" thickness. After workable equipment was developed and the large amount of variable parameters relative to lubrication, temperature and die design were narrowed and/or fixed during development work with the larger sizes, the drawing development for the .043" shapes proceeded at an accelerated rate.

Based on the above, a four-phase program was initiated. The phases are generalized as follows:

Phase I	Development of the drawing techniques for sizing as-extruded shapes having a cross section of 0. 125 inch.
Phase II	The development of drawing techniques for the production of shapes having an 0. 063 inch cross section from extrusions of 0. 125 inch section.
Phase III	The development of sizing procedures for extrusions having a cross section of 0. 075 inch. This was modified to start with nominal 0. 095 inch thick extrusions.
Phase IV	The development of drawing procedures to make 0. 040 inch section shapes from extrusions having an initial thickness of 0. 063 inch.

b. Equipment Development

1. Heating

Induction - Initial heating trials were concerned with the development of induction heating techniques. A 100 kw induction heating unit was procured, on a rental plan, from Lepel High Frequency Laboratories.

The temperature sensing device of the thermistor (infrared radiation) type produced by Mason Instrument Company was connected to the Pyrotel temperature controller which, in turn, controlled the 100 kw power pack. Figure 35 illustrates relative position of the 100 kw Lepel unit and Pyrotel RMF controller in relationship to the draw bench and induction coil.

The induction coil was three feet long and consisted of flat copper tubes wound around a ceramic (Fiberfrax) liner. Sight ports were provided in the liner through which the Mason instrument could read infrared radiation and record temperature. The coils were uniformly spaced 5/8 inches apart as received. The coil was mounted as shown in Figure 35

Sighting with the Mason instrument at a point 6 inches from either end of the coil resulted in a temperature 250°F higher in the center than at either end due to end cooling effect. With the refractory liner removed, the temperature was uniform along the entire length. The inverse temperature gradient in the exit half of the coil negated temperature control since the sensing device was seeing a temperature higher than that initially controlled. Under dynamic drawing conditions, uncorrected, the coil would develop a 500°F temperature fluctuation in a three-foot interval. To correct the condition, the coil was respaced with an additional two turns in the front end to obtain a hotter zone at the exit end. In addition, holes were drilled in the center portion of the liner to facilitate dissipation of heat. This resulted in a positive temperature gradient from the control point to the back and the unit controlled proportionately the power demands. The control point was placed 12 inches from the exit end to obtain improved control. All initial temperatures were determined by welding thermocouples to the test extrusion.

The potential effect of emissivity of various lubricant systems on determining metal temperature with the Mason instrument was ascertained by heating a bright pickled surface and one coated with a black graphite lubricant. The maximum temperature variability was only 25°F and thus presented no problem in the lubricant study.

Continuous problems were encountered with the induction heating system. During the initial trials, "shorting" between the titanium extrusion and the coil resulted from arcing of the extrusion to a wet liner. The highly absorbent fibrax liner material was wetted by absorbing water of condensation from the coil turns. The arcing was eliminated by applying a water resistant coating of glyptol to the O.D. of the liner and by the use of preheated cooling water to the coil. Other problems that were associated with the induction heating system were burnout of the coil due to overheating from insufficient cold water flow through the coil and splitting of the underground, water-cooled coaxial power lead from ice formation in the line.

The coil requirement to obtain a ± 25°F temperature control in the 800 - 1300°F temperature range did not perform as anticipated; uniform heating could not be obtained. A second sensor head was incorporated for uniform heating, and damping circuitry was installed to reduce response of the sensor to compensate for a time delay function. These factors reduced the temperature variance from ± 500°F to ± 100°F. This was still beyond the tolerance necessary for the program which required temperature control in order to evaluate a wide range of lubricants and develop the optimum lubricant system. The temperature controlling device was disregarded and temperature curves for constant power heating were developed. By heating with a constant power input, temperature variability was reduced to a nearly acceptable ± 50°F but at the expense of temperature and draw speed selection.

When attempts were made to draw thinner shapes, it was found that the equipment could not heat 1/16 inch and thinner sections to warm draw temperatures of 1000°F without major, costly modification. A decision was made to develop a resistance heated tube furnace and to dispense with the induction heater.

Radiant Tube, Resistance Heated Furnace

The radiant tube furnace, is illustrated in Figure 36

The central resistance heated tube chamber was Type 310 stainless steel, a nominal 3.00 in I.D. x 0.098 in. wall x 12 foot length. The tube was surrounded by 2800 series refractory Mg0 bricks and a carbon steel shell. One foot of the tube protruded on each end to which the water cooled copper power clamps were attached. Two G.E. 1500 amperes continuous duty DC rectifiers were installed in parallel to supply 3000 amperes, 0-40 volts DC. The primary power source was three phase 550 volts, approximately 200 KVA; the secondary was metered. The temperature was controlled by a controlling thermocouple.

The satisfactory temperature control in heating an extrusion longer than the furnace is depicted in Figure 37. The furnace, located about 6-8 inches away from the die stand, was set at 1325°F; the extrusion was then introduced with one end about 18-24 inches from the discharge port, heated 30 seconds, pushed through the die, and drawn at 12 fpm. In this curve the temperature varied only from about 870°F minimum to about 950°F maximum; one instantaneous peak of 1010°F was recorded. The power was generally on for 10-15 seconds (10-12V, 2500 A) and then off for 60-90 seconds. The Pyrotel head was used to measure draw temperatures and was placed 8 inches from the exit end of the furnace.

Minor, but objectionable arcing occurred sporadically when the thin edged extrusions were in contact with the extremities of the tube furnace. The severity and frequency of the areas of metal spark erosion are depicted in Figure 38. However, few failures through these notches were observed upon drawing. Initially, to circumvent this arcing, rings of Fiberfrax were inserted on both of the ends and the middle of the tube furnace to keep the extrusion from contacting and arcing to the tube. A more positive means of preventing arcing consisted of turning the furnace power off during the draw operation. This practice was feasible as the temperature losses during the short draw cycle were minor in the well-insulated furnace. However, this practice was limited to extrusions about 12 feet in length.

Resistance Heating and Electric Furnace

Due to equipment limitations (straightening facilities in particular) the warm draw program was transferred to the Titanium Metals Corporation upon installation of the new warm draw facility at Toronto, Ohio. The heating equipment consisted of a 20', three zone, side opening electric furnace. The furnace was placed in the draw bench trough adjacent to and lined up with the die stand. Electrode clamps were situated alongside the electric furnace for resistance heating the shapes prior to insertion in the furnace. Resistance heating was employed to minimize the time at temperature of the extrusion to avoid lubrication breakdown. The electric holding furnace was used to equalize the temperature throughout the length and obtain uniform heating.

This arrangement proved entirely satisfactory and is the type of equipment recommended for warm drawing.

2. Gripper-Head and Jaws

One of the most persistent problem areas which hindered progress in warm drawing was the inability to consistently grip and hold the extrusion during the drawing operation. The normal force distributed to the surface of the extrusion from jaws operating at 30° angles was not adequate. The three cylindrical jaws each actuated separately from a 500 pound pressure attained from a nitrogen bottle invariably permitted slippage and rapid point deterioration on almost any patterned, nitrided, steel jaws. Figure 39 illustrates two of the three jaws and the rounding off of the 1/8 inch diamond pattern teeth which rendered further drawing impossible. The jaw material was H-11 die steel nitrided to a 0.015 inch case depth.

Cutting of the O-ring viewed in the bottom cylinder in Figure 39 was a frequent occurrence in all three jaw inserts at one time or another; the net effect was an excessive loss of gripping pressure and failure to draw. The cutting of O-rings was attributed to one cylindrical insert progressing further than the other two separately actuated inserts and cutting of the ring on a metal stop. The frequency of this phenomenon increased with the shortening of the inserts from repeated recutting of the diamond pattern.

An effort was made to avoid some of the difficulties in jaw gripping by evaluating a simple form of pin insertion. For simplicity sake only one 1/2 inch diameter pin was inserted through the vertical leg. The point failed by shearing and no drawing transpired. No further efforts at pin gripping were attempted.

Several designs of the diamond pattern jaws were evaluated but none proved entirely successful. The best results were achieved with a modified 1/16 inch diamond pattern, illustrated in Figure 40. The positive gripping achieved with this improved design is viewed in Figure 41. The wide (1/8" diamond) did not penetrate the titanium extrusion surface to the same depth as the 1/16" pattern. However, only moderate success was achieved with the design. Efforts to improve gripping entailed torch heating the grippers to about 300/500°F; it was felt that in handling the thin 1/16 inch extrusions, the jaws would not then act as giant heat sinks and chill the sections to the point that securing the shape would not be possible. Moderate success was indicated but more desirable means of heating the jaws would be necessary.

The problem was finally solved by replacing the gripper head with an 8 inch Hufford Universal Gripper. The jaw inserts were of the same design as used in the Babcock & Wilcox stretcher straightener, but the insert material was different. The inserts manufactured by Hufford were 1020 carbon steel heat treated, carburized and then chrome plated. It was no longer necessary to actuate the jaws with 500 psig as had been the case with the old head; the new jaws were actuated with 80-100 psig bottled nitrogen or air. Laboratory testing prior to delivery of the jaws indicated that a 1-1/2 in x 1-1/2 in x 0. 120 in. thick T sustained a 43, 330 lb load (120 Ksi) without slippage.

Subsequent warm drawing trials justified the transition to the Hufford Universal Gripper heads; no slippage was encountered under the most adverse conditions.

3. Draw Dies

One of the major accomplishments of the program was the design and development of the split tungsten carbide draw dies. The original concept, designed by American Carbide Company, Union City, New Jersey and the modification designed by Republic Aviation are shown in Figure 42. A view of the die inserts assembled in the die case can be seen in Figure 43. The split die sections were held by means of screw loaded wedges.

The major reason for using the modified design (Figure 42) was to eliminate working the edges of the tee during a reduction pass which caused buckling and "Chevron" defects (See Figure 44). The new design permitted unrestrained working of the edges and eliminated the "Chevron" defect. In addition, the complicated . 010" recesses to contour the edges of the extrusion in drawing were eliminated so that machining time for the modified design was considerably less. Dimensional control was accomplished by altering the size of the three steel shims. It would be possible to incorporate end working in a final pass by introducing carbide end blocks with the desired radius.

Shims were made to accommodate changes in the die opening from . 093" to . 040" with one set of dies. Another advantage of the modified design is that it could be used for various tee configurations (and in fact, was used for the Part V work) resulting in considerable savings in tool cost.

Some of the difficulties encountered with the draw dies was cracking of the bottom block. This was traced to the fact that the top blocks and shim assembly exceeded the bottom dimension by . 0015" thereby resulting in some slop of the bottom block which resulted in cracking at the radius area.

The condition was overcome with careful dimensional control, assuring the bottom block being 0. 0005 inch larger than the cumulative size of the upper two top blocks and shim. Another problem was thermal fatigue which resulted in heat checking of the top right and left hand blocks, as seen in Figure 45. The blocks were not polished prior to photography.

It was assessed by the supplier that the defects were about 0.010 inch deep. To avoid this heat checking, the dies and die case were preheated to 500°F prior to usage in warm drawing.

No further difficulties were experienced with the draw dies, and periodic inspection of the dies indicated no wear was encountered.

c. Process Development

The process development consisted of an evaluation and development of a lubricant system, and an evaluation of drawing speeds and drawing temperature. In addition techniques were developed relative to pointing of the extrusions and guiding the extrusions to eliminate bending moments on the points as the extrusion is drawn. The initial work was conducted with four foot lengths prior to using ten and twenty foot lengths.

Lubricant System

Good lubrication during the draw operation is necessary to prevent seizure of the metal to the die and galling of the extrusion. The lubricant system must have the ability to wet the extrusion and adhere without spalling off during handling and during the preheat operation. The lubricant must also resist breakdown when subjected to the heat generated at the die face by the metal reduction.

Various lubricant systems such as colloidal graphite (Prodag, Aquadag), molydisulfide (Alpha-Molykote 196X) and Fiske 604 (lithium grease, aluminum, mica, molydisulfide, bentonite) have been investigated and employed successfully from 750°F to 1150°F over a chemical conversion coat. A glass-type lubricant such as Phosphatherm (a phosphate type glass) was investigated at 1150°F in a preliminary fashion with only mild success due to limited temperature control for such a lubricant.

The lubricant system which performed best and which was selected for the Part V work consisted of the following:

An Amchem Granodraw T subcoat which is a conversion coating was put on the extrusion to facilitate wetting of the extrusion by the lubricants. This was followed by a lime dip coat and a brush coating of Alpha Molykote 196X which is a moly disulphide. Fiske 604 lubricant, which is a Bentone type base product combined with graphite and aluminum powder and mineral oil, was applied at the die face.

Draw temperature and draw speed

Preheat temperatures ranging between 800°F and 1400°F and draw speeds between 6 ft. per minute and 24 ft. per minute were investigated. The temperature of the exiting extrusion can be controlled by varying the distance between the furnace exit and the die orifice at a preset furnace temperature and draw speed. This distance is critical as rapid cooling of the thin tee section occurs due to radiation losses. The 10' long furance was capable of heating the 1/16" thick and thinner extrusions uniformly to draw temperatures of 1000°F at the die entrance at draw speeds of 12/14 fpm without difficulty. The distance between the furnace and the die stand was 7" and the furnace was preset at 1350°F.

Higher preheat temperatures would result in lubrication burnoff and subsequent galling of the extrusion. Galling of the extruded surface due to lubricant breakdown is illustrated in Figure 46. The 1000°F draw temperature was found to be satisfactory in that relatively low draw loads (in the order of 7000 lbs. for a 10% reduction) were obtained.

With the 20' electric furnace at the TMCA facility, good results (low draw loads and elimination of galling due to lubricant breakdown) were obtained with a preset furnace temperature of 1050°F and a draw speed of 24 feet per minute.

Draw Force

Facilities for recording stress during warm drawing were incorporated in the drawing assembly at the Allegheny Ludlum plant. Figure 47 illustrates the location and nature of the load cell. The cell, a threaded round with a 1-1/2 inch diameter reduced section was calibrated in a 60,000 lb. Riehle universal testing machine. During the actual drawing, a Heiland Visicorder was incorporated into the equipment for a continuous record of loading.

At the TMCA facility, a recording ammeter was employed as an indication of the draw force. The ammeter measured the DC current to the motor pulling the trolley. At 100% motor amperage rating, a 50,000 pound pull would be exerted on the 50,000 pound draw bench.

The mean draw forces encountered were in the order of 5000 to 10,000 lbs. for 10% reductions.

Pointing

Both grinding and chemical milling of the points were utilized. The procedure employed consisted of grinding the fillet radii to insure insertion through the die and chem milling the points in a solution of 35 HNO_3 and 5HF. Metal removal was at the rate of 1 mil per minute. Undercutting at the air-liquid interface was prevented by taping that area of the shape. It should be emphasized that care must be exercised during the pointing operation to avoid making the points too thin. Excessively thin points caused numerous difficulties when the program was transferred to the TMCA facility in that continual point slippage and/or breakage occurred.

Point slippage occurred because the buildup of the pasty Fiske lubricant on the Hufford Jaws prevented closure on the excessively thin points. Point breakage occurred when the thin points could not carry the draw force. Further effort is required in the area of pointing extruded shapes to make the process attractive.

General

It was generally established that laminations, seams and striations greater than .006" could not be refined in the drawing process. Figure 48 shows the appearance of a lamination after drawing from 3/32" to .080".

Figure 49 illustrates typical distortions that were obtained after a warm draw pass resulting from non-uniform metal flow. Since the extrusions required straightening after each pass, hot stretch straightening (1500/1550°F) was employed which imparted an anneal to the extrusions. Therefore, it was not determined whether an in process anneal was necessary after each draw pass to avoid internal shear cracking due to work hardening of the section.

The warm draw process developed during Part IV accomplished the following general improvements in the extruded product:

1. Ironed out transverse glass markings and light striations (under .006" depth) on the extruded surface.

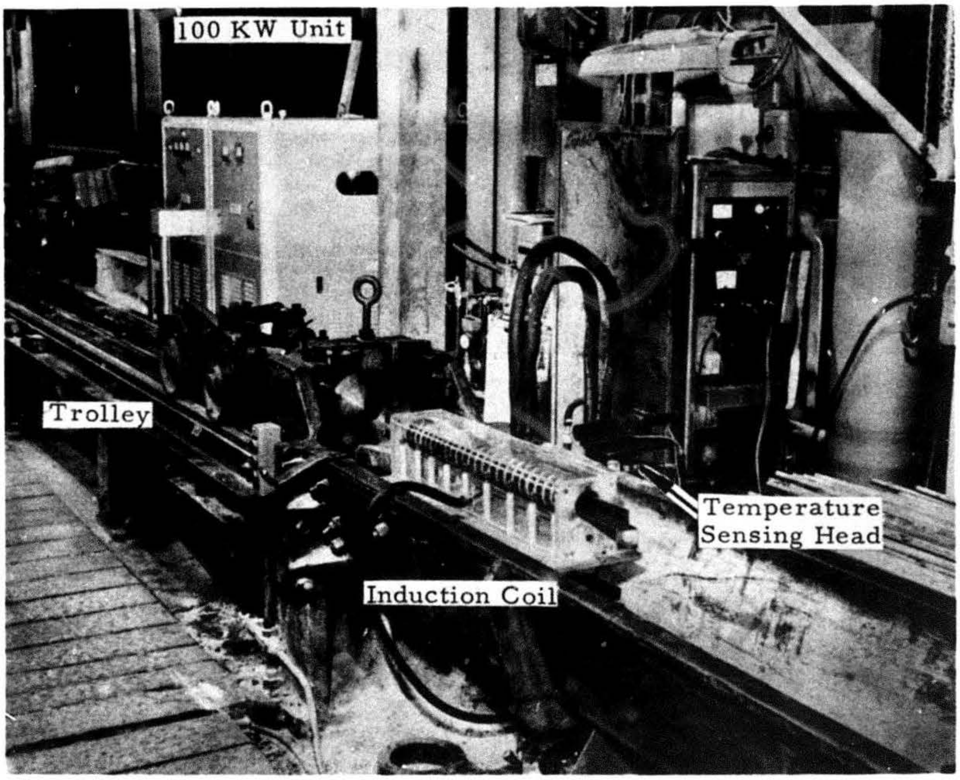
2. Improved surface finish approximately 50% (from 200 u in RMS to 100 u in RMS and from 125 u in RMS to 75 u in RMS).

3. Improved dimensional tolerances to ± .004" on thickness dimensions.

Tensile Property Survey and Microstructural Examination

A series of samples were procured from the as extruded and straightened extrusions and from extrusions after warm drawing to determine mechanical properties and heat treat response of the material before and after warm drawing. The data for the three alloys: Ti-7Al-4Mo; Ti-6Al-4V; and Ti-4Al-3Mo-1V are listed in Tables 6, 7, 8 and 9. Included in Table 6 are tensile tests at 1000°F which indicate the relative ease of drawing at this temperature for the three alloys. It can be seen that Ti-7Al-4Mo offers the greatest resistance to flow and Ti-6Al-4V the least. Table 7 reveals the properties of a nominal 3/32" T shape of Ti-7Al-4Mo warm drawn to 1/16". The properties are equivalent to the properties of Ti-7Al-4Mo as extruded shapes similarly heat treated, but slight improvements in heat treated ductility are indicated.

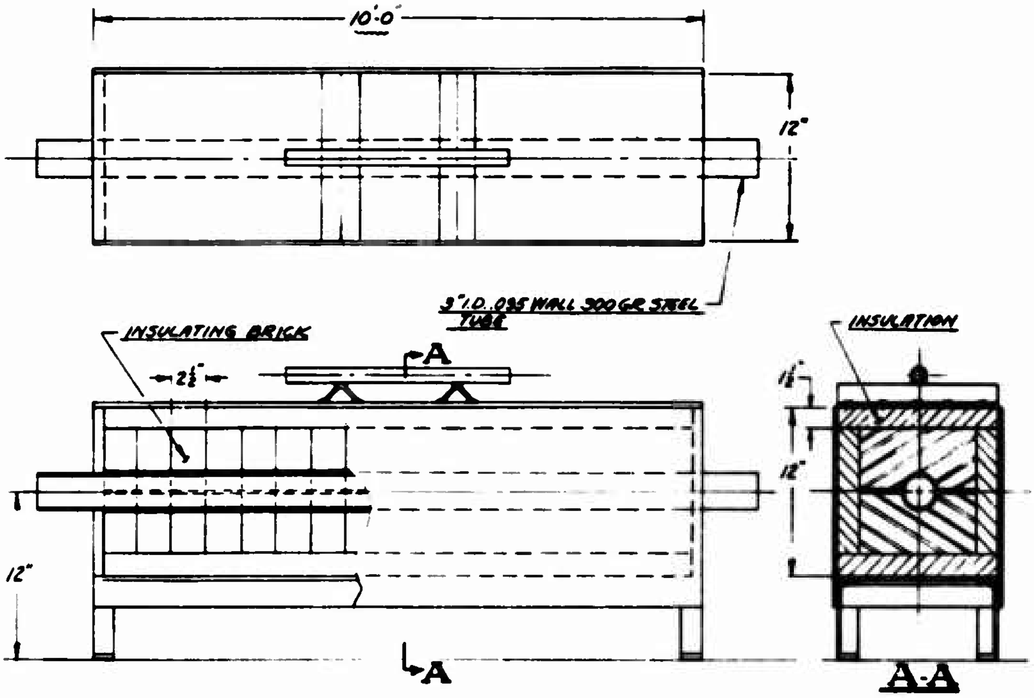
The material was examined metallographically in both the as extruded and straightened condition and after warm drawing. The photomicrographs are shown in Figures 50-57. A minor structural refinement is noted in the primary alpha particle size of the extrusions drawn to 1/16" from 3/32" when a comparison is made to an as-extruded 1/16" section (See Figures 54 and 55).



View of Warm Drawing Assembly,
Left Rear, 100 KW Unit; Right Rear Control Unit;
Left Front Trolley on Draw Bench; Right Front, Induction Coil

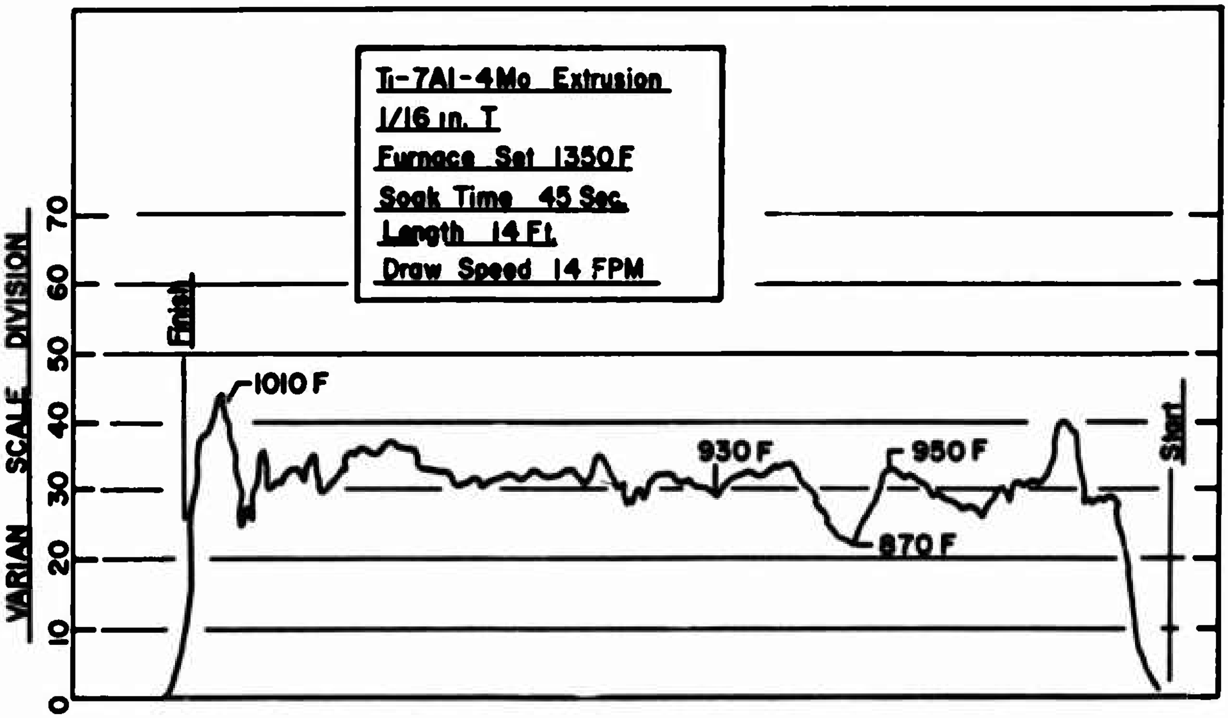
FIGURE 35

60520



Resistance Heated Stainless Steel
Muffle Tube Furnace

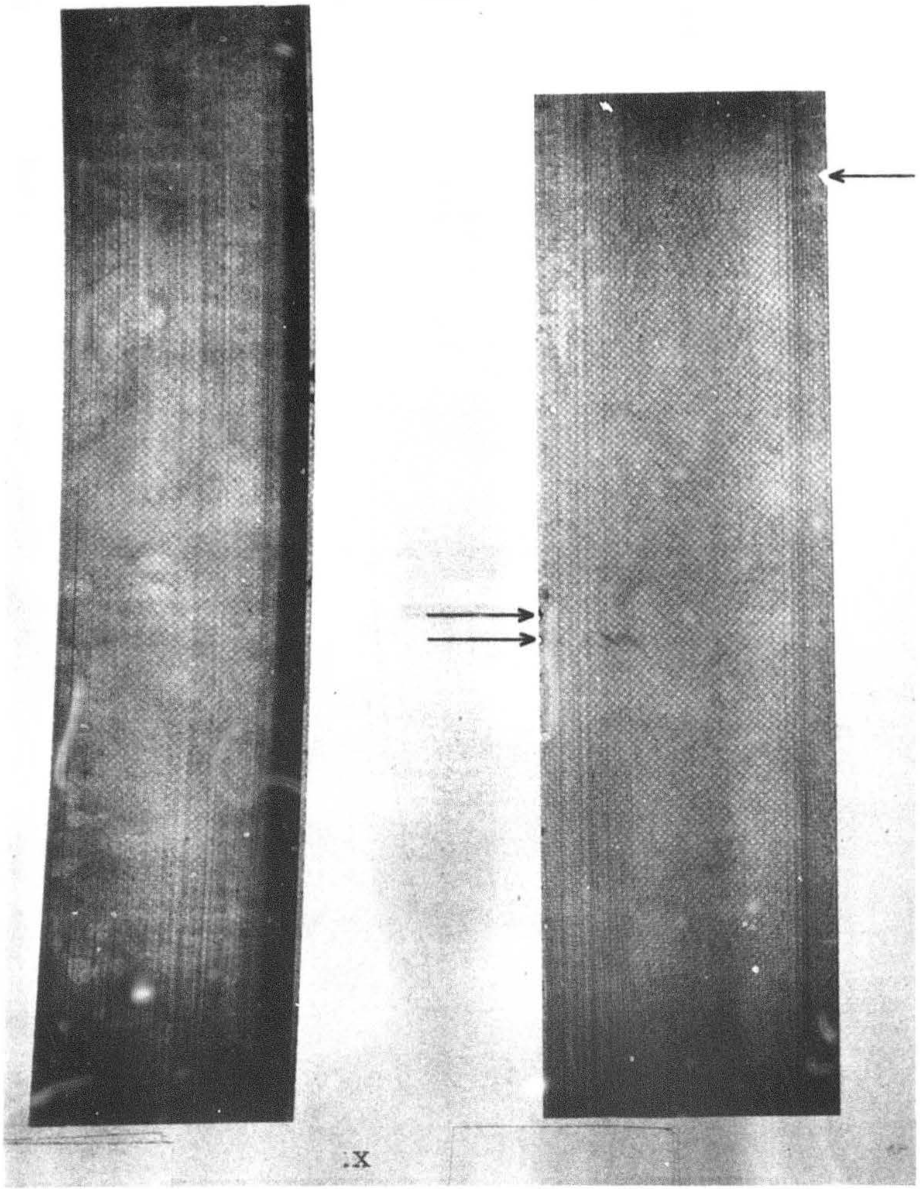
FIGURE 36



Temperature measured at die entrance, 8 inches away from the exit end of furnace

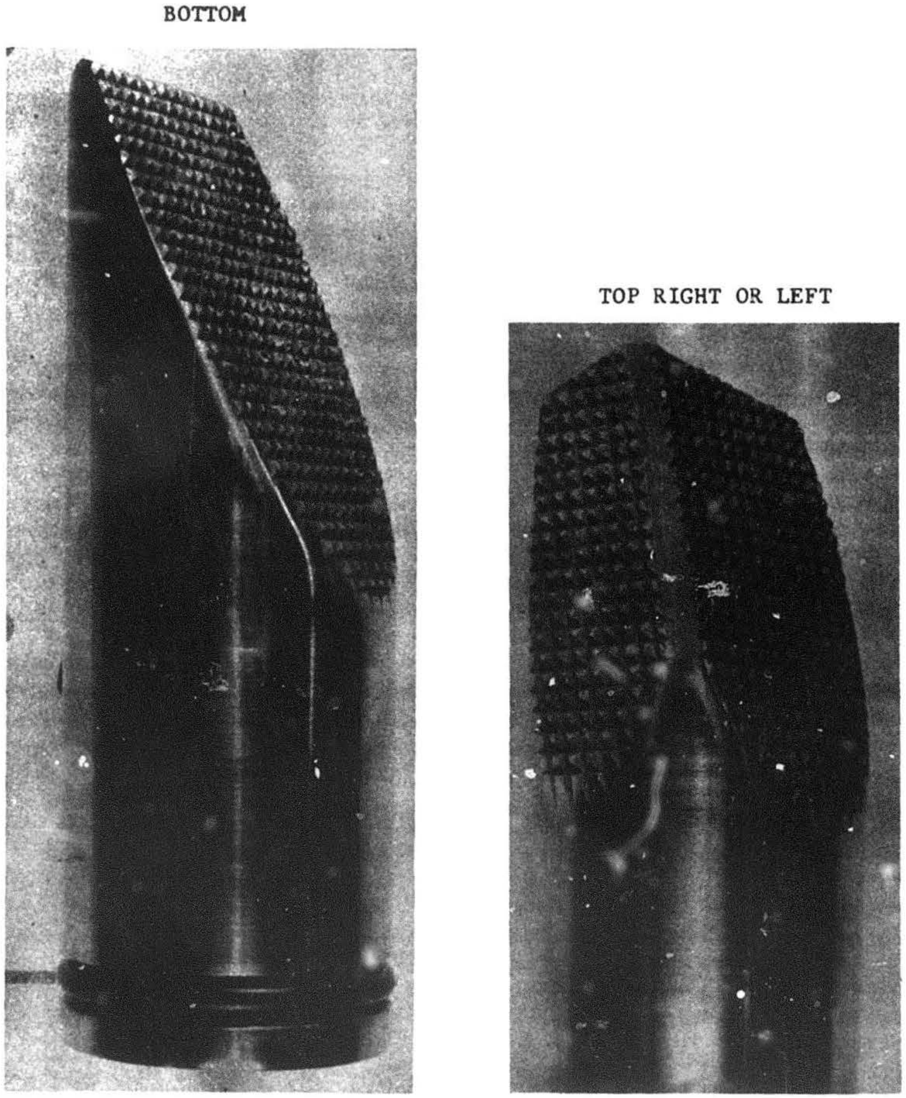
Temperature Uniformity Along the Length of a Warm Drawn Extrusion, Heated in a Resistance Heated Tube Furnace, Ten Foot Long

FIGURE 37



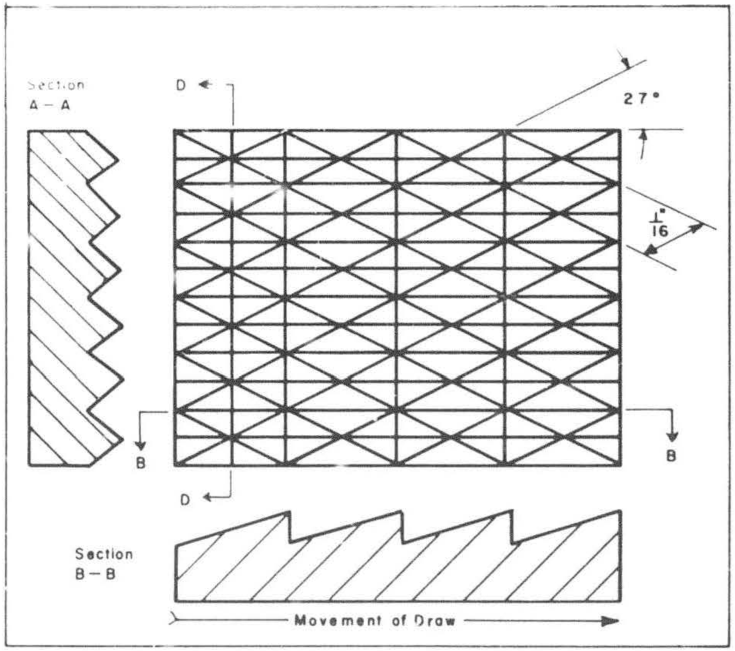
Arcing of Extrusion Extremities
During the .058" Pass. (Ext. #236)

FIGURE 38



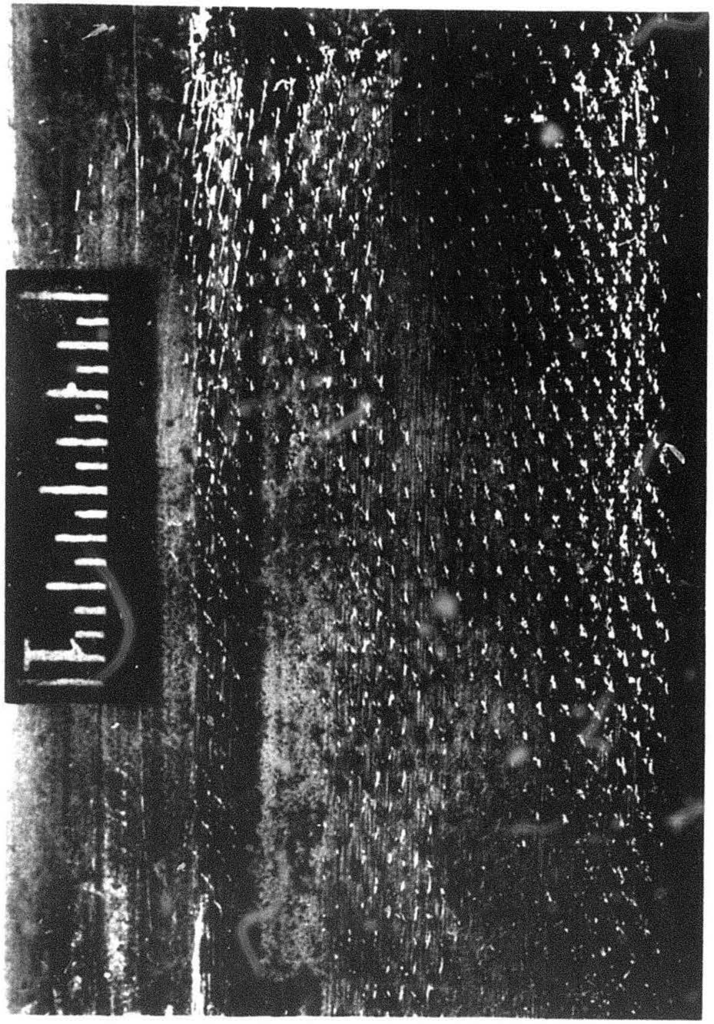
Jaws unable to grip with teeth in this condition.
Flattened Teeth in Nitrided H-11 Gripper Jaws
(1/8 Inch Waffle Pattern In-Line Design)

FIGURE 39



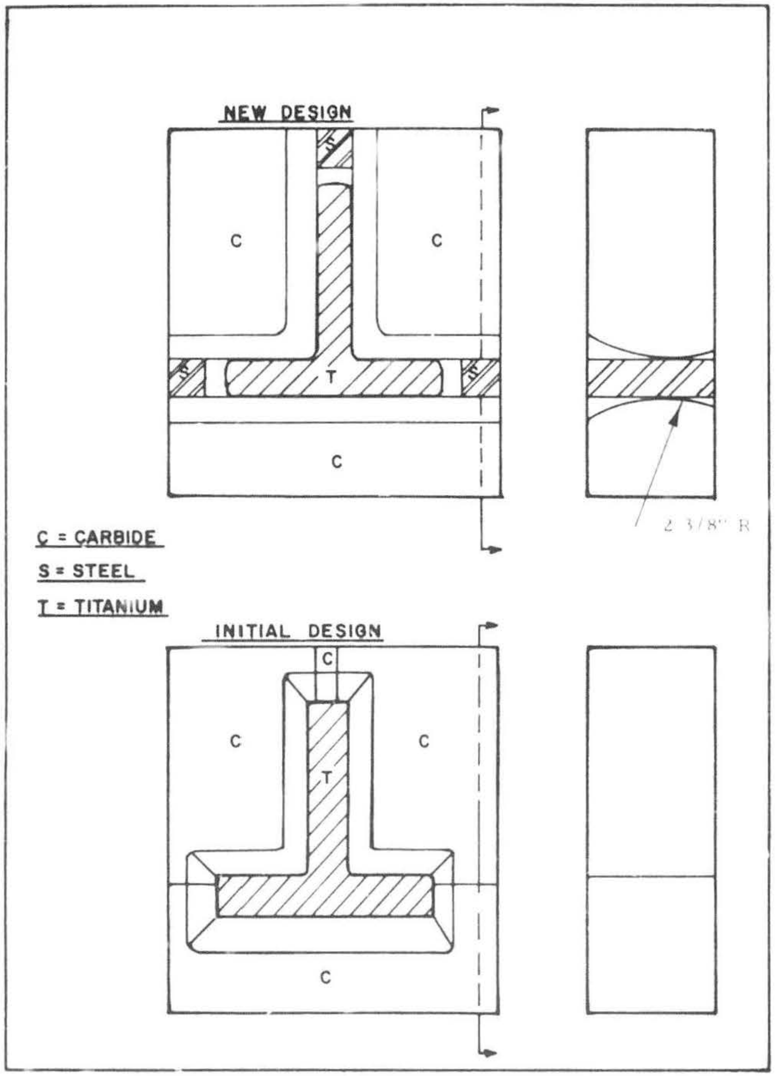
Views Illustrating the Modified 1/16 in.
Diamond Pattern Jaws

FIGURE 40



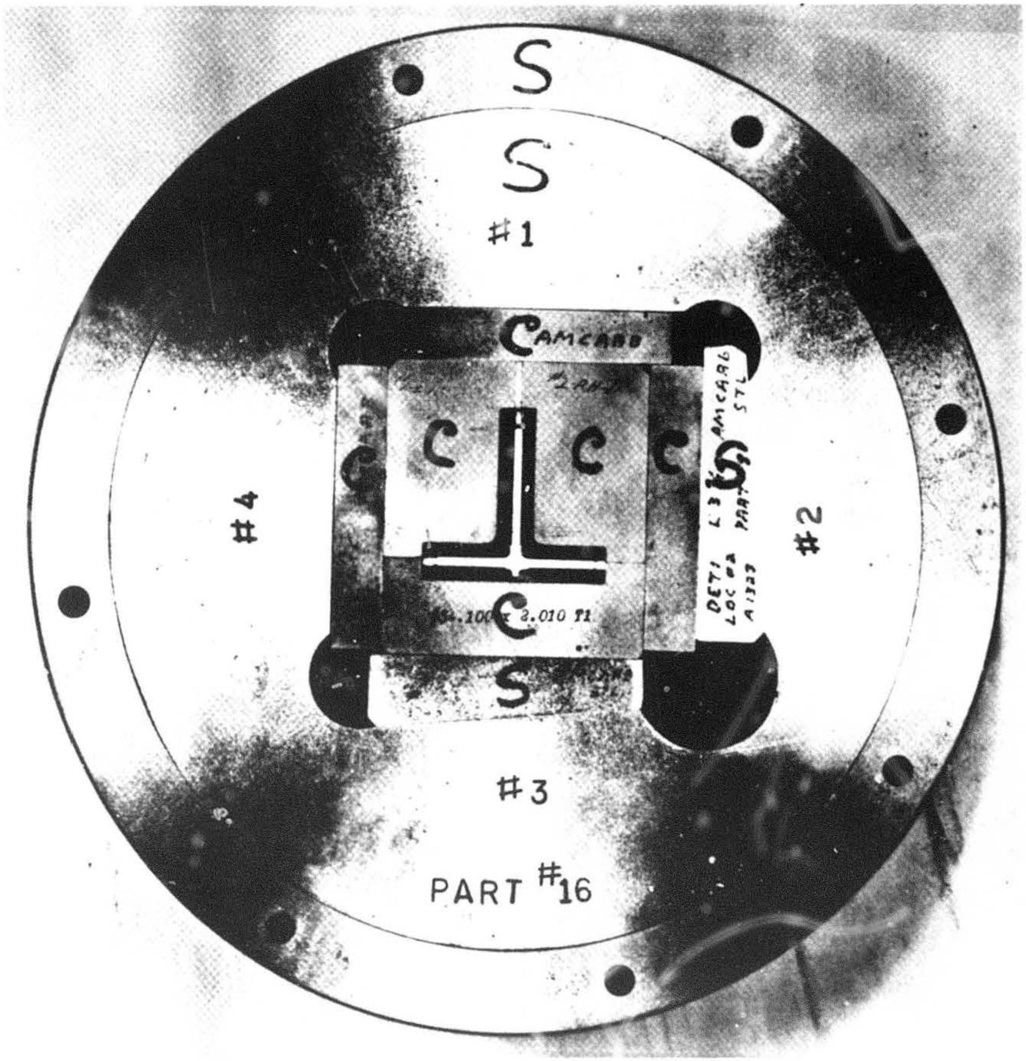
A View of the Gripper Impression From
the Modified 1/16" Diamond Pattern Jaw

FIGURE 41



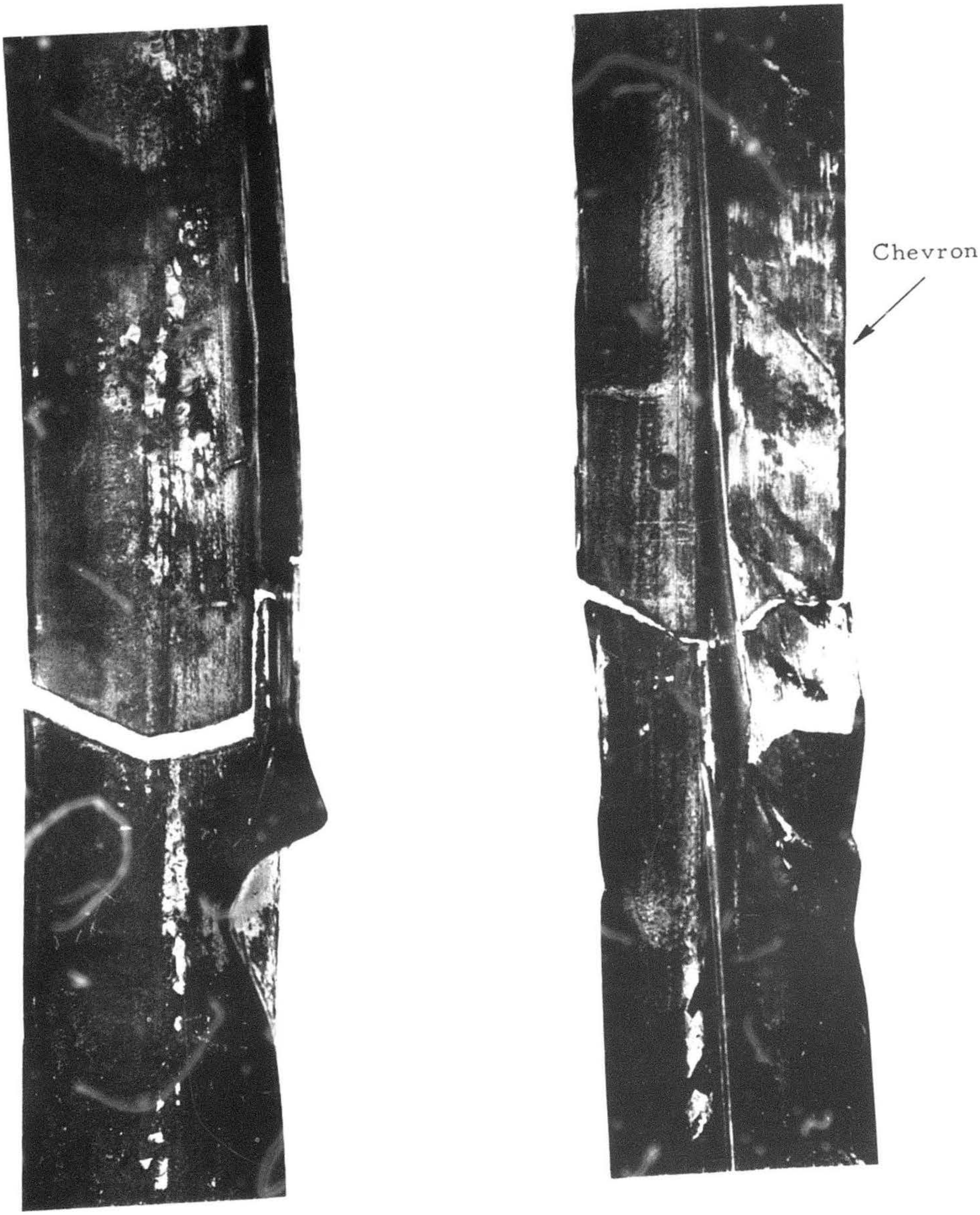
Sketch Illustrating Initial Die Design and Modified Design Permitting Unrestrained, Edge Metal Flow

FIGURE 42



A View of the Assembled 3-Piece Split Carbide Draw Die with the Steel Cover Plate Removed

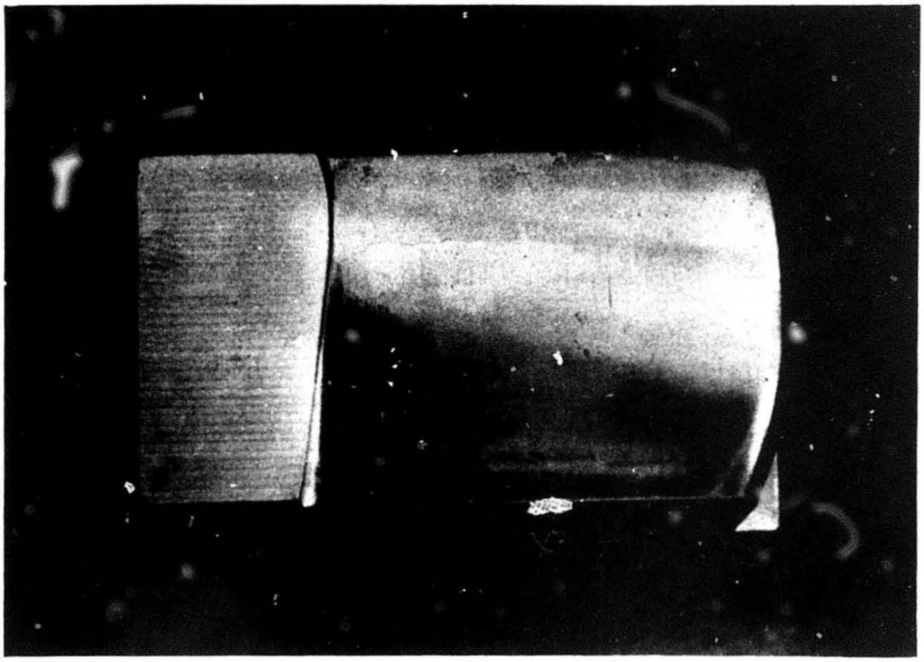
FIGURE 43

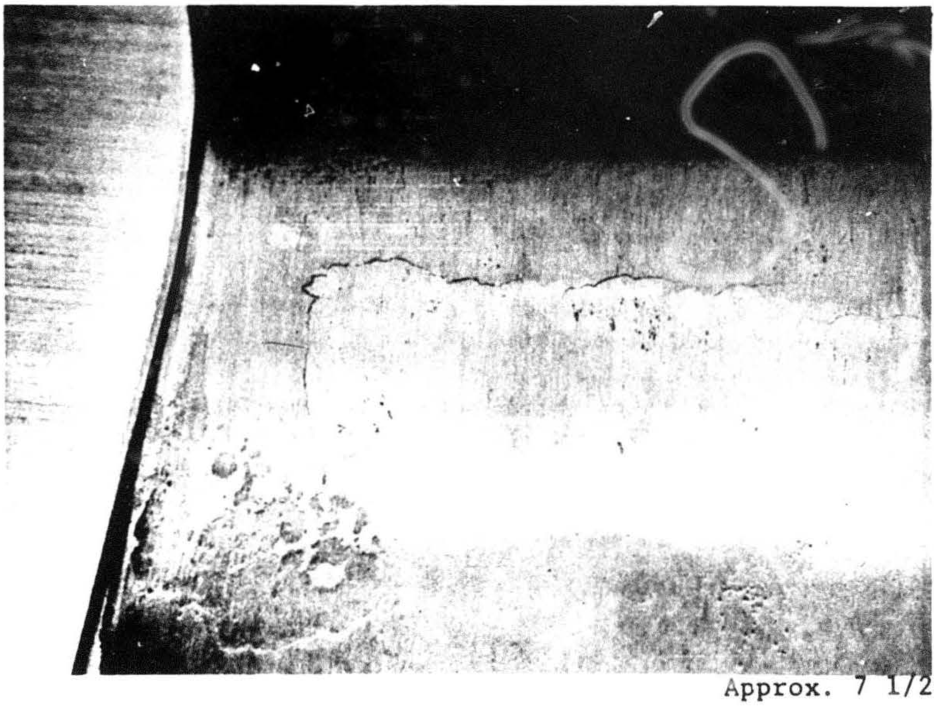


Buckling and Resultant Chevron Defects in a Nominal 1/16 in. T Extrusion of Ti-7Al-4Mo

FIGURE 44

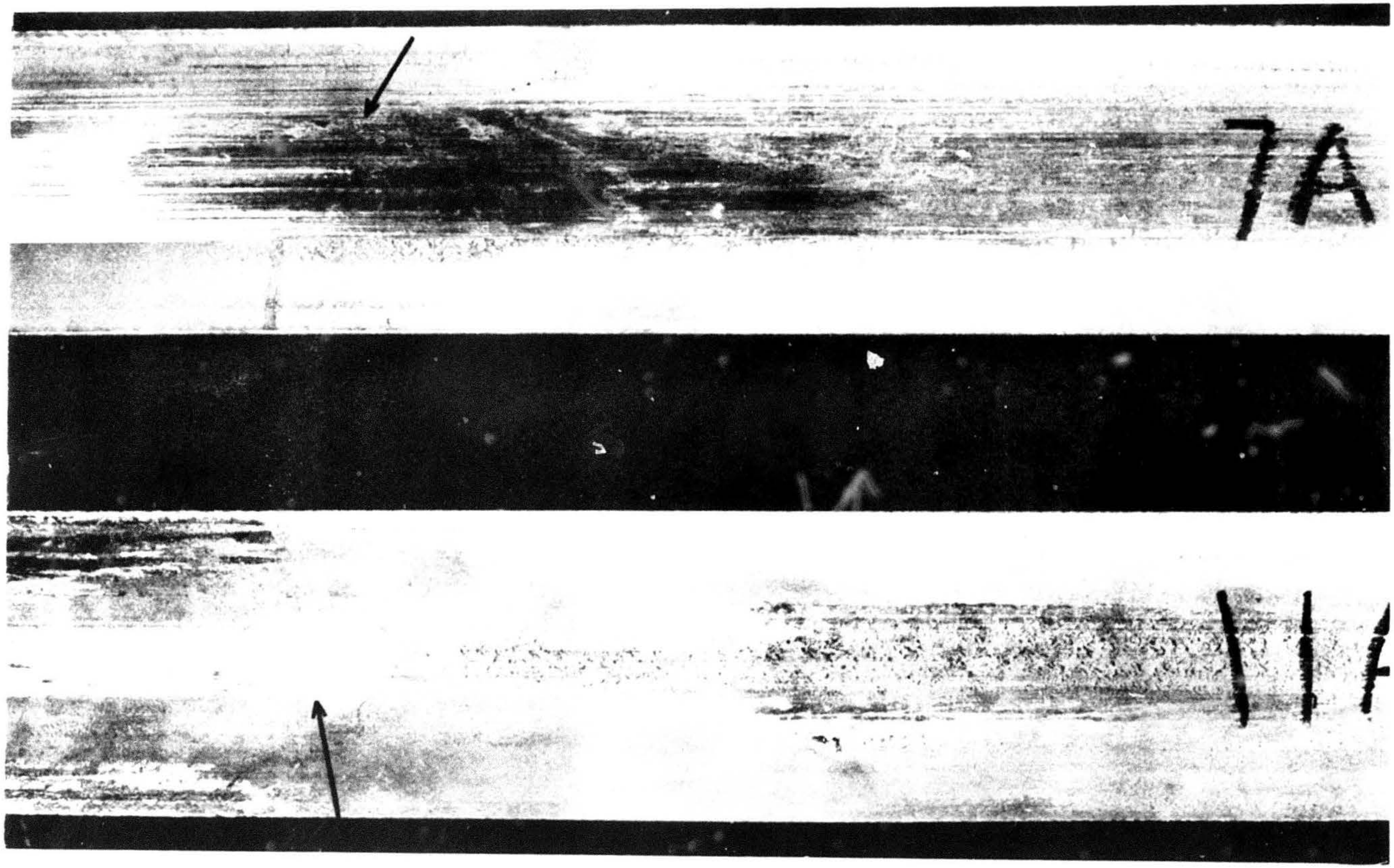
605288


Approx. 2 1/2X


Approx. 7 1/2X

Views Illustrating Heat Checking Noted in the Upper Right and Left Draw Die Inserts of Tungsten Carbide. Hairline Cracks are at Approximately the Bearing Line

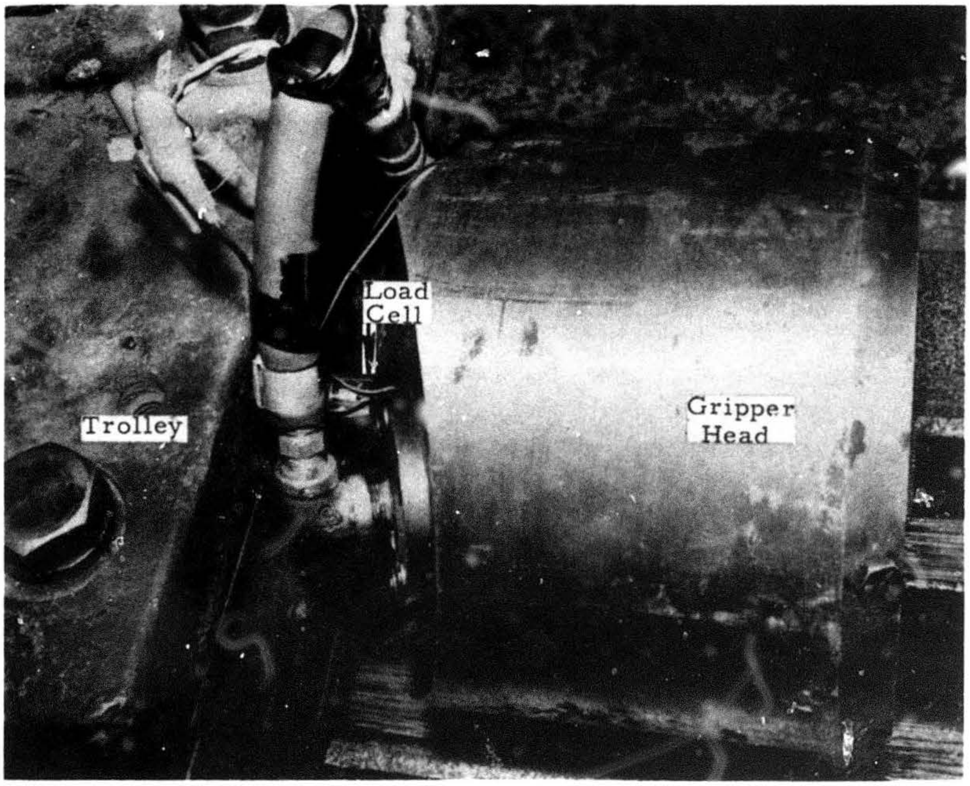
FIGURE 45



Galled areas (indicated by arrows) are a result of lubrication breakdown due to temperature fluctuation of the induction coil.

A Bottom View of Two T Extrusions Warm Drawn Directly Through the 0. 110" Die Using Mag 400 Stearate Soap as the Exterior Lubricant

FIGURE 46

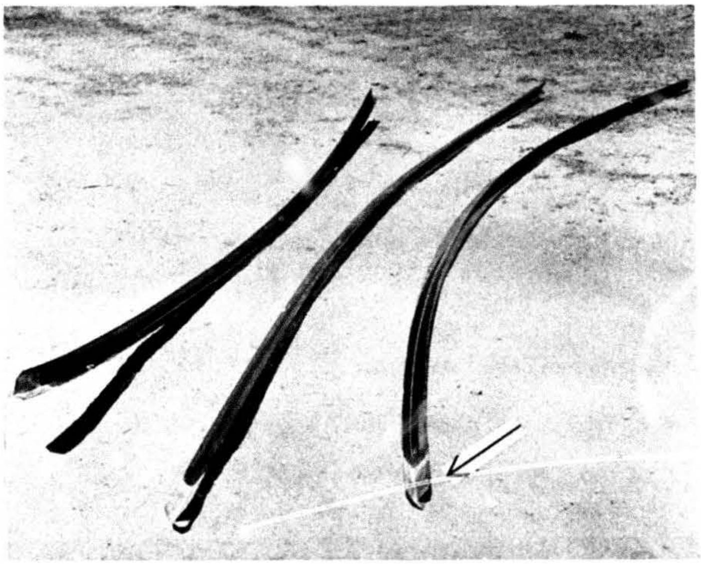


A View of the Gripper Head with Load Cell Located Between this Unit and Trolley

FIGURE 47

605248

A 3/32" Tee After Warm Drawing to 0.080". Ironing in Middle of Base Due to Heavy Fillet Reduction. Note Inability to cope with Seams in Warm Drawing
FIGURE 48



Distortion in As-Drawn Tee Extrusions, Resulting from Improper Die Alignment and Non-uniform Metal Flow. Arrow indicates mechanically Pointed Front Ends.

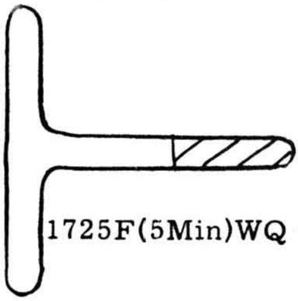
FIGURE 49

As Extruded & Straightened

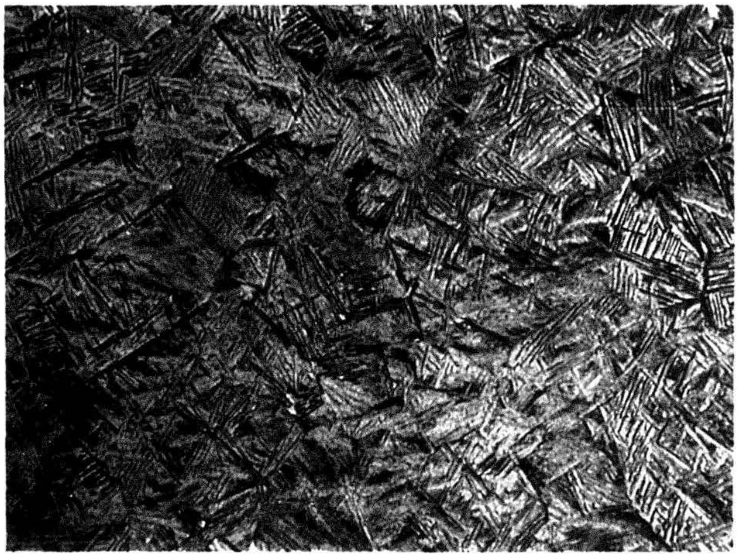
500X

Longitudinal Properties

UTS, Ksi	155.8
YS(0.2%), Ksi	141.4
El(1 in), %	15.6



1725F(5Min)WQ + 1000F(4Hrs)AC



500X

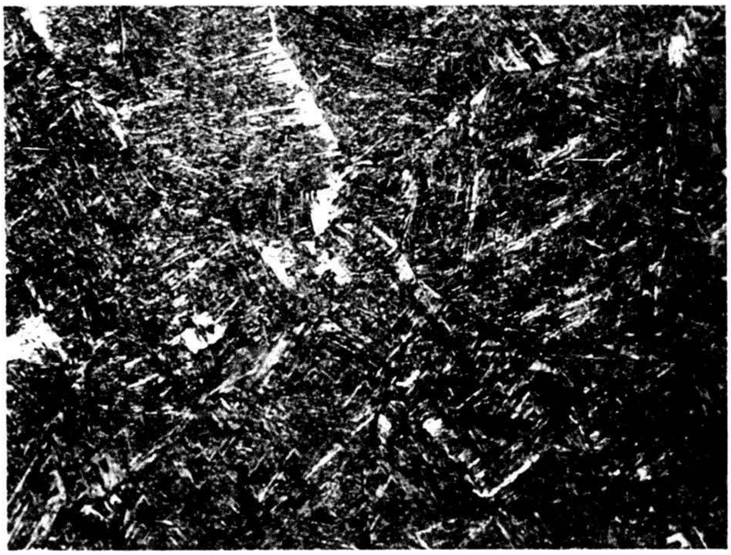
UTS, Ksi	178.4
YS(0.2%), Ksi	161.6
El(1 in), %	10.0

Transverse Microstructures of a nominal 1/16 in. T of 6Al-4V (B&W #226), as Extruded and Straightened and also in the Heat Treated Condition

FIGURE 50

605288

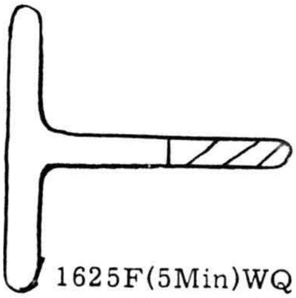
As Extruded & Straightened



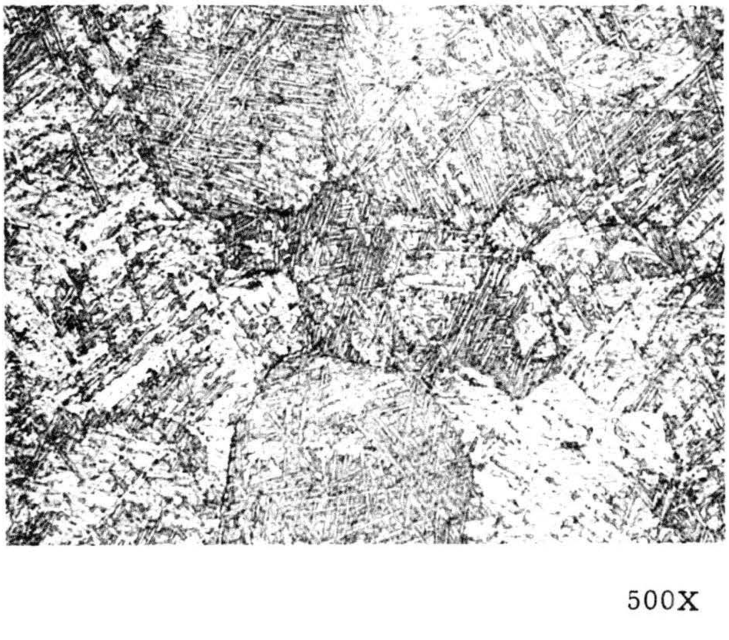
Longitudinal Properties

UTS, Ksi	147.2
YS(0.2%), Ksi	135.5
El(1 in), %	12.0

500X



1625F(5Min)WQ + 925F(12Hrs)AC



UTS, Ksi	167.4
YS(0.2%), Ksi	136.2
El(1 in), %	7.0

500X

Transverse Microstructures of a Nominal 1/16 in. T Extrusion of Ti-4Al-3Mo-1V (B&W #243) As Extruded and Straightened and also as Heat Treated

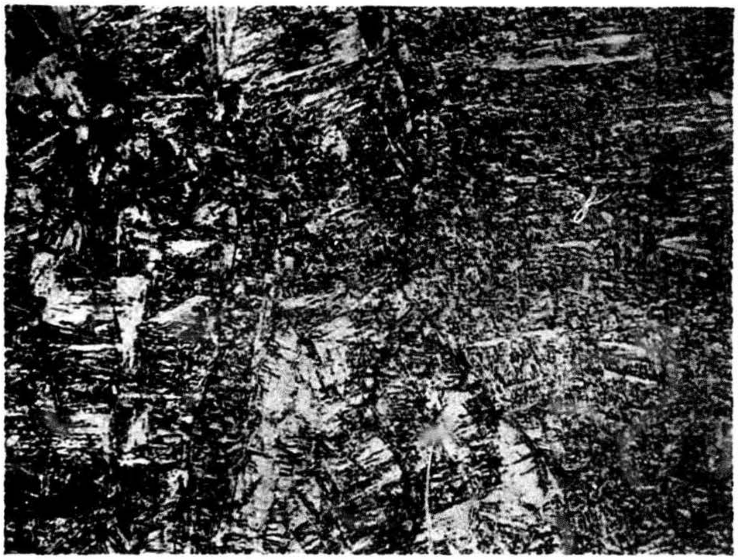
FIGURE 51

605288

Transverse

UTS, Ksi	164.4
YS(0.2%),Ksi	143.7
EL(1/2in)%	4.0

62-234D 500X



Longitudinal

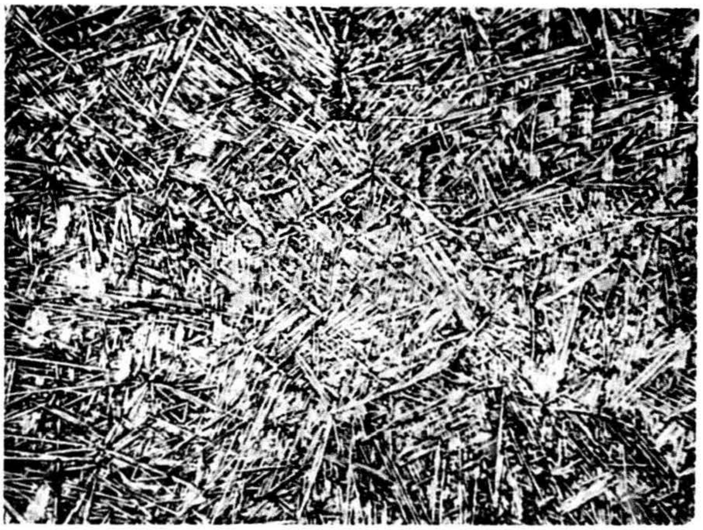
UTS,Ksi	169.7
YS(0.2%),Ksi	139.6
EL(1 inch)%	11.0

62-234C 500X

Microstructures of an As-Extruded 1/16 in. T of Ti-7Al-4Mo (Battelle #55)

FIGURE 52

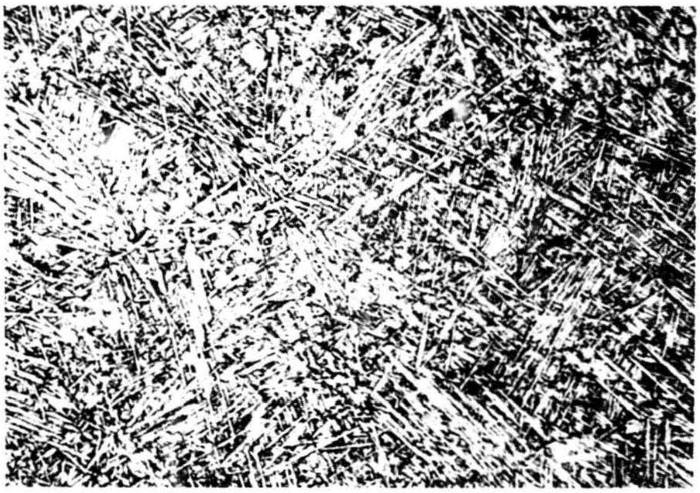
605288



Transverse

UTS, Ksi	179.5
YS(0.2%),Ksi	154.4
EL(1/2in),%	3.0

62-285G **500X**



Longitudinal

UTS,Ksi	189.0
YS(0.2%),Ksi	167.1
EL(1inch),%	3.5

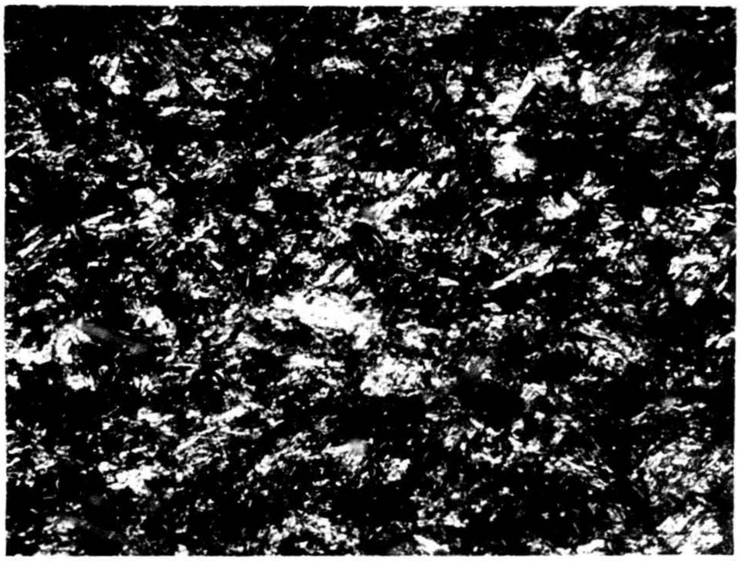
62-285H **500X**

Microstructures of a 1/16 in. T Extrusion (Battelle #55) of Ti-7Al-4Mo, Heat Treated 1750° F (5 min.) WQ + 1150° F (4 hrs.)AC

FIGURE 53

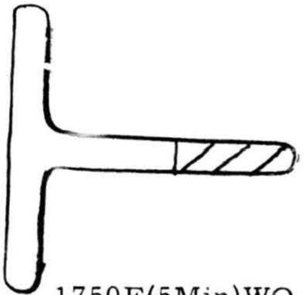
605 288

1450F(1/2Hr)FC to 1000F, AC

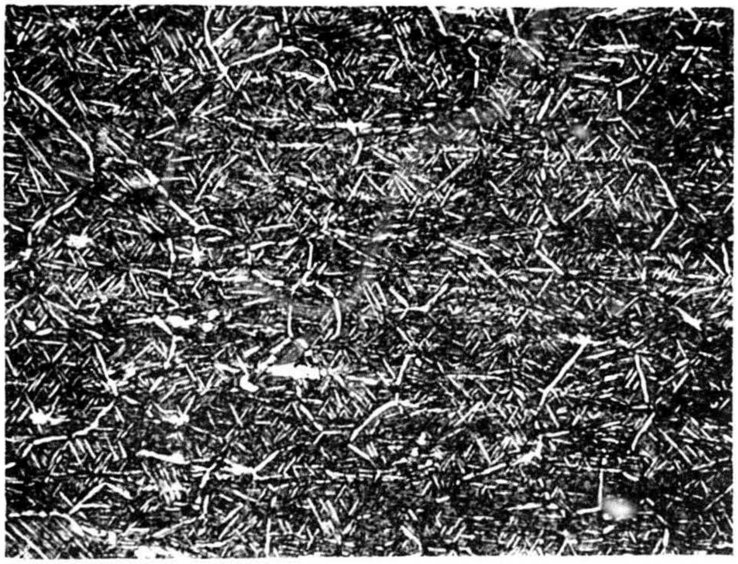


UTS, Ksi	177.0
YS(0.2%), Ksi	157.8
El(1 in), %	14.0

500X



1750F(5Min)WQ + 1150F(4Hrs)AC



UTS, Ksi	196.7
YS(0.2%), Ksi	175.0
El(1 in), %	7.0

500X

Transverse Microstructures of a Nominal 1/16 in. T of Ti-7Al-4Mo (B& W # 230), Annealed and also in the Heat Treated State

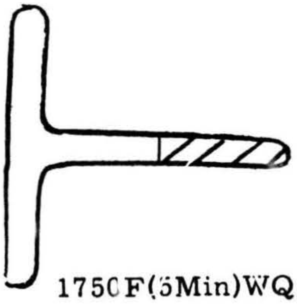
FIGURE 54

605288

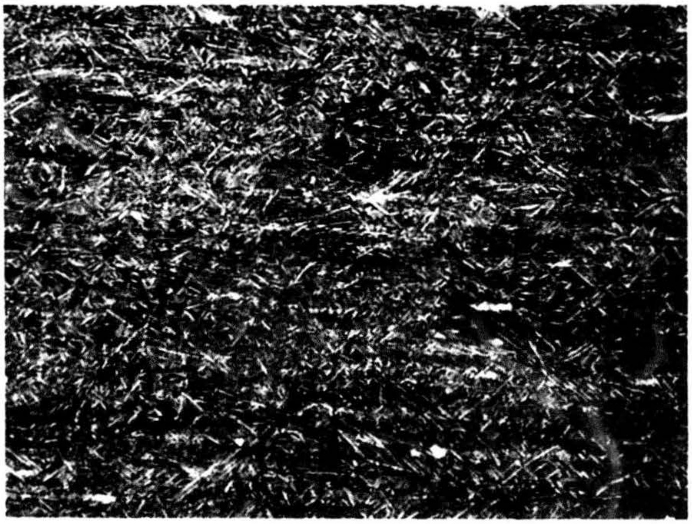
As Drawn to 0.065in

UTS, Ksi	184.6
YS(0.2%), Ksi	164.8
El(1 in), %	9.0

500X



1750F(5Min)WQ + 1150F(4Hrs)AC



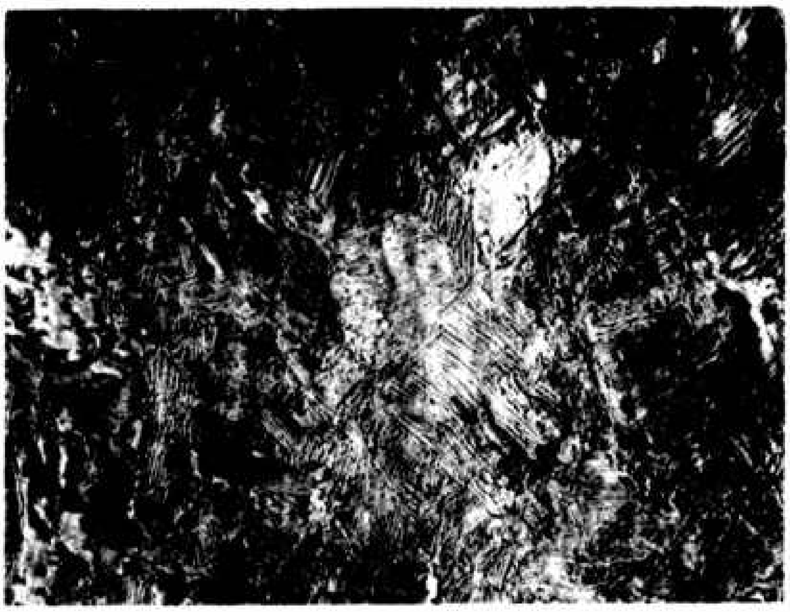
UTS, Ksi	202.3
YS(0.2%), Ksi	182.7
El(1 in), %	4.0

500X

Transverse Microstructures of a Nominal 3/32 in. T of Ti-7Al-4Mo (B&W # 223), As Warm Drawn to 1/16 in. and also in the Heat Treated Condition

FIGURE 55

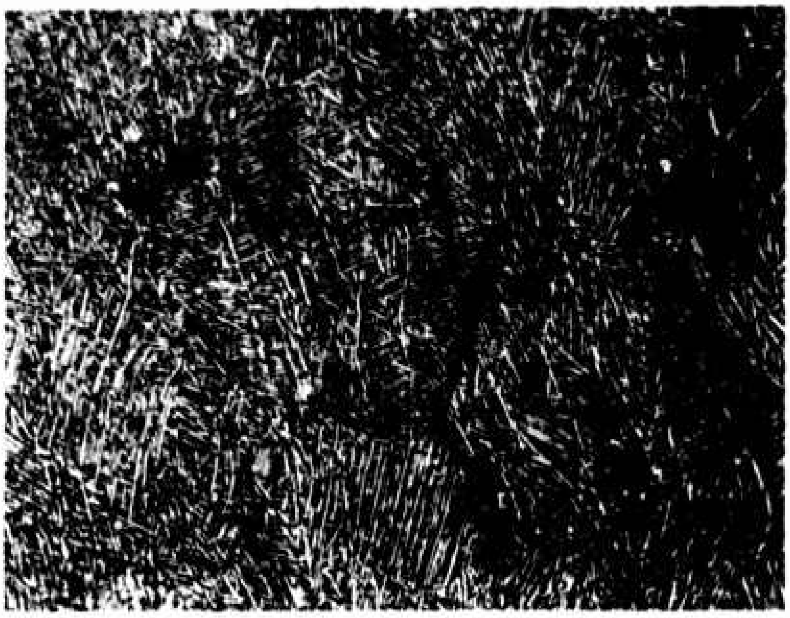
605288



Ti-6Al-4V
Warm Drawn
0.048in

As-Hot
(1550F)
Stretched

63-235B 500X



Ti-4Al-3Mo-1V
Warm Drawn
0.053in

As-Hot
(1550F)
Stretched

63-235C 500X

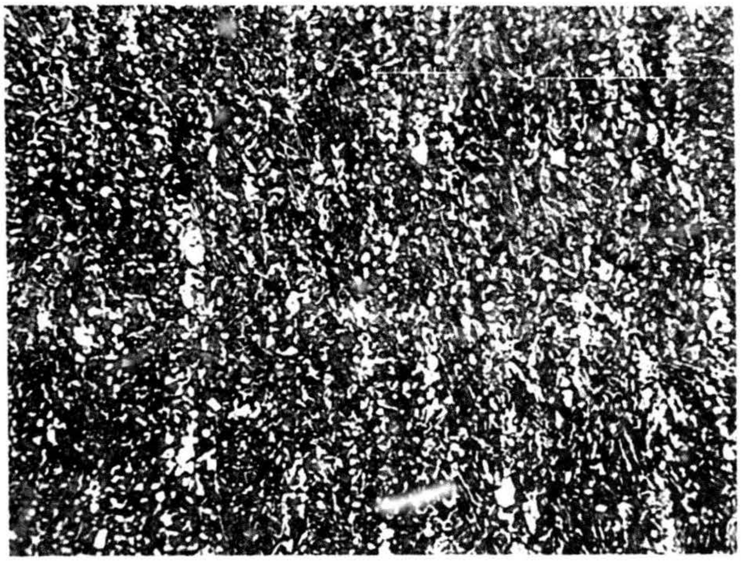
Transverse Microstructure of Ti-6Al-4V and Ti-4Al-3Mo-1V Alloys Warm Drawn From a Nominal 1/16 in. Thickness

FIGURE 56

605288

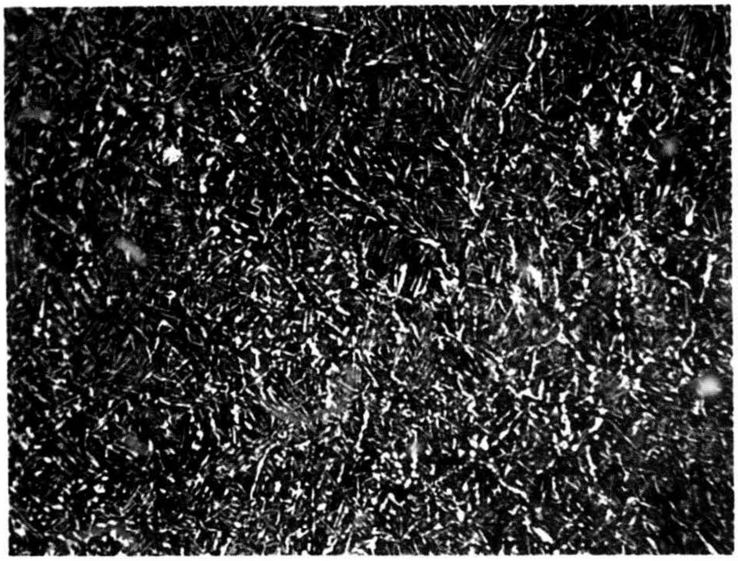
Longitudinal

UTS,Ksi 194.9
YS(0.2%) 168.1
EL(1in),% 6.0 Q



63-100A 500X

Transverse



63-100B 500X

Longitudinal and Transverse Microstructures of a Nominal 1/16 in. T Extrusion of Ti-7Al-4Mo (B&W #232) Warm Drawn to 0. 043 in. and Heat Treated

FIGURE 57

605218

TABLE 6

TENSILE PROPERTIES OF PART IV EXTRUSIONS *

Location	Direction	Condition		UTS Ksi	YS(0.2%) Ksi	EL(1/2-1")%
Ti-4Al-3Mo-1V - 1/16 in. T (B&W #243)						
A	L	Extruded & Straightened		147.2	135.5	12.0
B	L	" "		138.9	126.0	15.0
C	L	" "		135.8	122.3	12.5
D	L	" "	1000°F	96.2	78.6	22.5
G	T	" "		135.5	113.9	BOGL
A	L	1250°F (2 hrs) AC		152.8	141.0	10.0
B	L	" "		142.6	129.8	13.5
C	L	" "		137.3	121.7	13.5
D	L	" "	1000°F	94.3	80.9	16.0
G	T	" "		137.4	113.3	4.5
Ti-7Al-4Mo - 1/16 in. T (B&W #230)						
A	L	1450°F (1/2 hr) FC 100°F 1 hr to 1000°F AC		177.4	157.8	14.0
B	L	" "		168.6	151.9	10.0
C	L	" "		165.9	147.6	11.5
D	L	" "	1000°F	115.2	93.8	12.5
A	L	1750°F (5 min.) WQ + 1150°F (4 hrs.) AC		196.7	175.0	7.0
B	L	" "		193.6	168.7	6.0
C	L	" "		185.8	171.5	5.0
D	L	" "		202.5	176.6	5.0
Ti-7Al-4Mo - 1/16 in. T (Battelle #55)						
A	L	As Extruded		184.0	160.1	8.0
B	L	"		174.0	146.2	9.2
C	L	"		169.7	139.6	11.0
D	L	" 1000°F Test		121.3	94.3	11.0
E	L	1450°F (1/2 hr.)FC 100°F/Hr 1000°F AC		118.3	99.2	11.5
F	T	As Extruded		168.4	147.9	7.0

(Continued)

TABLE 6 (Continued)

Location	Direction	Condition		UTS Ksi	YS(0. 2%) Ksi	EL(1/2-1")%
G	T	As Extruded		164. 4	143. 7	4. 0
A	L	1750°F (5 min.) WQ + 1100°F (4 hr.) AC		208. 8	183. 3	6. 5
B	L	1750°F (5 min.) WQ + 1150°F (4 hr.) AC		192. 9	171. 7	4. 5
C	L	" "		189. 0	167. 1	3. 5
D	L	" "		202. 4	178. 3	8. 0
E	L	1750°F (5 min.) WQ + 1200°F (4 hr.) AC		188. 9	169. 4	9. 0
F	T	1750°F (5 min.) WQ + 1150°F (4 hr.) AC		-	-	-
G	T	" "		179. 5	154. 4	3. 0
Ti-6Al-4V - 1/16 in. (B&W #226)						
A	L	Extruded & Straightened		155. 8	141. 4	15. 0
B	L	" "		152. 2	135. 7	17. 0
C	L	" "		148. 7	131. 8	15. 0
D	L	" "	1000°F	90. 8	72. 8	22. 5
F	L	" "		152. 0	129. 2	10. 0
A	L	1725°F (5 min.) WQ + 1000°F (4 hrs.) AC		178. 4	161. 6	10. 0
B	L	" "		174. 1	157. 2	7. 0
C	L	" "		173. 0	153. 9	10. 0
D	L	" "		178. 6	162. 3	9. 0
F	L	" "		179. 6	158. 1	7. 5
A	L	1300°F (2 hrs.) AC		152. 5	138. 0	13. 0
B	L	" "		152. 3	135. 9	14. 0
C	L	" "		147. 8	132. 9	12. 0
D	L	" "	1000°F	85. 2	66. 1	19. 0
F	T	" "		143. 8	125. 4	9. 0
G	T	" "		146. 1	126. 2	10. 0
A	L	1675°F (5 min.)WQ+ 1000°F (4 hrs.) AC		177. 5	156. 1	12. 0
B	L	" "		171. 9	154. 1	8. 5

(Continued)

TABLE 6 (Continued)

Location	Direction	Condition	UTS Ksi	YS(0. 2%) Ksi	EL(1/2- ")%
C	L	1675°F (5 min.) WQ + 1000°F (4 hrs.) AC	169. 1	151. 1	9. 0
D	L	" "	174. 1	155. 3	12. 0

* Sheet tensile specimens with 1 inch gage length for longitudinal (L) samples and 1/2 inch gage length for transverse (T) samples. Surfaces machined about 0. 005/0. 010 in. per side.

Q Fracture occurred within 1/8 inch of gauge mark - therefore elongation value somewhat on low side of actual.

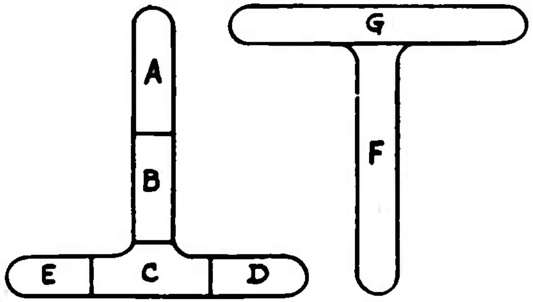
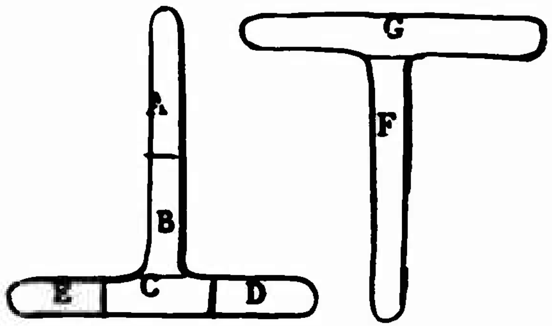


TABLE 7

TYPICAL TENSILE PROPERTIES * OF A Ti-7Al-4Mo EXTRUSION 3/32in T (NO. 223) WARM DRAWN TO 1/16in



Location	Direction	Condition	UTS Ksi	YS(0.2%) Ksi	EL(1/2-") %
A	L	As Warm Drawn	184.6	164.8	9.0
E	L	" " "	188.3	168.0	9.0
B	L	1450F(1/2hr)SC 100F 1hr to 1000F AC	170.8	152.4	14.0
C	L	" " "	172.8	157.6	10.0
D	L	" " "	183.5	164.7	14.0
F	T	" " "	162.1	140.4	12.0
G	T	" " "	170.7	148.6	7.0 Q
A	L	1750F(5min)WQ + 1100F(4hrs)AC	219.4	190.7	3.5
D	L	" + 1150F "	202.3	182.7	4.0
E	L	" + 1200F "	194.4	175.6	6.0
B	L	" + 1150F "	193.2	169.8	5.0
C	L	" " "	193.2	170.3	8.0
F	L	" " "	197.4	168.2	4.0 Q
G	L	" " "	205.5	173.4	7.0 Q

---

* Sheet type tensile specimens with 1 inch gage length in the L direction and 1/2 inch for the T direction; specimens machined 0.005/0.010in per side.

TABLE 8

ANNEALED* PROPERTIES OF PART IV EXTRUSIONS

Extrusion No.	Alloy	Drawn Web Thickness, In	UTS Ksi	YS(0.2%) Ksi	El(1 in) %
228	Ti-4Al-3Mo-1V	0.052	135.5	121.8	14.0
229	Ti-4Al-3Mo-1V	0.052	136.7	121.3	13.5
230	Ti-7Al-4Mo	0.058	170.3	156.6	6.0^{Q}
235	Ti-6Al-4V	0.048	150.3	130.9	13.0^{Q}
239	Ti-6Al-4V	0.052	154.5	140.9	15.0
240	Ti-4Al-3Mo-1V	0.058	132.2	114.0	14.0
245	Ti-4Al-3Mo-1V	0.052	132.6	117.2	10.5

* Heated 1550F(10 Sec.) hot, stretched (1/2 - 1 percent).

TABLE 9

HEAT TREAT RESPONSE IN PART IV EXTRUSIONS*

Extrusion No.	Alloy	Drawn Web Thickness, In.	Heat Treatment	UTS Ksi	YS(0.2%) Ksi	El(1 in) %
228	Ti-4Al-3Mo-1V	0.052	1650F(5Min)WQ+ 950F(4Hrs)AC	187.6	154.7	4.0^{Q}
229	Ti-4Al-3Mo-1V	0.052	" + "	188.2	156.1	6.0^{Q}
230	Ti-7Al-4Mo	0.058	1750F(5Min)WQ+1150F(4Hrs)AC	200.4	180.3	5.5
235	Ti-6Al-4V	0.048	1725F(5Min)WQ+1000F(4Hrs)AC	183.6	165.4	6.0
239	Ti-6Al-4V	0.052	" + "	184.0	167.4	8.0
240	Ti-4Al-3Mo-1V	0.058	1650F(5Min)WQ+ 950F(4Hrs)AC	184.0	153.5	4.0
245	Ti-4Al-3Mo-1V	0.052	" + "	186.9	153.8	4.0^{Q}

* Drawn from a nominal 1/16in extrusion thickness.

E PART V - EXTRUSION AND DRAWING OF TYPICAL RB-70 SHAPES

1. Introduction

In order to determine the practicability of the techniques developed under Part IV, two shapes required for the RB-70 Weapons System were selected for fabrication. The two shapes are shown in Figure 5. These shapes were selected since they represent a significant increase in the state-of-art of titanium extrusion and at the same time were compatible with the existing warm draw tooling. The material for the two shapes was Ti 6A1-4V.

To produce the shapes it was determined that it would be economically advantageous to extrude to as close to the finished dimensions as possible, consistent with the limitations of the extrusion process, so that the required draw reduction would be a minimum. With this in mind, it was decided to produce shape 64E15 by extruding to .093" cross section and warm drawing to the final .080", providing a reduction of .013" or 14%. The modified shape 64E12 was produced by extruding to .063" cross section and warm drawing to .043", providing a reduction of .020" or 32%. Detailed data was obtained, relative to dimensional uniformity, surface finish, micro structure and mechanical properties for both shapes, in the as-extruded condition and after various draw stages to ascertain the degree of improvement in warm drawing.

The cross sectional dimensions shown in Figure 5 were the dimensions selected at the start of Part V. However, as discussed later in the report, the scope of Part V was changed to include heat treatment of the shapes which resulted in a reduction of the nominal cross sectional thickness of each shape.

After heat treatment, five (5) extrusions were shipped to North American Aviation, Inc. for testing relative to NAA specifications applicable to the RB-70 Weapons System.

2. Extrusion Trials at Babcock and Wilcox Corporation

a) Initial Extrusion Trials of Part V

(1) Objectives

The objectives of the initial extrusion trials were to evaluate the techniques developed under Part IV, and supply extrusions for the warm drawing phase.

A secondary objective of the trials was to determine the production potential of extruding shapes for the RB-70 aircraft by demonstrating multi-hole extrusion capability.

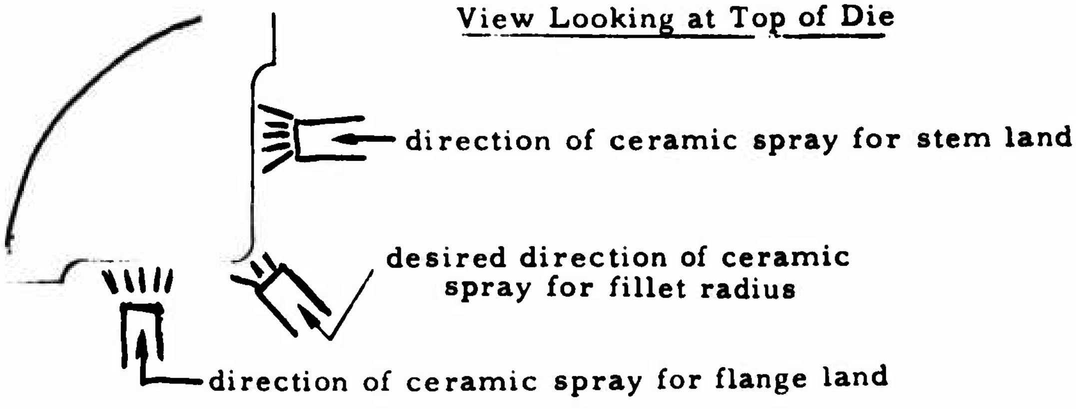
(2) Results and Evaluation

In the first two trials of Part V, a total of 30 pushes were made consisting of ten (10) pushes through the .063" orifice die, ten (10) pushes through the .093" orifice die and ten (10) pushes through the multiport die which contained two (2) .093" orifice tees. The extrusion data for these pushes is listed in the Appendix. The extrusion conditions for these trials were similar to the conditions for the final extrusion trial which are discussed in detail in the next section of this report.

During the first trial, a final evaluation was made of two glass systems which performed well during Part IV of the program. (E71B OD glass - E71 die glass and 318 OD glass - 3KB die glass). Poor results were obtained with the E71B-E71 combination in terms of heavy titanium pickup and wash of the dies and heavy scoring of the extrusions. Therefore, it was decided to use the 318-3KB combination for the balance of the program.

During the first trial, a lamination condition existed which indicated an uneven metal flow caused by nonuniform glass lubrication. Scalped discards from this trial are shown in Figure 58. During the second trial, the lamination condition was traced to the skid rails on which the billet was placed prior to insertion into the container. It was felt that the glass coating on the billet was being scraped off when the billet was pushed along the skid rails by the stem and/or the billet surface in contact with the skid rails was being chilled. Coating the rails with #85 glass slurry prior to placement of the billet on the rails eliminated this condition and no lamination defects were observed for the remainder of the program.

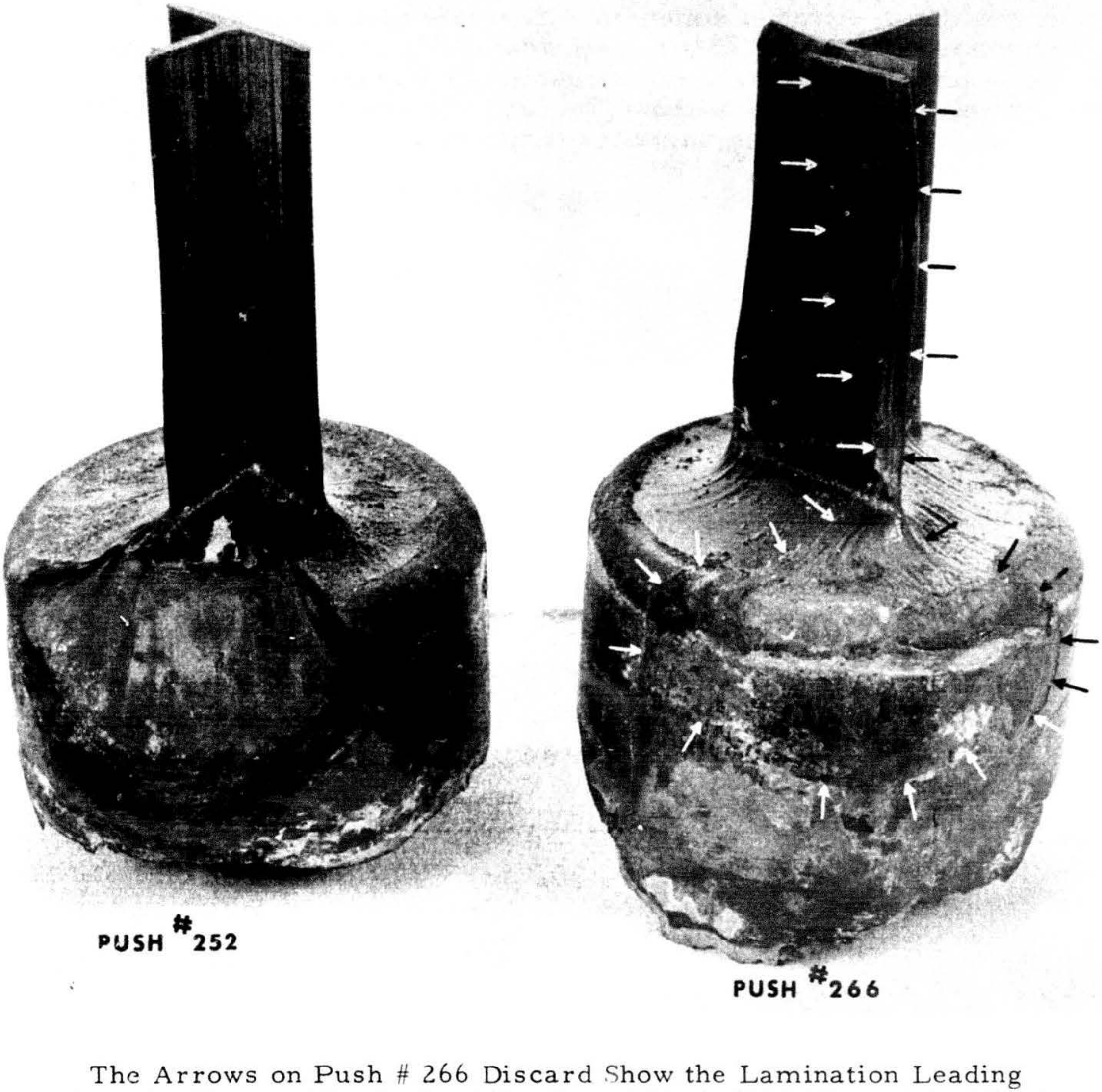
Examination of the dies for the second trial revealed that washing of the fillet radius consistently occurred and the areas of die wash corresponded to areas of scoring on the shapes. The relatively heavy die wash was attributed to a relatively light ceramic coating on the die radius which was not sufficient to act as a thermal barrier between the hot billet and the die material. The technique used in spraying the dies was to spray with the gun perpendicular to the die land to be sprayed. However, the spray gun was not aimed radially at the land of the fillet radius and the only ceramic pickup the fillet radius received was at an angle (from coating the stem and flange lands - see sketch below).



The spray technique was modified as shown above for the dies used in the third trial with excellent results. (See discussion in next section).

The production potential of extruding thin tee shapes in multiport dies was demonstrated by producing lengths of 17'0" and 16'8" in one push (approximately 34' of extrusion) but additional development work would be required to obtain good lubrication on all portions of the cross section.

The shapes were straightened by a combination of stretch and punch straightening developed under Part IV of the program. The detailed procedures used during these trials are presented in the section titled "Recommended Operational Procedure." No difficulties were experienced during these trials which were run very smoothly at the Babcock and Wilcox Corporation. Comparison of cross sectional dimensions after stretch straightening with as-extruded dimensions revealed that considerable dimensional contraction resulted after stretching 3%. This contraction is sufficient to require an allowance in extrusion die design. For the tee sections involved, the allowance should be 0.017" for the height and width dimensions and 0.0025" for the thickness dimensions.



The Arrows on Push # 266 Discard Show the Lamination Leading up into the Shape. The Scalped Portion of Push #252 Discard is Missing.

Butt Discards Showing Typical Billet Scalping and Lamination

FIGURE 58

6052.48

b) Final Extrusion Trial

The final extrusion trial of the campaign was performed at Babcock and Wilcox Corporation.

(1) Objectives

The objectives of the trial were to prove out the extrusion process developed during the program and to provide material for warm drawing NAA Shapes 64E12 and 64E15 by producing 20' lengths of the shapes in 0.093" and 0.063" cross sections.

(2) Facilities and Extrusion Practice

The extrusion press was a 2500-ton Loewy hydropress equipped with a 4-3/16" I. D. container and a 4-1/16" hardened steel stem for extruding 4" diameter billets. The 180,000 psi stress limitation in the steel stem required that the press extrusion force be limited to 1100 tons (1540 psi bottle pressure). The press is shown in Figure 59

The billet surfaces were belt ground to 100 grit, degreased, heated to 300°F and sprayed with #85 protection glass slurry prior to heating. The billets were then placed into a pre-heated (1800°F) stainless steel can, covered and given a 60 second argon purge. The can is then placed into a controlled argon atmosphere, electric resistance furnace. During billet heating, the glass slurry forms a protective film of glass over the billet. In subsequent extrusion, the glass film on the billet surface insulates the hot (1800°F) billet from the relatively cooler container liner (900°F).

The billets were transferred to the extrusion press manually in the stainless steel can and tipped out of the transport can onto the runout table where additional glass powder was applied.

After the billet was in position in the container, the stem was advanced rapidly until contact was made with the billet. The stem remained in this position for one or two seconds while upsetting the billet, and then extrusion proceeded in about two seconds.

The die was lubricated and protected from washout during extrusion by a film of glass which was continuously fuzed from a ring of compacted glass powder. The granular glass ring (shown in Figure 60a.) was inserted into the container adjacent to the die and three (3) glass wool pads were inserted next to the granular glass ring. The glass wool pads were slotted and shaped by hand into a "doughnut" form, the I. D. of which was larger than the tee opening of the die (to avoid die clogging). The thin glass fibers of the glass wool pads melt easily and provide the initial lubrication at breakthrough.

(3) Extrusion Parameters

The billet configuration is shown in Figure 60b. The convex faced nose created a reservoir of molten die glass which was available to the billet surface at the die opening. The relatively small radius (3/8") at the front face of the billet was employed to obtain good fillout at the front of the extrusion.

Shape 64E15 had an average die opening of 0.096" and width and height openings of 1.85" and 1.05" respectively. The cross sectional area for this shape was approximately 0.269 in ^{2}. With a container of 4-3/16" I. D., the extrusion ratio for this section was approximately 51 to 1. Shape 64E12 had an average die opening of 0.069" and width and height openings of 1.85" and 1.68" respectively. The cross sectional area for this shape was approximately 0.242 in ^{2} and tne extrusion ratio was approximately 57 to 1.

Peerless A tungsten steel dies heat treated to Rc 48-51 and sprayed with approximately 0.012" ceramic over a 0.002" undercoat of molybdenum were used for all the pushes. The dies were of three piece design to allow the application of the ceramic coating by the flame spray method. The die design is shown in Figure 61. The die orifice dimensions after coating are shown in Table 10. The thickness dimensions were obtained by feeler gage measurement and the width and height dimensions obtained with specially made inside calipers. All the dies were coated with alumina except dies 7E, 7BB, 8ZZ and 8VV which were coated with zirconia. The extent of ceramic coating on the dies is shown in Figure 62.

The temperature of the billet and tooling during the trial was as follows:

billet	1800°F
die	900°F
container	900°F
dummy block	400°F

A new chromium plated and polished liner was used for the trial.

The lubrication system employed consisted of the #85 billet coating, 318-14 mesh O. D. glass and 3KB-14 mesh die glass.

(4) Extrusion Trial

The trial schedule is listed in Table 11 with the conditions for each push. Force measurements are not listed due to faulty instrumentation. The data listed under the Remarks column are notes that were made during the trial and reflect the impressions made as the events occurred. A more detailed analysis of the conditions of the shapes and dies are presented in the Results section.

Four stainless steel heating cans were available which allowed flexibility in the billet heating cycle. Previously sprayed glass coated billets were categorically lined up in front of the four furnace entry positions in order to maintain continuous availability of hot billets in accordance with the heat soak schedule. The billets were charged into the furnace one every fifteen minutes.

The trial was set up to extrude eight (8) lengths through the 3/32" orifice dies followed by eight (8) lengths through the 1/16" orifice dies. Since this was the final trial, it was decided to hold all conditions as constant as possible to prove out the process. The trial was run very smoothly and no major difficulty was experienced. Glass coverage of the extrusion was not optimum in that the glass was not getting into the fillet radii on some of the shapes. Some variation was made on the last few pushes by adding more glass wool pads to correct this condition (see remarks in Table 11) but the additional glass wool did not noticeably improve the glass coverage. Examination of the dies after the trial revealed that on several dies the entrance radius at the fillet was sharper than the design radius (1/8" - 3/16" R instead of 1/4" R) and suggested that the glass flow in the fillet was restricted by the sharp radius.

The balance of the shape cross sections had excellent glass coverage with a thin, clear, bluish film of glass covering the entire length.

(5) Results

After deglassing and stretch straightening, the extrusions were visually inspected along the entire length and cross sectional measurements were taken at the back end, middle, front end, and at every foot from the front end until the dimensions were approximately equivalent to the dimensions at the middle of the extrusion (to determine the point at which good fillout was obtained). The measurements are tabulated in Table 12.

The conditions of the shapes and dies are presented below under the individual push number:

<u>Push No. 282</u>

Shape - good surfaces all over - light striations in fillet radii from front to back - slight amount of occasional pitting - edge radii sharp.
Shape rated good

Die - ceramic flaked off in several areas - all surfaces looked good
Die reusable

Push No. 283

Shape - light scoring and some pits on front end on right flange and right side of stem - light scoring on left flange and left side of stem with heavy scoring in left fillet radius toward back end - light scoring and a few areas of pitting on bottom of flange - edge radius sharp toward back end
Shape rated fair

Die - most of ceramic still intact - very light scoring in ceramic on bottom of flange
Die reusable

Push No. 284

Shape - good surfaces all over with light pitting distributed lightly over entire length - very light striations on bottom of flange with patches of pitting over the full length - slight sharpness on edge radius
Shape rated good

Die - die surfaces good - part of ceramic still intact
Die reusable

Push No. 285

Shape - all surfaces good over entire length with some pitting approximately 4' from the front end - very light striations toward back end - O. D. radius slightly rough
Shape rated good

Die - all surfaces good with light titanium pickup on left stem and right fillet radius
Die reusable

Push No. 286

Shape - left and right stem and flange good surfaces to light scoring front to back - bottom of flange numerous pits with very light striations front to back - some scoring on edge radii
Shape rated good

Die - almost all of the ceramic gone from land - no wash or wear on die
Die reusable

Push No. 287

Shape - very light striations on all surfaces full length - one area of fine pits on bottom of flange - light to medium scoring front to back in right radius - sharp radius on edge
Shape rated fair

Die - slight wash in right fillet radius - rest of die good
Die reusable but requires rework in radius

Push No. 288

Shape - very light striations full length on right flange - light scoring in right fillet radius at back end - stem rippled for 1' from front end - some pits toward front end on left side of flange - very light striations full length on left stem and radius and bottom of flange - slight sharpness on edge radius
Shape rated good

Die - heavy titanium pickup on top of ceramic in left fillet radius - rest of die lands good
Die reusable

Push No. 289

Shape - very light striations full length on right flange, right fillet radius and right stem - light striations toward back end of left flange - light striations in back end of left fillet radius - one area of pitting on left stem - light striations with discontinuous pitting on flange bottom - edge radius good
Shape rated good

Die - die surfaces good - part of ceramic still intact
Die reusable

Push No. 290

Shape - good surfaces all over with light pitting distributed lightly over entire length - very light striations on bottom of flange - edge radius good
Shape rated very good

Die - all surfaces good - ceramic flaked off in several areas
Die reusable

Push No. 291

Shape - light scoring and some pits on front end on right flange and right side of stem - light striations left flange and left stem - heavy scoring front to back on left fillet radius - very light striations on bottom of flange full length - occasional light pitting over entire length - slight sharpness on edge radius
Shape rated fair

Die - heavy titanium pickup on left fillet radius - rest of land good
Die Reusable

Push No. 292

Shape - light to medium scoring on back end of right flange - tear starting in stem approximately 6' from front end of left flange - slight ripple in stem 5' from front end of right stem - very light pitting right fillet radius - very light to light striations full length on bottom of flange with very light pitting.
Shape rated good

Die - all surfaces good - ceramic flaked off in several areas
Die Reusable

Push No. 293

Shape - very light striations over all surfaces - discontinuous pitting on all surfaces - kink 8' from front end of right stem - good edge radius
Shape rated very good

Die - all surfaces good - some ceramic still intact
Die reusable

Push No. 294

Shape - very light striations full length on all surfaces - fine pitting over entire surface - edge tears on flange from approximately 3' to 6' from front end edge radius good.
Shape rated good

Die - all surfaces good
Die reusable

Push No. 295

Shape - light striations front to back over all surfaces - slight pitting on all surfaces front to back - edge radius good
Shape rated good

Die - all surfaces good
Die reusable

Push No. 296

Shape - light striations front to back right flange, right stem, right fillet radius - light to medium scoring front to back left flange and left fillet radius - edge tears for first 7' - pitting on all surfaces - light striations front to back of bottom of flange - edge radius very sharp
Shape rated poor due to tear

Die - all surfaces good
Die reusable

Push No. 297

Shape - light to medium scoring front to back of right flange - some ripples on right stem - light to medium scoring front to back of bottom of flange edge radius very sharp
Shape rated fair

Die - all surfaces good
Die reusable

(6) Evaluation

Dies

An analysis of the results of the trial indicated that the dies performed excellently. Only one die out of the sixteen had some wash in the fillet radius (die 8TT - push 287) and this die was reusable with some rework.

The sixteen dies are shown after extrusion in Figure 63 and after extrusion and sand blasting in Figure 64. Figures 65 and 66 show closeups of die 7C - push 290 which was typical of the condition of the dies. Figure 65 shows that wear was obtained in the ceramic on the stem lands but an examination of Figure 66 shows that the base metal was untouched.

The lack of glass at the fillet radius of some of the shapes during extrusion made the trial a severe test of the ceramic coating. The lack of wash or wear on all of the dies except one is evidence of the excellent performance of the ceramic coating.

Surface Quality

Figure 67 shows the discards after the trial. No laps or laminations were noted on any of the discards or extruded shapes. Figure 68 is a closeup view of discard #295 which was typical of the discards. Examination of Figure 68 and Figure 69 (which is a section cutting the stem of discard #295) reveal the good metal flow obtained during extrusion.

The general surface quality of the extrusions was fair with light longitudinal striations running the length of the extrusions on most surfaces. The surface finish ranged between 50 and 370. The average surface finish was about 170 RMS. Figures 70 and 71 illustrate the typical surface quality of the extrusions produced during the trial. The as-extruded surface quality of two 1/16" extrusions processed for warm drawing can be seen in Figure 95. These views were taken of the back ends of the extrusions. Of the eight (8) 3/32" shapes, six (6) shapes were rated good and two (2) shapes were rated fair. Of the eight (8) 1/16" shapes, five shapes were rated good, two (2) shapes were rated fair and one (1) shape was rated poor (due to a tear in the flange). (See "Results" section for detailed description of shapes).

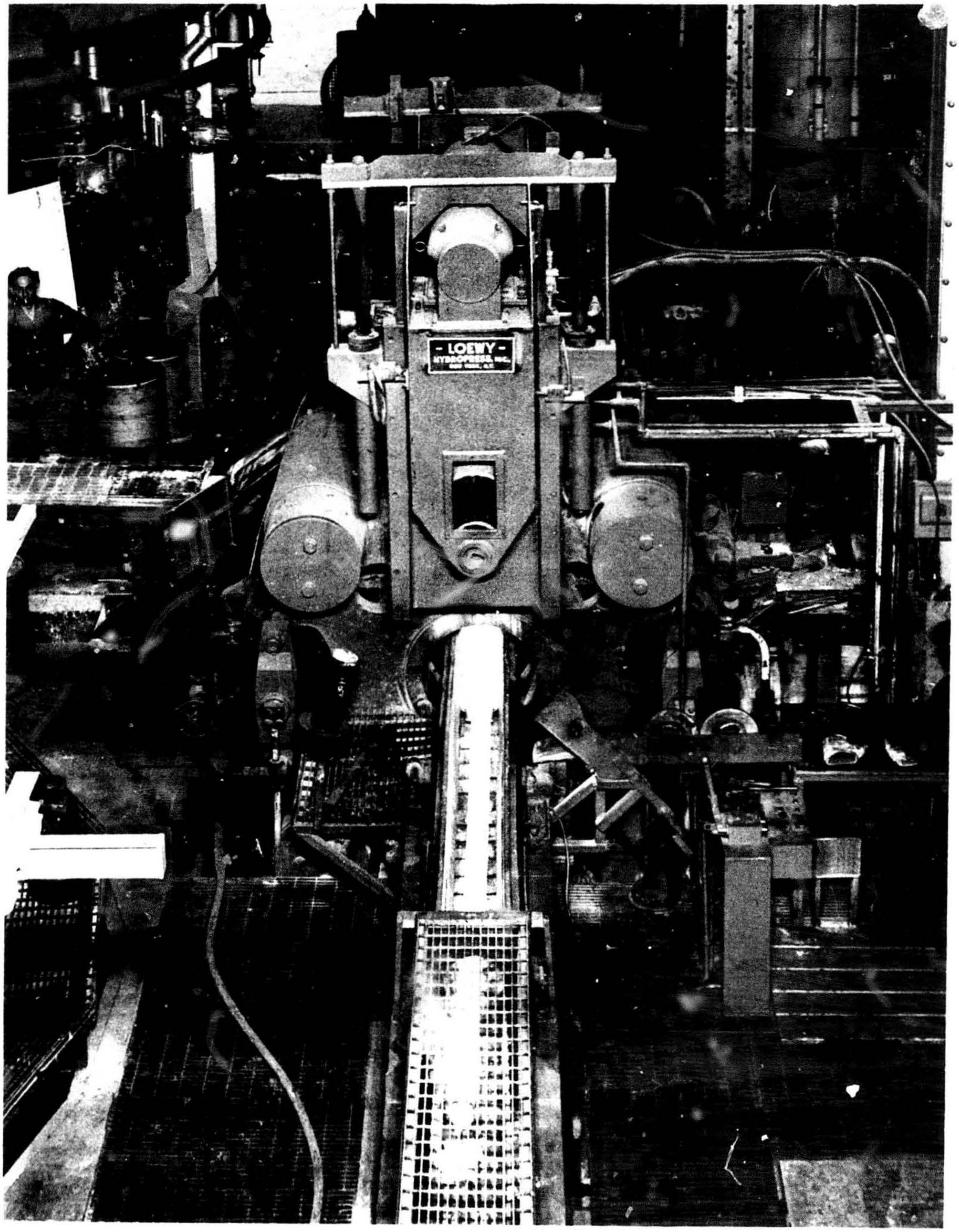
Dimensional Analysis

During the latter portion of the Part IV warm draw program (which was run concurrently with the extrusion effort in Part V) difficulty was experienced on the TMCA draw bench in drawing the shapes below .058". Based on a recommendation by TMCA that the Part V shapes could not be successfully drawn below .058", the extrusion dies for the final Part V trial were opened up by electric discharge machining. This was done to allow sufficient reduction in drawing to effect a surface improvement. The 1/16" dies were opened up to provide a nominal .072' opening after ceramic coating. In addition, the height and width dimensions of the tee were increased to insure that sufficient stock would be available for edge machining the shapes to the target dimensions. However, it was established that technical errors rather than process problems prevented drawing the shapes below .058". Two of the dies (7GG and 7CC - which were not coated with the previous group) were then coated with a heavier ceramic buildup and machined back to provide a nominal .063" orifice. The other 14 dies were not machined after application of the ceramic coating. The variation in die orifice size is due to the lack of control of buildup in the application of the ceramic spray. The variation in die dimensions after coating is tabulated in Table 13.

The extrusion cross section dimensions are listed in Table 12 and the dimensional variation of each extrusion is tabulated in Table 14. It can be seen from Table 14 that the maximum variation from front to back on any one leg of the extrusion is .010". This was obtained on extrusion 283 which had poor die fillout for the first several feet. However, extrusion 283 was 25' 9" long and dimensional tolerances for a 20' (target) length of the extrusion are considerably better than indicated in Table 14. Referring to Table 12, by cropping only 1 foot from extrusion #283, the variation from front to back on any one leg is reduced from .010" to .005". Cropping 3' from the extrusion would reduce the variation to .004" and would reduce the total variation on the three legs from .020" (see Table 14) to .014".

Also seen from Table 14, the average variation from front to back on any one leg was .004". This small variation is attributed to good die performance and glass practice. Again referring to Table 14, it can be seen that the maximum total variation on all three legs was .022" while the average total variation was .012". This variation is attributed to both variation in die opening and poor die fill for the first several feet. Again, cropping the extrusions to the target 20' would reduce the dimensional variation considerably.

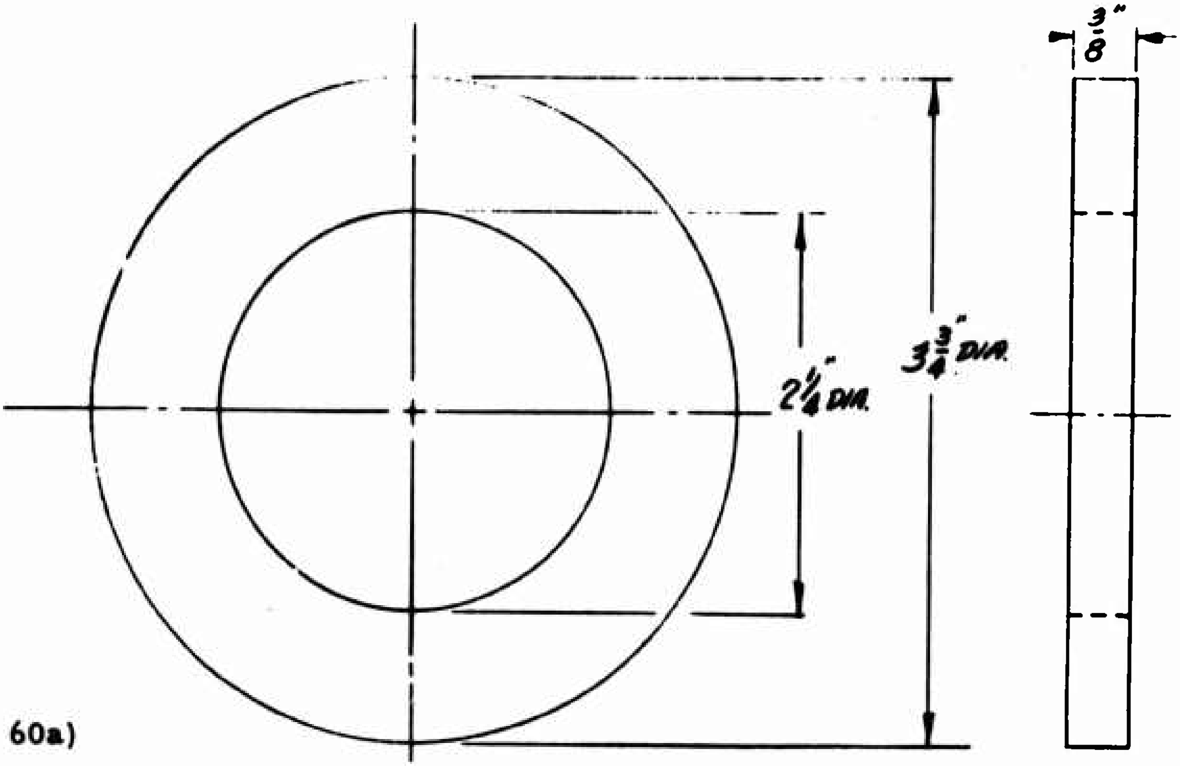
Table 14 reveals that all of the extrusions produced at the final trial with the exception of #283 are within ± .012" of nominal size. The low variation from front to back on each leg indicates that tighter extrusion tolerances could be attained by more accurately controlling the die orifice size in a finish machining operation.



2500 Ton Loewy Extrusion Press Used for the Titanium Extrusion Program at the Babcock & Wilcox Company

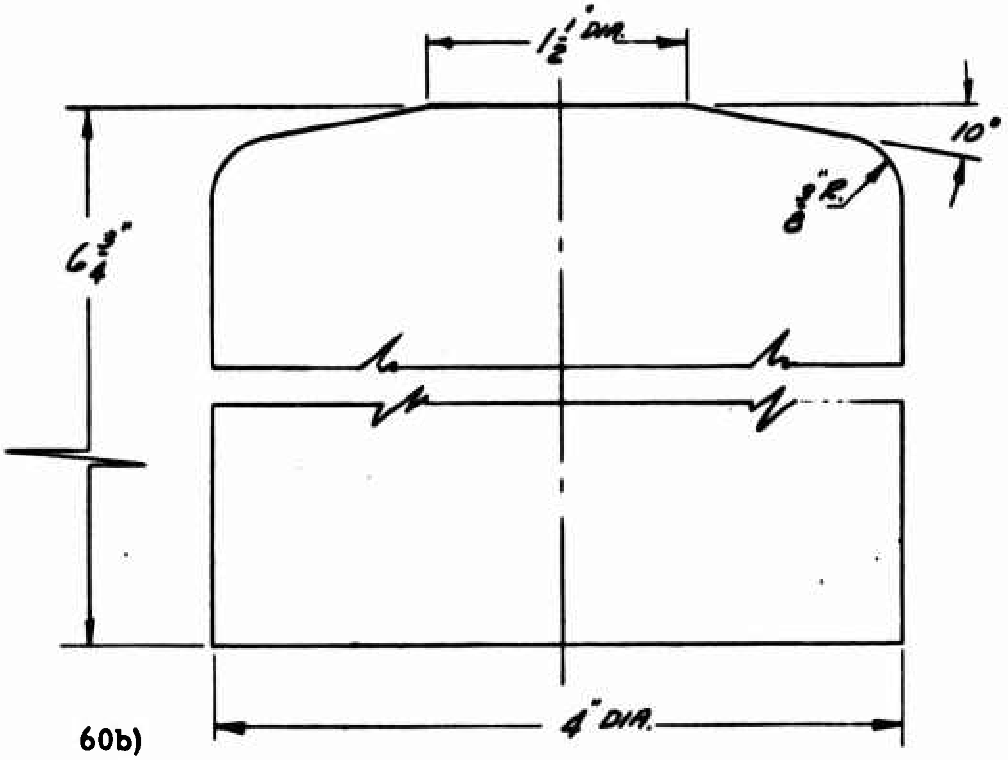
FIGURE 59

6-5-211



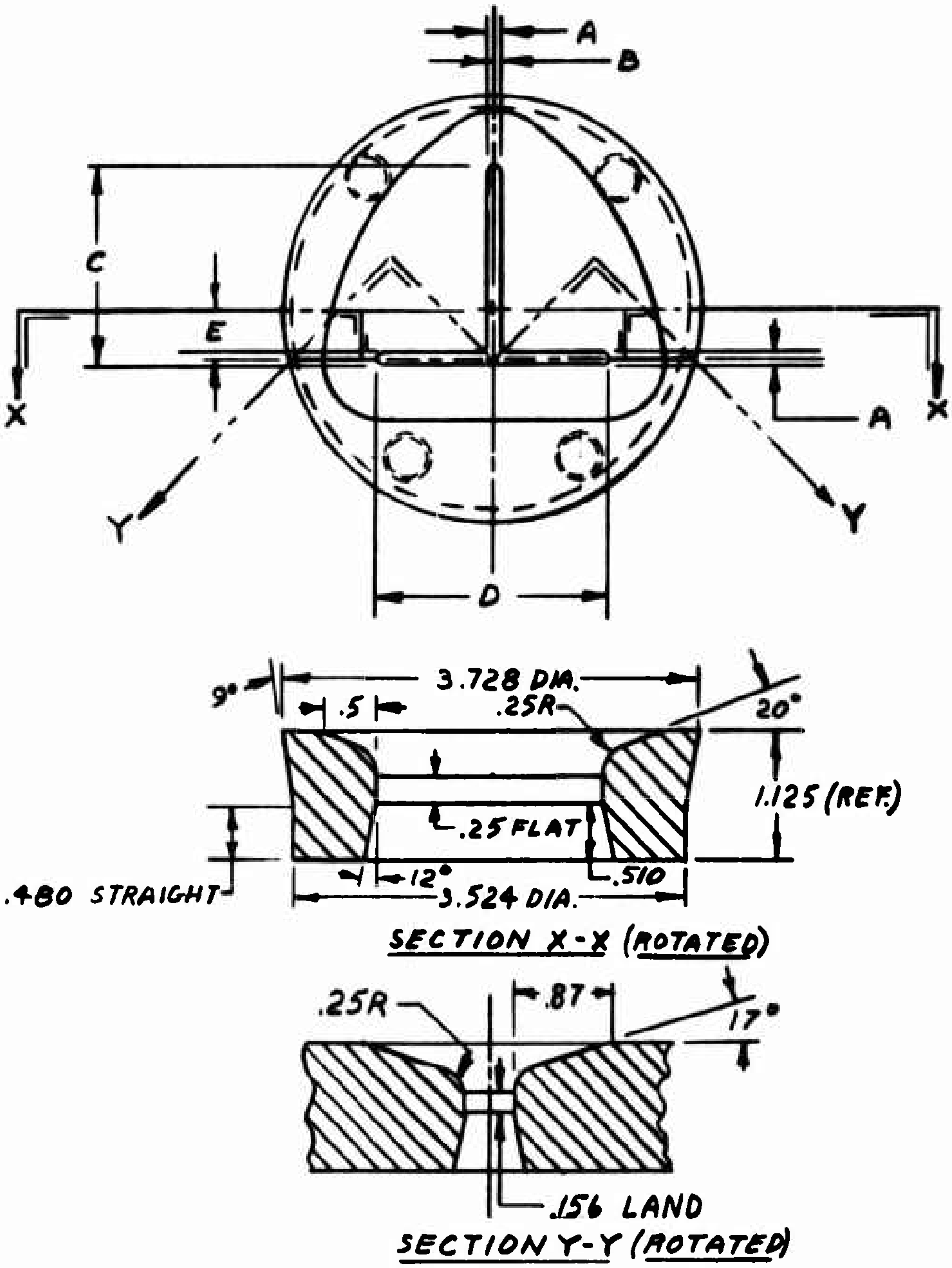
60a)

Granular Glass Ring Configuration



60b)

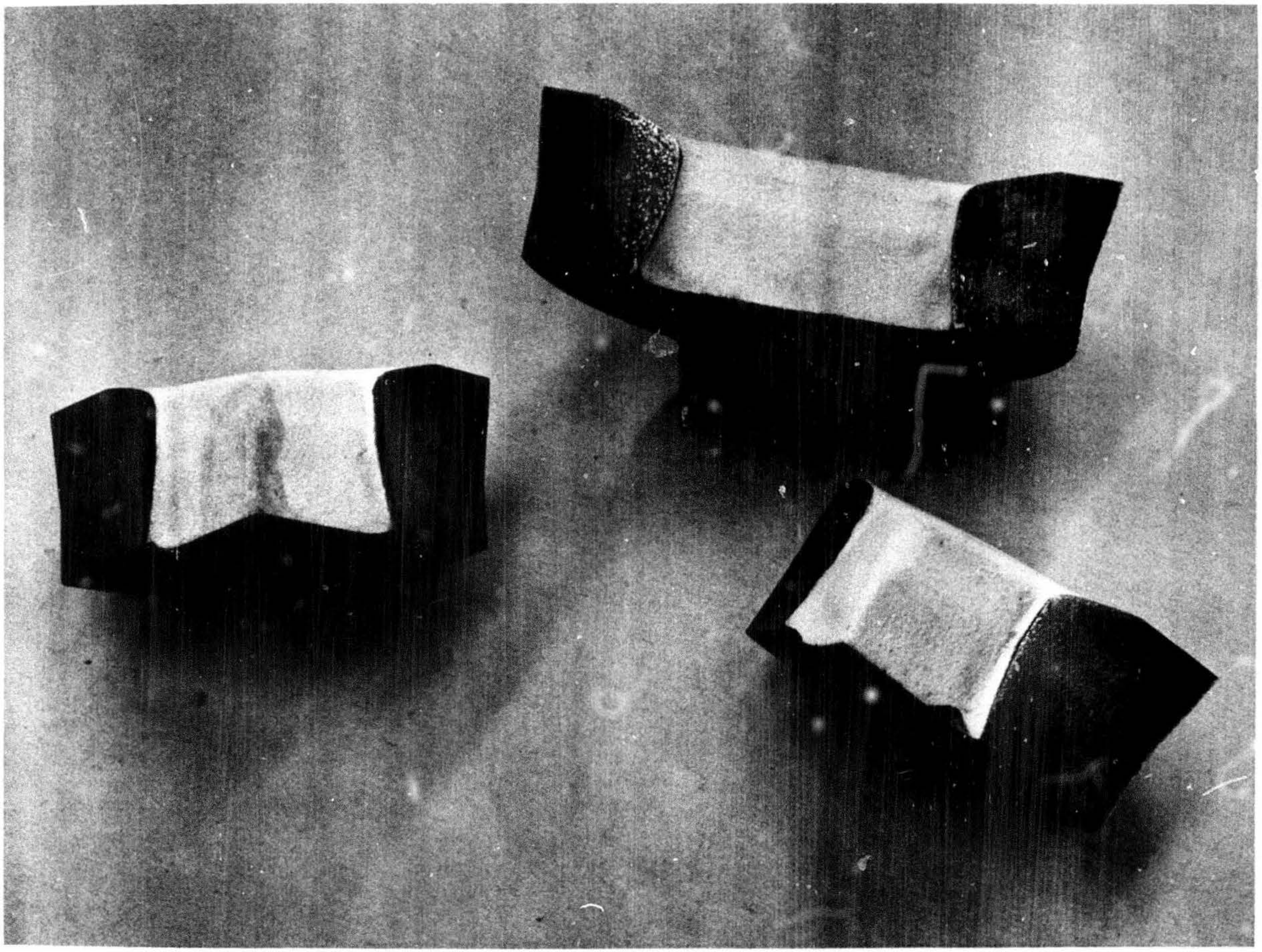
Convex Shaped Nose Billet Configuration
Glass Ring and Billet Configurations Used During Final Extrusion Trial
FIGURE 60



SHAPE*	A	B	C	D	E
676	.063	.0315	1.685	1.840	.410
676A	.072	.036	1.685	1.840	.410
677	.098	.049	1.050	1.840	.175

Modified Flat Face Die Design Used During Final Extrusion Trial

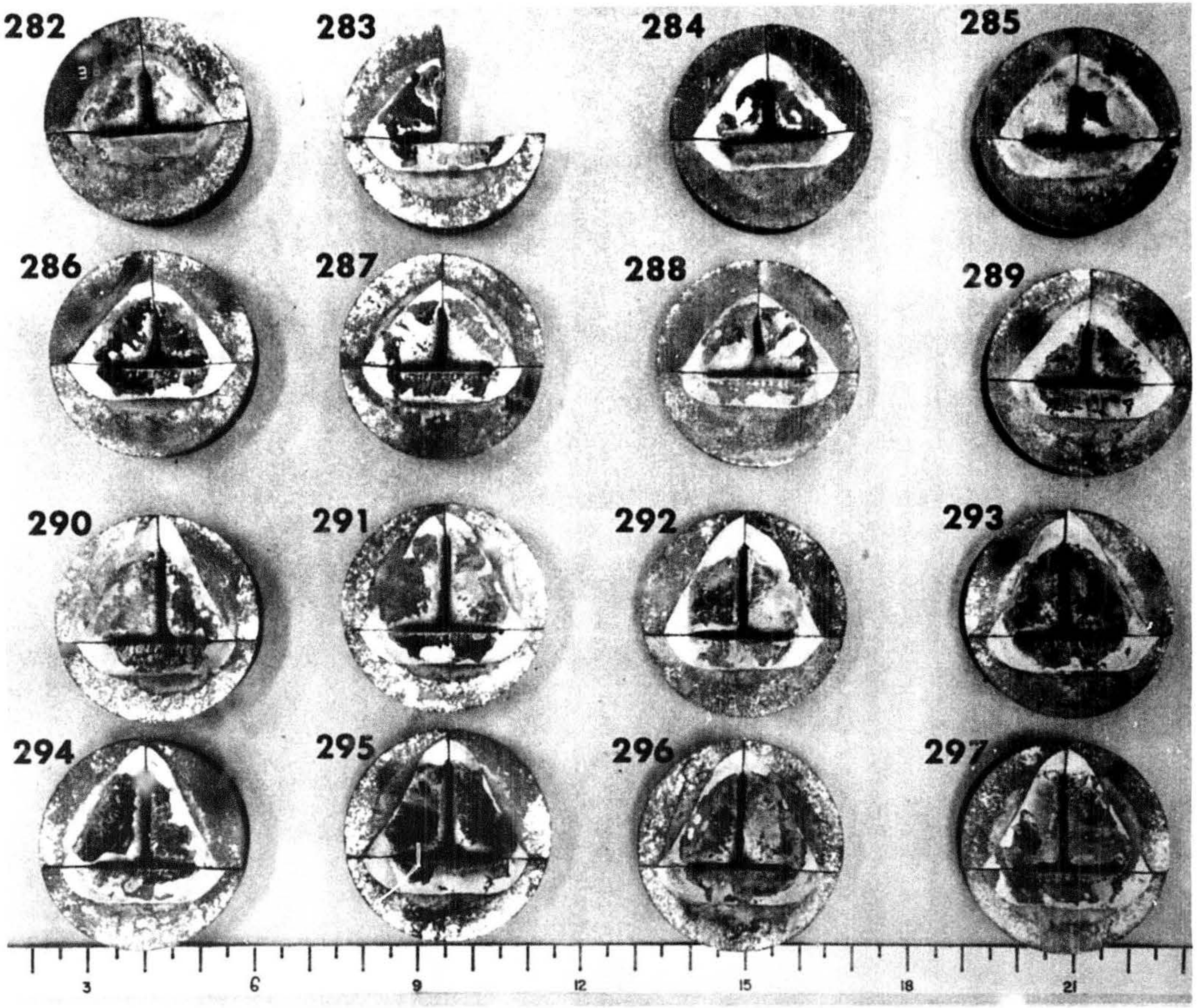
FIGURE 61



Photograph Showing Extent of Ceramic Coating on Three Piece Extrusion Dies

FIGURE 62

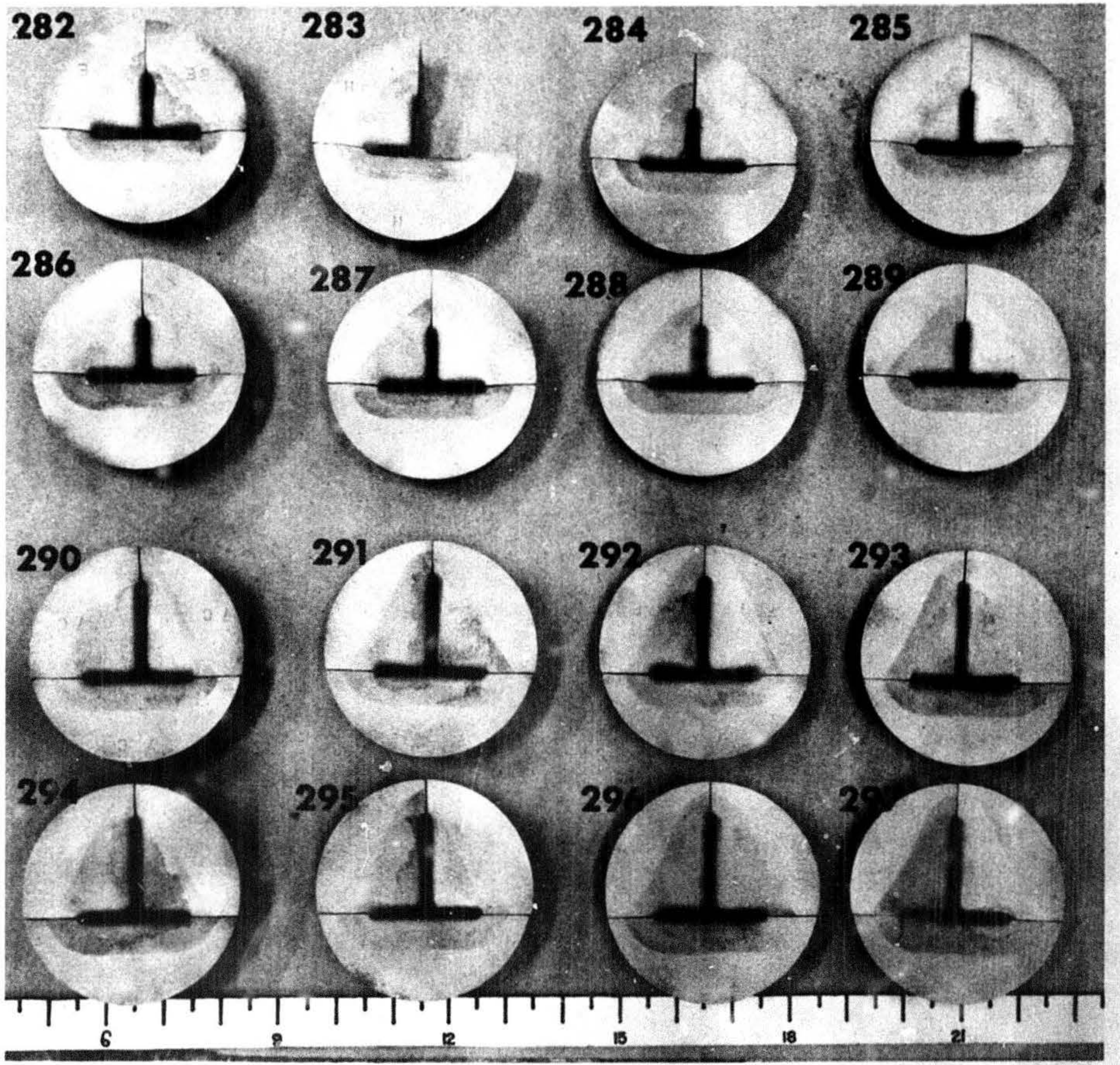
605288



Dies Used on Final Trial Shown After Extrusion

FIGURE 63

605288

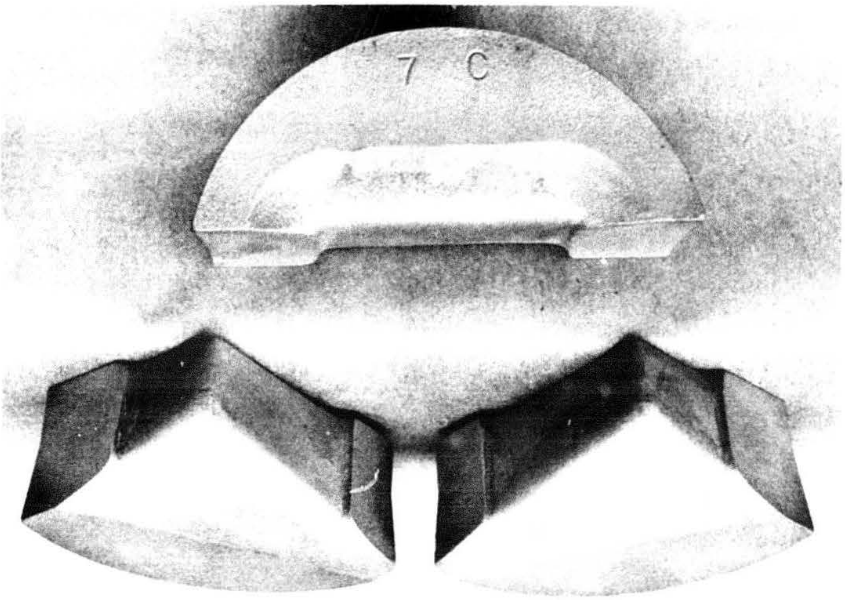


Dies Used on Final Trial Shown After Extrusion and Sand Blasting

FIGURE 64

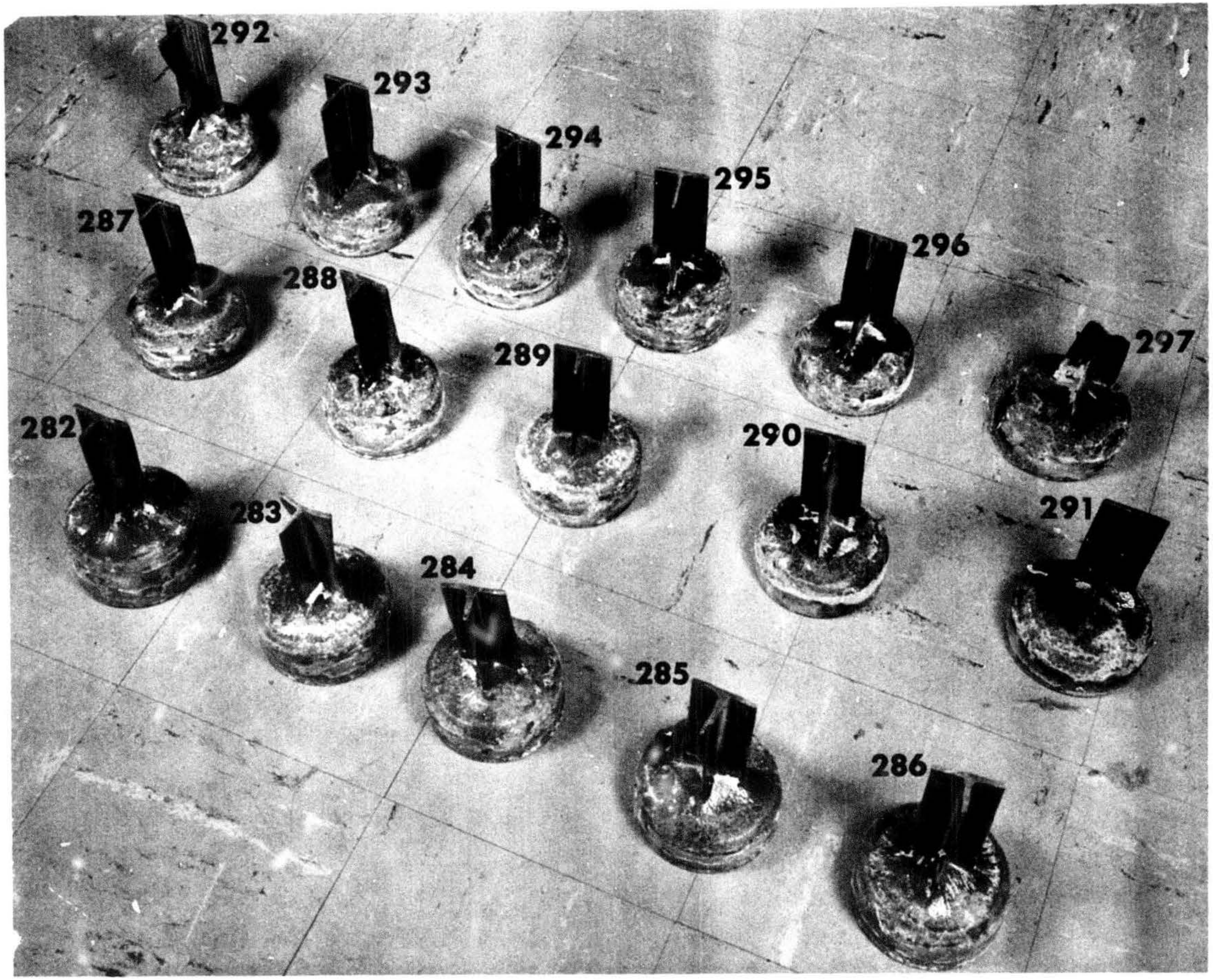
605288

Closeup of Die 7C (Push #290) After Extrusion
FIGURE 65



Closeup of Die 7C (Push #290) After Extrusion
and Sand Blasting

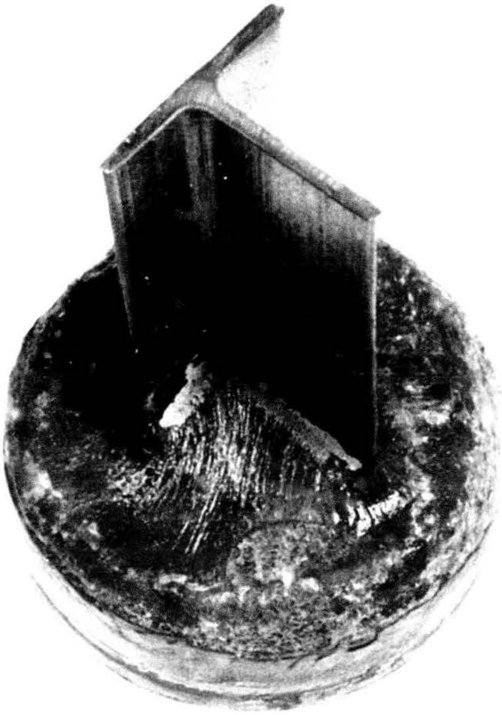
FIGURE 66



Discards From Final Extrusion Trial

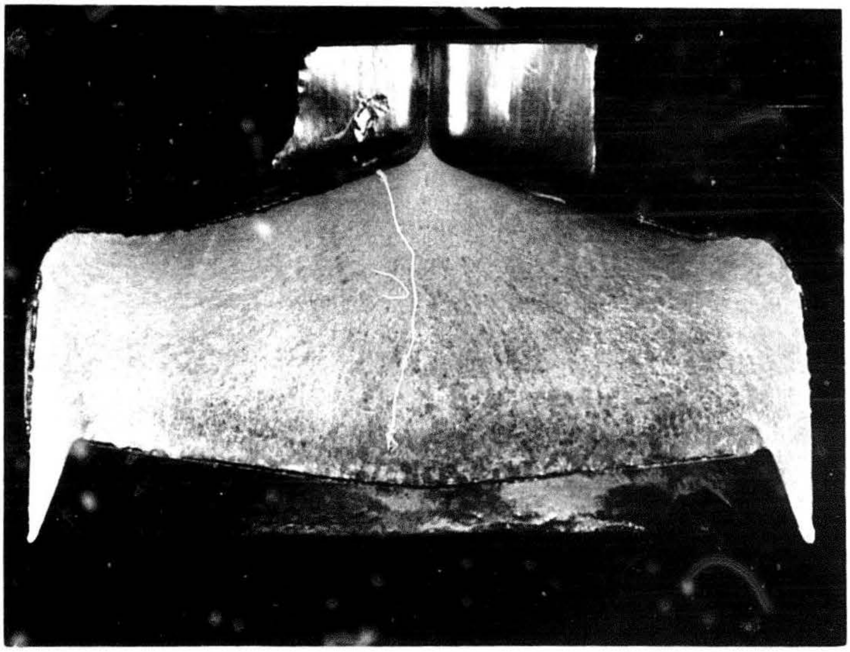
FIGURE 67

605288



Closeup of Discard # 295

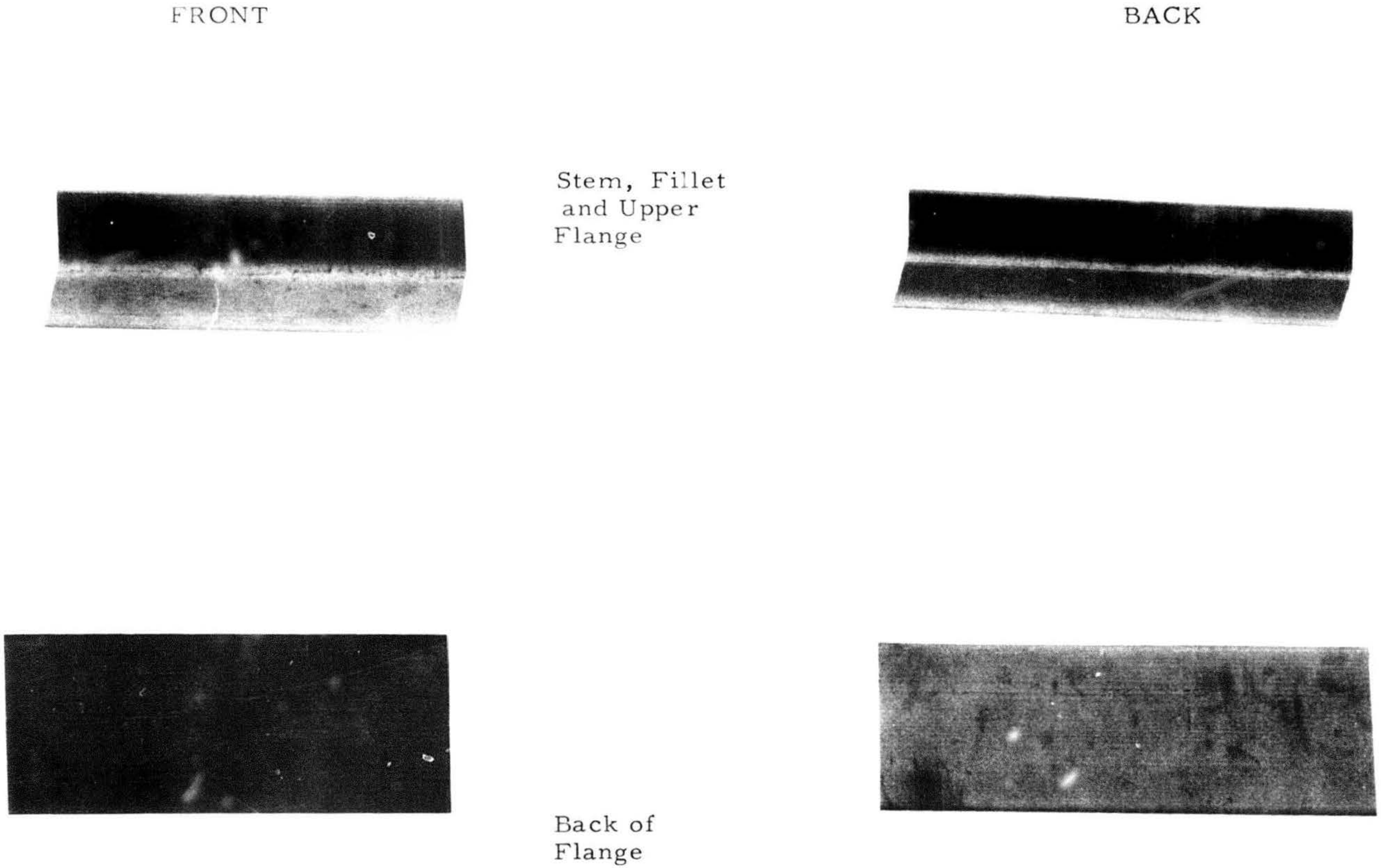
FIGURE 68



Sectioned View of Discard #295 Showing Metal Flow

FIGURE 69

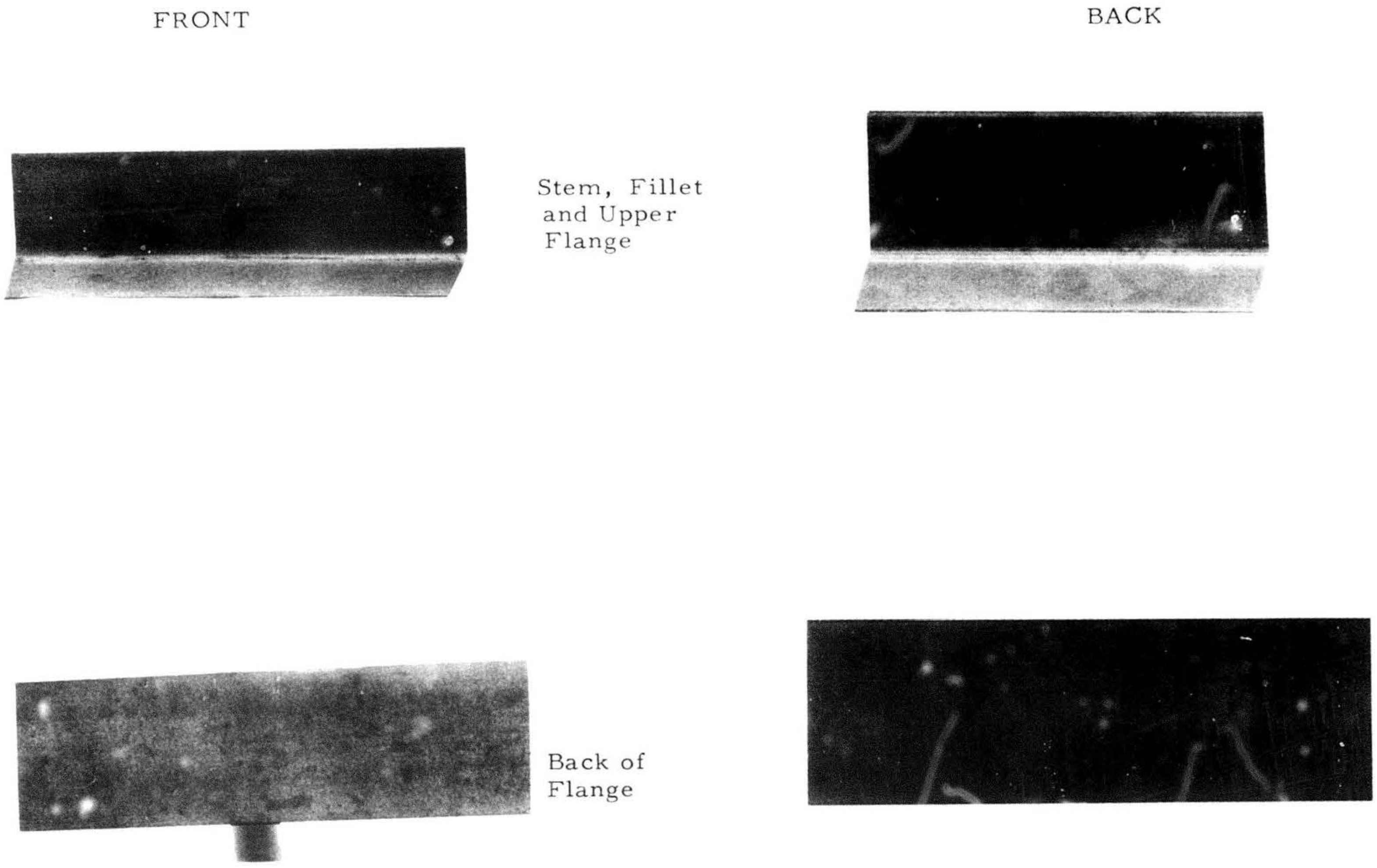
605 288



Views of Extrusion #287 Illustrating Typical Surface Quality of 3/32" Shapes Produced at Final Trial

FIGURE 70

685288



Views of Extrusion #291 Illustrating Typical Surface Quality of 1/16" Shapes Produced at Final Trial

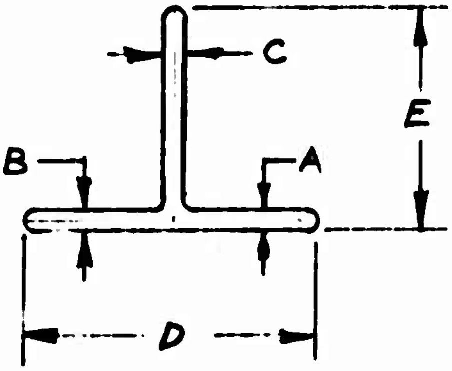
FIGURE 71

605281

TABLE 10

DIE ORIFICE DIMENSIONS* PRIOR TO EXTRUSION

DIE NO.	DIMENSIONS (INCHES)					PUSH NO.
	A	B	C	D	E	(REFERENCE)
8E	.098	.096	.106	1.847	1.063	282
8H	.095	.093	.093	1.835	1.050	283
8K	.096	.098	.101	1.828	1.054	284
8RR	.098	.099	.097	1.842	1.065	285
8SS	.109	.095	.100	1.839	1.058	286
8TT	.100	.099	.097	1.850	1.047	287
8VV	.097	.095	.095	1.853	1.049	288
8ZZ	.100	.100	.097	1.842	1.052	289
7C	.072	.074	.077	1.834	1.693	290
7DD	.071	.077	.076	1.842	1.689	291
7E	.076	.077	.070	1.830	1.680	292
7BB	.089	.088	.077	1.855	1.698	293
7EE	.075	.070	.075	1.846	1.690	294
7FF	.076	.075	.068	1.829	1.684	295
7GG	.064	.065	.062	1.830	1.686	296
7CC	.062	.065	.062	1.832	1.687	297



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* See "Evaluation" page 132 for discussion of die dimensions.

TABLE 11

FINAL EXTRUSION TRIAL DATA SHEET

PUSH NO.	BILLET HTG TIME (MIN)	BILLET TRANSFER TIME (SECS)	DIE NO.	DIE CTG	EXTRUSION LENGTH	REMARKS
282	83	54	8E	Zirconia	21' 9"	Difficulty removing cover from billet can - ctg on billet looked good coming out of can (no dark spots) - shape was dry in both fillet radii - balance had excellent glass coverage all over die ctg was removed in fillet but land did not appear to be washed shape looked good.
283	86	40	8H	Alumina	25' 9"	Billet looked good out of can - shape again dry in both fillet radii - excellent glass coverage all over except in fillet - die looked good - land and ctg held up well - shape looked good but had fine scoring in fillet where no glass coverage was obtained - vertical leg of shape had step on extremity (may be due to ctg bui on die - no laps on discard.
284	91	48	8K	Alumina	23' 1"	Billet was given two revolutions on glass table to try to cover a bad area in ctg - part of ctg seemed to be separated from the billet; however, no scale was noted on billet - discard had no lap and good glass coverage - the shape had excellent glass coverage except in fillet where very light score was noted - no step was observed on leg extremities - die ctg held up well.
285	92	36	8RR	Zirconia	23' 3"	Billet ctg looked good - billet was given a double roll in glass - shape looked excellent - left fillet radius was dry - right radius h good glass coverage - one section of shape in the middle of the extrusion was dry and appeared to be scored very lightly - may have been due to a bad spot in ctg that was not seen - difficulty getting die out of holder.
286	68	36	8SS	Alumina	21' 3"	Billet ctg looked good - shape looked excellent - slight step on vertical extremity - discard had no laps, good glass coverage and flow - ceramic on die intact.
287	73	45	8TT	Alumina	22' 10"	Shape looked good - fillet radii dry - glass was sparse in area from 3' to 9' from front end on bottom of horizontal leg but then picked up - balance of shape had excellent glass coverage - some titanium pickup noted right fillet radius of die.
288	72	42	8VV	Alumina	24' 4"	Billet ctg looked good - die looked good (ctg intact). Excellent glass coverage over entire shape.
289	72	36	8ZZ	Alumina		Results similar to above.
290	70	40	7C	Zirconia	19' 3"	Results similar to above - Shorter length due to shorter billet length (balance of available stock).
291	84	42	7DD	Alumina	22' 2"	Good glass coverage except in radius - some scoring in left radius - shape had undercut in right radius on back end - die had some Ti pickup on left radius (corresponding to undercut in shape) rest of die looked good.
292	88	36	7E	Alumina	24' 4"	Glass coverage good for first 14' and spotty for last 10' on both sides of horizontal leg.
293	97	35	7BB	Alumina	19' 8"	The granular glass ring was reduced in thickness to 1/4" instead of 5/16" and 1 extra glass wool pad was used (total of 4) to attemp to get more glass in the radius - good glass coverage over entire shape - discard had good glass coverage and flow.
294	90	42	7EE	Zirconia	23' 5"	Five glass wool pads used - shape looked good - excellent glass coverage all over - glass was spotty in fillets.
295	90	42	7FF	Alumina	23' 10"	Shape similar to 293 and 294 - dry in radii towards back end - heavy glass left on die - die had no wash or wear - die ctg removed but land held up.
296	96	40	7GG	Alumina	26' 5"	Four glass wool pads used since five pads did not show an improvement over four - shape had slight tears in flange (probably due to glass clogging die and restricting flow so that the material fails in tension) - heavy glass left on die.
297	98	-	7CC	Alumina	28' 1"	Three glass wood pads used - 1/4" thick granular glass ring inadvertently used with the (3) glass wood pads instead of a 5/16" thick ring - This coupled with the long length (due to a smaller orifice opening than the other dies) produced a shape with sparse glass covering.

CONSTANT CONDITIONS

Billet Temp. - 1800°F
Billet Length - 6 3/4"
Billet Config. - Convex Face
Billet Ctg. - #85
O. D. Glass - 318 - 14 Mesh
Die Glass - 3KB - 14 Mesh
Die Glass Config. - Ring + glass wood pads-three (3) glass wool pads used unless otherwise specified.

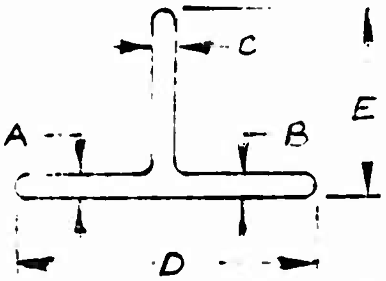
Container Temp. - 900°F
Die Temp. - 900°F
Dummy Block Temp. - 400°F
Die - Peerless A R_c 48-51
Chrome Plated Liner
Billet Htg - Electric Furnace Argon Atmosphere

TABLE 12

CROSS SECTIONAL DIMENSIONS

(AS EXTRUDED AND STRETCH STRAIGHTENED)

EXTRUSION NO.	FT. FROM FRONT END	Dimensions (inches) (See sketch for dimension locations)				
		A	B	C	D	E
	1	.091	.090	.095	1.706	.939
	2				1.723	.955
282	3				1.764	.978
	4				1.796	.992
	5				1.819	1.015
	Middle	.096	.095	.096	1.819	1.027
	Back end	.097	.095	.097	1.826	1.043
	1	.083	.084	.074	1.529	.86
	2	.086	.089	.078	1.600	.89
	3	.087	.090	.079	1.636	.92
283	4	.088	.090	.080	1.676	.94
	5				1.705	.97
	6				1.734	.99
	7				1.762	1.00
	Middle	.089	.092	.082	1.797	1.01
	Back end	.091	.094	.082	1.806	1.02



View Looking From Front End
Of Extrusion

TABLE 12 (continued)

CROSS SECTIONAL DIMENSIONS

(AS EXTRUDED AND STRETCH STRAIGHTENED)

EXTRUSION NO.	FT. FROM FRONT END	Dimensions (inches) (See sketch for dimension locations) A	B	C	D	E
284	1	.097	.097	.090	1.710	.980
	2				1.753	.992
	3				1.760	.984
	4	.098	.098	.091	1.781	.993
	Middle	.097	.098	.090	1.783	.988
	Back end	.097	.098	.090	1.780	.992
285	1	.092	.095	.093	1.780	1.011
	Middle	.092	.094	.092	1.776	1.006
	Back end	.093	.096	.095	1.798	1.016
286	1	.106	.092	.095	1.772	1.011
	2				1.776	
	Middle	.106	.089	.095	1.782	1.016
	Back end	.107	.090	.095	1.791	1.016
287	1	.097	.088	.093	1.766	.983
	2				1.788	.993
	Middle	.097	.088	.093	1.789	1.001
	Back end	.097	.089	.093	1.791	1.001

TABLE 12 (continued)

CROSS SECTIONAL DIMENSIONS

(AS EXTRUDED AND STRETCH STRAIGHTENED)

EXTRUSION NO.	FT. FROM FRONT END	Dimensions (inches) (See sketch for dimension locations) A	B	C	D	E
288	1	.089	.087	.091	1.727	.993
	2				1.725	.989
	3				1.747	
	4				1.747	
	5				1.755	
	Middle	.090	.085	.089	1.761	.980
	Back end	.092	.088	.092	1.771	.994
289	1	.092	.091	.093	1.753	.993
	2				1.752	
	3				1.772	
	Middle	.092	.091	.091	1.775	.994
	Back end	.094	.093	.092	1.794	1.007

290 See Table B-1 in Appendix B

TABLE 12 (continued)

CROSS SECTIONAL DIMENSIONS

(AS EXTRUDED AND STRETCH STRAIGHTENED)

EXTRUSION NO.	FT. FROM FRONT END	Dimensions (inches) (See sketch for dimension locations) A	B	C	D	E
291	1	.059	.067	.071	1.601	1.527
	2				1.655	1.557
	3				1.702	1.599
	4				1.727	1.625
	5				1.730	1.611
	6				1.788	1.632
	Middle	.062	.069	.076	1.798	1.638
	Back end	.065	.071	.077	1.809	1.643
292	See Table B-1 in Appendix B					
293	1	.089	.084	.067	1.752	1.533
	2				1.767	1.540
	3				1.777	1.564
	4				1.784	1.578
	5					1.587
	6					1.610
	7					1.636
	Middle	.089	.085	.068	1.796	1.642
	Back end	.089	.085 .081	.067	1.795	1.646
294 295	See Table B-1 in Appendix					

TABLE 12 (continued)

CROSS SECTIONAL DIMENSIONS

(AS EXTRUDED AND STRETCH STRAIGHTENED)

EXTRUSION NO.	FT. FROM FRONT END	Dimensions (inches) (See sketch for dimension locations)				
		A	B	C	D	E
296	1	.061	.054	.055	1.697	1.633
	2				1.727	1.621
	3				1.753	1.628
	4				1.743	1.638
	5				1.756	1.645
	6				1.765	
	Middle	.061	.052	.058	1.772	1.645
	Back end	.064	.056	.059	1.788	1.661
297	1	.058	.055	.049	1.716	1.572
	2				1.737	1.599
	3				1.761	1.604
	4				1.777	1.610
	5				1.783	1.615
	Middle	.061	.058	.051	1.795	1.620
	Back end	.065	.061	.054	1.805	1.640

TABLE 13

DIMENSIONAL VARIATION* OF DIE ORIFICE DIMENSIONS AFTER CERAMIC COATING

PUSH NO. (Ref.)	DIE	AVERAGE DIMENSION OF 3 LEGS	DIMENSIONAL RANGE OF 3 LEGS	NOMINAL DIMENSION	MAXIMUM VARIATION FROM NOM. ON ALL LE
282	8E	.100	.096 - .106	.098	+.008 -.000
283	8H	.094	.093 - .095	.098	+.000 -.005
284	8K	.098	.096 - .101	.098	+.003 -.002
285	8RR	.098	.097 - .099	.098	+.001 -.001
286	8SS	.101	.095 - .109	.098	+.011 -.003
287	8TT	.099	.097 - .100	.098	+.002 -.001
288	8VV	.096	.095 - .097	.098	+.000 -.003
289	8ZZ	.099	.097 - .100	.098	+.002 -.001
290	7C	.074	.072 - .077	.072	+.005 -.000
291	7DD	.075	.071 - .077	.072	+.005 -.001
292	7E	.074	.070 - .077	.072	+.005 -.002
293	7BB	**	-	-	-
294	7EE	.073	.070 - .075	.072	+.003 -.002
295	7FF	.073	.068 - .076	.072	+.004 -.004
296	7GG	.064	.062 - .065	.063	+.002 -.001
297	7CC	.063	.062 - .065	.063	+.002 -.001

* See Table 10

** Inadvertently machined oversize See Table 10 for dimensions.

TABLE 14

DIMENSIONAL VARIATION OF EXTRUSION CROSS SECTION THICKNESS
(Measured after stretch straightening)

Extrusion	Dimensional Range on each leg			Variation front to back on each leg			Dimensional Range on all 3 legs	Total Variation on 3 legs	Nominal Dimension	Variation from Nominal
	A	B	C	A	B	C				
282	.091 - .097	.090 - .095	.095 - .097	.006	.005	**.002**	**.090 - .097**	.007	.095	+.002 -.005
283	.083 - .091	.084 - .094	.074 - .082	.008	.010	**.008**	**.074 - .094**	.020	"	+.000 -.021
284	.097 - .098	.097 - .098	.090 - .091	.001	.001	**.001**	**.090 - .098**	.008	"	+.003 -.005
285	.092 - .093	.094 - .096	.092 - .095	.001	.002	**.003**	**.092 - .096**	.004	"	+.001 -.003
286	.106 - .107	.089 - .092	.095 - .095	.001	.003	**.000**	**.089 - .107**	.018	"	+.012 -.006
287	.097 - .097	.088 - .089	.093 - .093	.000	.001	**.000**	**.088 - .097**	.009	"	+.002 -.007
288	.088 - .092	.085 - .088	.089 - .092	.003	.003	**.003**	**.085 - .092**	.007	"	+.000 -.010
289	.092 - .094	.091 - .093	.091 - .093	.002	.002	**.002**	**.091 - .094**	.003	"	+.000 -.004
290	.076 - .080	.068 - .072	.071 - .073	.002	.004	**.004**	**.068 - .080**	.012	.069	+.011 -.001
291	.059 - .065	.067 - .071	.071 - .077	.006	.004	**.006**	**.059 - .077**	.018	"	+.008 -.010
292	.073 - .080	.068 - .073	.058 - .060	.007	.005	**.002**	**.058 - .080**	.022	"	+.011 -.011
293	*									
294	.064 - .069	.068 - .073	.067 - .069	.005	.005	**.002**	**.064 - .073**	.009	"	+.004 -.005
295	.068 - .071	.068 - .071	.058 - .060	.003	.003	**.002**	**.058 - .071**	.013	"	+.002 -.011
296	.061 - .064	.052 - .056	.055 - .059	.003	.004	**.004**	**.052 - .064**	.012	.060	+.004 -.008
297	.058 - .065	.055 - .061	.049 - .054	.007	.006	**.005**	**.049 - .065**	.016	"	+.005 -.011
			Average Variation	.004	.004	**.003**		.012		

* Die inadvertently machined oversize. The die and extrusion dimensions are listed in Tables 10 and 12 respectively.

3. Warm Drawing at Titanium Metals Corporation

a) Equipment and Procedures

Following incoming or in-process inspection, pointing and surface preparation and lubrication, each extrusion followed this sequence:

1. Preheat, electrical resistance
2. Transfer to electrically heated holding furnace to maintain preheat and draw temperature
3. Exit from holding furnace, pass point through die and grip point in Hufford grips attached to carriage of draw bench
4. Draw entire length through die
5. Stretcher straighten using resistance heating. Two Hufford grips are used for this operation. Electrical power may be applied through the Hufford grips or by attachment directly to the extrusion

The equipment and procedures involved are described below:

Rectifiers and Resistance Preheater

A bank of eight (8) 1200 ampere, 40 volt rectifiers are connected in parallel to provide electrical resistance heating for warm drawing. This same arrangement was also employed for resistance heating during stretcher straightening.

Variable lengths can be handled from a minimum of about 3 feet to a maximum of 21 feet. For these sections, a preheat of 1050°F was possible in less than 90 seconds by the use of four or five rectifiers set at 200/250 amperes.

Power is applied through the point on the fixed south end by means of a copper contact; exerting pressure vertically; the north end copper contact is movable to accommodate any length of extrusion up to the maximum of 21 feet.

The preheater is located immediately adjacent and parallel to the door of the electric holding furnace. All temperatures were checked manually with a contact pyrometer.

Electric Holding Furnace

The electrically powered holding furnace had an 8 x 8 in x 21 foot maximum usable length hearth. The floor of the hearth was a perforated metal plate which was in line with the center line of the draw bench and die stand. The furnace is rated at 80 KW, operating at 440V and was designed for use up to 1500°F.

Draw Bench

The draw bench was a 50,000 pound Aetna-Standard bench with variable speed control from 0 to 100 fpm. Through Part V, the draw bench speed was standardized at 24 fpm. An assessment of draw loads was made by incorporating a recording ammeter on the DC motor drive. The maximum drawn length on the bench (45 feet) far exceeds the preheat and holding furnace limitations.

A conical, tapered die holder was positioned in the die stand. This accommodated an 8 inch maximum O. D. steel die case engineered by American Carbide. For gripping of the extrusion during drawing, an air actuated Hufford Universal gripper (3 segments) was employed.

During drawing, the extrusion in the holding furnace was manually pushed through the die assembly into the Hufford jaws for point gripping. As the extrusion moved out of the furnace into the die stand, lubricant (Fiske 604) was applied by brushing. The Hufford jaws were made from heat treated H-13 die steel, subsequently nitrided by the Tuftride (Kolene) process. The knurled gripping surface of each jaw was a shallow criss-cross pattern with 1/16 in. diamond teeth.

Stretcher Straightener

The stretcher straightener consisted of two opposing Hufford grips, each rated at 100,000 lbs. pulling force. One grip was mounted on the draw carriage of the 50,000 pound bench and the second to the 15 ton hydraulic cylinder which, in turn, was mounted in a separate, detachable carriage, removed from the draw bench when not in use. When stretching, this carriage was mounted on the draw bench and hooked into the stationary draw bench chain.

During in-process straightening, the electrical power is attached directly to one end of the extrusion (pointed end) in order to preserve the point for subsequent drawing. On the opposite end, power is brought through the Hufford gripper. For final straightening, the point is cut off and power is then brought to the extrusion through the Hufford grips.

During final stretcher straightening, the position of the jaws was checked with a spirit level to assure that the ends are parallel and thus minimize twist in the final product. All temperatures were checked with either a contact pyrometer or an optical pyrometer. Limitations on the unit were the 15 ton hydraulic cylinder and a maximum length that can be handled, approximately 22 feet.

b) Drawing Shape 64E15

A drawing of 64E15 is illustrated in Figure 6 Initial work was conducted on two short lengths from extrusion 253 followed by work on 254 and 263. Upon completion of these four pieces, an additional six lengths were processed, namely 282, 284, 285, 286, 288 and 289.

Pointing

All incoming extrusions had a 1/16 in. fillet radius milled for a nine inch length on one end destined to become the point. The extrusions were then taped with acid resistant tape from the end of this nine inch length to an additional 9-12 in. length and then the point reduced to 0.070 in. + 0.000, -0.010 in. in a 15 percent acetic acid - 5 percent hydrofluoric acid bath. The function of the tape was to prevent or minimize undercutting at an air-liquid interface. This point would permit drawing through the two cycles.

Cleaning, Coating and Lubrication

All extrusions were cleaned by alternate immersion in a KOH bath at about 425°F, rinsing, immersion in a 15 percent H_2SO_4 bath at about 120°F, rinsing, flash pickling in a 15 HNO_3-1-1/2HF bath at RT, rinsing and then conversion coating in Amchem Granodraw "T" (3 ox/gallon) and drying. The extrusions were all to have been lime dip coated at this point but as there existed difficulty in developing a good, dry coat which would not spall off on resistance heating, the lime coat was disbanded for these shapes. Two coats of Alpha-Molykote 196X were applied over the dry conversion coat by brushing and air drying between coats.

During resistance preheating, at about a temperature of 400/500°F, the power was turned off and Fiske 604 brushed over the entire warm extrusion. In addition, Fiske 604 was applied at the die face during the actual draw.

Dies

All extrusions were scheduled to be drawn through two passes, one a sizing pass primarily to work the fillet radii and a second pass to finished web thickness. No edge working was to occur in any of these passes. These passes were as follows:

1. 0.090 in.
2. 0.080 in.

Prior to drawing, the die assembly was preheated to approximately 500°F to prevent and minimize thermal fatigue failure of the carbide blocks.

A view of the draw die assembly is shown in Figure 42. The size change is accomplished by altering heat treated steel shims S.

Heating and Drawing, Straightening

The coated extrusions were resistance preheated to about 400/500°F, Fiske 604 applied by brushing over all surfaces and then the extrusion heated to 1000°F and manually inserted into the electric holding furnace set at 1050°F.

It was generally necessary to air blast the point during resistance preheating to prevent overheating and possibly sustain a point break in the drawing operation.

The extrusions were soaked at 1050°F for one minute and then the extrusion was inserted manually through the preheated dies into the Hufford gripper jaws and drawing started at a draw speed of 24 fpm. Fiske 604 lubricant was applied at the die face during the drawing operation. A recording ammeter was incorporated on the D. C. drive; this provided a good indication of the draw forces involved. No abnormal peak loads were seen in starting the actual draw operation. Typical load curves are shown in Figure 72, approximately 10-12 percent of the total draw force merely represents power required to move the draw chain.

After each draw pass, the extrusions were cleaned by multiple immersions in KOH and H_2SO_4 and inspected dimensionally. It was generally necessary to remove excessive Fiske 604 lubricant from areas which were not reduced in the first draw pass by means of a Scothbrite pad and 6161 solvent; the 425°F KOH bath could not remove this excess lubricant without this operation.

After the cleanup and inspection, the extrusions were then stretcher-annealed by resistance heating to 1550/1600°F for about 20 seconds accomplishing an anneal and straightening by stretching between 1/2 and 1-1/2 percent longitudinal strain. Following the stretcher-anneal, the extrusions were then again cleaned by means of KOH and H_2SO_4 immersions and then reinspected.

The cleaned extrusions, after the first draw pass and anneal, were then recoated, reheated, redrawn and restraightened as for the first pass. However, this time the extrusions were drawn through dies presenting an 0. 080 in. web thickness; again the dies were end free working.

In the original scope of the contract, the extrusions were not scheduled for any further processing. However, it was decided to perform mill heat treatment on these extrusions since they are not used in the annealed condition.

Heat Treatment

A 1/8 to 1/4 in. diameter hole was drilled on the front end of each extrusion to facilitate a rapid withdrawal and quench after solution treatment. This is particularly important in solution treating these thin extrusions, since radiated heat losses are rapid. All extrusions were then solution treated 1725F (2 min.) and water quenched within 3 seconds. The degree of distortion in water quenching these extrusions required that they be re-stretcher straightened.

It was intended that two of the extrusions be supplied in the solution treated and aged condition and the remaining six be supplied in the solution treated only condition. It will be discussed later that extrusions to specifications for solution treated only material (150 Ksi maximum yield strength) cannot be supplied for in stretcher straightening (1 - 1-1/2 percent) at temperatures below aging or omega embrittlement (400/450F) the yield strength is increased from about 115 Ksi to 155/165 Ksi. However, after descaling, extrusions 282, 284, 285, 286, 288 and 289 were successfully stretcher straightened at 400/450F (20 seconds). The remaining two extrusions 254 and 263 were in essence aged by stretcher straightening at aging temperatures of 1000/1025F. Figure 73 shows the distortion after solution treatment and the straightness after stretch straightening following solution treatment.

Tensile Property Survey

A test slice was removed from one end of each finished extrusion plant heat treated and straightened and a tensile property evaluation made. It was only feasible to acquire tests in the longitudinal direction. These results appear in Table 15. It is readily seen that it was not possible to supply straightened extrusions in the solution treated only condition as the yield strength was generally well in excess of 150 Ksi. Only a minor strength spread existed when a 1000F (4 hrs) AC aging treatment was imposed on test specimens in the laboratory.

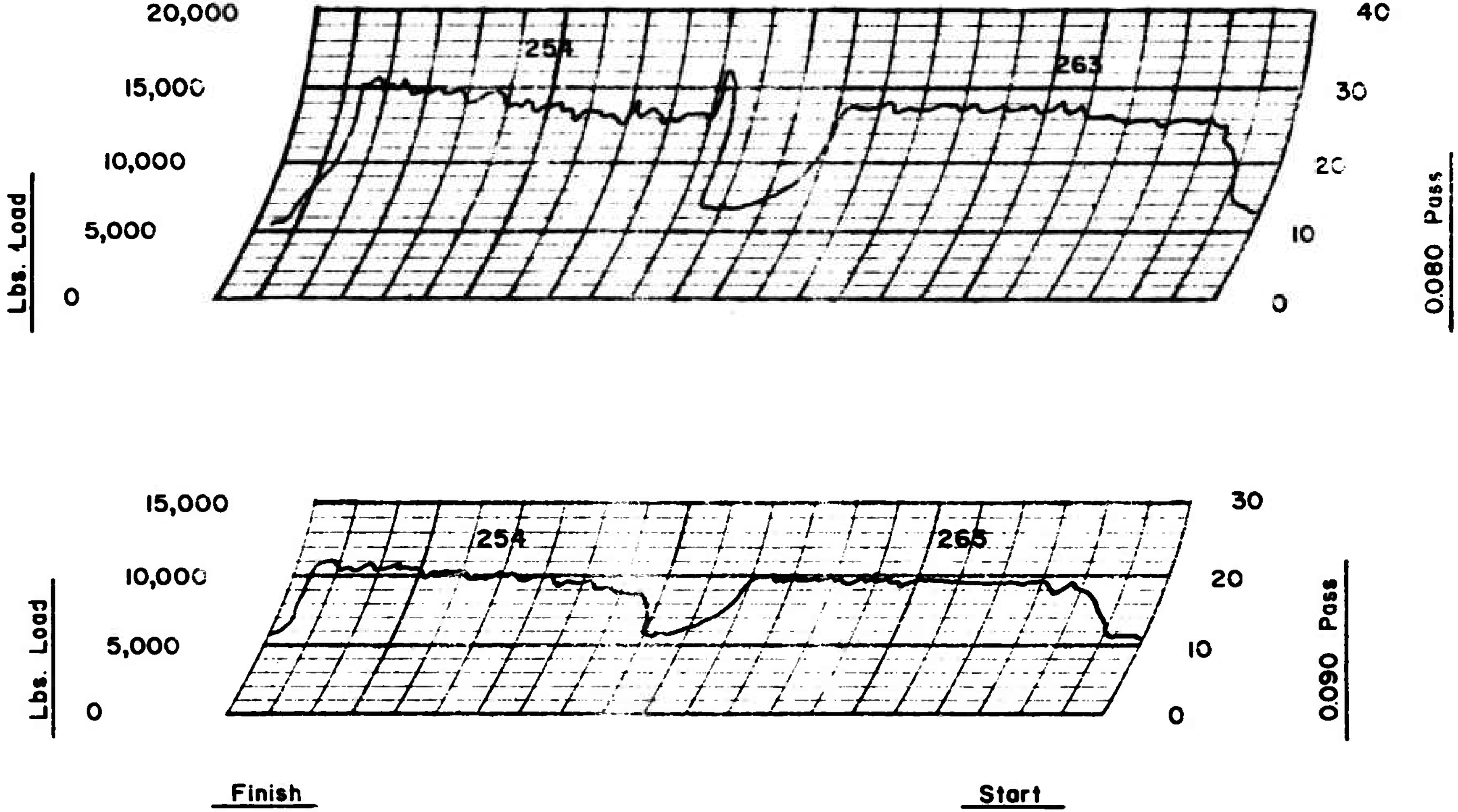
It would be recommended that the aging or stretch-aging temperature of this Ti-6Al-4V material be increased to 1100F to reduce the strength level more closely to the maximum 150 Ksi required for solution treated only extrusions. Table 15 also reveals that aging has occurred upon stretch aging at 1000/1025F.

A laboratory study was initiated to delineate the stage at which alterations in strength were noted in solution treated only extrusions. As can be seen from the data in Table 16, were it not for the stretch straightening required, the yield strength would be as low as 133 Ksi but imposing a 1-1/2 percent longitudinal strain, as in stretcher straightening, the yield strength increased to 162 Ksi. The effects of exposure to a 425F KOH bath are relatively minor and insignificant. Additional laboratory heat treat studies revealed the heat treat response of the as-extruded 3/32 in. thick "T" extrusions and this data can be seen in Table 17. This increase in strength in the drawn extrusions may be associated with the microstructural changes introduced by warm drawing; the transverse microstructures of the as-extruded and warm drawn shapes in the heat treated condition can be seen in Figure 74. A refinement of the primary alpha platelet areas can readily be noted.

Edge Machining

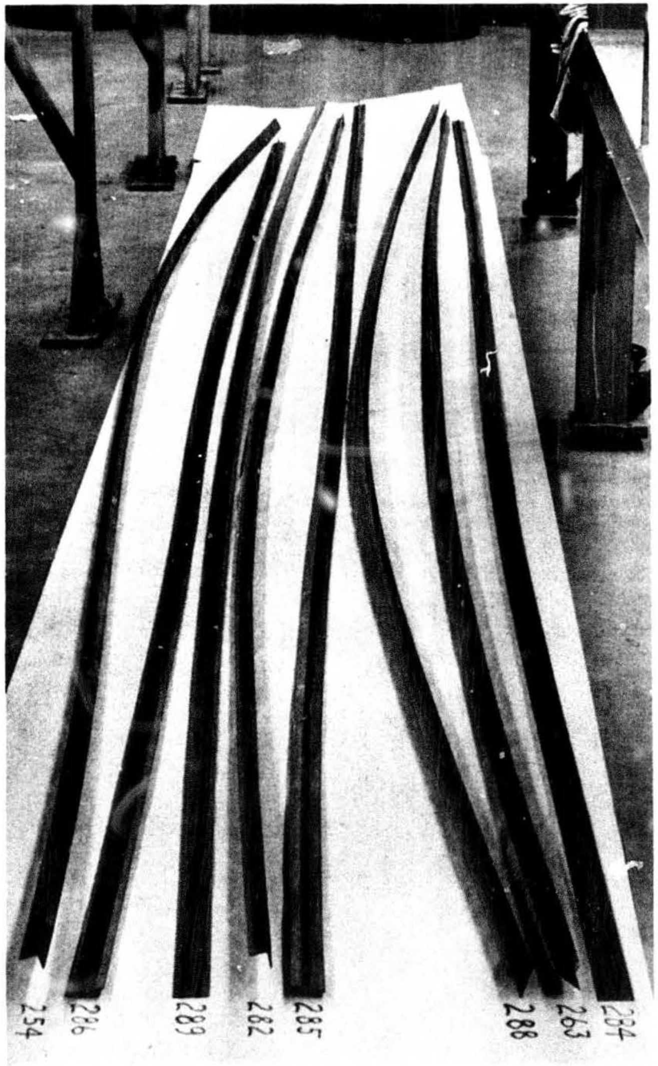
Upon a review of the dimensional survey of the 64E15 extrusions, it was decided to attempt edge machining of two extrusions (282, 285) which appeared to exhibit sufficient stock to machine to the required size of 1.000 ± 0.005 in. x 1.750 ± 0.005 in. The other extrusions were already under this size and machining to another size to clean up the undrawn edges was not considered. Edge machining was adopted for conditioning of the edges rather than warm drawing; this was to prevent metal losses by development of a "chevron" buckle in excessive edge working and to present a much improved dimensional integrity by edge machining as the final operation.

Figure 75 summarizes the total dimensional history from one starting extrusion to the finish, drawn and edge machined part.



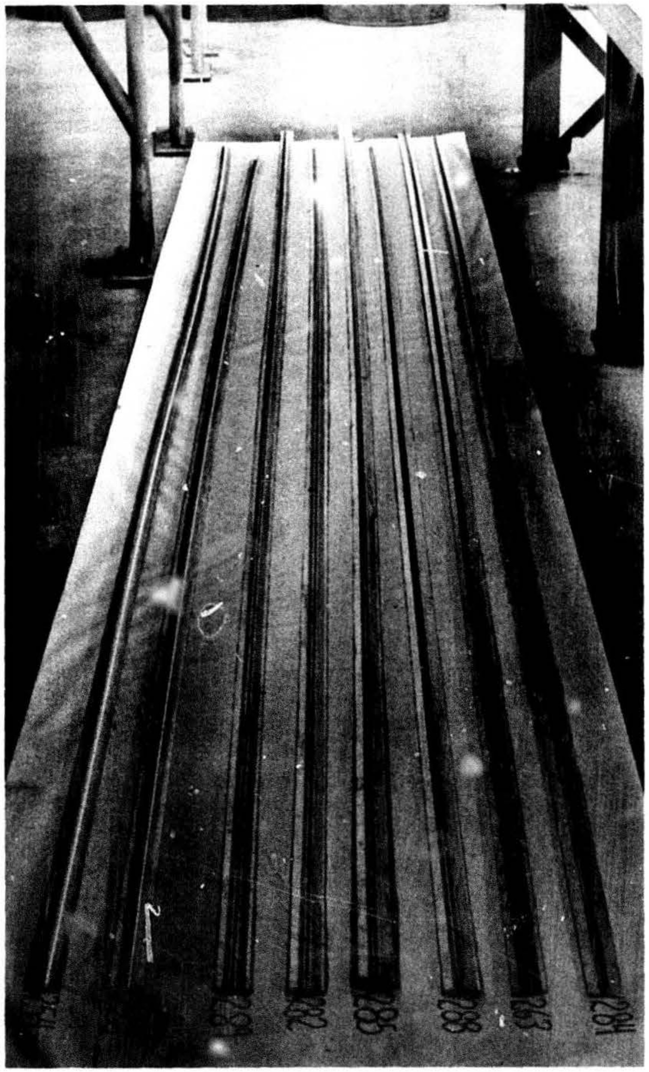
Typical Load Curves During Warm Drawing of 64E15 Extrusions at 1050°F. Two Pass Cycle

FIGURE 72



64E15 Extrusions After Solution Treatment

FIGURE 73 (a)



64E15 Extrusions After Solution Treatment and Stretch Straightening
FIGURE 73 (b)

605E88

T6428-D

Extruded & Warm Drawn (.080-in.) in 2 Passes & STA

Etch: HNO_3-HF Mag: 500X

T6428-B

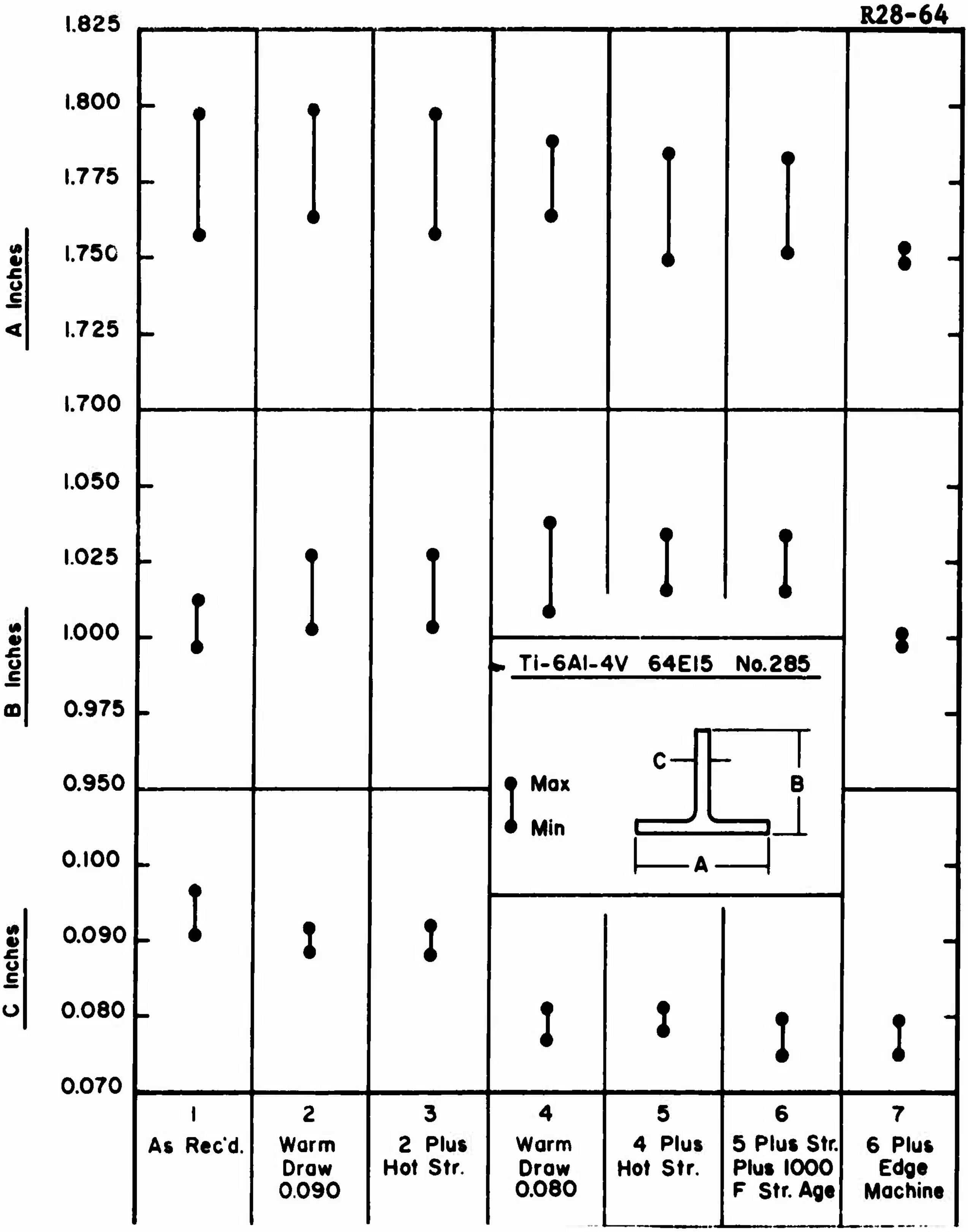
Extruded (0.095) & STA

Etch: HNO_3-HF Mag: 500X

Photomicrographs of 64E15 Extrusions Showing Differences in Microstructure Between As-Extruded and Drawn Shapes After Full Heat Treatment

FIGURE 74

605288



Alteration in Dimensions Through all Processing Stages
for 64E15 Extrusion #285

FIGURE 75

TABLE 15

Tensile Property Survey of 64E15 Extrusions of Ti-6Al-4V (64E15) Warm Drawn 2 cycles (15.8% Reduction) to 0.080 in. and Plant Heat Treated

Ext. No.	UTS Ksi	YS(0.2%) Ksi	EL(1 in) %
(A) -1725°F (2 min)WQ + Warm Stretch 400/450°F			
282	193.2	174.7	6.0
284	177.3	159.7	11.5
285	173.1	153.6	10.0
286	186.6	165.5	6.0
288	177.4	152.9	10.0
289	188.4	172.3	7.0
(B) -(A) + 1000°F (4 hrs)AC in Laboratory			
282	188.8	172.5	8.0
284	191.3	176.4	6.0
285	189.9	174.3	7.0
286	187.9	172.9	7.0
288	186.6	172.4	7.0
289	187.9	174.6	6.0
(C) -1725°F (2 min)WQ + Hot Stretch 1000/1025°F AC			
254	198.2	182.1	6.0
263	194.2	182.1	6.0
(D) -(C) + 1000°F (4 hrs)AC in Laboratory			
254	194.2	179.4	6.0
263	192.1	178.1	8.0

TABLE 16

Effect of Thermal and Strain Variables on As-Solution Treated Ti-6Al-4V Extrusions (64E15)

Condition	Test Temp	UTS Ksi	YS(0.2%) Ksi	El (1 in) %
(A) 1725°F (2 min) WQ	RT	171.7	129.3	12.0
(B) (A) + 425°F (1/2 hr) AC (Simulating KOH Cycles)	RT	171.3	133.4	12.5
(C) (B) + 1-1/2% Stretch at (425°F (AC)	RT	172.4	162.4	13.0
(Simulating 425°F stretcher straightening)	425°F	-	99.9	1.5
(D) (C) + 425°F (1/2 hr) AC (Simulating KOH cycle after warm stretch)	RT	174.1	166.8	10.0
(E) (B) + 1-1/2% Stretch at RT	RT	174.9	159.9	10.0 BS

Note: Vapor blast and pickle after every thermal cycle

TABLE 17

Heat Treat Response of As-Extruded 64E15 Extrusions

Ext. No.	Web Thickness	Heat Treatment	UTS Ksi	Ys(0. 2%) Ksi	El(1 in) %
284	0. 095	1725°F(2min)WQ + 1000°F(4hrs)AC	180. 2	161. 4	8. 0
284	0. 095	" + "	185. 0	166. 3	-
286	0. 095	" + "	181. 4	164. 2	8. 0
286	0. 095	" + "	181. 1	162. 7	7. 0
286	0. 095	1725°F(2min)WQ	165. 9	119. 4	13. 0

c) Drawing Shape 64E12 (modified)

Material

Eight extrusions were selected for application to this phase of the warm draw program. These were nominal 1/16 in. thick "T" extrusions to be warm drawn to supply finished extrusions to print 64E12 depicted in Figure 5.

The irregularity in web thickness on several of these extrusions can be seen from Figure 76. It will be discussed later how these constricted areas contributed to much material loss in actual warm drawing.

Procedures

The general processing outline for this five stage warm drawing was as follows, in all cases utilizing end free drawing:

1. Inspect incoming extrusions
2. Machine 1/16 in. fillet radii for 9 in. point length
3. Point, chemically, to 0.050 in. web thickness + 0.000, -0.010 in.
4. Clean, pickle in KOH, H_2SO_4 and HNO_3-HF baths
5. Conversion coat, lime coat, brush coat Alpha Molykote 196X
6. Resistance preheat 1050°F
7. Discharge into electric holding furnace set at 1050°F and commence drawing without any holding time.
8. Hook up and draw at 24 fpm applying Fiske 604 lubricant by brushing while drawing through preheated dies. First die pass 0.065 in. for all but 264, 292, 294 and 295. For these, the first die pass opening was 0.075 in. This was done to minimize the reduction since the fillet radius was 11/64 inch.
9. Clean, pickle as in Step 4
10. Inspect
11. Hot stretcher anneal 1550/1600°F

12. Clean, pickel as in Step 4

13. Inspect

14. Repeat Step 5

15. Repeat Step 6

16. Repeat Step 7

17. Warm draw second pass of 0.058 in. drawing again at 24 fpm

18. Repeat Step 4

19. Inspect

20. Repeat Step 11, stretcher annealing

21. Repeat Step 4

22. Inspect

23. Repoint to 0.040 + 0.000, -0.010

24. Repeat Steps 5, 6 and 7

25. Warm draw third pass of 0.053 in. drawing again at 24 fpm

26. Repeat Step 4

27. Inspect

28. Repeat Step 11 stretcher annealing at 1550/1600°F

29. Repeat Step 4

30. Inspect

31. Repeat Steps 5, 6 and 7

32. Warm draw fourth pass of 0.047 in drawing at 24 fpm

33. Repeat Step 4

34. Inspect

35. Repeat Step 11 stretcher annealing at 1550/1600°F

36. Repeat Step 4

37. Inspect

38. Repoint to 0. 030 + 0. 000, -0. 010

39. Repeat Steps 5, 6 and 7

40. Warm draw fifth pass of 0. 043 in. drawing again at 24 fpm

41. Repeat Step 4

42. Inspect

43. Repeat Step 11, stretcher annealing at 1550/1600°F

44. Repeat Step 4

45. Inspect

Per the original scope of the program, no heat treatment was to be conducted on these extrusions. However, the scope of the program was altered to include heat treatment of the shapes and solution treatment and restraightening was performed. Five lengths were solution treated 1725°F (15 seconds) WQ. The extrusions were again descaled by KOH, H_2SO_4 and HNO_3-HF immersions and either stretched at 400/450°F or 1000/1025°F as required and then again descaled as above. Two lengths were of sufficient stock to warrant edge machining to 1. 600 in. ± 0. 005 in. x 1.750 in. ± 0. 005 in.

<u>Warm Drawing First Pass (0. 065 or 0. 075 in.)</u>

The anticipated die sequence in five stage drawing of Part V extrusions was as follows:

1. 0. 065
2. 0. 058
3. 0. 053
4. 0. 047
5. 0. 043

These are all nominal 10 percent reductions. The first five extrusions (260, 261, 266, 290 and 292) were drawn through the 0. 065 in. pass, selecting those extrusions which would pose only minimal problems. This generally implied that the web thickness was no thicker than 0. 065 in and only the heavy fillet radii (9/64 to 11/64 in.) would be worked through the 0. 125 in die radius. The remaining extrusions (264, 292, 294 and 295) generally possessed combinations of heavy webs (greater than 0. 065 and up to 0. 080 in) and fillets (11/64 in.); these extrusions then received their first pass through an 0. 075 in. die opening, end free drawing.

Table 18 summarizes the pertinent draw bench data such as mean draw loads, areas of working and the like. Generally the heavy over-working of the fillet resulted in rather extreme build up of heat (approx. 300°F) in this region and subsequent lubricant breakdown and metal seizure. An 11/64 in fillet radius reduced to 1/8 in. upon drawing represents a severe local deformation of 27 percent reduction in thickness; the accompanying heat buildup and attendant galling can thus be rationalized.

Due to the heavy working of the fillet, minor growth of about 0. 025 in. of the vertical leg occurred upon comparison to the starting extrusion dimensions.

This can be noted by comparison of dimensions after the first pass (Table B2) and the starting dimensions (Table B1). Comparison of Table B2 with Table B3 (dimensions after stretcher straightening-annealed) revealed that little change (contraction) in dimensions transpired in this operation.

Reasons for metal loss in the first warm draw pass, be it 0. 065 in. or 0. 075 in. , were associated with physical separation of the vertical leg from the horizontal flange upon emerging from the draw die. This type of failure is depicted in Figure 77. Referring back to Figure 76, reasons for this metal failure are rather obvious. The thin areas in the starting extrusions, adjacent to oversize fillet radii, were heated more readily in resistance preheating and during the drawing operation with overworking of the fillet zones the thin areas are incapable of sustaining the draw forces; thus metal separation ensues, initially necking, however.

A microstructural examination adjacent to the failure revealed the further thinning or necking of the thin spot in the web of the vertical leg and the development of strain induced porosity near the tensile fracture. (See Figure 78).

Warm Drawing Second Pass (0. 058 in.)

After surface preparation, lubrication and the like, the extrusions were then preheated and drawn through the second pass to 0. 058 in. The exception to this was extrusion 292 which was worked 0. 075 in. and then 0. 065 in. The 0. 058 in. pass was then the third for this extrusion. This extrusion again revealed extensive separation of the vertical leg from the horizontal flange for reasons discussed previously and had to be scrapped.

The draw forces, as noted in Table 19, were generally higher than for the first sizing pass. No undue damage was inflicted by going from 0. 075 in. pass to 0. 058 in. on the three extrusions but this merely resulted in slightly higher draw forces than going from 0. 065 in. to 0. 058 in.

As can be seen from Figure 79, point damage was extensive after the second draw pass and all had to be removed prior to the stretcher straightening-annealing operation. Representative causes for failure were buckling upon release of the extrusion through the draw die, tearing of tapered knife edges of the point or start of separation of the vertical leg from the horizontal flange in the point, generally due to undercutting in the original extrusion.

The dimensions of the extrusions after the second draw and also after stretcher annealing is tabularized in the Appendix in Tables B-4 and B-5.

All extrusions were machined in the fillet for a nine inch length and then chemically pointed to 0.040 in. + 0.000, -0.010 prior to the third draw.

Warm Drawing Third Pass (0.053 in.)

The extrusions were prepared for third pass warm drawing as for the previous two passes; the same heating and drawing techniques were utilized. As can be seen from the pertinent draw bench data in Table 20, it became necessary to scrap the second extrusion, number 295, as physical separation of the vertical leg from the horizontal occurred. The failure typified in extrusion 295 is shown in Figure 80; this, however, is a picture of extrusion number 266 which failed in an identical fashion four (4) feet from the rear end of the extrusion.

Almost invariably, it became necessary to repoint all extrusions at this stage for after the 0.053 in. pass, most extrusions exhibited point failure.

From this stage on, pointing (machining of fillet and chemically milling of flats) was conducted in laboratory facilities to exercise the greater control necessary to warm draw thin extrusions. The tendency to cut into the web thickness in machining the fillet radius in the point or over-pickling of the point thickness was thus curtailed. It was thus possible to pull an extrusion through the 0.048 in. die opening with a point thickness as great as 0.040 in. Care had to be exercised in cutting off the old points as the angularity of the vertical leg could be ruined and all other control in pointing would be of no avail.

The dimensional measurements of these extrusions after the third draw pass and after the stretcher-anneal operation is presented in Table B-6 and B-7 in the Appendix.

Warm Drawing Fourth Pass (0.047 in.)

The remaining six lengths of the starting eight extrusions were again prepared and warm drawn as in earlier passes. The draw bench performance data is summarized in Table 21. There was a tendency for rippling of the edges of these warm drawn extrusions as a 0.001 in. variation in web thickness from side to side would induce extreme undulations and require excessive stretcher straightening to remove these ripples. Here again, point breakage was encountered for, in general, the points were too thin (as low as 0.025 in.) to sustain the shock of the extrusion emerging from the die and buckling or metal failure occurred.

The variability of the dimensions of the extrusions, after being drawn through the 0.047 in. die opening and after stretcher straightening, is summarized in Table B-8 and B-9 in the Appendix.

Final Warm Draw Pass - (0.043 in.)

Six extrusions were capable of being drawn through the required five warm draw passes. Prior to introducing this last pass, it was again necessary to repoint. Again the laboratory was assigned to machine the radius in the point and to chem-mill the point. Here the points varied from only 0.032 to 0.038 in. in web thickness, thus incorporating a strong point to pull the extrusion through the 0.043 in. die opening. It would not have been practical to control the size much closer than that demonstrated here. The operation, however, was time consuming, requiring nearly 3/4 hour for accurate machining of the fillet radii and another 1/4 hour for preparation and actual pickle pointing.

Pertinent draw bench data is summarized in Table 22. No unusual problems were introduced but, in general, all extrusions exhibited excessive waviness of the web thicknesses.

Throughout this program, the draw forces were recorded for each pass by means of a recording ammeter hooked into the DC motor circuit. Figures 81 and 82 reveal the pressure versus time curves for the two longest extrusions processed; the data represents the load curve for each of the five passes. Beyond the first pass, wherein extrusion number 290 was heavily worked and 294 only lightly in the fillets, the draw forces were essentially the same. Ordinarily about 10/12 percent of the available bench capacity is used merely to drive the chain. Galling can be readily detected on these charts such as on extrusion 290 towards the rear end of the first 0.065 in. pass and minor galling at the extreme end of extrusion 294 at the 0.058 in. pass.

The dimensions of the extrusions after the fifth, and final, draw pass to 0.043 in. thickness and after stretcher straightening is presented in the Appendix in Table B-10 and B-11.

Straightness and overall view of the completed 64E15 extrusions are viewed in Figure 84.

With the change in scope to include heat treatment, five (5) of the six (6) extrusions finished through the 0.043 in. draw pass were plant solution treated and aged. Extrusion 260 was left in the annealed condition.

Heat Treatment

Five of the six extrusions were selected for heat treatment at TMCA. Extrusions numbers 261, 264, 266, and 294 were solution treated 1725°F (15 seconds) and water quenched. As can be seen in Figure 84, considerable distortion developed in solution treating of these extrusions.

Extrusion 264 was stretcher straightened at 400°F and the remainder at approximately 1000°F. The appearance of the three longest lengths after restraightening is noted in Figure 85. It was necessary to stretch more than 1 1/2 percent in about every case to restore straightness.

The tensile property survey of these three long lengths revealed the values noted in Table 23. The heat treat response is essentially that noted in the original extrusions and summarized in Table 24, however, marked microstructural refinement in warm drawing could be noted by viewing Figure 86.

A dimensional survey was made on the extrusions after straightening of the solution treated product; this data appears in the Appendix in Table B-12. From this data, it was decided to machine the edges of two extrusions. Warm drawing of the edges was not considered for reasons discussed earlier.

Edge Machining

Extrusions 290 and 294 had nearly sufficient stock on the leg height and width to machine the edges to the required 1.600 in ± 0.005 in x 1.750 in ± 0.005 in. Figure 87 shows the dimensional controls exhibited in these two extrusions. These lengths were pickled one mil in a HNO_3-HF bath and shipped to North American Aviation for inspection with the 64E15 extrusions.

Figure 88 summarizes the history of extrusion 290 from the incoming extrusion size, progressively through all five draw passes, heat treatment and final edge machining.

Table 18

Draw Bench Data

0.065 or 0.075in First Pass - 64E12

Ext. No.	Pass	Draw Temp.	Mean Load	Remarks
260	0.065	1050F	7,500 lbs	Heavy working of fillet radii. Galling on bottom of horizontal flange. Final 2 feet fractured.
261	0.065	1050F	3,000 lbs	Drawn OK. Worked fillet radii only. No galling.
264	0.075	1050F	3,000 lbs	Drawn OK. Worked fillet radii only. No galling.
266	0.065	1050F	10,000 lbs	Heavy working of fillet radii only. Minor galling in fillet. Final 3 feet fractured.
290	0.065	1050F	12,000 lbs	Fillet radii worked heavy. Galling on bottom of horizontal flange. Final 2 feet fractured.
292	0.075	1050F	3,500 lbs	Heavy working of fillet radii and horizontal flange. Final 30 in. ruptured. No galling.
292	0.065	1050F	-	Broke point. Unable to draw
292	0.065	1050F	3,000 lbs	Drawn OK. Last 30 in ruptured.
294	0.075	1050F	5,000 lbs	Heavy working of fillet radii. No galling.
295	0.075	1050F	3,500 lbs	Heavy working of fillet radii. No galling.

All draw speeds 24 fpm.

Table 19

Draw Bench Data

0.058in Second Pass - 64E12

Ext. No.	Pass	Draw Temp.	Mean Load	Remarks
260	0.058	1050F	12,000 lbs	60-second delay in hookup. 10ft-6in drawn then severe galling developed. Point slipped from gripper. 7 feet cut out undrawn.
261	0.058	1050F	5,000 lbs	Drawn OK. Half of horizontal and vertical flanges worked.
264*	0.058	1050F	8,000 lbs	9ft-3in drawn through die when point broke. Galling developed on horizontal flange. Vertical leg worked. 10ft-3in section undrawn.
266	0.058	1050F	6,000 lbs	Final 7in. separation of horizontal and vertical legs point broke. Flat surfaces partially worked.
290	0.058	1050F	9,000 lbs	Drawn OK. No galling, all surfaces worked.
292*	0.058	1050F	--	Delay in hookup, pulled point off.
292	0.058	1050F	--	Repointed; Hufford jaws wouldn't hold point. Had to cut extrusion from die.
292	0.058	1050F	--	4 feet drawn with vertical leg separation immediately. Balance undrawn. Piece scrapped.
294*	0.058	1050F	10,000 lbs	Drawn OK. All flat surfaces worked.
295*	0.058	1050F	11,000 lbs	Final 2 feet broke in die. Gall developed on bottom of horizontal flange. No work on vertical leg.

* Previous first pass 0.075in
All draw speeds 24 fpm.

Table 20

Draw Bench Data

0.053in Third Pass - 64E12

Ext. No	Pass	Draw Temp.	Mean Load	Remarks
260	0.053	1050F	9,000 lbs	Work all flat surfaces. Final 2 feet broke in die.
261	0.053	1050F	5,500 lbs	30-second delay in hookup. All flat surfaces worked except extreme edges. Point buckled.
264	0.053	1050F	6,500 lbs	Drawn OK. All flat surfaces worked except extreme edges. No galling. Point ruptured.
266	0.053	1050F	5,500 lbs	Drawn OK. Vertical leg ruptured 4 feet from rear. No galling. All flat surfaces worked.
290	0.053	1050F	--	Broke point, unable to draw; cut from die.
290	0.053	1050F	7,500 lbs	Repointed. Drawn OK. One side of horizontal flange badly ripped. All flats worked, no galling.
294	0.053	1050F	6,500 lbs	All flat surfaces worked. One side of horizontal flange worked harder than other causing tremendous side sweep. Point broke.
295	0.053	1050F	--	Point broke, couldn't draw.
295	0.053	1050F	--	After drawing 3 feet, metal separating horizontal from vertical flange in many places. Extrusion scrapped.

All draw speeds 24 fpm.

Table 21

Draw Bench Data

0.047in Fourth Pass - 64E12

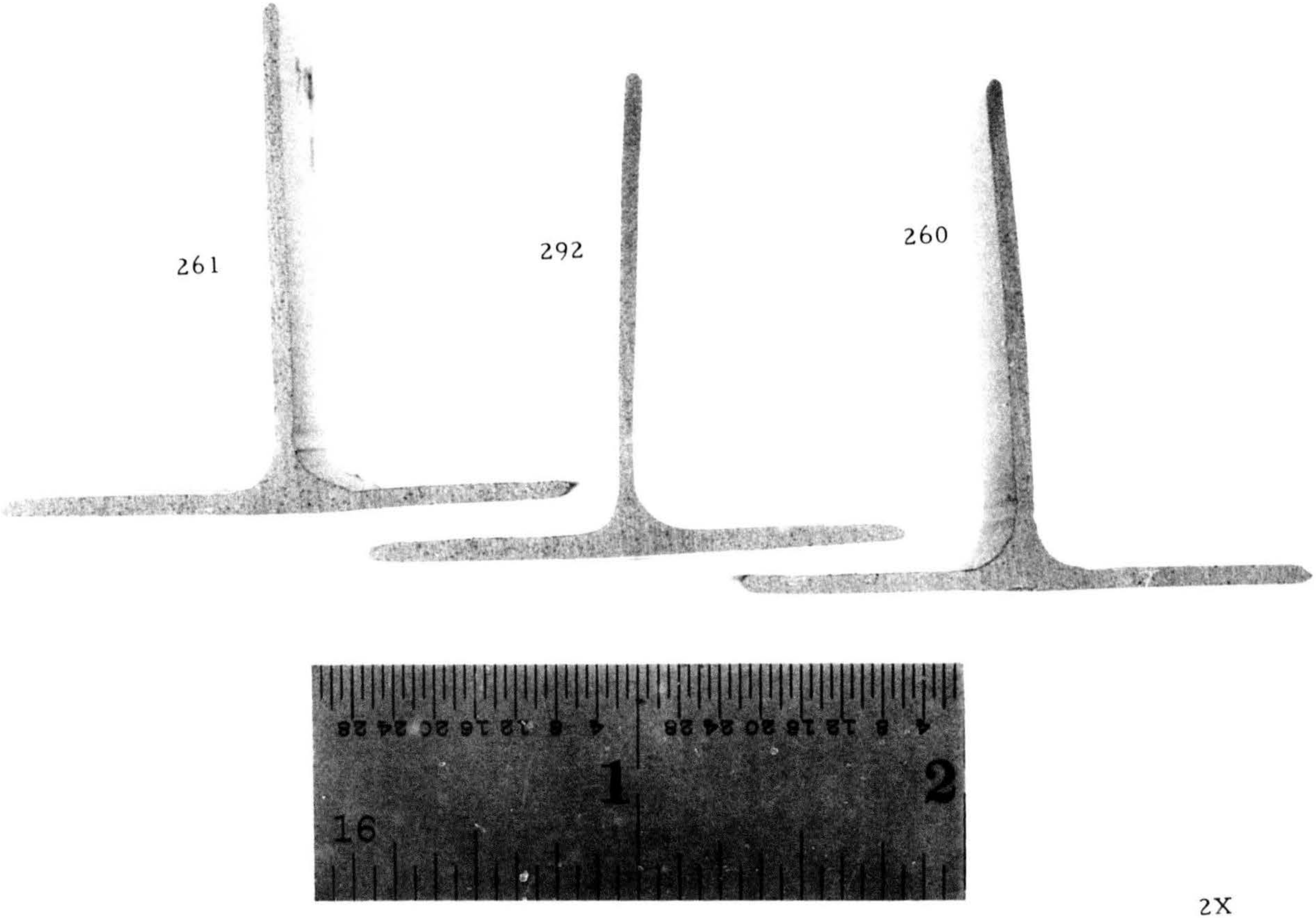
Ext. No.	Pass	Draw Temp.	Mean Load	Remarks
260	0.047	1050F	5,500 lbs	Broke point, regripped and drew OK. All flat surfaces worked.
261	0.047	1050F	3,500 lbs	Drawn OK. All flat surfaces worked except extreme edges. No galling. Point still good.
264	0.047	1050F	6,500 lbs	Delay in hookup. Drawn OK. All flats worked.
266	0.047	1050F	3,500 lbs	Drawn OK - all but last 2-1/2 feet as point broke. All flats worked. One side of horizontal flange worked harder than other.
290	0.047	1050F	3,500 lbs	Drawn OK. Rippling at one leg of horizontal flange. All flat surfaces worked; point buckled at end.
294	0.047	1050F	--	Broke point, couldn't draw
294	0.047	1050F	5,500 lbs	Drawn OK. Twisting from one side of horizontal flange working harder than other. All flat surfaces worked good. Point broke.

Table 22

Draw Bench Data

0.043in Fifth Pass - 64E12

Ext. No.	Pass	Draw Temp.	Mean Load	Remarks
260	0.043	1050F	5,500 lbs	Drawn OK. Too short to resistance heat. Heated entirely in holding furnace.
261	0.043	1050F	8,500 lbs	Progressive galling from beginning. Final 3ft broke in die. Areas still not worked on both horizontal and vertical legs.
264	0.043	1050F	7,000 lbs	Drawn OK. Final 3/4in end split. All flats worked. No galling.
266	0.043	1050F	5,500 lbs	Drawn OK. Final 1/2in split; point split. Horizontal leg rippled.
290	0.043	1050F	5,500 lbs	Drawn OK. Minor galling in vertical leg. All edges rippled.
294	0.043	1050F	4,500 lbs	Drawn OK. One side of horizontal flange worked harder than other; extrusion corkscrewed.



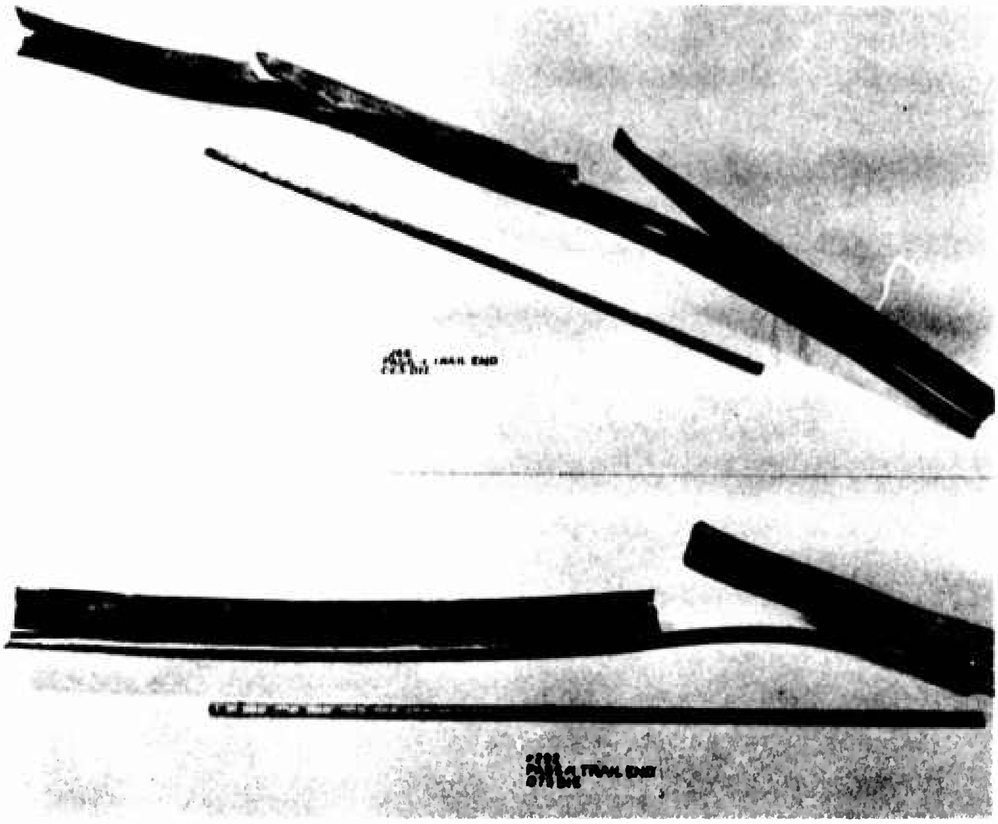
2X

M63-335-B

Profile of Several 64E12 Extrusions Exhibiting Constricted Areas in Vertical Leg

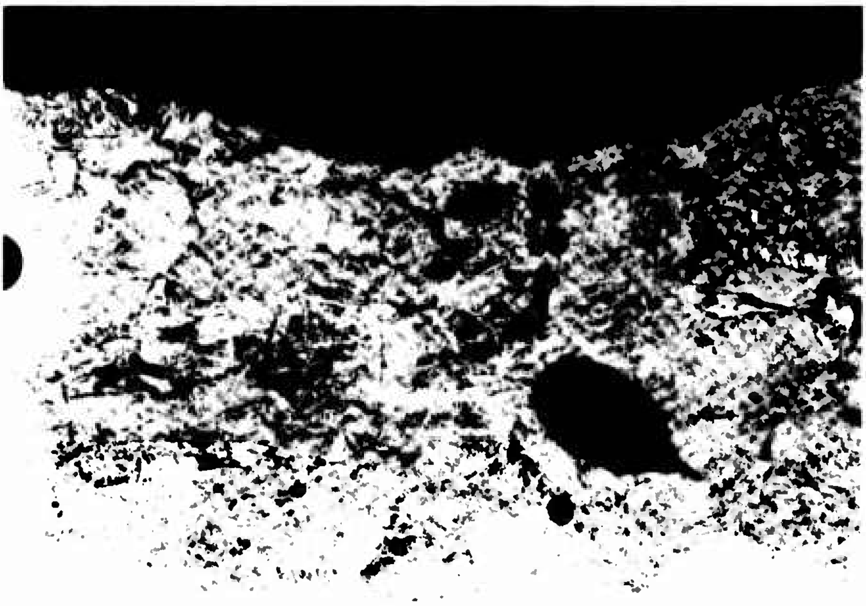
FIGURE 76

605288



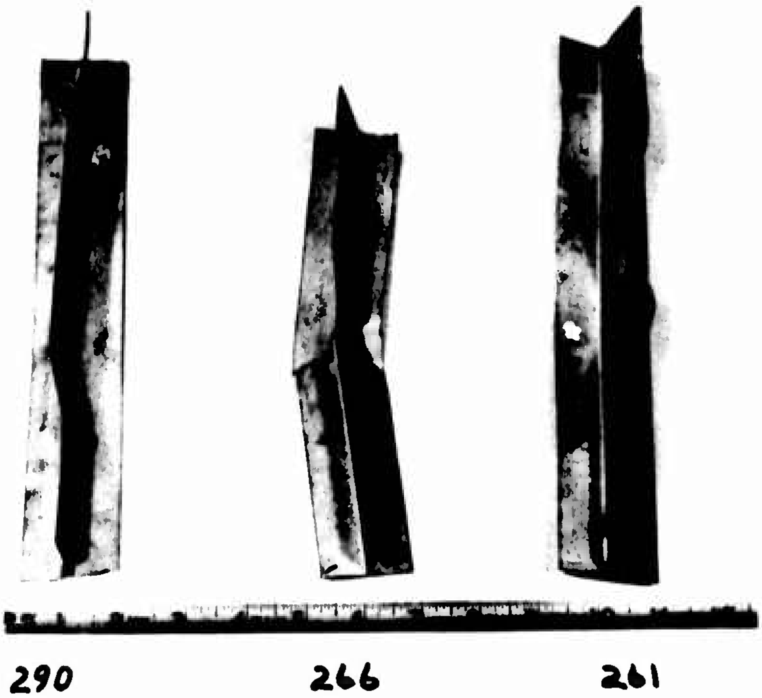
Mode of Failure of Several 64E12
Extrusions After First Draw Pass

FIGURE 77



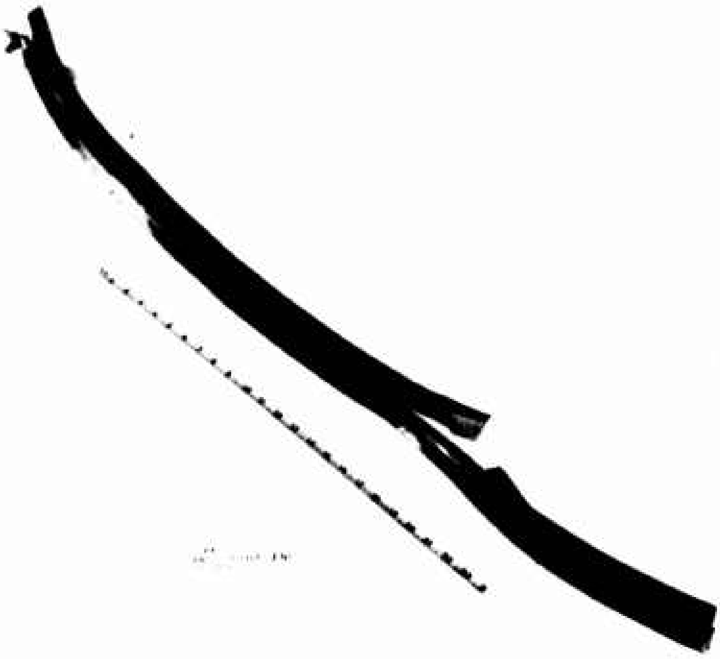
Necking and Strain-Induced Porosity
Noted in Areas Adjacent to Failures in Figure 77

FIGURE 78



Various Point Failures Noted Upon Drawing 64E12 Extrusions Through a Draw Pass

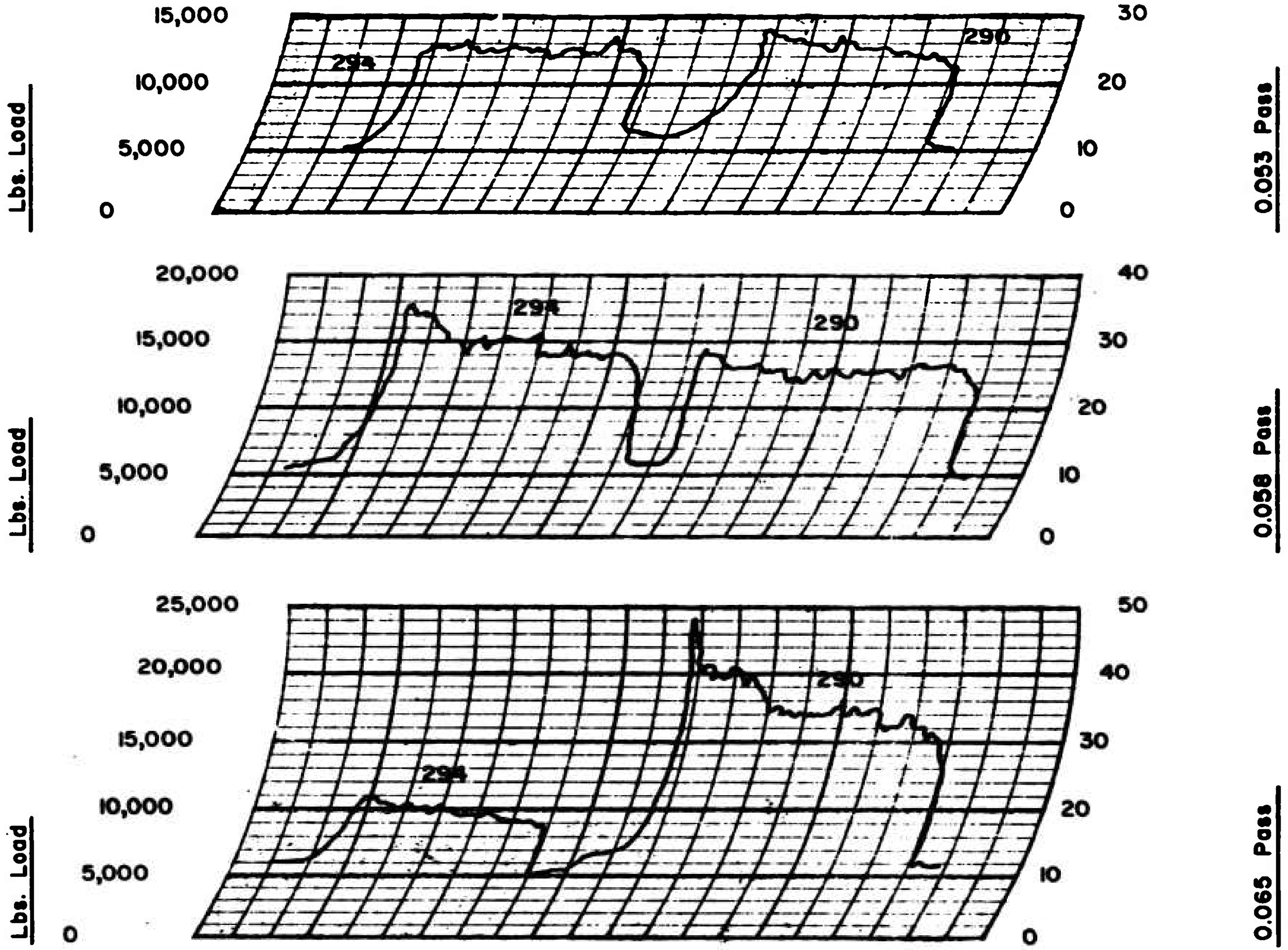
FIGURE 79



Failures Due to Separation of the Vertical Leg; Failure Occurring in Third Pass

FIGURE 80

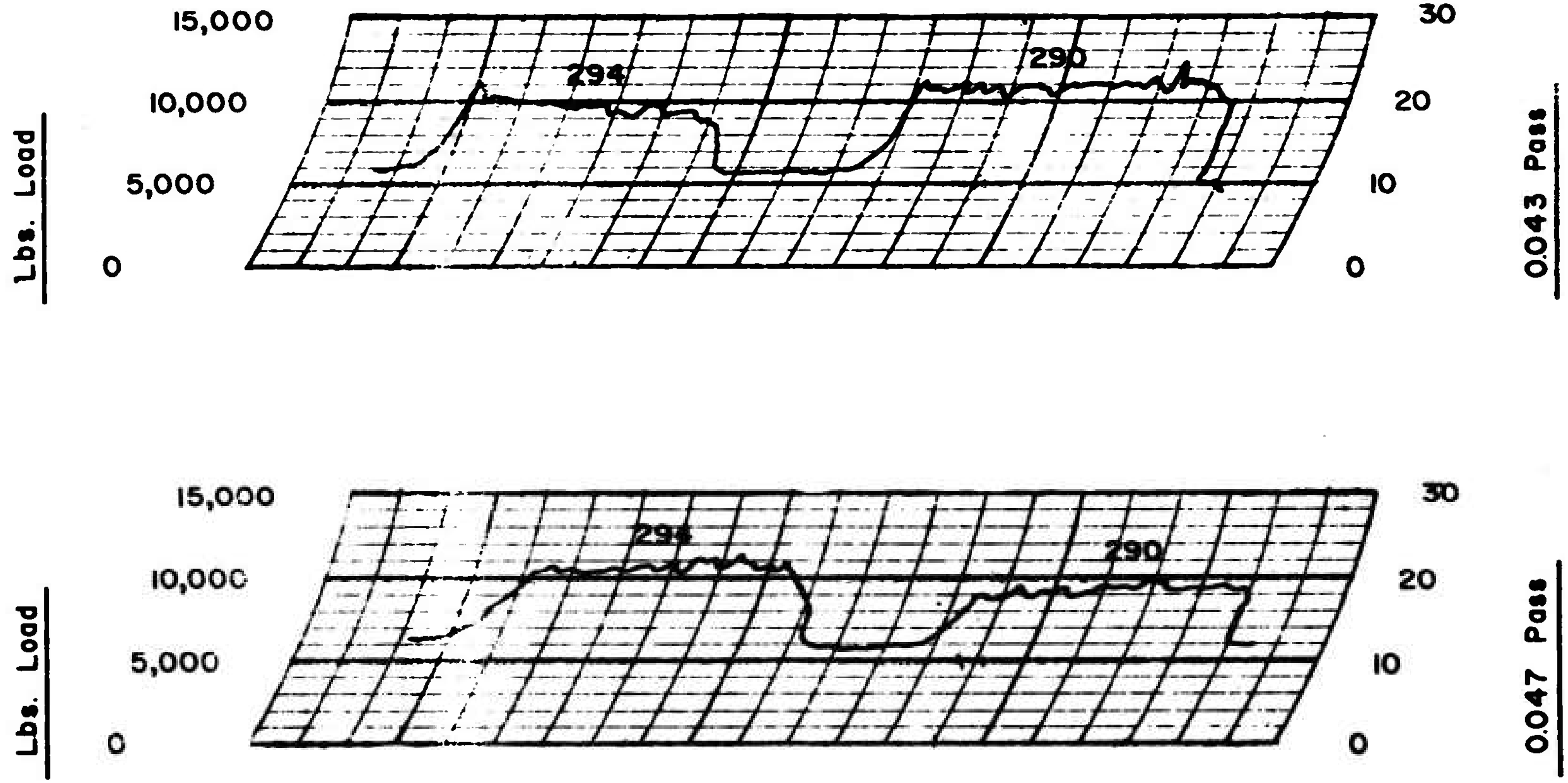
605288



Plot of Pressure Versus Draw for the First Three Passes on Two 64E12 Extrusions

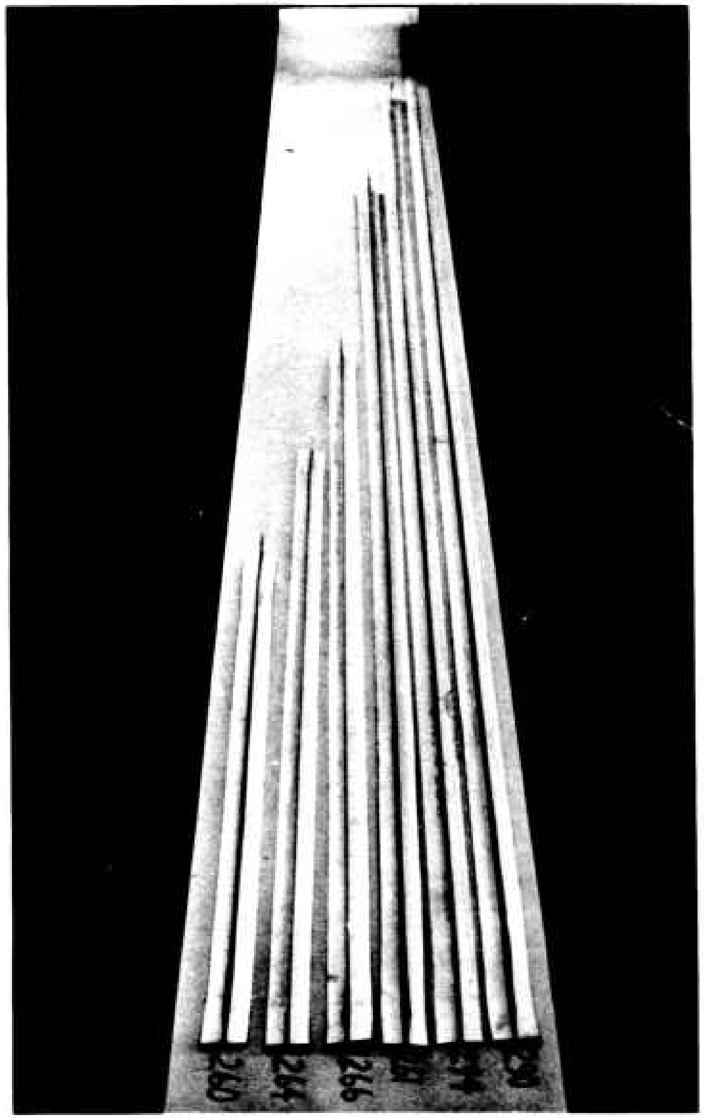
FIGURE 81

R39-64



Pressure Versus Draw Chart for the Last Two Passes
on Two 64E12 Extrusions

FIGURE 82

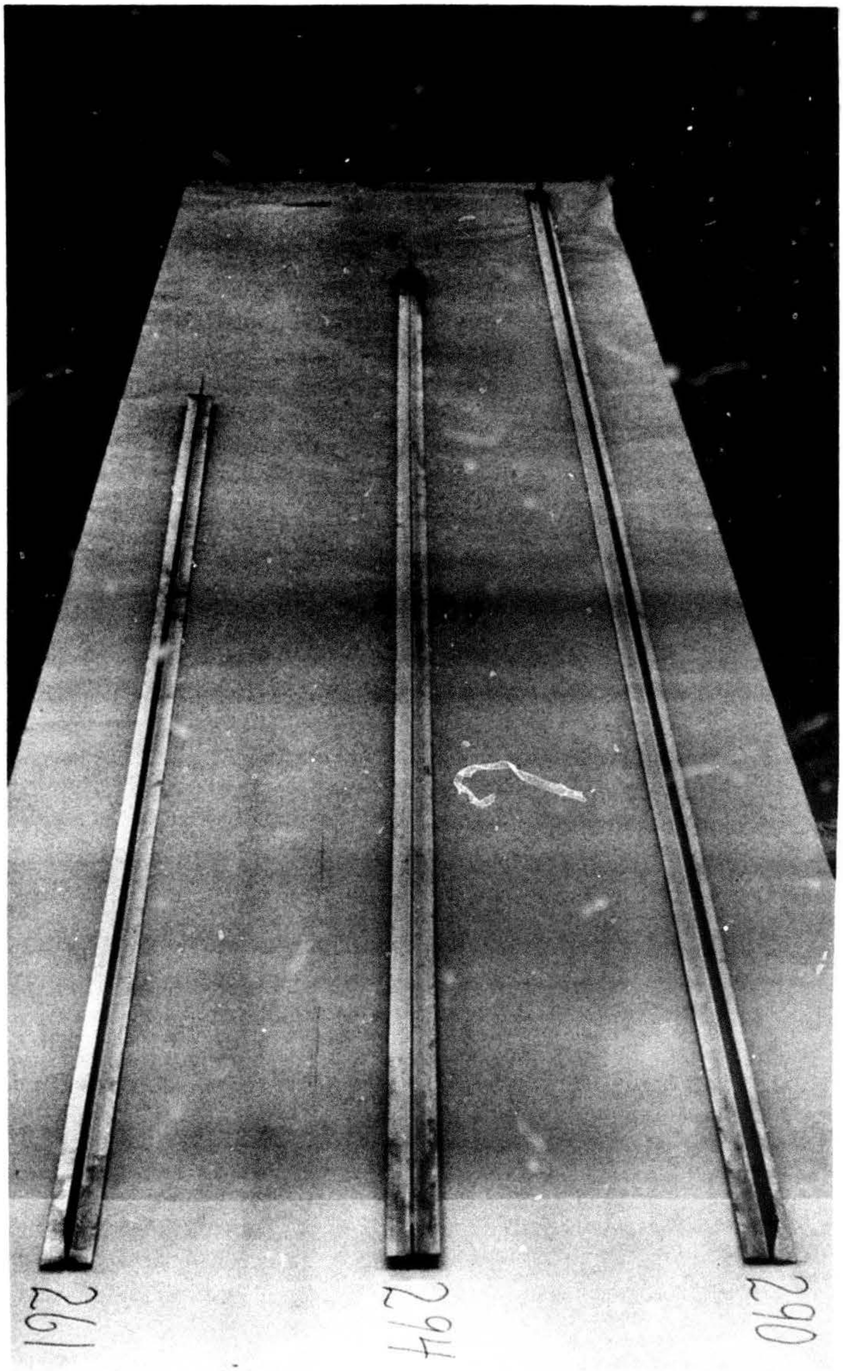


Straightness of the Six 64E12 Extrusions
Drawn Through all Five Warm Draw Cycles
Prior to Solution Treatment
FIGURE 83

Distortion of 64E12 Extrusions After
Solution Treatment

FIGURE 84

605288



Three Longest Lengths of 64E12 Extrusions After Restraightening Following Solution Treatment

FIGURE 85

As-Extruded
0.065in
Plus STA

64-28-F 500X

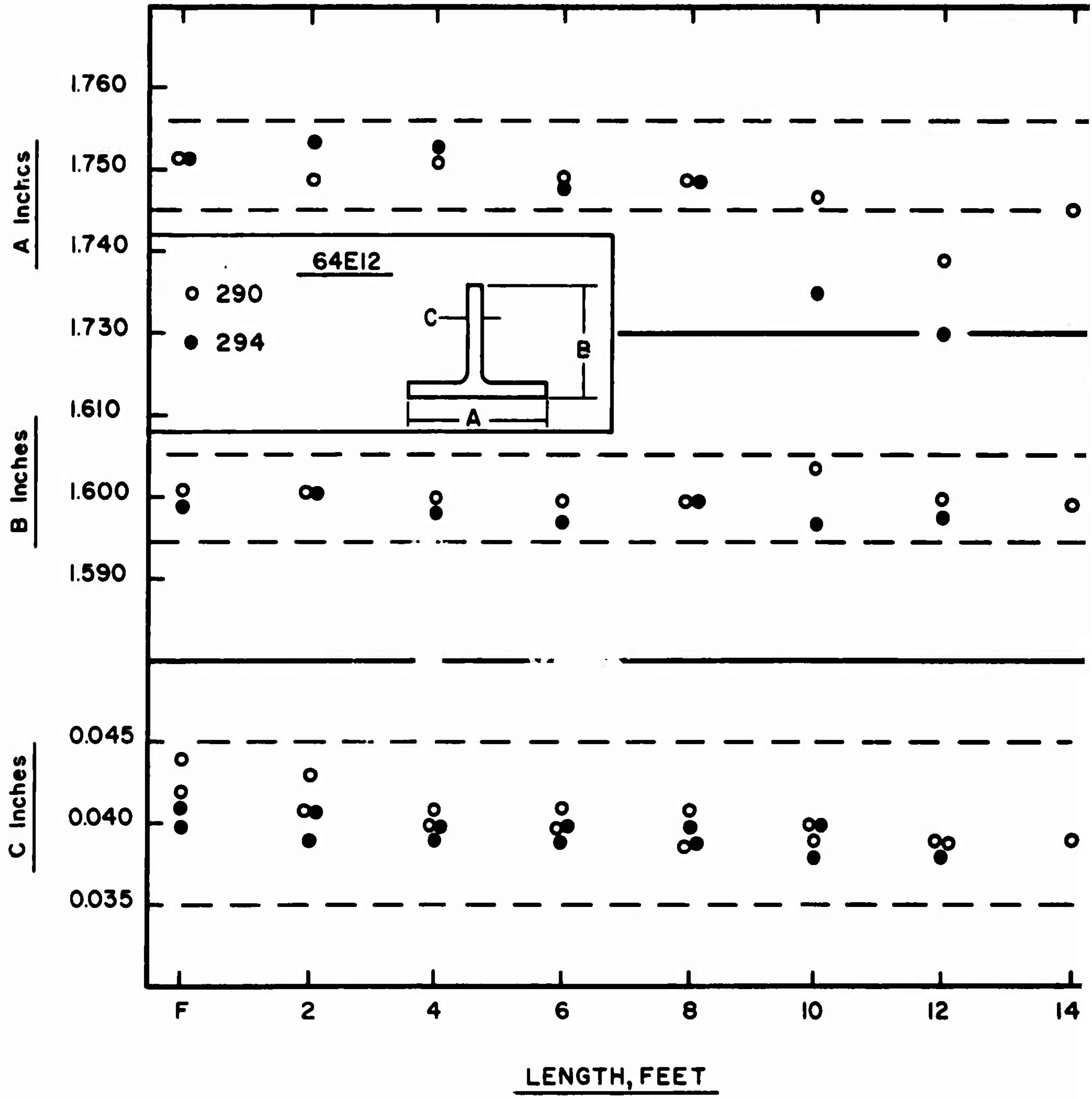
Warm Draw
0.040in (5 passes)
Plus STA

64-28-H 500X

Marked Alteration and Refinement in Transverse Microstructure Typical of 64E12 Extrusions

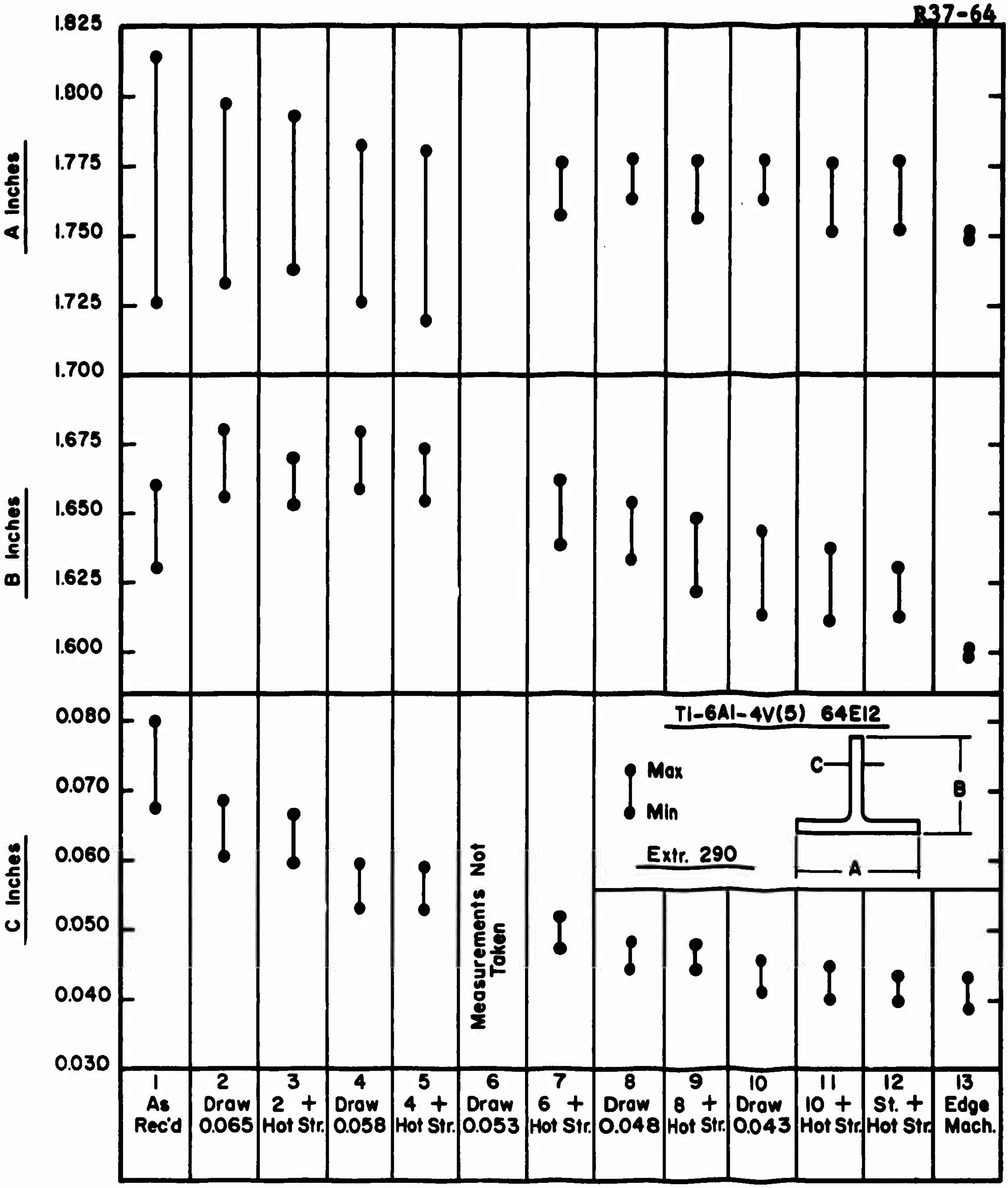
FIGURE 86

605288



Dimensional Control Exhibited in Two 64E12 Extrusions
After Final Edge Machining

FIGURE 87



Step by Step Alteration in Dimensions Throughout Entire Processing of 64E12 Extrusion # 290

FIGURE 88

TABLE 23

Tensile Property Survey of 64E12 Extrusions of Ti-6Al-4V (64E12) Warm Drawn 5 Cycles to 0.043in and Plant Heat Treated

Ext. No.	UTS Ksi	YS(0.2%) Ksi	EL(1in) %
(A) 1725F(15sec)WQ + Hot Stretch 1000F(AC)			
261	175.3	165.3	5.5
290	176.2	158.5	5.5
294	178.1	158.6	8.0
(B) -(A) + 1000F(4hrs)AC in Laboratory			
261	187.2	172.7	8.0
290	173.2	162.8	10.0
294	173.8	164.0	8.5

TABLE 24

Heat Treat Response of As-Extruded 64E12 Extrusions

Ext. No.	Web Thickness	Heat Treatment	UTS Ksi	Ys(0.2%) Ksi	El(1in) %
261	0.065	1725F(15Sec)WQ + 1000F(4hrs)AC	186.2	167.8	10.0
261	0.065	" + "	187.7	171.4	10.0
290	0.065	" + "	186.0	170.2	9.0
290	0.065	" + "	181.8	164.7	7.0
294	0.065	" + "	181.7	165.4	8.0
294	0.065	" + "	186.4	163.7	7.5
294	0.065	1725F(15Sec)WQ	158.7	117.8	12.0

4. Evaluation

a. Surface Quality and Surface Finish

The as-extruded surface finish measurements for six of the nominal 3/32 in. extrusions are shown in Table 25. The progressive surface improvement by warm drawing two extrusions from a nominal 3/32 in. thick tee in two light passes to 0.080" is shown in Figures 89 and 90. Table 26 reveals the RMS readings at each stage. Figures 91 and 92 show the surface quality of the 0.080" extrusions.

Table 27 reveals the as extruded surface finish measurements of the nominal 1/16" extrusions. Comparison of Table 27 with Table 28 reveals the improvement in surface finish by warm drawing. The improvement in surface quality by warm drawing the nominal 1/16" extrusions to 0.043" in five draw passes is shown in Figures 93, 94 and 95.

Detailed surface finish measurements on the five extrusions submitted to NAA for inspection are shown in Figure 96. The high readings were generally over areas containing light striations which can be seen in certain of the photograph closeups. These can be related back to defects in the as-extruded material which were not completely ironed out. Typically, the surface adjacent to the striation was in the order of 80 u in RMS while the measurement over the striation would be upwards of 120 u in RMS. This can be seen in Figure 95. The surface of the warm drawn extrusion #290 (upper part of photo) measures 70-80 u in RMS except in areas at the center of the flange (100 - 120 u in RMS) and the upper part of the flange (120 - 150 u in RMS). Examination of Figure 95 shows the light striations at the center and upper part of the flange. Referring to the extruded surface in Figure 95, the severity of striations that cannot be tolerated in extrusion to attain a warm drawn product (30% reduction) of 100 u in RMS can be observed. Also, the severity of striations that can be tolerated can be seen from the photograph.

b. Metallurgical Analysis

A metallurgical evaluation of the 6Al-4V titanium alloy extrusions was conducted to complete Part V of the program.

Three investigations were conducted independently by North American Aviation, Titanium Metals Corporation and Republic Aviation Corporation to evaluate the extrusions. The tensile property survey conducted at TMCA is included in the previous section on warm drawing and the testing at NAA is discussed in the next section. The processing employed on the extrusions evaluated by Republic Aviation in Part V are shown in Table 29 while a tabulation of the mechanical properties is shown in Table 30. Extrusion #253 is representative of the 0.080 inch thick shapes forwarded to North American Aviation for qualification testing. Figure 97a through c illustrate photomicrographs of the extrusion after several processing variations. In the as-extruded and straightened condition (Figure 97a) the structure consists of a coarse Widmanstatten (basketweave) structure. There appears to be some evidence of primary alpha present in the structure indicative of the extrusion having exceeded the beta transus for a short period of time.

The tensile properties (Figure 97a) indicate that some minor hardening by alpha precipitation has occurred during cooling from the extrusion temperature. This occurs because the cooling is sufficiently rapid to allow retention of more than the equilibrium amount of beta phase which now transforms to alpha. A gradual refinement of the basket weave structure is observed when additional warm working is imparted to the extrusion.

No strength increase is seen after the first draw and straightening operation, (Figure 97b) due to the minor amounts of deformation introduced into the extrusion. The increase in strength noted after an additional drawing and straightening operation (Figure 97c) is due to the plastic deformation experienced. (10% reduction @ 950°F.) The effect of the 1550°F treatment after drawing is considered negligible due to the insufficient (less than 30 seconds) time at temperature. Figure 97d shows the mechanical properties and microstructure obtained on the extrusion which was heat treated by direct (1000°F/4 hours) aging, while Figure97e shows the effects of solution treatment (1750°F/30 minutes) and aging (1000°F/4 hours). The conspicuous absence of martensite (alpha prime) is due to an inadvertent delay during quenching. This delay resulted in cooling below the M_s before quenching, thus producing a basketweave alpha-beta matrix with primary alpha growing from the grain boundaries. Previous data has shown that quench delays of greater than 10 seconds cause reductions in as quenched strength. It is felt that strengths in excess of those shown are obtainable if a complete (long time) solution heat treatment is employed with a maximum quench delay time of 10 seconds.

Photomicrographs and mechanical property tests of extrusion #270 are shown in Figure 98a, b, and c. As previously described (extrusion #253), the micro structure consists of a Widmanstatten structure with evidence of primary alpha present. The increase in strength observed upon directly aging after extruding is likely due to an additional beta to alpha transformation. As in the previous extrusion, the lack of alpha prime can be attributed to a delay in quenching. The differences between this extrusion and #253 (Figs. 97 & 98) appear to lie in the size of the alpha plates (formed from the primary alpha on cooling) present after STA heat treatment.

Although the strength (Fty) of extrusion #270 was slightly higher than #253, elongations were lower. This can be attributed to the greater amount of deformation (from drawing and stretch straightening) imparted to extrusion #253, and consequently the finer Widmanstatten and alpha platelet structure formed after heat treating.

The effect of the additional deformation is to break-up the large alpha-beta structure formed by extruding above the beta transus. A microstructure obtained by heating above the beta transus (in the absence of mechanical work) usually results in an embrittled material. However, mechanical working (at temperature) is directly proportional to the ductility restored after processing. Figure 99a, b and c illustrate the microstructures obtained on extrusion #271. It should be noted here that extrusions #271, 270 and 253 differ only in their post-extrusion processing. The mechanical properties and microstructures obtained on extrusions #271 and 270 differed only slightly, indicative of the first stretch straightening operation (3% @ 1100°F) having a negligible effect on mechanical properties. This is also seen upon observation of the tensile data from extrusion #253. The first strength increase is seen only after heavy (10%) drawing operations. It should be noted that on all shapes extruded at 1800°F with a 51:1 ratio, no contamination was noted.

Examination of extrusions #277 and 273 (Figure 100a through d) show the microstructures and mechanical properties obtained on shapes extruded (1800°F) at 24:1 and 57:1 ratios respectively. Figure 100a indicates that the extrusion exceeded the beta transus during fabrication. This can be seen from the small prior beta grain size. Only very small amounts of primary alpha can be noted in the relatively large basketweave structure. The flange area (Figure 100b)shows a stabilized alpha phase at the surface (0. 0008-inches thick). However, no hardness differences between this surface and the core were noted.

The microstructure, and mechanical properties of extrusion #273 can be seen in Figure 100c. Plastic deformation received by the material (57:1 extrusion ratio) has resulted in a fine Widmanstatten structure. The stabilized alpha phase noted in the flange (Figure 100d)showed no hardness differences between this surface and the core. This is due to the fact that a rather high composition of alpha stabilizing interstitials must be present before any hardness difference is seen. The alpha case thus formed is due to the diffusion of alpha stabilizing elements (from the glass lubricant) into the surface of the extrusion. Figure101a through f illustrate photomicrographs of the front and rear ends of extrusion #272.

The microstructure seen in Figure 101a, c and e indicate that the material has just exceeded the beta transus. As indicated by the flow observed in Figure 101a, only partial recrystallization has occurred in the front of the extrusion.

The photomicrographs shown in Figure 101b, d and f illustrate the microstructures obtained from the rear of the same (#272) extrusion. Note the larger Alpha platelets, and lack of initial flow seen in this area of the extrusion. This is indicative of the higher temperatures obtained toward the rear of the extrusion as a result of increased friction. The alpha phase seen on the surface of the extrusion (Figure 101e and f) failed to show any hardness differences with the base metal. The sketch in Figure 101 shows the locations where photomicrographs were taken.

c) Inspection by North American Aviation

(1) Introduction

Five extrusions were submitted to North American Aviation Inc. for evaluation relative to application for the RB-70 Weapons System. Two of the extrusions were of the modified 64E12 configuration and three extrusions were of the 64E15 configuration. The extrusions submitted to NAA were 290, 294, 282, 285 and 289. These extrusions were reidentified by NAA as 64E12, #1 and #2 and 64E15, #1, #2 and #3. All extrusions were in the solution treated and aged condition.

(2) Procedure

One sample from each end of each extrusion was tensile tested at room temperature and one sample from one end of each extrusion was tensile tested at 700 ± 10° F to the requirements of NAA Material Specification LB0170-147 " Titanium Alloy (6Al-4V) Bars, Rods and Shapes, Extruded." Tensile tests were performed on flat specimens selected from the vertical leg of the 64E12 extrusions and from the base of the 64E15 extrusions.

Each extrusion was checked dimensionally to the drawing requirements for 64E12 (modified) and 64E15 shapes as shown in Figure 5. Measurements were made at each end of each extrusion and at one foot intervals.

In addition, all extrusions were: (1) fluorescent penetrant inspected, (2) analyzed for chemical composition, and (3) metallographically examined at 100 and 500X. Chemical analyses for Al, V and Fe were performed by x-ray fluorescence; O_2 and C by Leco gas analyzer; N_2 by the Kjeldahl method; and H_2 by hot vacuum extraction.

(3) Results

Tensile results are shown in Tables 31 and 32. Elevated temperature tensile data for one of the 64E15 extrusions were invalid due to shearing of one of the specimen holding pins. The minimum ultimate strength requirement was reached, however, before the holding pin failed, indicating that the strength of the specimen was satisfactory. From Table 31, it can be seen that for the 64E12 extrusions there was a wide variation in strength from one end to the other.

Results of dimensional measurements are shown in Table 33. The dimensional range is recorded where it was found that dimensional requirements were not met. RMS values ranged from 40 to 190 for the 64E12 extrusions with an average of 115. Values for the 64E15 extrusions ranged from 30 to 130 with an average of 80. NAA Material Specification LB0170-147 stipulates that surface finish should be equivalent to RMS/100 or better.

Fluorescent penetrant inspection revealed no surface defects other than rounded shallow pits. The pits and a scale pattern noted on the extrusion surfaces are typical of titanium that has been descaled by chem-milling (acid pickling).

Results of chemical analyses are listed in Table 34. Hydrogen content for one of the 64E12 extrusions was high, i. e. , 170 ppm. Two additional analyses on this extrusion showed 165 and 182 ppm.

Microstructural examination of each extrusion revealed an acicular alpha structure. Prior beta grain boundaries were evident in all extrusions; however, these boundaries were almost completely broken up at the intersection of the horizontal and vertical legs. No inclusions, laminations or separations were noted in the microstructural specimens examined.

d. Summary

A workable process was demonstrated to produce "T" shape 64E15 by a combination of extrusion and warm drawing processes. In the final extrusion trial, eight of the eight nominal 3/32" thickness 64E15 extrusions were considered suitable for warm drawing, indicating a development of satisfactory die design, billet heating practices, lubrication and straightening techniques for the extruded lengths.

In the Part V warm drawing trials, eight of eight extrusions were successfully drawn two passes to 0.080 in. thickness in 20 foot lengths, indicating a development of satisfactory die design, lubrication and drawing practices, straightening techniques and anneal and heat treat cycles for the drawn lengths. The eight 20' lengths consisted of six extrusions from the final extrusion trial and two extrusions that were drawn earlier.

It was found feasible to produce 0.043" titanium "T" shapes by extruding to nominal 0.065 in. and warm drawing in five passes to 0.043" with present technology. Six of the original eight extrusions were drawn the required five cycles of nominal 10 percent wall reductions but with much attendant material loss and greater difficulty than in drawing shape 64E15 to 0.080". The longest drawn finished length was approximately 15 feet.

Originally five extrusions were to be submitted in the annealed condition to North American Aviation for testing. The extrusions after the final anneal operation were within the required print dimensions of 0.080" ± .005" and 0.043" ± .005" for the two shapes (see Table B13 and B11 in Appendix). After fabricating the extrusions to size, it was decided to heat treat the extrusions so that they could be inspected in the condition in which they are used. The stretch straightening and pickling operations after heat treatment reduced the cross sectional thicknesses to nominal dimensions of 0.075" and 0.040" which were under the NAA print dimensions (see Table 33). The cropping of the extrusions after the final stretch straightening operation reduced the length of the extrusions to approximately 18' and 10' for the 64E15 and 64E12 extrusions, respectively.

The NAA inspection revealed that all the extrusions met the requirements for minimum mechanical properties and internal structure, one of the 64E12 extrusions failed to meet the requirement for minimum hydrogen content and the surface finish (RMS) for the 64E12 extrusions was unsatisfactory. The surface finish (RMS) for the 64E15 extrusions was found to be satisfactory.

Failure of one of the extrusions to meet the requirement for minimum hydrogen content suggests that a vacuum anneal be given the extrusions after the final draw pass and prior to solution treatment. However, additional testing would have to be performed to determine the necessity of this operation.

The failure of the 64E12 extrusions to meet the minimum surface finish requirement of 100 u in RMS can be traced to longitudinal striations in the extruded surface which were not completely ironed out during warm drawing. The longitudinal striations are caused by pickup on the extrusion die which appears to be the major problem area in titanium extrusion of thin shapes. Scoring due to die wash and/or coating failure and laminations due to improper flow were eliminated. Warm drawing did improve the surface finish of the 64E12 extrusions from a scatter of RMS values from 60/290 in the extrusion to a range of 40/190 with an average of 115. The 64E15 extrusions after warm drawing ranged from 30 to 130 with an average of 80.

Warm drawing also refined the coarse Widmanstatten microstructure of the extrusions, but no real improvement in heat treated ductility was noted by this alteration in microstructure.

Solution treatment of the shapes, especially the thin 0.040" extrusions, resulted in severe distortion. This necessitated a high degree (1-1/2%) of hot stretch straightening to remove the quench distortion which tended to induce crowning across the flange in the transverse direction. The extrusions could not be supplied in the solution treat only condition. Upon stretch straightening of the solution treated extrusion at 400/450°F, the yield strength is increased by about 30 ksi to values in excess of 150 ksi. Some form of restrained die quenching from solution treating temperatures appears necessary to prevent severe distortion which, in turn, necessitates a stretch straightening type operation. The procedures and facilities for supplying extrusions in the fully aged condition were found to be adequate.

Edge machining was demonstrated as being a feasible method of finishing the edges of the "T" to the finished print tolerances of ± 0.005". The alternative of warm drawing the edges was not attempted as work in Part IV revealed severe metal losses due to column failure. Several of the extruded shapes did not have sufficient stock to machine the edges to the required print dimensions. It appears necessary to provide approximately 0.070/0.090" over the print dimension on the extruded leg height and width to assure sufficient stock for edge machining.

Processing difficulties in drawing the 64E12 shapes related to the as-extruded product quality were as follows:

(1) Excessive fillet radii (9/64 to 11/64 in.) for the 1/8 in. draw die radius resulting in excessive heat buildup in the fillet area and lubricant breakdown in warm drawing. The heavy working of an oversize fillet generally resulted in extrusion and growth of the vertical leg (0.020 in.). For ease of drawing, the incoming fillet radii should not exceed the draw die radii.

(2) Thin spots on the vertical leg near the fillet radii were as much as 0.012 inch thinner than the adjacent web thicknesses resulting in their inability to sustain the draw load and thus resulting in separation of the vertical leg from the horizontal flange. These thinner areas upon resistance preheating are hotter than the heavier areas; this condition contributed to metal separation by further necking and eventual tensile type failures.

(3) Uneven web thicknesses which resulted in pickle pointing problems. In pickling the thickest leg to pass through a die opening, the thinner legs are under-pickled and too weak to sustain a draw load.

The above difficulties were in part due to an attempt to utilize ceramic coated extrusion dies without a finish machining operation; the intent being to develop a process as economical as possible within the tolerance requirements of the warm draw process. However, the high material loss in warm drawing the thin shapes indicates that relatively close dimensional tolerances are required in the extruded product to realize efficient warm drawing of thin shapes. Therefore, it appears that a finish machining operation on the ceramic coated extrusion dies is mandatory.

Processing difficulties related to the actual warm draw operation generally centered on the following:

(1) Failure to point to the proper web thickness, machining through or excessive thinning of the fillet radius or chemical undercutting at the air-liquid interface during pickle pointing. All these conditions would result in failure of the point to grip in the jaws, failure to sustain the draw forces and break or buckling and fracturing of the point upon successful completion of the draw.

(2) Extreme waviness or corrugation of the flanges resulted from as little as 0.001/0.002 inch variation in working of web thicknesses below 0.058 inch thickness. This required stretcher straightening more than the nominal 1 percent usually found adequate.

The above difficulties suggest that the present pointing practice is inadequate for thin shapes and new pointing techniques must be developed. Until an economical and accurate pointing process is developed, it is recommended that the extrusions be pointed to accommodate one 10 percent die pass only.

TABLE 25

Surface Finish of 64E15 Extrusions

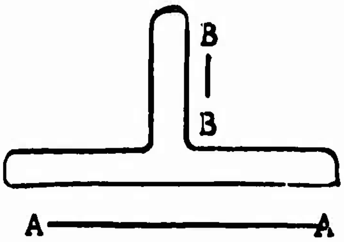
Nominal 0.095in

As-Extruded

	RMS			
	Horizontal Leg (H)		Vertical Leg (V)	
Ext. No.	Min.	Max.	Min.	Max.
282	140	370	50	350
284	110	220	80	210
285	100	260	90	180
286	120	230	70	220
288	100	180	70	120
289	110	220	60	130

TABLE 26

In-Process Variation in Surface Finish of Warm Drawn 64E15 Extrusions (*)

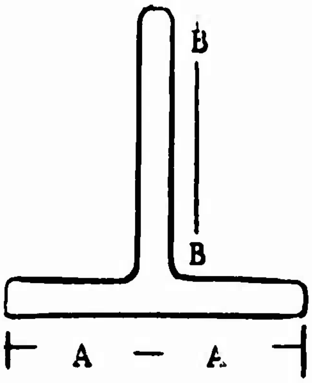


Ext. No.	Stage of Processing	RMS Horizontal Leg(A-A) Min.	Max.	Vertical Leg(B-B) Min.	Max.
263	As-Extruded	60	130	60	130
263	1st draw 0.090	40	80	30	85
263	2nd draw 0.080	30	70	20	55
253	As Extruded	50	120	45	110
253	1st draw 0.090	40	80	45	85
253	2nd draw 0.080	20	65	15	40

(*) All pickled approximately 1 mil in 35 HNO_3-5HF bath prior to profilometer measurements.

TABLE 27

Surface Finish of As-Extruded 64E12 Extrusions, Nominal 0.065in.

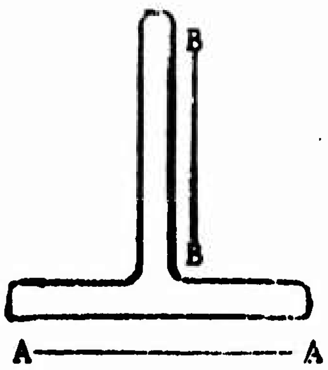


	RMS			
	Horizontal Leg (A-A)		Vertical Leg (B-B)	
Ext. No.	Min.	Max.	Min.	Max.
260	60	260	70	180
261	60	180	100	220
264	50	150	50	210
266	90	160	90	190
290	110	290	100	240
292	90	290	70	190
294	70	180	60	250
295	80	270	70	240

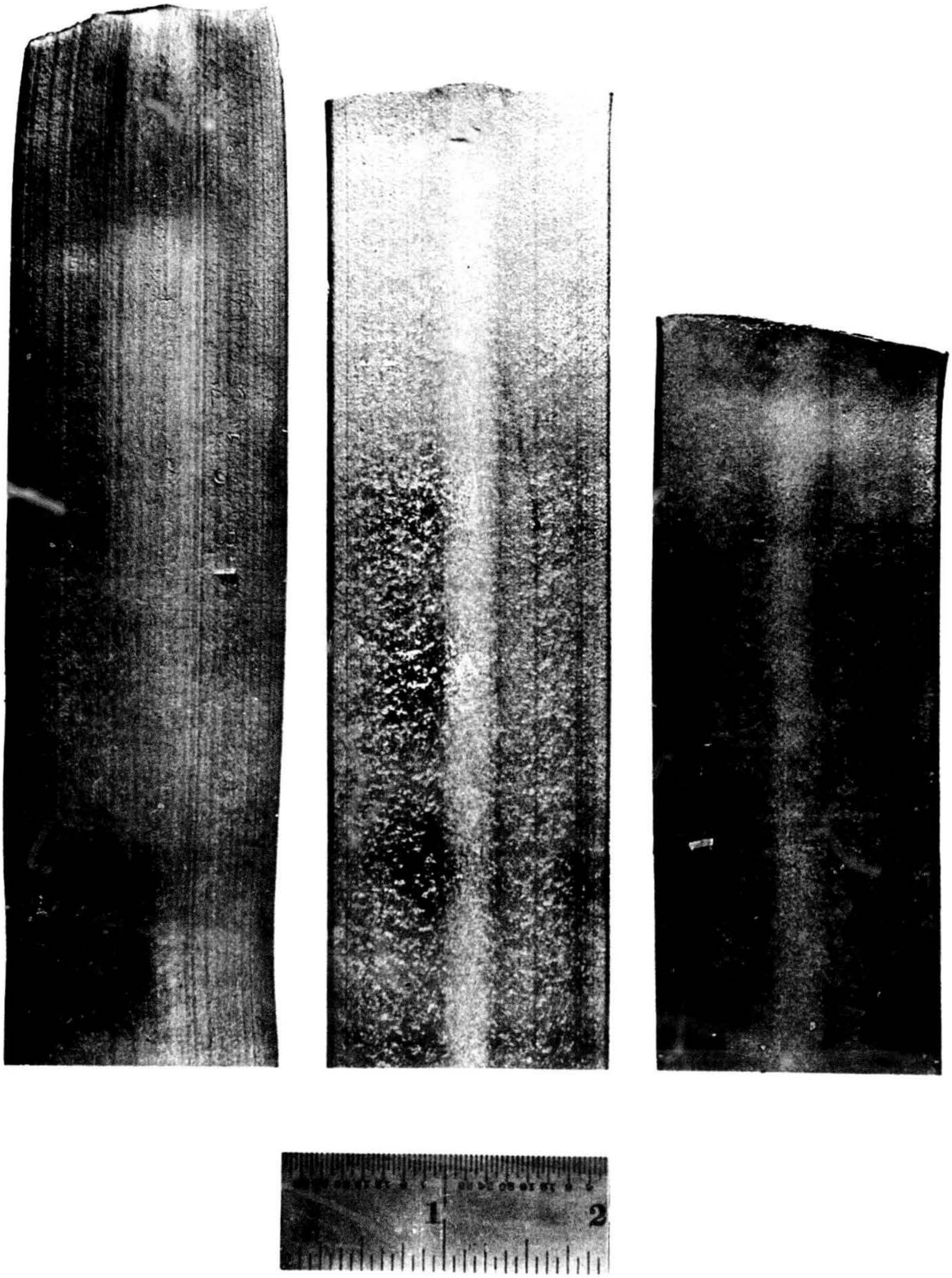
All pickled approximately 1 mil in 35 HNO_3-5HF bath prior to profilometer measurements.

TABLE 28

Surface Finish of Finished Warm Drawn 64E12 Extrusions Nominal 0.043in.



	RMS			
	Horizontal Leg (A-A)		Vertical Leg (B-B)	
Ext. No.	Min.	Max.	Min.	Max.
260	60	100	40	80
261	70	100	60	100
264	40	80	40	70
266	70	100	60	80
290	70	150	60	170
294	50	100	60	90

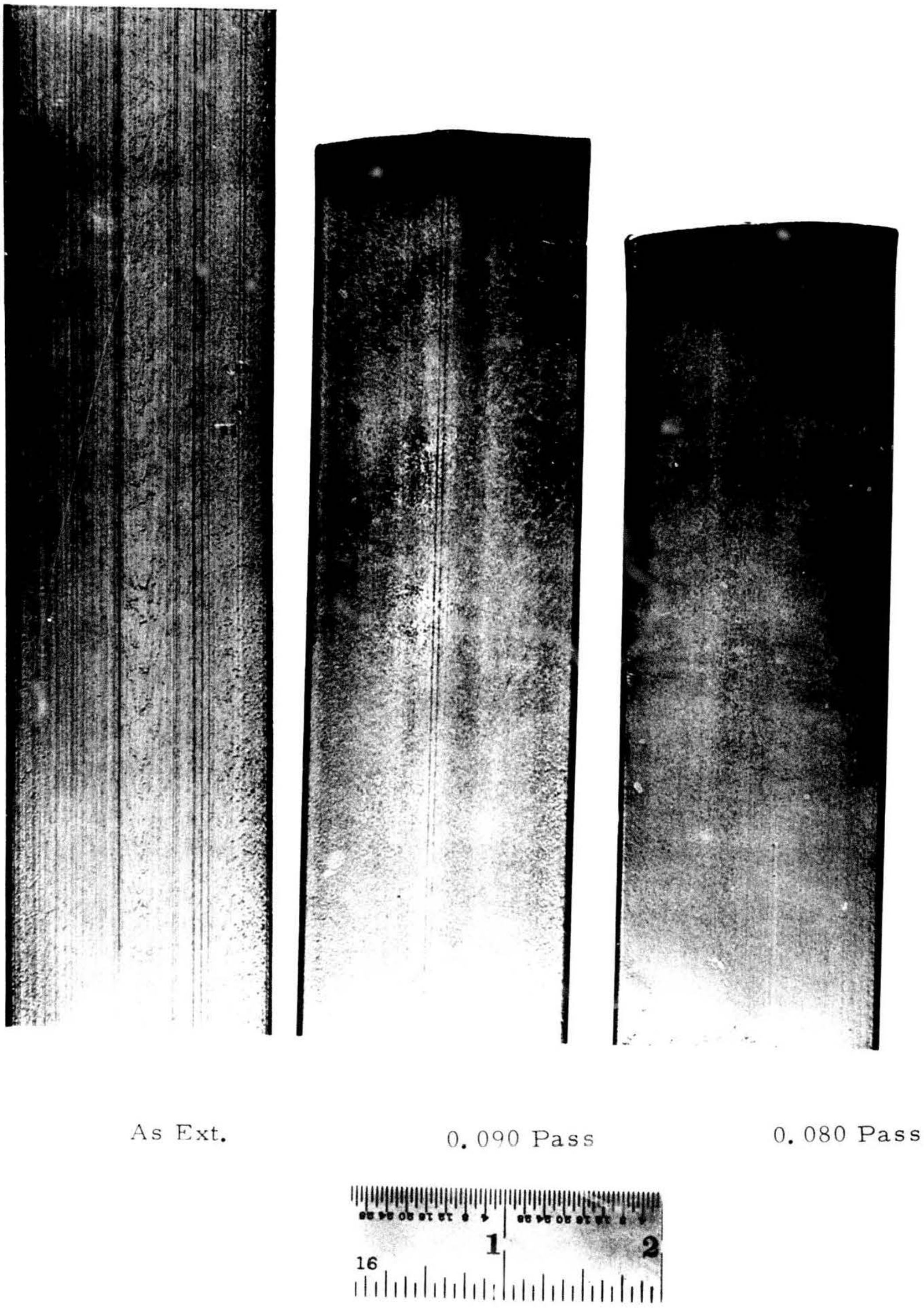


As Ext. 0.090 Pass 0.080 Pass

Alteration and Improvement in Surface Quality of Extrusion # 253
By Warm Drawing

FIGURE 89

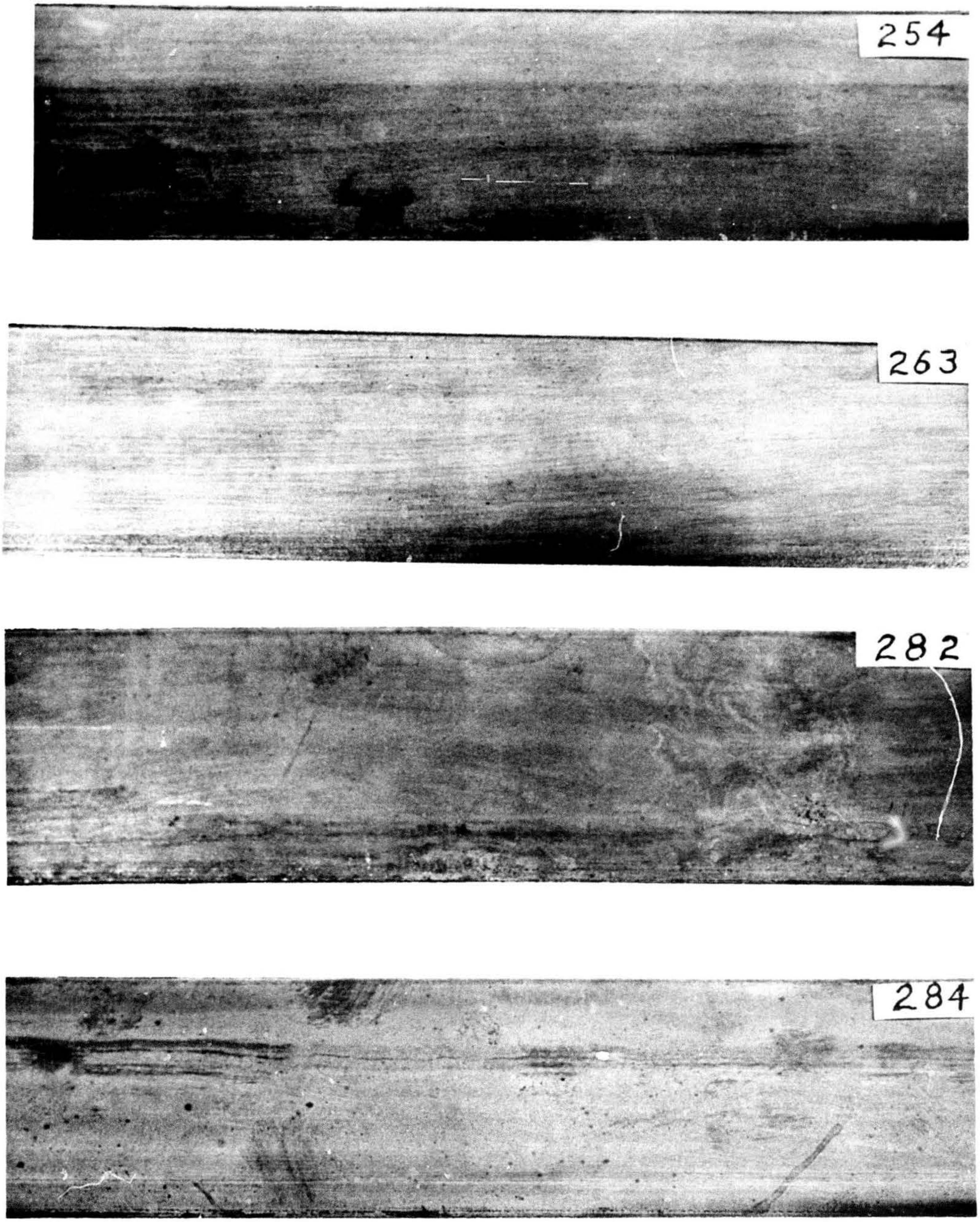
605 - 88



Alteration and Improvement in Surface Quality of Extrusion # 263 by Warm Drawing

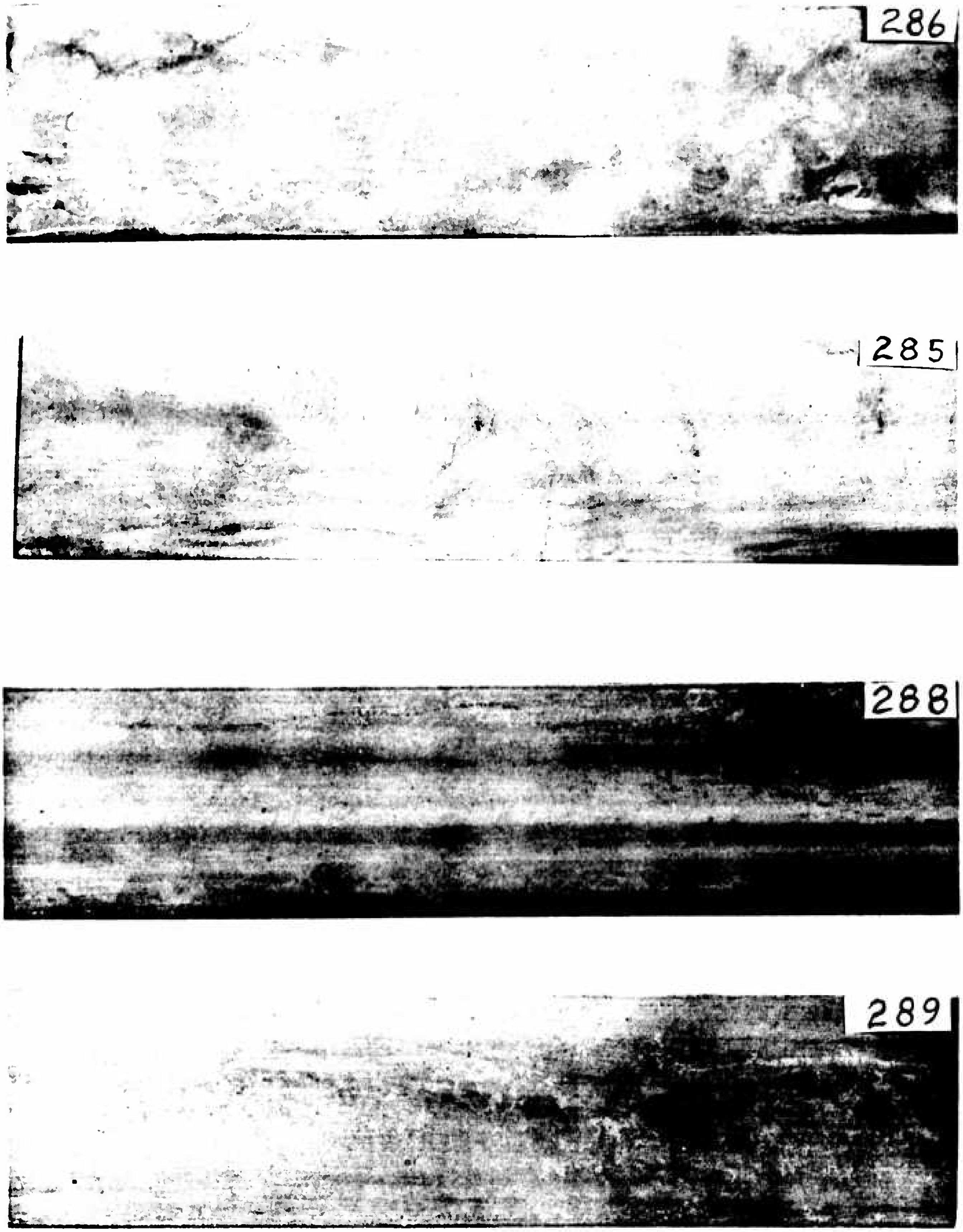
FIGURE 90

605288



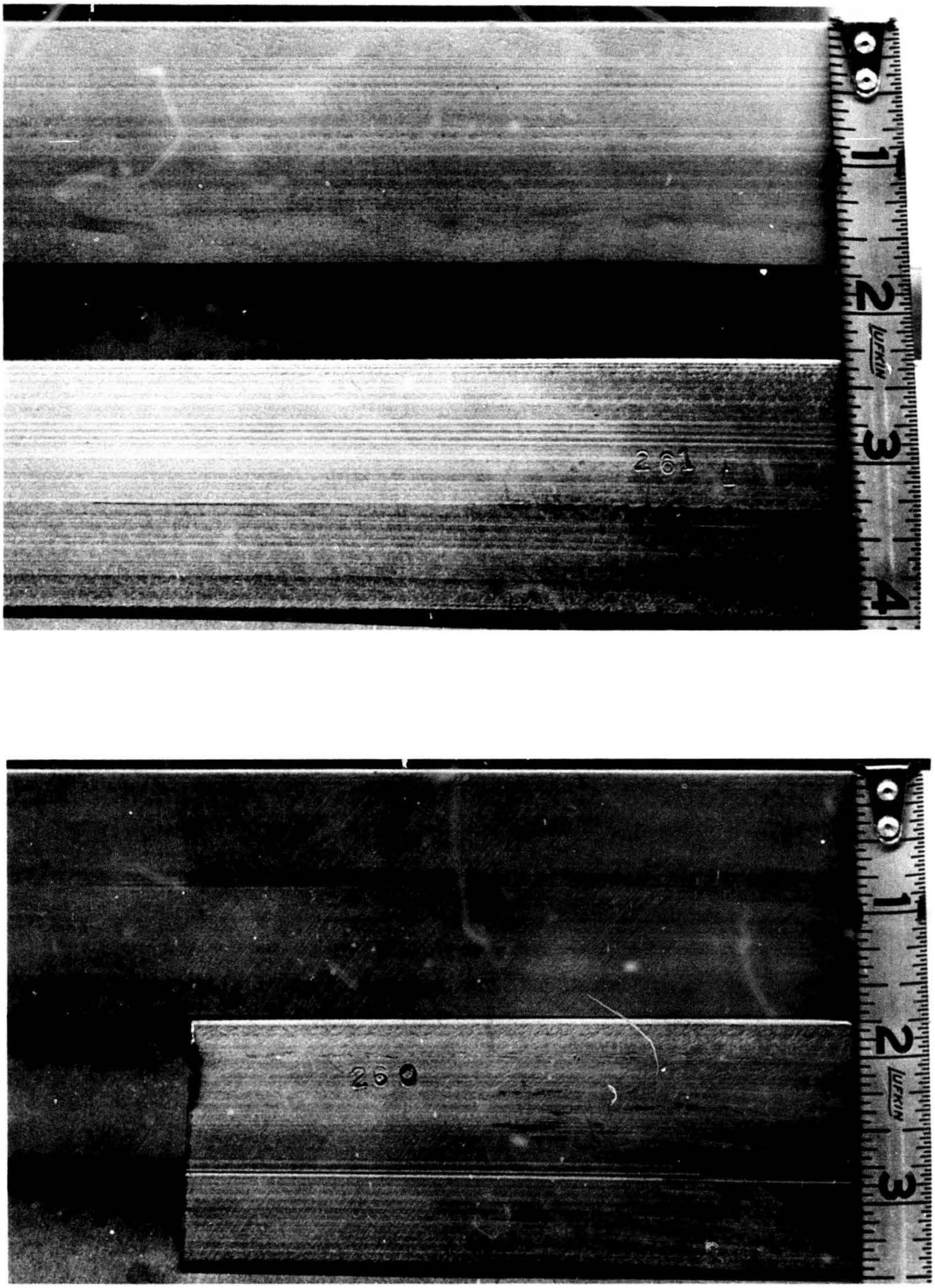
Plan View of Horizontal Flange of Finished 64E15 Extrusions 254, 263, 282, 284

FIGURE 91



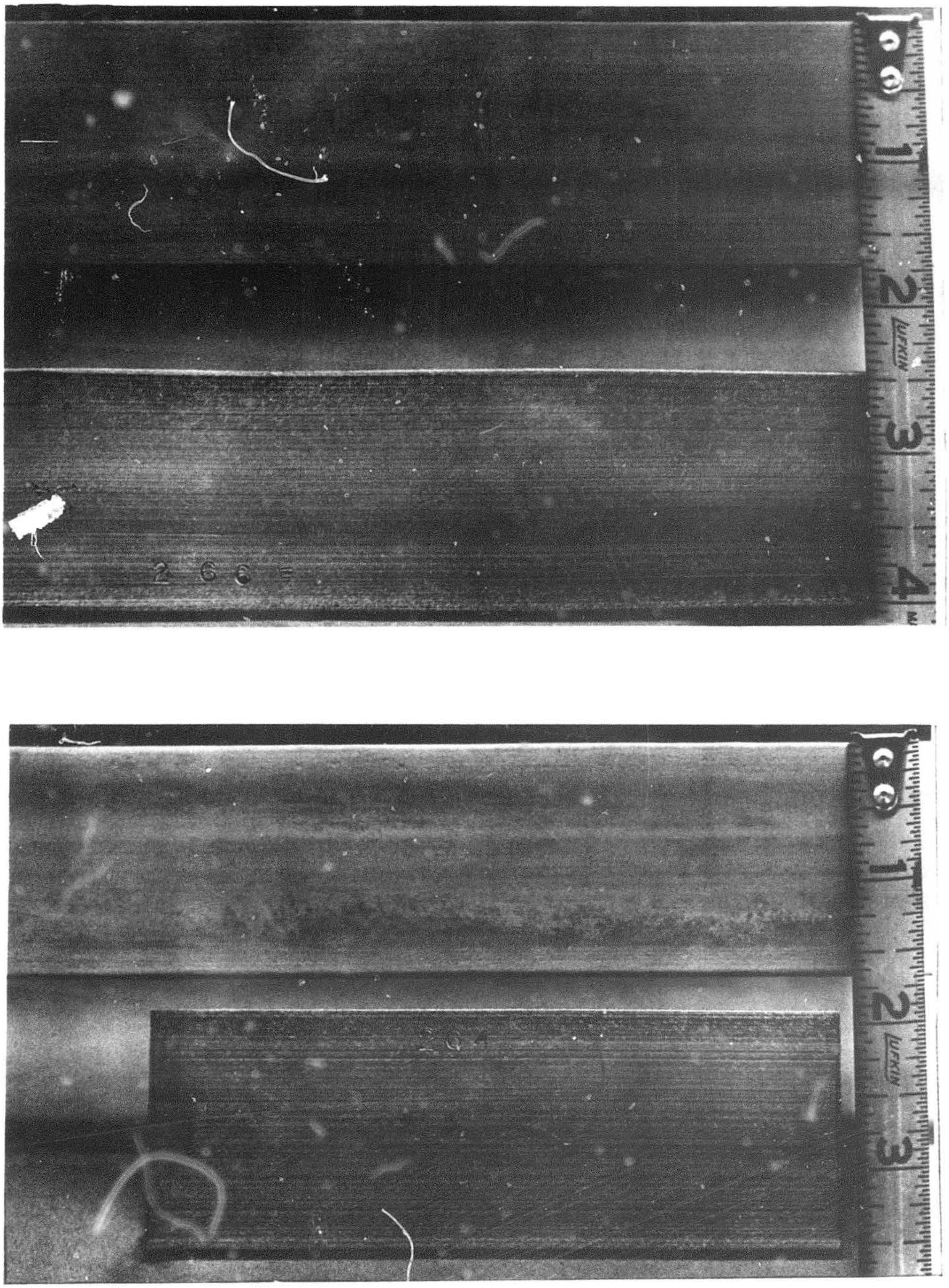
Plan View of Horizontal Flange of Finished 64E15 Extrusions 286, 285, 288 and 289

FIGURE 92



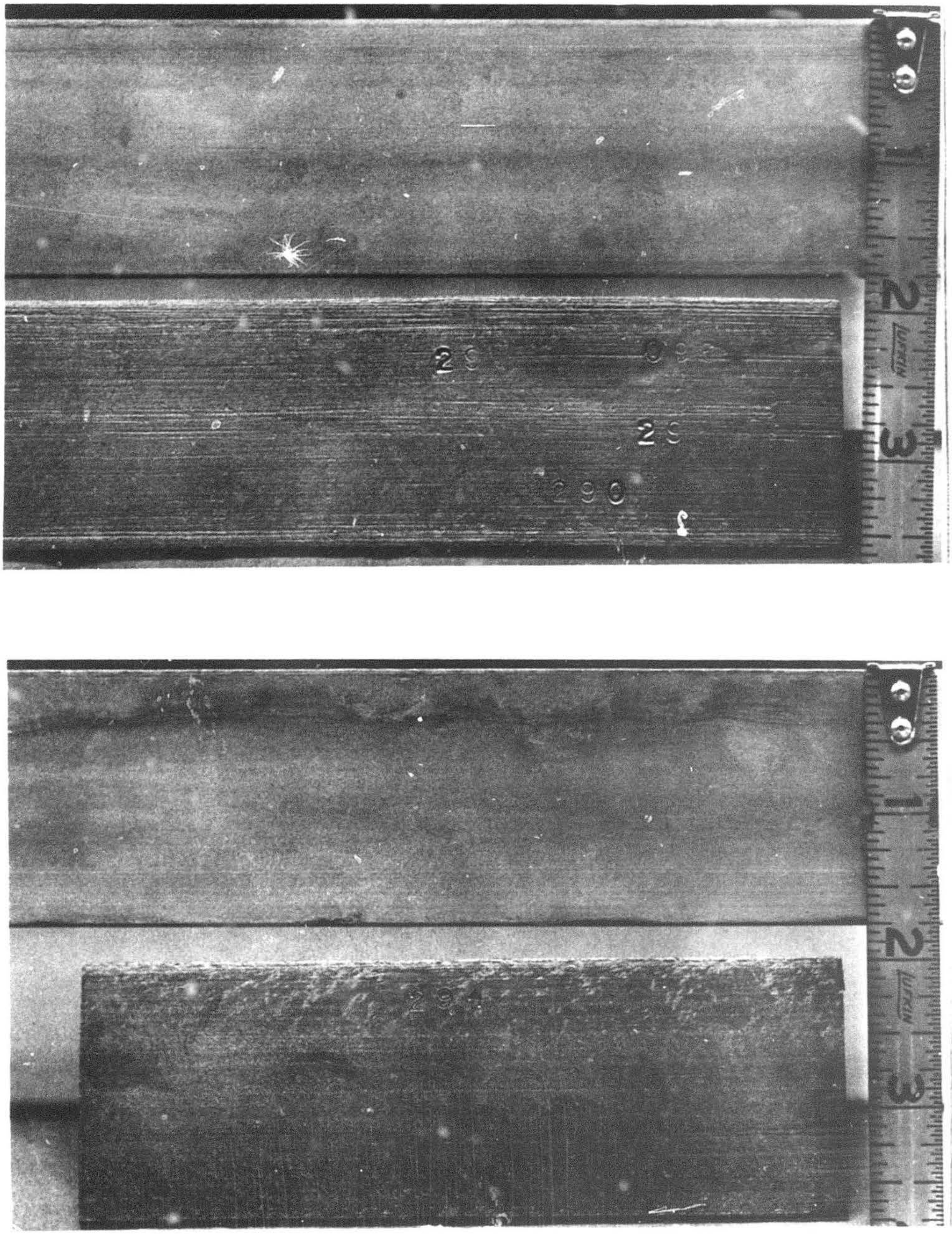
Starting and Finished Surface Quality of 64E12 Extrusions #260 and 261
FIGURE 93

605288



Starting and Finished Surface Quality of 64E12 Extrusions #264 and 266

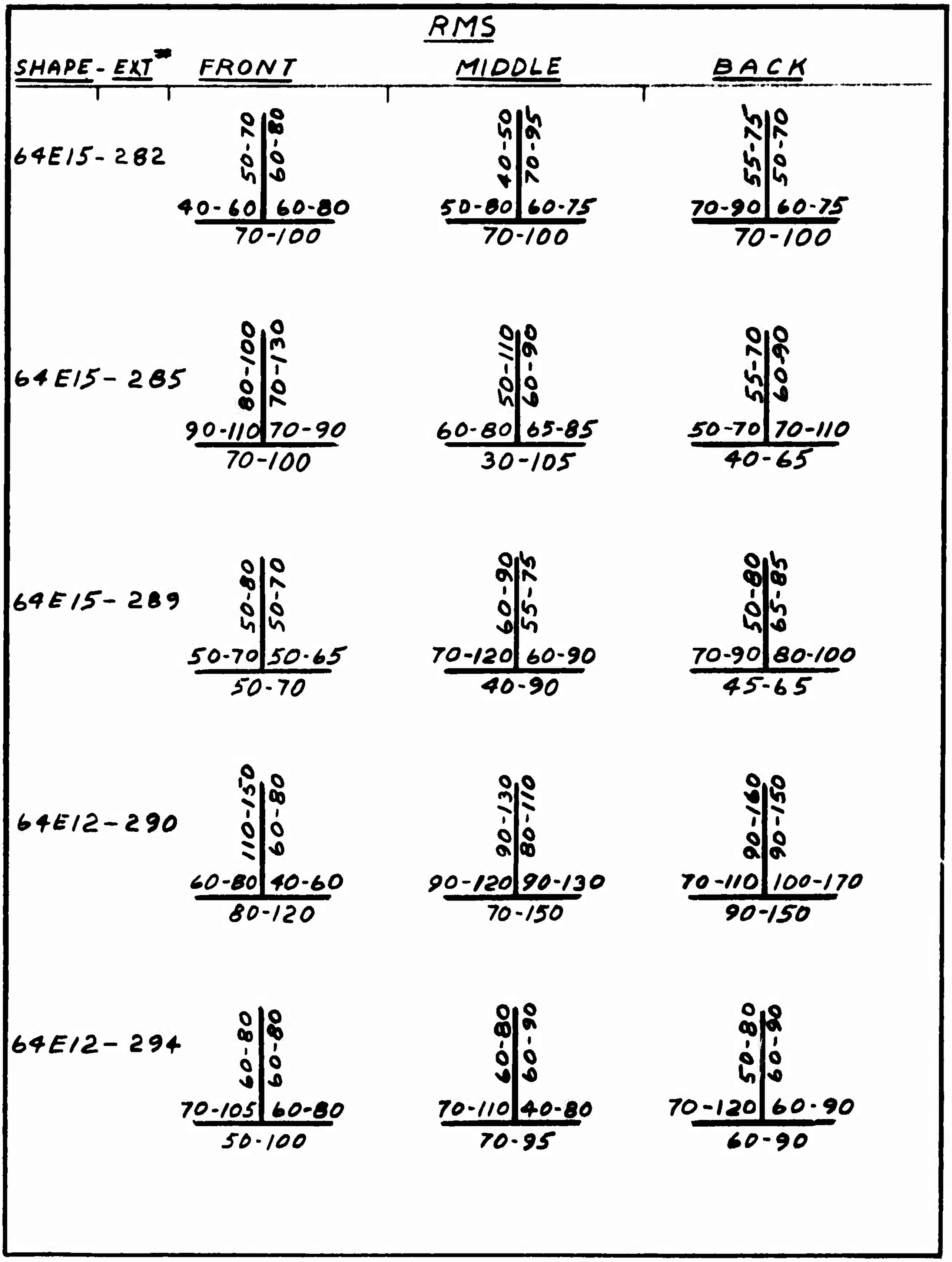
FIGURE 94



Starting and Finished Surface Quality of 64E12 Extrusions #290 and 294

FIGURE 95

605 [illegible]



Surface Finish Measurements of Five (5) Heat Treated Finished Extrusions
FIGURE 96

TABLE 29

PROCESSING HISTORY OF EXTRUSIONS EVALUATED AT RAC

Extrusion Number	Billet Temp. (°F)	Billet Heat-Up Time Hrs.	Min.	Billet Coating on O. D.	Die and Pad Lubricant	Extrusion Ratio and Temp.	Thickness (inches)	Processing History
253	1800	1	15	#85 Glass & 318 Glass	3KB & Glass Wool	51/1 1800°F	3/32	Extruded + 3% stretch straightened @ 1100°F + drawn 3% @ 950°F + 1.5% stretch straighten @ 1500°F + drawn 10% @ 950°F + 1.5% stretch straighten @ 1500°F
270	1800	1	45			51/1 1800°F	3/32	Extruded + 3% stretch straighten @ 1100°F
271	1800	1	42			51/1 1800°F	3/32	As Extruded
272	1800	1	24			57/1 1800°F	1/16	As Extruded
273	1800	1	22			57/1 1800°F	1/16	Extruded + 3% stretch straighten @ 1100°F
277	1800	1	27			24/1	3/32	As Extruded - (Multi-port - 2 extrusions from single push.

TABLE 30

MECHANICAL PROPERTIES OF 6Al-4V TITANIUM ALLOY EXTRUSIONS EVALUATED AT REPUBLIC AVIATION

Condition	Extrusion No.	Ftu (ksi)		0.2% Fty (ksi)	% e in 1"	Hardness (Rc)
X(1)+ SS (3% @ 1100°F)	253	a(6)	154.8	136.2	12.0	35.0
		b	154.0	140.2	13.0	35.5
		c	154.1	137.6	13.0	35.0
X + SS (3% @ 1100°F) + D(3) (3% @ 950°F) + SS (1.5% @ 1550°F)		a	154.7	133.9	12.0	35.5
		b	155.1	134.1	12.0	35.0
		c	158.0	144.2	12.0	35.5
X + SS (3% @ 1100°F) + D (3% @ 950°F) + SS (1.5% @ 1550°F) + D (10% @ 950°F) + SS (1.5% @ 1550°F)		a	166.2	157.9	9.0	38.0
		b	163.4	155.4	7.0	36.5
		c	163.0	147.9	10.0	37.0
+ A(4)		a	164.6	159.1	13.0	39.0
		b	165.1	139.4	13.0	38.0
		c	163.9	143.6	12.0	38.5
+ STA(5)		a	177.6	166.2	10.0	40.0
		b	178.1	164.2	10.0	40.5
		c	179.5	160.1	10.0	40.0
X	271	a	158.6	129.9	12.0	36.0
		b	158.0	132.5	12.0	35.5
		c	156.7	129.1	12.0	36.0
X + A		a	162.8	150.3	13.0	39.0
		b	160.2	146.4	13.0	38.0
		c	161.3	151.3	15.0	38.0
X + STA		a	173.2	158.5	10.0	40.0
		b	176.6	164.5	10.0	41.5
		c	177.7	169.5	10.0	41.5

TABLE 30 (continued)

Condition	Extrusion No.	Ftu (ksi)		0.2% Fty (ksi)	% e in 1"	Hardness (Rc)
X + SS (3% @ 1100°F)	270	a	156.2	136.4	13.0	36.0
		b	155.6	135.7	13.0	36.0
		c	155.3	131.6	14.0	35.5
X + SS (3% @ 1100°F) + A		a	149.5	138.9	22.0	37.0
		b	160.3	152.9	14.0	38.5
		c	160.4	150.5	15.0	37.5
X + SS (3% @ 1100°F) + STA		a	182.3	169.3	6.0	43.5
		b	178.9	166.7	6.0	43.0
		c	181.5	169.9	8.0	42.0
X	277	a	148.5	125.3	9.5	-
		b	152.7	119.4	8.5	-
		c	150.5	126.3	11.5	-
X + SS (3% @ 1100°F)	273	a	151.8	128.1	8.0	-
		b	152.5	119.0	10.0	-
		c	154.1	131.8	8.5	-

(1)	X	As Extruded
(2)	SS	Stretcher Straightened
(3)	D	Drawn
(4)	A	Aged 1000° (4 Hrs) A. C.
(5)	STA	Solution Treated (1725°/ 1/2 Hr) W. Q. + 1000°F (4 Hrs) A. C.
(6)	a	flange
	b	flange
	c	stem

EXTRUSION #253

Fig. 97 a MR 4-1-1A
As Extruded and Stretch Straightened (1)
Etch: Krolls Mag: 500X

Ftu (ksi)	0.2% Fty (ksi)	% e (in 1")		Ftu (ksi)	0.2% Fty (ksi)	% e (in 1")
154.8	136.2	12.0	a*	154.7	133.9	12.0
154.0	140.2	13.0	b*	155.1	134.1	12.0
154.1	137.6	13.0	c*	158.0	144.2	12.0

Fig. 97 b MR 4-1-1B
As Extruded and Stretch (2)
Straightened and Drawn and SS (3)
Etch: Krolls Mag: 500X

Fig. 97 c MR 311-6C1
As Extruded, Stretch
Straightened, Drawn
and SS 2 passes
Etch: Krolls Mag: 500X

Ftu (ksi)	0.2% Fty (ksi)	% e (in 1")		Ftu (ksi)	0.2% Fty (ksi)	% e (in 1")
166.2	157.9	12.0	a	164.6	159.1	13.0
163.4	155.4	9.0	b	165.1	139.4	13.0
163.0	147.9	7.0	c	163.9	143.6	12.0

Fig. 97 d MR 4-1-1-C5
As Extruded, Stretch
Straightened, Drawn
and SS 2 passes plus
Age (5)
Etch: Krolls Mag: 500X

Fig. 97 e MR 4-1-1D
As Extruded, Stretch
Straightened, Drawn
and SS 2 passes plus
STA (6) (5)

	Ftu (ksi)	0.2% Fty (ksi)	% e (in 1")
a	177.6	166.2	10.0
b	178.1	164.2	10.0
c	179.5	160.1	10.0

Photomicrographs of titanium alloy 6Al-4V extrusion (#253) 3/32" thick, extruded at 1800°F at a 51:1 ratio. The fabrication sequence is shown chronologically from Figure 97 a to Figure 97 e. As can be noted, a relatively coarse Widmanstatten (basket weave) structure exists in all but the material which was solution treated (1750°F) quenched, and aged (1000°F - 4 hrs.). As the number of past-extrusion processes are increased, a gradual refining of the alpha platelets may be observed. Absence of alpha prime (martensite) ordinarily expected after solution treating at 1750°F is due to inadvertent delay during quenching. This delay resulted in cooling below M_s before quenching, thus producing a coarse basket-weave alpha-beta matrix with primary alpha growing from the grain boundaries

a*	flange
b*	flange
c*	stem

(1) 3% @ 1100°F
(2) 3% @ 950°F
(3) Stretch Straighten - 1.5% @ 1500°F
(4) Drawn (10% @ 950) + Stretch Straighten 1.5% @ 1500°F
(5) 1000°F/4 Hrs.
(6) 1750°F (1/2 hr.) WQ

Photomicrographs of Extrusion # 253

	Ftu (ksi)	0.2% Fty (ksi)	% e (in 1")
a	156.2	136.4	13.0
b	155.6	135.7	13.0
c	155.3	131.6	14.0

Fig: 98 a MR 3-11-6A
Extruded & Stretch Straightened
Etch: Krolls Mag: 500X

	Ftu (ksi)	Fty (ksi)	% e (in 1")
a	149.8	138.9	22.0
b	160.3	152.9	14.0
c	160.4	150.5	15.0

Fig: 98 b MR 4-1-H2
Extruded & Stretch Straightened & Aged
Etch: Krolls Mag: 500X

	Ftu (ksi)	Fty (ksi)	% e (in 1")
a	182.3	169.3	6.0
b	178.9	166.7	6.0
c	181.5	169.9	8.0

Fig: 98 c MR 4-1-1-G
Extruded & Stretch Straightened & STA
Etch: Krolls Mag: 500X

Photomicrographs of titanium alloy 6Al-4V extrusion (#270) 3/32" thick extruded at 1800°F, at a 51:1 ratio and stretch straightened 3% at 1100°F. Figures 98 a and 98b show the coarse Widmanstatten (basket weave) structure. It should be noted that this material has reached temperatures beyond the beta transus during extrusion. Figure 98c shows structure obtained after a 1750°F solution treatment (water quench) followed by a 1000°F (4 hr.) age. Absence of alpha prime (Martensite) expected after this heat treatment is due to an inadvertent delay during quenching. This delay resulted in cooling below M_s before quenching thus producing a coarse basketweave alpha-beta matrix with primary alpha beginning to grow from the grain boundaries.

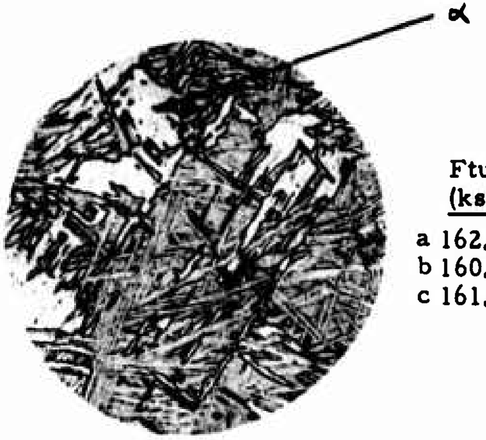
Photomicrographs of Extrusion # 270

FIGURE 98

605288

	Ftu (ksi)	0.2% Fty (ksi)	% e (in 1")
a	158.6	129.9	12.0
b	158.0	132.5	12.0
c	156.7	129.1	12.0

Fig: 99 a MR 3-11-6E
As Extruded
Etch: Krolls Mag: 500X



	Ftu (ksi)	0.2% Fty (ksi)	% e (in 1")
a	162.8	150.3	13.0
b	160.2	146.4	13.0
c	161.3	151.3	15.0

Fig: 99 b MR 4-1-1E
As Extruded & Aged
Etch: Krolls Mag: 500X

	Ftu (ksi)	0.2% Fty (ksi)	% e (in 1")
a	173.2	158.5	10.0
b	176.6	164.8	10.0
c	177.7	169.5	10.0

Fig: 99 c MR 4-1-1F9
As Extruded & STA
Etch: Krolls Mag: 500X

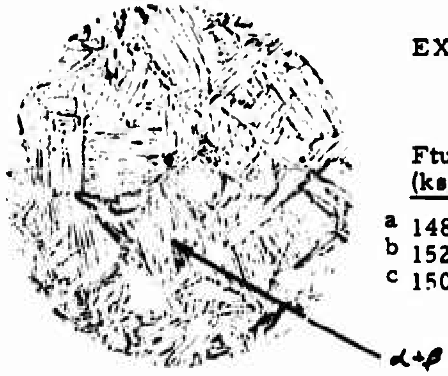
Photomicrographs of titanium alloy 6Al-4V extrusion (#271) 3/32" thick extruded at 1800°F, at a 51:1 ratio. Figure 99 a and 99b show a coarse Widmanstatten (basket weave) structure. It should be noted that this material has reached temperatures beyond the beta transus during extrusion. Figure 99c shows the structure obtained after a 1750°F solution treatment (water quench) followed by a 1000°F (4 hr.) age. The absence of alpha prime (martensite) expected after this heat treatment is due to an inadvertent delay during quenching. This delay resulted in cooling below the M_s before quenching thus producing a coarse basketweave alpha-beta matrix with primary alpha beginning to show Widmanstatten growth from the grain boundaries.

Photomicrographs of Extrusion # 271

FIGURE 99

605288

EXTRUSION #277



	Ftu (ksi)	0. 2% Fty (ksi)	% e (in 2")
a	148. 5	125. 3	9. 5
b	152. 7	119. 4	8. 5
c	150. 5	126. 3	11. 5

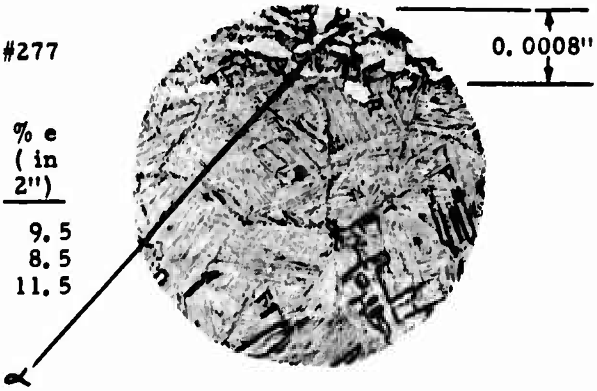


Fig: 100 a MR 3-9-2-2A
As Extruded - Center
Etch: Krolls Mag: 500X

Fig: 100 b MR 3-9-22I
As Extruded - Edge
Etch: Krolls Mag: 500X

Photomicrographs of a titanium alloy multiport extrusion (#277) 3/32" thick extruded at 1800°F at a 24:1 ratio. The material has been heated just above the beta transus as can be seen from the small prior beta grain size.
Although the flange shows a stabilized alpha phase at the surface (0. 0008" thick), no hardness differences between this surface layer and the base metal were noted. This is due to the fact that an exceptionally high composition of alpha stabilizing interstitials must be present before any difference is seen. Any embrittlement present would be revealed by bend and/or toughness testing. The structure consists of Widmanstatten alpha-beta platelets.

EXTRUSION #273

	Ftu (ksi)	0. 2% Fty (ksi)	% e (in 2")
a	151. 8	128. 1	8. 0
b	152. 5	119. 1	10. 0
c	154. 1	131. 8	8. 5

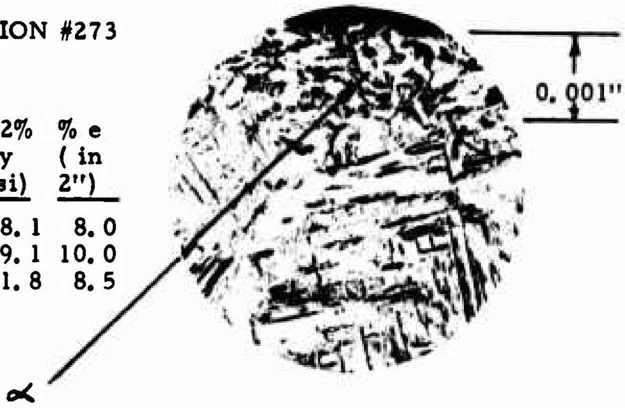


Fig: 100 c MR 3-9-22D
As Extruded & Stretch Straightened
Center
Etch: Krolls Mag: 500X

Fig: 100 d MR 3-2-22H
As Extruded & Stretch
Straightened - Edge
Etch: Krolls Mag: 500X

Photomicrographs of a titanium alloy extrusion (#273) 1/16" thick, extruded at 1800°F, at a 57:1 ratio and stretch straightened 3% at 1100°F. The material has been heated above the beta transus as can be seen by the presence of alpha phase outlining the prior beta grains. The very fine alpha platelets in the Widmanstatten configuration seen in this structure (Fig. 100 d) are a result of more severe (58:1) reduction during extrusion and more rapid cooling (due to small thickness) from the extrusion temperature. These processing variables would tend to produce a structure higher in beta content. No hardness differences were noted between the high alpha surface (at flange) and the base metal.

Photomicrographs of Extrusions # 277 and 273

FIGURE 100

605288

Fig. 101 a MR 3-11-6E9
As Extruded
Etch: Krolls Mag: 100X

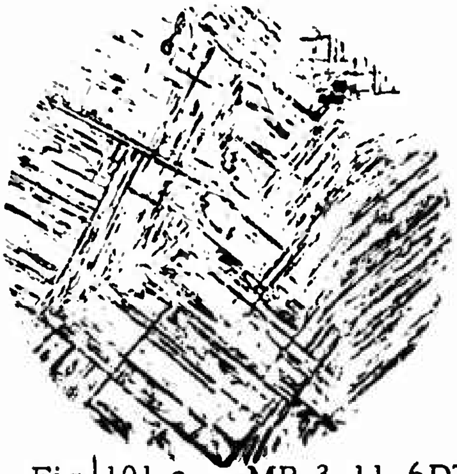
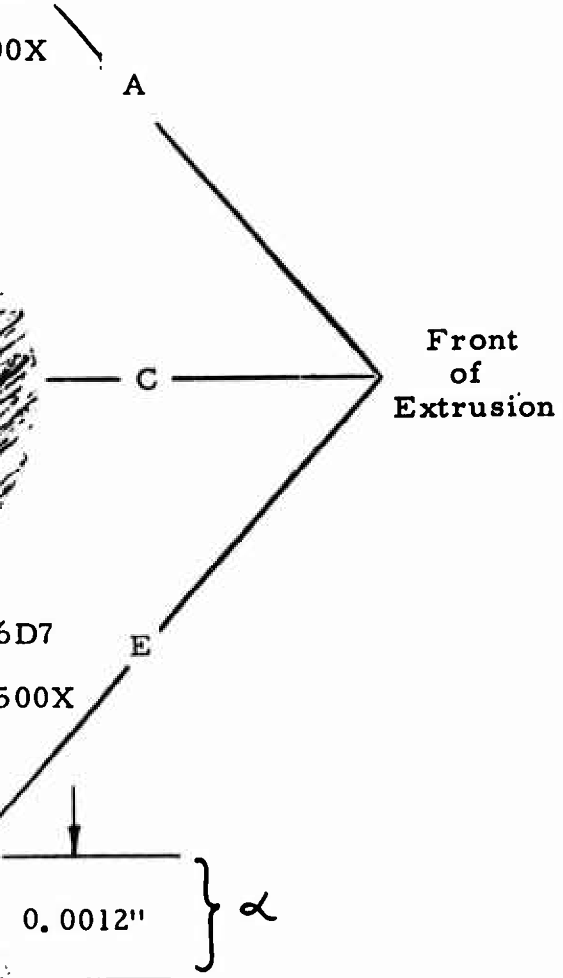
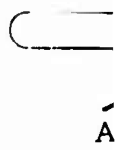


Fig. 101 c MR 3-11-6D7
As Extruded
Etch: Krolls Mag: 500X

Fig. 101 e MR 3-11-6E4
As Extruded
Etch: Krolls Mag: 500X

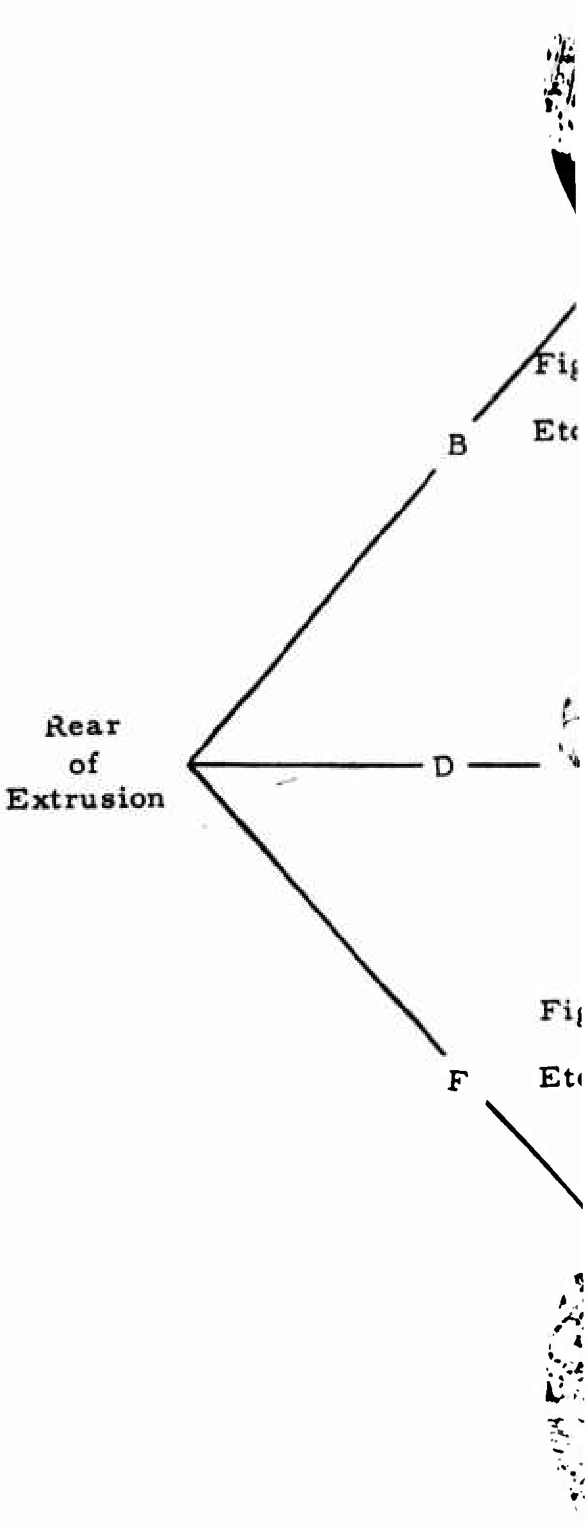


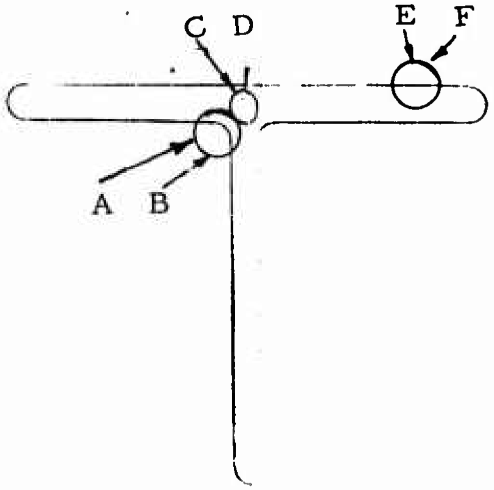
Photomicrograpl
#272 (1/16" thicl
microstructures
the material has
As indicated by t
complete recrys
the front of the e
which appear not
The microstructu
f, illustrate the
rear of the same
platelets and lacl
of the extrusion.
temperatures obt
extrusion as a re
alpha phase seen
(rear and front),
differences with
below shows the
graphs were take



Photomic

Photomicrograph of titanium alloy 6Al-4V extrusion #272 (1/16" thick) extruded at a 57:1 ratio. The microstructures seen in Figures a, c, and e show the material has just exceeded the beta transus. As indicated by the flow observed in Figure a, complete recrystallization has not occurred in the front of the extrusion and there are some areas which appear not to have reached the beta transus. The microstructures shown in Figures b, d, and f, illustrate the microstructures obtained from the rear of the same extrusion. Note the larger platelets and lack of metal flow seen in this area of the extrusion. This is indicative of the higher temperatures obtained toward the rear of the extrusion as a result of increased friction. The alpha phase seen on the surface of the extrusion (rear and front), do not show any hardness differences with the base metal. The schematic below shows the locations where photomicrographs were taken.





Fi

Et

Phctomicrographs of Extrusion # 272

FIGURE 101

Al-4V extrusion
l ratio. The
c, and e show
eta transus.
Figure a,
ccurred in
are some areas
e beta transus.
res b, d, and
tained from the
e larger
in this area
of the higher
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he extrusion
rdness
e schematic
tomicro-

Fig. 101 b MR3-11-6D-10
As Extruded
Etch: Krolls Mag: 100X

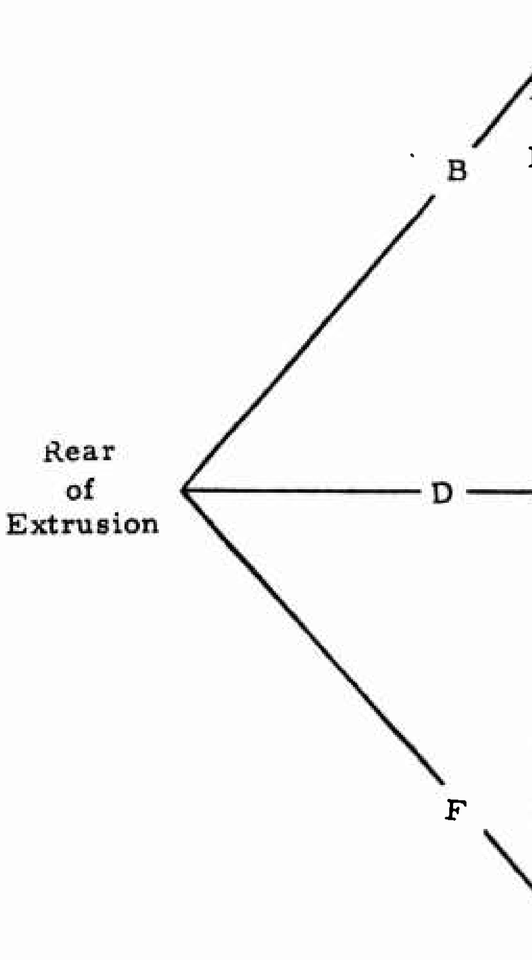
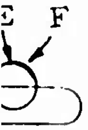


Fig. 101 d MR 3-11-6D-S
As Extruded
Etch: Krolls Mag: 500X



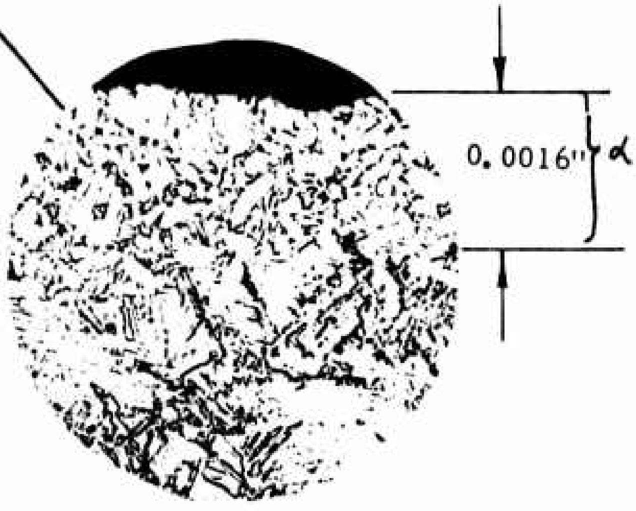


Fig. 101 f MR 3-11-6D8
As Extruded
Etch: Krolls Mag: 500X

sion # 272

373

TABLE 31

ROOM TEMPERATURE TENSILE RESULTS OF EXTRUSIONS EVALUATED AT NAA

EXTRUSION NO.	SPECIMEN	UTS, KSI	YS, KSI 0.2% OFFSET	ELONGATION, % 2 INCHES
290	A	188.8	175.5	6.5
	B	175.5	162.1	7.0
294	A	175.3	158.6	8.5
	B	199.2	181.6	6.0
282	A	172.9	151.3	8.5
	B	173.6	154.5	10.0
285	A	184.2	169.5	6.5
	B	187.6	172.2	6.0
289	A	181.6	168.1	7.0
	B	181.4	169.1	6.0
Required Tensile Properties		160.0 (Minimum)	150.0 (Minimum)	6.0 (Minimum)

TABLE 32

ELEVATED TEMPERATURE TENSILE RESULTS (700 ± 10F)

EXTRUSION NUMBER	UTS, KSI	YS, KSI 0.2% OFFSET
290	126.8	107.9
294	125.4	96.5
282	131.4	109.0
285	*	-
289	129.7	101.7
Required Tensile Strength	110.0 (Minimum)	90.0 (Minimum)

* Tensile stress on specimen was 123.6 KSI when holding pin failed.

TAB

DIMENSIONAL MEASUREMENTS

Extrusion No.		Thickness	Radius	Height
	Required	(0.043 + 0.005")	(0.125 ± 0.005")	(1.600 ± 0.005"
290		*Unsatisfactory(1)	Satisfactory	Satisfactory
294		*Unsatisfactory (2)	Satisfactory	Satisfactory

DIMENSIONAL MEASUREM

Extrusion No.		Thickness	Radius	Height
	Required	(0.080 ± 0.005")	(0.125 ± 0.005")	(1.000 ± 0.005"
289		*Unsatisfactory(4)	Satisfactory	Satisfactory
285		*Unsatisfactory(5)	Satisfactory	Satisfactory
282		*Unsatisfactory(7)	Satisfactory	Satisfactory

* See Summary page 197

1 of 2

TABLE 33

SUREMENTS OF 64E12 (MODIFIED) EXTRUSIONS

eight	Width	Straightness	Twist	Angle	Re
.600 ± 0.005")	(1.750 ± 0.005")	(0.010" per ft)	(1/2° per ft, max. 3°)	(± 1/2°)	(1)
tisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	
					(2)
tisfactory	Unsatisfactory(3)	Satisfactory	Satisfactory	Satisfactory	
					(3)

MEASUREMENTS OF 64E15 EXTRUSIONS

ight	Width	Straightness	Twist	Angle	Re
.000 ± 0.005")	(1.750 ± 0.005")	(0.010" per ft)	(1/2° per ft, max. 3°)	(± 1/2°)	
tisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	(4) thi 0. (
tisfactory	Satisfactory	Unsatisfactory(6)	Satisfactory	Satisfactory	(5) thi 0. (
					(6)
tisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	(7) thi to

IFIED) EXTRUSIONS

	Straightness	Twist	Angle	Remarks
05")	(0.010" per ft) Satisfactory	(1/2° per ft, max. 3°) Satisfactory	(± 1/2°) Satisfactory	(1)Variation in thickness (0.042" to 0.037")
ry(3)	Satisfactory	Satisfactory	Satisfactory	(2)Variation in thickness (0.040" to 0.037") (3)First 3' undersize balance of 8' satisfactory

EXTRUSIONS

	Straightness	Twist	Angle	Remarks
05")	(0.010" per ft)	(1/2° per ft, max. 3°)	(± 1/2°)	
	Satisfactory	Satisfactory	Satisfactory	(4)Variation in thickness (0.077" to 0.073")
	Unsatisfactory(6)	Satisfactory	Satisfactory	(5)Variation in thickness (0.079" to 0.073") (6)0.020" kink
	Satisfactory	Satisfactory	Satisfactory	(7)Variation in thickness (0.076" to 0.069")

3 of 2

TABLE 34

CHEMICAL COMPOSITION

EXTRUSION NUMBER	H PPM	Al %	V %	Fe %	C %	N %	O %
290	115	6. 65	3. 93	0. 16	0. 025	0. 021	0. 051
294	170*	6. 40	3. 84	0. 15	0. 040	0. 016	0. 087
282	83	6. 54	3. 82	0. 15	0. 050	0. 011	0. 116
285	39	6. 37	3. 97	0. 14	0. 035	0. 016	0. 103
289	22	6. 46	3. 98	0. 14	0. 025	0. 022	0. 097
Composition Requirements	125 (Max)	5. 50-6. 75	3. 50-4. 50	0. 30 (Max)	0. 10 (Max)	0. 07 (Max)	0. 20 (Max)

* Results of two additional samples are: 165 and 182 ppm.

IV. RECOMMENDED OPERATIONAL PROCEDURE

A. EXTRUSION

Procedure

1. Belt grind billet surfaces to 100 grit

2. Degrease billet

3. Heat billet to 300°F and spray with protection glass slurry. Oven dry.

4. Place billet into preheated (1800°F) stainless steel can. Cover can and argon purge for 60 seconds.

5. Place can into controlled argon atmosphere electric furnace. Soak 60 minutes.

6. Transfer billet to extrusion press as fast as possible (20 to 40 seconds).

7. Remove billet from can on runout table.

8. Give billet a double roll on the runout table to apply additional glass powder to billet surface.

9. Place glass ring/glass wool die pads into container against die face.

10. Place billet in container.

11. Advance stem rapidly until contact is made with billet.

12. Hold stem in position for one or two seconds while upsetting billet.

13. Extrude

Conditions

1. Chromium plated liner

2. Die temperature - 900°F

3. Container temperature - 900°F

4. Dummy block temperature - 400°F

5. Die material - Peerless "A" tungsten steel, R_c - 48-52

6. Die coating - ceramic

7. Coating thickness - .010 - .020 inches per side

8. Billet protection glass - #85 coating

9. Billet O. D. lubricant - 318 glass - 14 mesh

10. Die lubricant - 3KB - 14 mesh glass ring
(3) glass wool pads

B. POST EXTRUSION

Deglass

1. Dip in 30% solution of sodium hydroxide at about 425° F for approximately one (1) minute

2. Water rinse

3. Dip in 15% sulphuric acid bath for approximately one (1) minute

4. Water rinse

5. Steam blast

Straightening

1. Insert one end of extrusion between jaws of stationary head on stretcher press.

2. Detwist manually sufficiently so that shape can be completely detwisted on press with one revolution of rotating head. Lock the detwisted end in the movable jaw.

3. Resistance heat extrusion through insulated jaws to 1000° - 1100° F, maintaining tension in the part.

4. Stretch to approximately 3% of the original extrusion length. An allowance of about 3" of springback for 20 foot lengths is made in determining the amount the extrusion is stretched.

5. Cut the power and air cool the extrusion under a constant diminishing tension until approximately 2 inches of contraction occurs. Release the air pressure holding the jaw grips so that further release of tension will cause the extrusion to bow slightly in compression and force the jaw grips to open.

6. Remove camber and bow by "gag" straightening on a hydraulic press (while the extrusion is still warm - over 300° F).

C. WARM DRAW

Procedure

1. Machine fillet radii over a 9" end length to insure insertion into draw die.

2. Chemically point extrusion ends in a 15% acetic acid - 5% hydrofluoric acid bath to 0.010" - 0.020" less than 1st pass dimension. Tape the air-liquid interface to prevent undercutting between the point and base extrusion.

3. Chemically clean extrusions by alternate immersion in a KOH bath at about 425°F, rinsing; immersion in a 15% H_2SO_4 bath at about 120°F, rinsing; flash pickling in a 15 HNO_3 - 1 1/2 HF bath at room temperature and rinsing. Conversion coat with Amchem Granodraw "T" (3 oz/gallon); rinse, lime dip coat (4-8 oz/gallon) at 160 - 180°F, multiple immersion (3-4 dips about 1 minute each) with hot air drying between dips; brush coat two layers of Alpha Molykote 196X with air drying between coats.

4. Resistance heat extrusion to 1050°F at a station adjacent to holding furnace in draw bench trough.

5. Place extrusion in the holding furnace at 1050°F and hold for 0-1 minutes depending on shape thickness.

6. Hook up extrusion and draw at 24 feet per minute. (10% reduction per pass). Die is preheated to approximately 500°F.

7. Brush apply die face with Fiske 604 lubricant during draw cycle.

8. In-process straighten extrusions by stretch annealing at 1550° F.

9. Heat treat extrusions according to recommended heat treat cycle for designated alloy.

10. Pickle and final straighten extrusions (stretch straightening temperature is dependent on heat treat condition).

11. Machine extremities of extrusions to bring the end dimensions within size.

12. Clean, inspect and test.

APPENDIX A

Extrusion Trial Data Sheets

The original extrusion data sheets are reproduced in Appendix A for reference. Duplication of extrusion push numbers may be somewhat confusing since each extruder numbered his pushes consecutively beginning with 1. However, the original push numbers have been maintained so that the data would correlate with the identification on the extrusions.

Several assigned push numbers were not used where the unavailability of tooling or problems in billet heat-up voided the push. The push numbers used and the total number of pushes are listed below for clarity. The entire program encompassed 535 pushes.

	Push Numbers	Total Each Extruder	Total Each Part
Part I - Survey (no pushes)			
Part II			
Babcock & Wilcox	1-20, 24-66, 69-82	77	
U. S. Steel	1-74	74	
H. M. Harper	1-55	55	
			206
Part III			
Babcock & Wilcox	83-131, 133-138, 140-141, 144-155, 160-175	85	
Cefilac	1-62	62	
			147
Part IV			
Babcock & Wilcox	176-245	70	
Battelle	1-66	66	
			136
Part V			
Babcock & Wilcox	251-256, 258-297	46	
			46
	Total Number of Pushes		535

PART II EXTRUSION TRIAL
DATA SHEETS

BABCOCK AND WILCOX COMPANY

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

RUN No	MATERIAL	BILLET DIA.	BILLET TEMP °F	HEATING CONDITION (1)	HTG TIME (MIN)	BILLET LUBRICANT	[redacted] LUBRICANT DIE	EXTRUSION PRACTICE	DIE DESIGN (2)	DIE MATERIAL RC ③	DIE TEMP °F	BILLET TRANSFER TIME (SEC)	EXTR TIME (SEC)		MAX PRESSURE READING	MAX PRESS ON BILLET (PSI)	MAX FORCE ON BILLET (TONS)	EXTRUSION LENGTH (FEET)
1	C135AMD	4 1/16"×8"	1820	ELEC FURN ARGON ATMOS	85	POWD 3KB	3KB PAD	REGULAR	26230	BA Rc 44-48	—	—	—	PARTIAL STICKER			1050	5'-8"
2	"	"	1920	"	190	"	"	"	"	"	—	—	—				891	48' APPROX.
3	"	"	1930	"	205	"	"	"	"	"	—	—	—				945	47' APPROX.
4	"	"	1930	"	211	"	"	SCALPING	"	"	—	—	—				—	58' APPROX.
5	"	"	1930	"	220	GREASE	GREASE	"	"	"	—	—	—				918	40' APPROX.
6	"	"	1930	"	230	POWD 3KB	3KB PAD	"	"	"	—	—	—				675	16' APPROX.

(1) BILLETS COATED WITH #85 GLASS FRIT.

(2) STANDARD DIE DESIGN

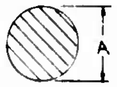
(3) DIES MADE OF BRIGHTON ALLOY

RUN No	MATERIAL	EXTRUSION SURFACE FINISH (4)	DIE CONDITION	EXTRUSION SECTION DIMENSIONS FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
1	C135AMD	DEEP LONGITUDINAL SCRATCHES	WASHED	.406 .410				—				—				#4 - SURFACE SEVERLY
2		"	"	.410 .413				.405 .460				.452 .472				SCRATCHED BUT BEST OF GROUP AND COMPLETELY
3		"	"	.410 .413				.384 .430				.409 [illegible]				ROUND AT CENTER
4		"	"	.402 .406				.407 .408				.838 .595				#6 - NO IMPROVEMENT
5		"	"	.410 .416				.412 .430				.412 .459				IN SURFACE OVER .408" DIA. ROUNDS
6				.748 .749				.744 .732				.754 .738				

(4 THESE SCRATCHES [illegible]TENDED THE FULL LENGTH OF EXTR[illegible] PRODUCT

GENERAL DATA

DATE : OCTOBER 15, 1957
COMPANY : BABCOCK & WILCOX CO.
LOCATION : BEAVER FALLS, PA.



NOMINAL DIMENSION:
A - .408
B - AND
C - .750
D -

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 96:1 & 28:1
CONTAINER DIAMETER 4 3/16"

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

RUN No	MATERIAL	BILLET DIA (1)	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT OD	[redacted] LUBRICANT ID	DIE LUBRICATION	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSF TIME (SEC)	EXTR TIME (SEC)		MAX PRESSURE READING	MAX PRESS ON BILLET (PSI)	MAX FORCE ON BILLET (TONS)	EXTRUSION LENGTH ~~(FEET)~~ INCHES
7	4340	4.0"×5"	2250	SALT BATH	—	GREASE GRAPHITE	—	GRAPHITE PAD	1" DIA.	BA Rc 44-48	—	—	—				—	56 1/2"
8	"	"	2240	"	—		—	"	"	"	—	—	—				—	55 1/2"
9	"	"	2250	"	—	[illegible] TV	POWD TV	GWG PAD	26399	"	—	—	—				820	58-61-63
10	"	"	2250	"	—	POWD 3KB	POWD 3KB	318 PAD	"	"	—	—	—				840	72-53-53
11	"	"	2250	"	—	"	"	3KB PAD	"	"	—	—	—				840	58-54-56
12	"	"	2250	"	—	GREASE GRAPHITE	POWD GRAPHITE	HEAVY GRAPHITE PAD	"	"	—	—	—				850	44-56-43
13	"	"	2250	"	—	"	"	NARROW GRAPHITE PAD	"	"	—	—	—				792	51-44-30

(1) BILLETS #7 & #8 SOLID

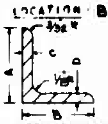
#9 TO #13 DRILLED WITH 2.388" HOLE

RUN No	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS (8) FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
7	4340	ROUGH FRONT END	NO CHANGE	.981				.981				.982				(8) THREE ANGLES
8	"	" " "	NO CHANGE	.984				.985				.984				PRODUCED ON
9	"	POOR	CRACKED	.990 .922 .955	1.000 .998 .774	.086 .076 .084	.109 .110 .095	.953 .967 .982	.970 .976 .995	.086 .084 .075	.094 .102 .095	.968 .971 1.015	.974 .970 1.375	.070 .083 .088	.092 .102 .092	EACH PUSH #9-#13
10	"	INCOMPLETE SEPARATION	"	.910 — —	— .745 —	.048 — .075	— .099 .094	[illegible] — .945	— .916 .946	.081 — .078	— .095 .100	.946 .950 .947	.958 .952 .952	.082 .081 .088	.098 .099 .104	
11	"	" "	WASHED	.918 1.007 —	.980 — 1.000	.076 .086 —	.081 — .077	1.068 .990 1.125	.990 .840 .950	.025 .070 .085	.032 .096 .088	1.065 .984 1.017	.990 1.313 1.028	.088 .087 .082	.095 .095 .082	
12	"	FAIR	" (2)	.997 .964 .913	.946 .976 .948	.080 .079 .072	.090 .093 .104	.959 .943 .973	.982 .975 .960	.077 .076 .079	.091 .106 .104	.957 .958 .975	.942 .947 .970	.078 .071 .085	.098 .090 .094	
13	"	POOR	"	.980 .960 —	1.000 .959 —	.086 .083 —	.098 .097 —	1.014 1.011 .995	1.004 .990 .933	.098 .077 .084	.098 .098 .096	.966 .966 1.004	.994 .918 .980	.090 .078 .094	.093 .077 .082	

(2) DIE WASHED PROGRESSIVELY MORE ON PUSHES #11, #12, & #13

GENERAL DATA

DATE NOVEMBER 26, 1957
COMPANY BABCOCK & WILCOX CO.
LOCATION BEAVER FALLS, PA.



NOMINAL DIMENSION
A - 1.000"
A - 1.000"
C - .094"
D - .094"

CROSS SECTION VIEW

PUSHES #7 & #8 WITH 1" ROUND

PRESS CAPACITY (TONS) 880
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 22:1
CONTAINER DIAMETER 4 3/16"

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

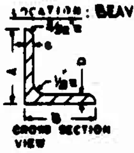
RUN NO	MATERIAL	BILLET DIA. (1)	BILLET TEMP. °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	LUBRICANT ID	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSFER TIME (SEC)	EXTR. TIME (SEC)		MAX PRESSURE READING	MAX PRESS. ON BILLET (PSI)	MAX FORCE ON BILLET (TONS)	EXTRUSION LENGTH (FEET)
14	MS821	4½"x5"	1765	ELEC FURN ARGON ATMOS	53	GREASE GRAPHITE	POWD. GRAPHITE	GRAPHITE PAD POWD GREASE/GRAPHITE	26399	WA Rc44-46	550	21	—	STICKER			880	—
15	C125AMG	"	1765	"	63	"	"	"	"	"	"	24	—	STICKER			880	—
16	MS821	"	1810	"	73	POWD 318	POWD 318	318 PAD	"	"	"	25	—	STICKER			880	—
17	MS821	"	1835	"	105	POWD 3KB	POWD 3KB	3KB PAD	"	"	"	28	—	STICKER			880	—

(1) BILLETS DRILLED WITH 2.388" HOLE

RUN NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	

GENERAL DATA

DATE : NOVEMBER 28, 1957
COMPANY : BABCOCK & WILCOX CO.
LOCATION : BEAVER FALLS, PA.



CROSS SECTION VIEW

NOMINAL DIMENSION:
A - 1.000
B - 1.000
C - .094
D - .094

PRESS CAPACITY (TONS) 880
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 22:1
CONTAINER DIAMETER 4 3/16"

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

PUSH No	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT OD	CONTAINER LUBRICANT ID	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSFER TIME (SEC)	EXTR TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX PRESS ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH INCHES
18	4340	4.0" x 2.380" ID	2250	SALT BATH	90	POWD TV	POWD TV	GWG PAD	26399	BA Rc 44-48	550	–	–	TAPERED MANDREL			–	41
				(NO COATING)										TO PRODUCE SINK AT FRONT END.				41
																		40
19	4340	4.0" x 2.386" ID	2250	SALT BATH	100	POWD TV	POWD TV	GWG PAD	26399	BA Rc 44-48	550	34.6	3.0	" "			–	40½
				(NO COATING)														33
																		33
20	C135 AMO	4 1/16" x 2.388" ID	1920	ELEC FURN ARGON ATMOS	110	POWD 3KB	POWD 3KB	3KB PAD	26399	BA Rc 44-48	550	28.2	3.6	~~TAPERED MANDREL~~ FULL LUBRICATION			–	25½
				(#85 COATING)										MANDREL HOLDER BROKE ONLY PARTIAL EXTRUSION				25½
														OBTAINED				25½

PUSH #20 BILLET WAS STICKER FROM PUSH #15

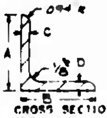
BECAUSE OF BROKEN MANDREL HOLDER PUSHES #21, 22 + 23 COULD NOT BE MADE.

EXTRUSION SECTION DIMENSIONS

PUSH No	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT A	FRONT B	FRONT C	FRONT D	CENTER A	CENTER B	CENTER C	CENTER D	END A	END B	END C	END D	REMARKS
18	4340	GOOD	OK	980	1.000	.183	181	1.005	1.009	.086	.091	955	947	.087	.093	
				975	988	.182	.176	.972	1.003	.091	.088	.928	945	.088	.085	
				983	955	.172	.201	959	1.010	.082	.093	924	957	.080	.094	
19	4340	GOOD	SAME DIE AS #18 OK	934	960	.176	.203	972	990	.078	.090	958	960	.075	.093	
				984	989	.182	–	1.019	–	.114	–	971	937	.084	–	INCOMPLETE SEPARATION OF THESE TWO ANGLES
				1.003	972	–	.179	–	1.006	–	.100	968	962	–	.090	
20	C135 AMO	SURFACE ROUGH EDGES POOR	SAME DIE AS #19 OK	959	978	.094	.152	–	–	–	–	1.041	1.058	.086	.092	
				939	951	.132	.148	–	–	–	–	.960	1.030	.079	.093	
				939	942	.152	.151	–	–	–	–	.980	1.002	.092	.079	

GENERAL DATA

DATE: DECEMBER 13, 1957
COMPANY: BABCOCK + WILCOX CO
LOCATION: BEAVER FALLS, PA



CROSS SECTION VIEW

NOMINAL DIMENSION
A - 1.000
B - 1.000
C - .094
D - .094

PRESS CAPACITY (TONS) 800
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 22:1
CONTAINER DIAMETER 4 3/16"

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

PUSH No	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT O.D	CONTAINER LUBRICANT I.D.	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSFER TIME (SEC)	EXTR TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX PRESS ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH INCHES
24	4340	4.0" x SOLID	2250	SALT BATH	64	POWD TV	–	GWG PAD	26515	BA Rc 44-48	550	22.8	4.2	FULL LUBRICATION			–	134
				(NO COATING)														105
																		84
25	4340	←												NOT EXTRUDED →				
26	C135 AMO	4 1/16" x SOLID	1930	ELEC FURN ARGON ATMOS	94	POWD 3KB	–	3KB PAD	26515	BA Rc 44-48	550	28.8	3.6	FULL LUBRICATION			–	111 (1)
				(#85 COATING)										DIE PARTIALLY PLUGGED WITH				57½ (1)
														GLASS				51 (1)

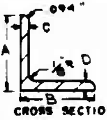
(1) LENGTH OF COMPLETE ANGLE ONLY. SEE REMARKS

EXTRUSION SECTION DIMENSIONS

PUSH No	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT A	FRONT B	FRONT C	FRONT D	CENTER A	CENTER B	CENTER C	CENTER D	END A	END B	END C	END D	REMARKS
24	4340	GOOD	DIE #1 - OK	901	911	.097	.102	.955	.965	.098	.099	937	933	.083	.095	
				.935	986	.098	.098	984	.999	.097	.098	968	.988	.097	.092	
				.948	.948	.091	.093	.985	.984	.091	.099	.988	993	.091	.090	
25	4340	←	NOT EXTRUDED													→
26	C135 AMO	SOME AREAS SURFACE IS FAIR	DIE #2 - OK	–	–	–	–	438	984	.121	.097	.560	964	.148	.097	FRONT ENDS NOT COMPLETE ANGLE - SIDES SPLIT
		MUCH OF ANGLES ARE SPLIT APART		–	–	–	–	913	.446	.083	.107	968	.518	.094	.096	APART BECAUSE DIE WAS PARTIALLY PLUGGED
				–	–	–	–	981	.979	.085	.086	947	.979	.095	.087	71", 112" + 113" OF FRONT END DID NOT EXTRUDE INTO COMPLETE ANGLE

GENERAL DATA

DATE: DECEMBER 13, 1957
COMPANY: BABCOCK + WILCOX CO.
LOCATION: BEAVER FALLS, PA



CROSS SECTION VIEW

NOMINAL DIMENSIONS
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 25:1
CONTAINER DIAMETER 4 3/16"

MRD-C-5207

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

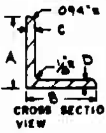
RUN NO	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT OD	CONTAINER LUBRICANT ID	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSF TIME (SEC)	EXTR TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX PRESS ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH ~~[illegible]~~ INCHES
27	C135 AMO	4 1/16" × 5" SOLID	1930	ELEC FURN ARGON ATMOS	147	POWD 3KB	—	3KB PAD	26515	BA Rc 44-48	550	26.4	4.8	SCALPED			—	96
																		50 (1)
																		4 (1)
28	C135 AMO	4 1/16" × 5" SOLID	1930	"	138	FISKE IN CONTAINER	—	THIN GRAPHITE PAD SWABBED WITH G&G	26515	BA Rc 44-48	550	20.4	4.2	FULL LUBRICATION			—	214
														TWO PORTS PLUGGED WITH GRAPHITE ONLY ONE ANGLE EXTRUDED				—
																		—
29	C135 AMO	4 1/16" × 5" SOLID	1930	"	166	FISKE IN CONTAINER	—	VERY THIN GRAPHITE PAD SWABBED WITH G&G	26515	BA Rc 44-48	550	15.6	2.4	SCALPED			—	84
														ONLY TWO ANGLES EXTRUDED.				150
																		—

(1) LENGTH OF COMPLETE ANGLE ONLY SEE REMARKS

RUN NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS FRONT A				CENTER A				END A				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
27	C135 AMO	FAIR SURFACE LIGHT SCRATCHES	DIE #3 - OK	.808	.977	.083	.093	.858	.971	.083	.093	.910	.970	.083	.092	
		"		—	—	—	—	.957	.963	.086	.100	.955	.962	.093	.098	FRONT END SPLIT FOR 56"
		ROUGH SURFACE		—	—	—	—	—	—	—	—	.956	.957	.094	.089	FRONT END SPLIT FOR 93"
28	C135 AMO	HEAVY LONGITUDINAL SCRATCHES	DIE #3 - OK	.942	.969	.089	.106	.493	1.047	.160	.197	.563	1.079	.194	.179	
		"														
		"														
29	C135 AMO	"	DIE #4 - DISCARD	.777	.995	.085	.099	.822	.998	.115	.122	.472	1.083	.135	.124	HEAVY BREAKS - LAST HALF OF ANGLE
		"	STUCK IN DIE - NO EXAMINATION MADE	.598	.989	.091	.103	.572	1.018	.111	.114	.609	1.088	.157	.165	
		"														

GENERAL DATA

DATE : December 13, 1957
COMPANY : Babcock & Wilcox Co
LOCATION : Beaver Falls, Pa



CROSS SECTION VIEW

NOMINAL DIMENSION:
A - 1.000
B - 1.000
C - .094
D - .094

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 25:1
CONTAINER DIAMETER 4 3/16"

MRD-C-5207

HH CONTAINER 12-20

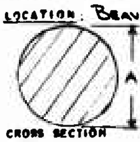
TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

RUN NO	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT OD	CONTAINER LUBRICANT ID	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSF TIME (SEC)	EXTR TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX PRESS ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH ~~[illegible]~~ INCHES
30	MS 821	4 1/16" O.D. × 5" LONG SOLID BILLETS	1930	ELEC FURN ARGON ATMOS	118	POWD 3KB	—	3KB PAD	26230	BA Rc 44-48	550	21.0	4.2	FULL LUBRICATION			880	116
31	MS 821		1930	"	123	POWD 3KB	—	3KB PAD	26230	BA Rc 44-48	550	20.2	3.6	SCALPED			770	116
32	MS 821		1930	"	130	FISKE IN CONTAINER	—	THIN GRAPHITE PAD SWABBED WITH G&G	26230	BA Rc 44-48	550	19.2	4.8	FULL LUBRICATION			990	101 1/2
33	MS 821		1930	"	138	POWD GWG	—	GREASE & GRAPHITE SWABBED ON DIE	26230	BA Rc 44-48	550	24.6	4.2	SCALPED			880	99

RUN NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
30	MS 821	FRONT - ROUGH MIDDLE & BACK - GOOD	DIE #5 - OK	.741 / .744				.744 / .746				.748 / .750				
31	MS 821	"	DIE #6 - OK	.748 / .752				.751 / .754				.752 / .754				
32	MS 821	FRONT - GOOD MIDDLE - ROUGH	DIE #5 - WASHED	.751 / .756				.710 / .753				.701 / .768				LAST HALF OF ROUND WAS TORN BADLY.
		BACK - TORN	HEAVILY ON ONE SIDE													
33	MS 821	FRONT - GOOD MIDDLE - FAIR	DIE #6 - WASHED	.749 / .751				.750 / .757				.750 / .768				
		BACK - LONGITUDINAL SCRATCHES														

GENERAL DATA

DATE : December 13, 1957
COMPANY : Babcock & Wilcox Co
LOCATION : Beaver Falls, Pa



CROSS SECTION VIEW

NOMINAL DIMENSION:
A - .750"
B -
C -
D -

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 28:1
CONTAINER DIAMETER 4 3/16"

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

RUN NO	MATERIAL	BILLET DIA.	BILLET TEMP °F	HEATING CONDITION (1)	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT TEMP	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSFER TIME (SEC)	EXTR TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX PRESS ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH INCHES
34	C135 AMO	SOLID	1930	Elect Furn Argon Atmos	64	Powd GWG	800	3KB Pad	26399	BA Rc 44-48	440	21.6	2.4	Scalping			1090	86
																		90
																		91 ½
35	MS 821	x S x	1930	"	68	Powd GWG	550 (2)	3KB Pad	26399	BA Rc 44-48	440	22.8	2.4	Scalping			1090	125
																		90½
																		89
36	C135 AMO	4½	1930	"	113	Powd GWG	950	3KB Pad	26399	BA Rc 44-48	540	23.4	2.4	Scalping			1010	99
				(1) Billets coated with #85 frit														97
				(2) Temperature after push														79

EXTRUSION SECTION DIMENSIONS

RUN NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
34	C135 AMO	Inside - Good Outside - Fair	Die #1 Good	.975	.990	.097	.102	.969	.986	.097	.102	.966	.990	.097	.095	
				.963	.964	.099	.104	.965	.969	.097	.099	.962	.978	.098	.097	
				.884	.937	.094	.096	.967	.973	.092	.096	.975	.965	.087	.093	
35	MS 821	Fair	Die #2 - One corner of one [illegible]	.962	.931	.086	.090	.966	.974	.088	.092	.947	.959	.083	.085	Two pieces torn last half
			Plugged Not washed	.820	.918	.073	.097	.701	.950	.091	.093	.560	.972	.095	.100	
				.785	.956	.085	.091	.848	.956	.088	.087	.887	.948	.091	.079	
36	C135 AMO	Inside - Good Outside - Fair	Die #8 Good	1.017	.973	.090	.090	1.005	.976	.092	.093	.967	.972	.086	.093	
		(Longitudinal scratches)		.998	.984	.092	.095	.956	.982	.090	.094	.990	.972	.091	.092	
				.996	1.003	.087	.091	.993	.988	.088	.089	.968	.992	.083	.087	

GENERAL DATA

DATE : December 20, 1957
COMPANY : Babcock + Wilcox
LOCATION : Beaver Falls, Pa.

CROSS SECTION VIEW

NOMINAL DIMENSIONS
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1100
STEM DIAMETER 4 1/16
EXTRUSION RATIO 22:1
CONTAINER DIAMETER 4 3/16

12/27/57

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

RUN NO	MATERIAL	BILLET DIA.	BILLET TEMP °F	HEATING CONDITION (1)	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT TEMP	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSFER TIME (SEC)	EXTR TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX PRESS ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH INCHES
37	MS 821	SOLID	1930	Elect Furn Argon Atmos	85	Powd GWG	900	3KB Pad	26399	BA Rc 44-48	445	21.6	1.8	Scalping			935	113
																		102½
																		43
38	C135 AMO	x S x	1930	"	128	Powd GWG	1000	Grease + Graphite swabbed on die	26399	BA Rc 44-48	520	24.6	2.4	Scalping			1010	56
																		52½
																		60
39	MS 821	4½	1930	"	145	Powd GWG	950	Grease + Graphite swabbed on die	26399	BA Rc 44-48	535	25.2	1.8	Scalping			980	131
																		86½
																		—

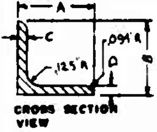
(1) Billets coated with #85 frit.

EXTRUSION SECTION DIMENSIONS

RUN NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
37	MS 821	Inside - Good Outside - Fair	Die #7 OK	.992	1.003	.096	.097	.988	.981	.097	.096	.982	.987	.100	.102	
				.987	.831	.092	.099	.972	.914	.091	.099	.981	.962	.091	.098	
				.723	.961	.087	.098	.734	.966	.089	.096	.740	.974	.092	.097	
38	C135 AMO	Poor	Die #9 - Discard stuck to die -	1.020	1.002	.101	.104	1.019	1.002	.098	.113	1.012	1.086	.118	.098	
		Deep scratches	No examination	.999	1.023	.097	.108	1.013	1.014	.101	.111	1.022	1.005	.112	.136	
				.991	.978	.099	.102	1.004	.996	.096	.109	1.009	1.019	.119	.108	
39	MS 821	Poor	Die #10 - Two parts washed	.981	.988	.094	.100	1.014	1.028	.117	.108	1.051	1.051	.147	.150	Only two angles
		Deep scratches	Badly	.988	.986	.093	.096	.993	.987	.087	.099	.979	1.008	.066	.109	Extruded.

GENERAL DATA

DATE : December 20, 1957
COMPANY : Babcock + Wilcox Co.
LOCATION : Beaver Falls, Pa.



CROSS SECTION VIEW

NOMINAL DIMENSIONS
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1100
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 22:1
CONTAINER DIAMETER 4 3/16"

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

Run No.	Material	Billet Dim.	Billet Temp °F	Heating Condition (1)	Htg Time (min)	Billet Lubricant OD	Container Lubricant Temp	Die Lubricant	Die Design	Die Material Rc	Die Temp °F	[illegible] (sec)	[illegible]	Extrusion Practice	[illegible]	[illegible] (psi)	[illegible] (tons)	Extrusion Length [illegible] inches
40	C135 AMO	.	1930	Elect Furn [illegible]	158	None	950	Grease + Graphite [illegible] only	26399	BA R 44-48	570	24.0	2.4	Scalping			1100	147
		5																—
		x																—
41	MS 821	[illegible] SOLID	1930	Elect Furn [illegible]	172	None	1000	Grease + Graphite [illegible] only	26399	BA R 44-48	560	216	2.4	Scalping			1010	164 ½
		4																—
																		—

(1) Billets scaled by removing from furnace and remaining in air for five minutes before return to furnace. No coating used.

Run No.	Material	Extrusion Surface Finish	Die Condition	Front A	Front B	Front C	Front D	Center A	Center B	Center C	Center D	End A	End B	End C	End D	Remarks
40	C135 AMO	Deep longitudinal scratches	Die # 11 - Two ports plugged - one port washed badly	1.029	1.027	.098	.100	1.094	1.063	.146	.154	1.094	1.063	.170	.172	Only one angle extruded
41	MS 821	Deep longitudinal scratches	Die # 12 - one port washed badly	.971	.975	.099	.098	.987	1.027	.118	.121	1.063	1.063	.151	.166	Only one angle extruded

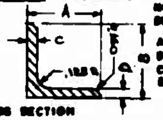
(Extrusion section dimensions)

GENERAL DATA

DATE : December 20, 1957

COMPANY : Babcock + Wilcox

LOCATION : Beaver Falls, Pa.



NOMINAL DIMENSIONS
A - 1.000"
B - 1.000"
C - .094"
D - .094"

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 1100
STEM DIAMETER 4 1/16
EXTRUSION RATIO 22:1
CONTAINER DIAMETER 4 3/16"

TEST GROUP No 5 -

Jan 8, 1958

MRD-C-5207

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

USN Nº	MATERIAL	BILLET DIA.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER ~~LUBRICANT~~ TEMP	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSFER TIME (SEC)	EXTR. TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX PRESS ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH ~~(FEET)~~ INCHES
42	C135 AMO	4-½ x 5 x Solid	1660	Elec Furn Argon Atmos	99	Powd GWG	980	318 Pad	26515	B.A. Rc 44-48	600	22.8	-	Scalping			-	-
				#85 Coating														
43	MS 821		1760	Elec Furn Argon Atmos	140	Powd GWG	860	318 Pad	26515	BA Rc 44-48	540	28.2	-	Scalping			-	-
				#85 Coating														
44	C135 AMO		1810	Elec Furn Argon Atmos	173	Powd GWG	980	Thin 318 Pad	26515	B.A. Rc 44-48	830	28.2	30	Scalping			-	113 ½
				#85 Coating														90 ½
																		-

EXTRUSION SECTION DIMENSIONS

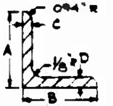
USN Nº	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT A	FRONT B	FRONT C	FRONT D	CENTER A	CENTER B	CENTER C	CENTER D	END A	END B	END C	END D	REMARKS
42	C135 AMO		Die #1													Sticker
43	MS 821		Die #7													Sticker
45	C135 AMO	Good	Die #8 Good	.962	.917	.095	.102	1.008	.971	.093	.099	1.007	.982	.091	.098	One die port plugged with glass - only two
				.967	.985	.087	.094	.990	.981	.089	.092	.981	.993	.090	.093	angles extruded

GENERAL DATA

DATE : December 27, 1957

COMPANY : Babcock + Wilcox Co

LOCATION : Beaver Falls, Pa.



CROSS SECTION VIEW

NOMINAL DIMENSIONS

A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 22:1
CONTAINER DIAMETER 4 3/16"

TEST GROUP No 5 -

MRD-C-5207

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

USN Nº	MATERIAL	BILLET DIA.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER ~~LUBRICANT~~ TEMP	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSFER TIME (SEC)	EXTR. TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX PRESS ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH ~~(FEET)~~ INCHES
45	MS 821	4½ x 5 x Solid	1800	Elec Furn Argon Atmos	197	Powd GWG	930	318 Pad	26515	BA Rc 44-48	940	22.2	28	Scalping			-	-
				#85 Coating														
46	C135 AMO		1800	Elec Furn Argon Atmos	224	Powd GWG	870	Grease + Graphite	26515	B.A Rc 44-48	890	22.8	30	Scalping			-	55
				#85 Coating														52
																		67
47	MS 821		1900	Elec Furn Argon Atmos	380	Powd GWG	920	Grease + Graphite	26515	B.A Rc 44-48	915	19.2	30	Scalping			-	66
				#85 Coating														72
																		51

EXTRUSION SECTION DIMENSIONS

USN Nº	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT A	FRONT B	FRONT C	FRONT D	CENTER A	CENTER B	CENTER C	CENTER D	END A	END B	END C	END D	REMARKS
45	MS 821		Die #13													Sticker
46	C135 AMO	Front - Good	Die #17 washed slightly	.981	.998	.103	.105	.992	.987	.104	.105	.981	1.000	.111	.117	
		Back - Longitudinal Scratches	Some pick-up tongue washed considerably	Angle taken by Republic Aviation Corp Representative												
				1.009	.993	.108	.108	1.011	.993	.108	.112	1.019	.999	.110	.122	
47	MS 821	Surface Rough	Die #15 Discard stuck to die - no examination of die made	.994	1.003	.088	.091	1.011	1.008	.084	.083	—				
		Back ends torn badly		.980	.999	.095	.107	.969	.987	.084	.108	—				
				.978	1.027	.102	.092	—	1.030	—	.108	—				

GENERAL DATA

DATE : December 27, 1957

COMPANY : Babcock + Wilcox Co.

LOCATION : Beaver Falls, Pa

CROSS SECTION VIEW

NOMINAL DIMENSION

A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 22:1
CONTAINER DIAMETER 4 3/16"

Test Group No 5 -

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

USN No	Material	Billet Dia.	Billet Temp °F	Heating Condition	Htg Time (Min)	Billet Lubricant	Container ~~Lubricant~~ Temp	Die Lubricant	Die Design	Die Material RC	Die Temp. °F	Billet Transf. Time (Sec)	Extr Time (Sec)	Extrusion Practice	Max Pressure Reading	Max Press on Blt (PSI)	Max Force on Blt (Tons)	Extrusion Length Inches
48	C135 AMO	4 1/16 × 5 × Solid	1800	Elec Furn Argon Atmos	266	Powd GWG	950	318 Pad	26515	B A R_c 44-48	970	24.0	4.1	Scalping			—	80
				#85 Coating														78
																		68
49	MS 821		1900	Elec Furn Argon Atmos	405	Powd GWG	900	318 Pad	26515	B A. R_c 44-48	925	21.6	31	Scalping[1]			—	172
				#85 Coating														113
																		—
50	C135 AMO		1800	Elec Furn Argon Atmos	279	Powd GWG	1015	318 Pad	26515[2]	B A R_c 44-48	970	21.6	4.0	Scalping			—	75
				#85 Coating														75
																		52

(1) Dummy block too hot - it mushroomed no scaling action took place

EXTRUSION SECTION DIMENSIONS

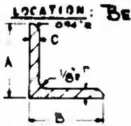
USN No	Material	Extrusion Surface Finish	Die Condition	Front				Center				End				Remarks
				A	B	C	D	A	B	C	D	A	B	C	D	
48	C135 AMO	Fair	Die #16 No washing	Angle taken by Republic Aviation Corp Representative												
			Some pick-up	986	992	.096	094	981	967	.092	.099	968	962	.093	.091	
				988	964	090	.095	.996	.973	098	.098	987	973	099	.091	
49	MS 821	One angle torn entire length	Die #14 - one port washed													One port of die was plugged with glass —
		One angle torn back end	Badly													Only two angles were extruded
		Neither piece competely filled														
50	C135 AMO	Surface fair	Die #19 Two ports- OK	907	888	090	.096	.964	931	.095	.098	.984	.976	.096	.092	(2) Special die recessed
		Front end was rough	One port plugged by angle	920	919	090	094	964	966	095	.095	.983	.983	.093	.091	at center to form pocket for lubrication
				923	947	092	099	951	.993	.094	.102	.966	1.004	.093	.103	

GENERAL DATA

DATE : December 27, 1957

COMPANY : Babcock & Wilcox Co.

LOCATION : Beaver Falls, Pa



CROSS SECTION VIEW

NOMINAL DIMENSION:
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 22:1
CONTAINER DIAMETER 4 3/16"

Test Group No 5

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

USN No	Material	Billet Dia.	Billet Temp °F	Heating Condition	Htg Time (Min)	Billet Lubricant	Container Lubricant	Die Lubricant	Die Design	Die Material RC	Die Temp °F	Billet Transf. Time (Sec)	Extr Time (Sec)	Extrusion Practice	Max Pressure Reading	Max Press on Blt (PSI)	Max Force on Blt (Tons)	Extrusion Length Inches
51	MS 821	4 1/16" × 5" × Solid	1900	Elec Furn Argon Atmos	431	Powd GWG	950	318 Pad	26515[1]	B.A. R_c 44-48	820	19.0	30	Scalping			—	108
				#85 Coating														89 1/2
																		62
52	C135 AMO		1800	Elec Furn Argon Atmos	335	Powd 318	1000	318 Pad	26515	B A R_c 44-48	1000	204	3.8	Full Lubrication			—	65
				318A Coating										Not Scalped				114
																		112

EXTRUSION SECTION DIMENSIONS

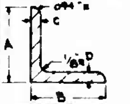
USN No	Material	Extrusion Surface Finish	Die Condition	Front				Center				End				Remarks
				A	B	C	D	A	B	C	D	A	B	C	D	
51	MS 821	Poor	Die # 20 OK	Front half taken by Republic				.993	983	.108	.102	1.023	—	.100	—	(1) Special die-recessed
		Back ends torn on two pieces		.872	.824	.094	.102	923	.878	.096	.102	.931	.935	.082	.105	at center to form pocket for lubricant
				.849	.836	.098	.099	—	986	.101	.101	—	—	—	—	Angle not filled out
52	C135 AMO	Poor	Die #18 Discard stuck	Front end split Entire length not completely filled out												Die broke
		Back ends torn on both pieces	to die- no examination	987	976	.093	.088	.997	1.022	.087	.091	995	1.027	.077	.100	
			of die made	1.018	1.015	.095	.101	1.016	1.023	.093	.104	1.061	1.054	.092	.105	

GENERAL DATA

DATE : December 27, 1957

COMPANY : Babcock & Wilcox Co

LOCATION : Beaver Falls, Pa



CROSS SECTION VIEW

NOMINAL DIMENSION:
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 22:1
CONTAINER DIAMETER 4 3/16"

Test Group No. 6

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

MRC-C 5207

PUSH No.	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER ~~LUBRICANT~~ Temp	Die Lubricant	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSFER TIME (SEC)	EXTR. TIME (SEC)	Extrusion Practice	MAX. PRESSURE READING	MAX PRESS. ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH ~~FEET~~ INCHES
53	C135 AMO	4" x 5"	1790	Elec Furn Argon Atmos	107	Powd GWG	400	Thin 318 Pad	26515	B.A. R.44-48	850	21.0	1.2	Scalping			–	75
		Solid		#85 Coating														78
																		82
54	C135 AMO	4" x 6½"	1790	Elec Furn Argon Atmos	135	Powd GWG	400	Thin 318 Pad	26515	B.A. R.44-48	850	39.6	2.4	Scalping			–	84
		Solid		#85 Coating														84
																		88
55	4340	4" x 5"	2250	Salt Bath	87	Powd TY	400-500	Thin GWG Pad	26515	B.A. R.44-48	400-500	15.0	3.0	Full Lubrication			–	77½
		Solid																60
																		78

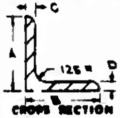
PUSH No.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS FRONT A	B	C	D	CENTER A	B	C	D	END A	B	C	D	REMARKS
53	C135 AMO	Inside - Good	Die #7 OK	Piece sent to Republic Aviation												
		Outside - Rough		1.008	.985	.098	.103	.997	.985	.099	.106	1.002	.986	.101	.106	
		And Scratched		.945	.938	.093	.100	.982	.981	.096	.102	.982	.982	.094	.102	
54	C135 AMO	Both inside	Die #16 OK	.935	.977	.087	.098	.974	.966	.092	.100	.966	.965	.091	.105	
		And outside		1.015	.986	.101	.109					1.008	1.020	.102	.099	Piece badly twisted
		Surfaces scratched		.951	.926	.097	.095	.989	.998	.100	.101	.998	.981	.098	.101	
55	4340	Good	Die #1 Die broke		No measurements made											

GENERAL DATA

DATE : January 2, 1958

COMPANY : Babcock + Wilcox

LOCATION : Beaver Falls, Pa.



CROSS SECTION VIEW

NOMINAL DIMENSION:
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060

STEM DIAMETER 4 1/16

EXTRUSION RATIO 25:1

CONTAINER DIAMETER 4 3/16

Test Group No. 6

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

MRC-C 5207

PUSH No.	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER ~~LUBRICANT~~ Temp	Die Lubricant	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSFER TIME (SEC)	EXTR. TIME (SEC)	Extrusion Practice	MAX. PRESSURE READING	MAX PRESS. ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH ~~FEET~~ INCHES
56	4340	4" x 5"	2250	Salt Bath	125	Powd TY	400-500	Thin GWG Pad	26515	B.A. R.44-48	400-500	36.0	1.8	Full Lubrication			–	76
		Solid																79
																		81½

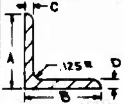
PUSH No.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS FRONT A	B	C	D	CENTER A	B	C	D	END A	B	C	D	REMARKS
56	4340	Good	Die #8 OK		No measurements made											

GENERAL DATA

DATE : January 2, 1958

COMPANY : Babcock + Wilcox

LOCATION : Beaver Falls, Pa.



CROSS SECTION VIEW

NOMINAL DIMENSION:
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060

STEM DIAMETER 4 1/16

EXTRUSION RATIO 25:1

CONTAINER DIAMETER 4 3/16

MRD-C-1207

Test Group No. 7

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

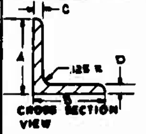
RUN NO.	MATERIAL	BILLET DIA.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER ~~LUBRICANT~~ Temp	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSFER TIME (SEC)	EXTR TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX PRESS ON BILLET (PSI)	MAX FORCE ON BILLET (TONS)	EXTRUSION LENGTH ~~SPEED~~ INCHES
57	C135 AMO	4"x5"	1800	Elec Furn Argon Atmos	55	Powd GWG	400	318 Pad	26515	B.A. R44-48	900	30.6	2.1	Scalping			–	71
		Solid		#85 Coating				Regular Grit										71
																		63 1/2
58	C135 AMO	4"x4 13/16"	1800	Elec Furn Argon Atmos	43	Powd GWG	400	318 Pad	26515	B.A. R44-48	900	27.6	2.4	Scalp with			–	74
		Solid		#85 Coating				Regular Grit						Ring guide				72
																		64
59	C135 AMO	4"x4 13/16"	1800	Elec Furn Argon Atmos	73	Powd GWG	400	318 Pad	26515	B.A. R44-48	900	25.8	3.0	Scalp with			–	83
		Solid		#85 Coating				Fine Grit						Ring guide				78
																		83

EXTRUSION SECTION DIMENSIONS

RUN NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
57	C135 AMO	Good	Die #28 Good	987	966	095	.100	1.023	1.023	.101	.103	.995	1.004	.098	.102	
				.996	981	087	.102	1.029	1.024	099	.104	990	.994	.101	.104	
				922	982	093	100	977	994	094	.101	990	994	093	.102	
58	C135 AMO	Surfaces	Die #7 Tongue washed	971	973	090	100	993	985	096	.103	997	986	097	.102	
		Scratched Slightly	Some pick-up	996	994	.102	108	1.003	996	.103	.111	1.005	1.003	.105	.113	
				991	951	092	094	.991	962	096	098	987	996	097	.102	
59	C135 AMO	Good	Die #23 Discard stuck to die	1.003	.722	098	095	1.009	.774	.100	.100	1.050	.557	.103	.100	Glass partially plugged die- angles only
		Very light		1.003	.878	091	098	1.004	.925	096	.100	1.024	.956	.097	.101	Partially filled out
		Scratches		.822	.774	092	096	.838	.870	096	.098	.887	.922	093	.099	

GENERAL DATA

DATE : January 3, 1958
COMPANY : Babcock & Wilcox
LOCATION : Beaver Falls, Pa.



NOMINAL DIMENSIONS
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 25:1
CONTAINER DIAMETER 4 3/16"

MRD-C-1207

Test Group No. 7

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

RUN NO.	MATERIAL	BILLET DIA.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER ~~LUBRICANT~~ Temp	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSFER TIME (SEC)	EXTR TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX PRESS ON BILLET (PSI)	MAX FORCE ON BILLET (TONS)	EXTRUSION LENGTH ~~SPEED~~ INCHES
60	C135 AMO	4"x4 7/8	1800	Elec Furn Argon Atmos	114	Powd GWG	400	318 Pad	26515 (1)	B.A. R44-48	930	26.4	2.4	Scalp with			–	73
		Solid		#85 Coating				Fine Grit						Guide ring				74
																		75
61	C135 AMO	4"x9 5/8"	1800	Elec Furn Argon Atmos	49	Powd GWG	400	Thick 318 Pad	26515	B.A. R44-48	1050	25.2	5.4	Scalp with			–	39
		Solid		#85 Coating				Fine Grit						Guide ring				30
																		–
62	C135 AMO	4"x9 5/8"	1800	Elec Furn Argon Atmos	98	Powd GWG	650	318 Pad	26515 (1)	B.A. R44-48	920	29.4	3.6	Scalp with			–	181
		Solid		#85 Coating				Regular Grit						Guide ring				181
																		159

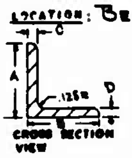
(1) Increased inlet slope
(2) Die measured before use

EXTRUSION SECTION DIMENSIONS

RUN NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
60	C135 AMO	Fair - surfaces	Die #21 One port washed	998	994	092	.102	1023	1021	097	.106	992	1023	099	.112	Badly twisted
		Scratched		1.023	1.028	095	.101	1.028	1029	099	102	1.008	1.066	099	.102	
				.999	1.026	095	.101	.997	1.002	.098	.103	998	1.000	.097	.103	
61	C135 AMO	Front end	Die #25 (2) Washed slightly	840	861	094	094	990	976	.094	095					Partial sticker
		Rough - Good		865	861	075	.095	1.001	985	092	094					
		After 12"														
62	C135 AMO	Poor -	Die #22 (2) Washed badly	973	940	095	.096	995	998	.104	.100	1.023	1.025	.135	.153	
		Heavy scratches		981	944	087	097	991	987	.106	.102	1.033	1.018	.154	.108	
				.817	.909	.090	.092	.966	.992	.093	.095	1.012	1.002	.120	.153	

GENERAL DATA

DATE : January 3, 1958
COMPANY : Babcock & Wilcox
LOCATION : Beaver Falls, Pa.



NOMINAL DIMENSIONS
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 25:1
CONTAINER DIAMETER 4 3/16"

TEST GROUP No 7

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

PUSH NO	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER TEMP	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSF TIME (SEC)	EXTR TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX UNIT ON BILLET (PSI)	MAX FORCE ON BILLET (TONS)	EXTRUSION LENGTH INCHES
63	C135 AMO	4"x4"	1800	ELEC FURN ARGON ATMOS	84	POWD GWG	400	318 PAD	26515	BA Rc44-48	920	24.6	14.2	SCALP WITH			–	34
		SOLID		#85 COATING				FINE GRIT						RING GUIDE – SLOW SPEED				35
																		36
64	C135 AMO	4"x4 5/8"	1800	ELEC FURN ARGON ATMOS	187	POWD GWG	400	THIN 318 PAD	26515	BA Rc44-48	1030	28.8	2.4	SCALP WITH			–	73
		SOLID		#85 COATING				REGULAR GRIT						RING GUIDE				74
																		54
65	MS 821	4"x5"	1920	ELEC FURN ARGON ATMOS	214	POWD GWG	600	3KB PAD	26515	BA Rc44.48	920	28.8	1.8	SCALP WITH			–	111
		SOLID		#85 COATING				REGULAR GRIT						RING GUIDE				114
																		100

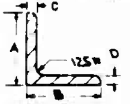
(1) DIE MEASURED BEFORE USE (.097, .099, .099)

EXTRUSION SECTION DIMENSIONS

PUSH NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
63	C135 AMO	LIGHT SCRATCHES	DIE #28 BROKEN	885	.875	091	.095	951	905	.093	.088	.997	952	.093	.099	
				980	945	.094	.092	1.000	984	.098	.103	996	1.006	.100	.103	
				1.002	980	100	.097	995	1.000	.106	.099	1.004	1.004	.100	.102	
64	C135 AMO	GOOD	DIE #26 (1) OK	.999	1.000	.101	.103	1.000	1.002	.101	.104	.993	1.002	.101	.106	GLASS PARTIALLY PLUGGED ONE PORT - FRONT END
				968	981	.092	.093	997	1.002	.098	.096	990	995	.097	.100	OF ANGLE SPLIT AND NOT COMPLETELY
												1.007	975	.086	.087	FILLED OUT
65	MS 821	POOR	DIE #27 WASHED SLIGHTLY													FRONT ENDS SPLIT
																AND ANGLES NOT
																FILLED OUT.

GENERAL DATA

DATE JANUARY 3, 1958
COMPANY BABCOCK & WILCOX
LOCATION. BEAVER FALLS, PA.



CROSS SECTION VIEW

NOMINAL DIMENSION:
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 25:1
CONTAINER DIAMETER 4 3/16"

TEST GROUP No 7

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

PUSH NO	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER TEMP	DIE LUBRICANT	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSF TIME (SEC)	EXTR TIME (SEC)	EXTRUSION PRACTICE	MAX PRESSURE READING	MAX UNIT ON BILLET (PSI)	MAX FORCE ON BILLET (TONS)	EXTRUSION LENGTH INCHES
66	MS 821	4"x5"	1920	ELEC FURN ARGON ATMOS	206	POWD GWG	600	3KB PAD	26515	BA Rc44-48	930	25.2	2.4	SCALP WITH			–	106
		SOLID		#85 COATING				FINE GRIT						RING GUIDE				84
																		84
67	MS 821	4x10"	NOT EXTRUDED – NO DIES AVAILABLE															
68	MS 821	4x10 1/8"																
69	C135 AMO	4"x7"	1800	ELEC FURN ARGON ATMOS	33	POWD GWG	650	THICK 3KB PAD	26515 (2)	BA Rc44-48	900	22.8	3.0	SCALP WITH			–	116
		SOLID (1)		#85 COATING				REGULAR GRIT						RING GUIDE				133
																		103

(1) STICKER FROM PUSH #61

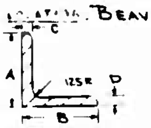
(2) RECESSED TO FORM POCKET FOR LUBRICANT

EXTRUSION SECTION DIMENSIONS

PUSH NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
66	MS 821	FAIR - HEAVY	DIE #2 OK	894	901	.085	.096	970	948	.091	.103	977	972	.097	.101	
		SCRATCHES		887	937	.086	.078	.922	974	.087	.092	940	981	.090	.090	
				927	848	.085	.087	.964	933	.084	.084	955	983	.087	.088	
69	C135 AMO	FAIR - HEAVY	DIE #24 WASHED BADLY	.867	.997	.093	.095	987	997	.099	.100	994	997	.115	.099	
		SCRATCHES		SENT TO REPUBLIC AVIATION CORP.												
				1.004	.752	.095	.095	984	1.004	.099	.103	.104	987	.094	.109	TWISTED

GENERAL DATA

DATE JANUARY 3, 1958
COMPANY BABCOCK & WILCOX
LOCATION. BEAVER FALLS, PA.



CROSS SECTION VIEW

NOMINAL DIMENSION:
A - 1.000"
B - 1.000
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1060
STEM DIAMETER 4 1/16"
EXTRUSION RATIO 25:1
CONTAINER DIAMETER 4 3/16"

Test Group No 8

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34038

Run No	Material	Billet Size	Billet Temp °F	Heating Condition	Htg Time (min)	Billet Lubricant O.D.	Container Lubricant Temp	Die Lubricant	Die Design	Die Material Rc	Die Temp °F	Billet Transf Time (sec)	Extr Time (sec)	Extrusion Practice	Max Pressure Readings	Max Pressure on Billet (psi)	Max Force to Billet (tons)	Extrusion Length Inches
70	18-8	4x6	2300	Elec Furn Induction	49 37	Powd GWG	500	Thin GWG Pad Reg Mesh	26562	LCT-2 Rc 41-42	770	24.0	30	Full Lubrication			1015	115½
				#85 Coating					#7									100
																		82
71	C135 AMo	4x5¾	1800	Elec Furn Argon Atmos	105	"	"	Thin 318 Pad Reg Mesh	"	"	1000	33.0	1.8	Scalped with Guide Ring			1050	93
				#85 Coating					#8									85
																		78
72	C135 AMo	4x5 5/16	1800	"	134	"	"	" Fine Mesh	"	"	950	-	-	"			1080	92
									#9									80½
																		78

EXTRUSION SECTION DIMENSIONS

Run No	Material	Extrusion Surface Finish	Die Condition	Front A	Front B	Front C	Front D	Center A	Center B	Center C	Center D	End A	End B	End C	End D	Remarks
70	18-8	Good	Slight wash	1.014	1.003	.111	.124	1.027	1.012	.109	.125	1.012	1.013	.110	.119	
		FE's Rough		1.003	917	.108	097	1004	993	.107	.097	981	974	.105	.097	
				.565	989	.134	092	.642	1018	.114	.107	757	1025	.106	.109	
71	C135 AMo	FE - Rough Center - Good	Good	.862	-	.113	-	952	512	.121	.104	1013	.601	.135	.106	Die ports partially plugged with glass
		BE - Poor		968	.941	104	098	1003	1002	.112	.105	1.013	1022	.116	.113	Two angles not filled completely
				-	.808	-	.109	538	.911	.114	.115	.812	986	.111	.117	
72	"	Very Good	Discard stuck in die	951	.998	.119	.103	982	.993	.123	.104	999	1.004	.123	.104	
		Some light scratches		993	995	.107	997	995	1002	.112	.102	996	1.004	.112	.103	
		FE - Rough		991	917	.104	.108	1002	958	.111	.108	1009	996	.110	.112	

GENERAL DATA

DATE: March 31, 1958

COMPANY: Babcock & Willcox

LOCATION: Beaver Falls, Pa

NOMINAL DIMENSIONS
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1080
STEM DIAMETER 4 1/16
EXTRUSION RATIO 25:1
CONTAINER DIAMETER 4 3/16

Test Group No. 8

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34038

Run No	Material	Billet Size	Billet Temp °F	Heating Condition	Htg Time (min)	Billet Lubricant O.D.	Container Lubricant Temp	Die Lubricant	Die Design	Die Material Rc	Die Temp °F	Billet Transf Time (sec)	Extr Time (sec)	Extrusion Practice	Max Pressure Readings	Max Pressure on Billet (psi)	Max Force to Billet (tons)	Extrusion Length Inches
73	C135 AMo	4x5½	1800	Elec Furn Argon Atmos	154	Powd GWG	500	Thin 318 Pad Reg Mesh	26562	LCT-2 Rc 41-42	1200	31.8	2.1	Scalped with Guide Ring			1050	106
				#85 Coating					#5									106
																		97
74	"	4x5 3/8	"	"	107	"	"	"	"	"	1200	26.4	-	"			1080	18
								Preheated	#10									25
																		15
75	"	4x10	"	"	84	"	"	Thick 318 Pad Reg Mesh	"	"	1150	33.0	-	"			1080	-
								Preheated	#14									-
																		-

EXTRUSION SECTION DIMENSIONS

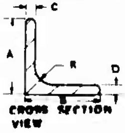
Run No	Material	Extrusion Surface Finish	Die Condition	Front A	Front B	Front C	Front D	Center A	Center B	Center C	Center D	End A	End B	End C	End D	Remarks
73	C135 AMo	FE - Rough Center - Good	Discard stuck to die	969	-	.121	-	1017	-	.123	.111	1.024	-	.117	.108	
		BE - Poor		←	Not			Filled			Out				→	
				872	996	109	.103	943	1010	.112	.103	1.005	1009	.117	.097	
74	"		"													Partial Sticker
75	"															Sticker

GENERAL DATA

DATE: March 31, 1958

COMPANY: Babcock & Willcox

LOCATION: Beaver Falls Pa



NOMINAL DIMENSIONS
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1080
STEM DIAMETER 4 1/16
EXTRUSION RATIO 25:1
CONTAINER DIAMETER 4 3/16

Test Group No. 8

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

Item No.	Material	Billet Dia.	Billet Temp °F	Heating Condition	Htg Time (min)	Billet Lubricant OD	Container Lubricant Temp	Die Lubricant	Die Design	Die Material Rc	Die Temp °F	Billet Transfer Time (sec)	Extr. Time (sec)	Extrusion Practice	Max Pressure Reading	Max Press. on Billet (psi)	Max Force on Billet (tons)	Extrusion Length Inches
76	C135 AMo	4x9 13/16	1800	Elec. Furn Argon Atmos #85 Coating	45	Powd GWG	500	Thin 318 Pad Reg. Mesh	26562 #13	LCT-2 R. 41-42	900	34.2	–	Scalped with Guide Ring			1080	– – –
77	"	4x4 13/16	"	"	63	"	900	"	" #6	"	900	31.8	1.8	"			1015	99 92 1/2 61 1/2
78	"	4x9 1/4	"	"	79	"	800	"	" #3	"	950	30.8	–	"			1080	– – –

EXTRUSION SECTION DIMENSIONS

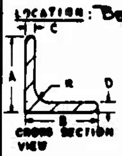
Item No.	Material	Extrusion Surface Finish	Die Condition	Front A	Front B	Front C	Front D	Center A	Center B	Center C	Center D	End A	End B	End C	End D	Remarks
76	C135 AMo															Sticker
77	"	Fair but	Discard stuck to die	.912	.961	.116	.103	.976	.996	.117	.101	1.014	1.010	.118	.101	
		somewhat rough		.894	.904	.112	.110	.930	.956	.111	.112	.966	1.004	.109	.116	
																Angle not filled out
78	"															Sticker

GENERAL DATA

Date : March 31, 1958

Company : Babcock & Wilcox

Location : Beaver Falls, Pa.



Nominal dimensions:
A - 1.000"
B - 1.000"
C - .094"
D - .094"

Press capacity (tons) 1080

Stem diameter 4 1/16"

Extrusion ratio 25:1

Container diameter 4 3/16"

Test Group No. 8

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

Item No.	Material	Billet Dia.	Billet Temp °F	Heating Condition	Htg Time (min)	Billet Lubricant OD	Container Lubricant Temp	Die Lubricant	Die Design	Die Material Rc	Die Temp °F	Billet Transfer Time (sec)	Extr. Time (sec)	Extrusion Practice	Max Pressure Reading	Max Press. on Billet (psi)	Max Force on Billet (tons)	Extrusion Length Inches
79	C135 AMo	4x8 7/8	1800	Elec. Furn Argon Atmos #88 Coating	80	Powd GWG	650	2 Thin 318 Pads Reg. Mesh	26562 #2	LCT-2 D. 41-42	950	33.6	2.4	Full Lubrication			910	185 142 161
80	"	4x8 5/8	1850	"	67	"	1090	"	" #11	"	900	36.6	2.4	Scalped with Guide Ring			980	215 149 147
81	"	4x8 3/4	1850	"	50	"	900	"	Modified Flat Flat #8	"	900	34.2	3.0	"			1080	146 197 301

EXTRUSION SECTION DIMENSIONS

Item No.	Material	Extrusion Surface Finish	Die Condition	Front A	Front B	Front C	Front D	Center A	Center B	Center C	Center D	End A	End B	End C	End D	Remarks
79	C135 AMo	Surface Fair FE - Rough	Discard stuck in die	.941	.952	.103	.104	.918	1.023	.105	.104	1.006	1.032	.106	.102	
		Edges Poor		1.005	1.009	.107	.107	1.020	1.017	.111	.108	1.060	1.065	.110	.107	
				.880	.715	.108	.104	1.007	.856	.107	.101	1.023	.955	.106	.103	
80	"	Rough	"	.928	.951	.118	.108	1.024	1.024	.117	.108	1.050	1.055	.116	.110	
				–	.852	.117	.107	.689	.953	.115	.105	.854	1.024	.114	.106	
				–	–	.108	.109	.825	.770	.109	.110	.953	.865	.111	.111	
81	"	Poor	"	←				Not Filled		Out		→				
				←				Not Filled		Out		→				
				.830	.673	.118	.102	.981	.950	.132	.107	.986	1.018	.113	.126	

GENERAL DATA

Date : March 31, 1958

Company : Babcock & Wilcox

Location : Beaver Falls, Pa

Nominal dimensions:
A - 1.000"
B - 1.000"
C - .094"
D - .094"

Press capacity (tons) 1080

Stem diameter 4 1/16

Extrusion ratio 25:1

Container diameter 4 3/16

Test Group No. 8

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

RUN No.	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT Temp	Die Lubricant	DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSFER TIME (SEC)	EXTR. TIME (SEC)	Extrusion Practice	MAX. PRESSURE READING	MAX PRESS. ON BILLET (PSI)	MAX FORCE ON BILLET (TONS)	EXTRUSION LENGTH INCHES
82	C135 Ann.	4×8½	1900	Elec. Furn. Argon Atmos. #88 Coating	42	Powd Glass	900	2 Thin 316 Paste Reg. Mesh	26562 #1	LCT-2 R.51-52	900	–	–	Scalped with Guide Ring			1080	412½
																		261½
																		66

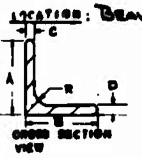
RUN No.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT A	FRONT B	FRONT C	FRONT D	CENTER A	CENTER B	CENTER C	CENTER D	END A	END B	END C	END D	REMARKS
82	C135 Ann.	Poor Badly Torn	Discard stuck in Die	←			Not	Filled		Out				→		Temperature too High!

GENERAL DATA

DATE : March 31, 1958

COMPANY : Babcock & Wilcox

LOCATION : Beaver Falls, Pa.



NOMINAL DIMENSIONS
A - 1.000"
B - 1.000"
C - .094"
D - .094"

PRESS CAPACITY (TONS) 1080
STEM DIAMETER 4¼
EXTRUSION RATIO 25:1
CONTAINER DIAMETER 4⅜"

PART II EXTRUSION TRIAL DATA SHEETS

UNITED STATES STEEL CORPORATION

TEST DATA OF EXTRUSION TRIALS AF33(600) 34898

MRO-C-5207

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)
1	1015 Steel	12"	2130	Muffle Fce.	180	No. 85 Glass Frit	None		Cast Conical	E-14 Steel R 20C	300	35	4		-	-	350	20
2	"	8-1/4"	2080	" "	60	"	Fisk #601		Cast Flat Face	"	"	75	5		-	-	400	18
3	"	"	2100	Muffle Fce. 5 cfh Argon	35	"	"		Cast Conical	"	"	35	-		-	-	500	-
4	"	"	2130	Muffle Fce. 15 cfh Argon	65	Powdered No.85 Glass	"		"	"	"	"	4		-	-	500	-
5	"	"	2200	" "	60	"	"		"	"	"	"	-		-	-	400	17

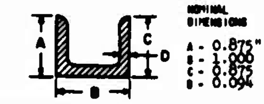
PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
1	1015 Steel	Tears and Wavy Edges	Deformed Badly									.925	1.070	.920	.082 .105 .086	Dimensions of cross-section were poor
2	"	Heavy Ridges	"					Not Determined								Only about half of Section Extruded
3	"	-	OK					No Extrusion								Die Almost Completely Closed
4	"	-	Deformed Very Badly					No Extrusion								One Flange did not Extrude - Die Closed
5	"	Good	Partly Deformed					Not Determined								

GENERAL DATA

DATE : August 16, 1957

COMPANY : National Tube Division

LOCATION: Gary, Indiana



CROSS SECTION VIEW

PRESS CAPACITY (TONS) 500

STEM DIAMETER 2.782"

EXTRUSION RATIO 27

CONTAINER DIAMETER 2-15/16"

TEST DATA OF EXTRUSION TRIALS AF33(600) 34898

MRO-C-5207

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)
6	1015 Steel	8-1/4"	2000	Muffle Fce. 8 cfh Argon	60	Powdered No.85 Glass	Fisk #601		Cast Flat Face	E-14 Steel R 20C	300	35	-		-	-	500	-
7	"	"	2300	Muffle Fce. 10 cfh Argon	35	"	"		"	"	"	"	4		-	-	300	16
8	"	"	2150	In Molten No.85 Glass	70	Molten No.85 Glass	None		Cast Flat Face	"	"	40	"		-	-	400	10
9	"	"	2350	Muffle Fce. 10 cfh Argon	60	Powdered No.85 Glass			Cast Conical	"	"	"	"		-	-	300	14
10	"	"	2130	In Molten No.85 Glass	30	Molten No.85 Glass			"	"	"	"	"		-	-	500	-
11	"	"	2160	"	45	Molten No.85 Glass			Halcomb Flat Face	"218" R 40C	"	"	-		-	-	250	14
12	"	"	2100	Muffle Fce. 10 cfh Argon	30	Powdered No.85 Glass			"	"	"	"	6		-	-	500	0'-8"
13	Ti 155A	"	2120	"	37	Powdered 3KB Glass			"	"	"	"	-		-	-	500	-
14	"	"	2100	In Molten 3KB Glass	30	Molten 3KB Glass			"	"	"	"	-		-	-	500	-
15	1015 Steel	"	2150	Muffle Fce. 10 cfh Argon	45	Powdered No.85 Glass			"	"	"	"	-		-	-	500	-

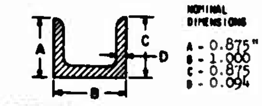
PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
6	1015 Steel	-	Deformed Slightly					No Extrusion								
7	"	Good	OK					.900	1.020	.898	.095 .095 .100					
8	"	One Flange Wavy and Torn	OK					Not Determined								
9	"	Good	OK					.912	1.012	.886	.105 .102 .104					
10	"	-	Deformed Badly					No Extrusion								
11	"	Excellent	OK					.898	1.015	.883	.100 .100 .102					
12	"	"	OK					Not Determined								Only 8" Product
13	Ti 155A	-	OK					No Extrusion								
14	Ti 155A	-	OK					No Extrusion								
15	1015 Steel	-	OK					No Extrusion								

GENERAL DATA

DATE : August 16, 1957

COMPANY : National Tube Division

LOCATION: Gary, Indiana



CROSS SECTION VIEW

PRESS CAPACITY (TONS) 500

STEM DIAMETER 2.782"

EXTRUSION RATIO 27

CONTAINER DIAMETER 2-15/16"

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)
16	Ti 155A	5-7/8"	2270	Muffle Fce. 10 cfh Argon	40	Powdered 3KB Glass	None		Halcomb Flat Face	"218" R 40C	300	40	4			-	350	9'-6"

PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
16	Ti 155A	Front-OK Back-Scratches	Die Pick-Up					.917	1.045	.905	.122 .115 .115					

GENERAL DATA

DATE : August 16, 1957
COMPANY : National Tube Division
LOCATION: Gary, Indiana

NOMINAL DIMENSIONS
A - 0.875"
B - 1.000
C - 0.875
D - 0.094

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 500
STEM DIAMETER 2.782"
EXTRUSION RATIO 27
CONTAINER DIAMETER 2-15/16"

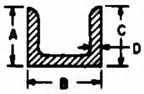
TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)
17	1015 Steel	8-1/4"	2275	In Container In Salt Pot	52	None	Fisk #604 Grease		Halcomb Flat Face	"218" R 50C	300	35	5		-	-	400	9'-11"
				With Argon														
18	Ti 155A	6"	2180	In Molten #9771 Glass	61	Molten #9771 Gl.	None		"	"	"	34	-		-	-	500	-
19	"	6"	2200	"	30	"	"		"	"	"	64	-		-	-	500	-
20	"	6"	2200	In Container In Salt Pot	40	None	Fisk #604 Grease		"	"	"	46	6		-	-	400	9'-6"
				With Argon														
21	"	8"	2000	"	35	"	"		"	"	"	27	6		-	-	500	11'-9"
22	"	8"	1750	"	30	"	"		"	"	"	34	6		-	-	500	15'-11"
23	"	8"	1640	"	30	"	"		Two-Part "218"	Halcomb R 50C	"	36	-		-	-	500	-

PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
17	1015 Steel	Badly Torn	Fractured					.880	1.000	.930	.093 .098					
18	Ti 155A	-	OK					No	Extrusion							
19	"	-	OK					No	Extrusion							
20	"	Flanges Wavy and Torn	Slight Die Pick-Up					.925	1.010	.900	.095 .115					
21	"	Partly Torn Flanges	Fractured					.910	1.011	.895	.090 .107					
22	"	Torn Flanges	Pick-Up					.890	1.005	.800	.090 .098					
23	"		OK					No	Extrusion							

GENERAL DATA

DATE : October 10, 1957
COMPANY : National Tube Division
LOCATION: Gary, Indiana



NOMINAL DIMENSIONS
A - 0.875"
B - 1.000
C - 0.875
D - 0.094

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 500
STEM DIAMETER 2.782"
EXTRUSION RATIO 27
CONTAINER DIAMETER 2-15/16"

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

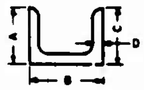
MRB-C-5207

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)
24	Ti-155	6-1/4 x 2-3 4"	1800	In container in Salt Pot with Argon	30	None	Fisk #604 Grease	Container Pre-heated by Open flame through out run. Fisk grease and plumbago on Die.	Break-down + Flat Face	Halcomb 218	500 F	30	-	Slow Extrusion Attempted, Failed to Extrude.		3500	500	None
[illegible]	"	"	1800	"	31	"	"	"	Flat Face 1/8" Land	"	"	25	-	"		"	"	"
[illegible]	"	"	1550	"	30	"	"	"	"	"	"	30	-	"		"	"	"
[illegible]	"	"	1650	"	33	"	"	"	"	"	"	35	3	Fast Application of Press Force		"	"	[illegible]
[illegible]	"	"	1800	"	32			" Aluminum Follower	"	"	"	35	2	"		3100	[illegible]	10'-2"
29	"	"	1800	"	42	"	Fisk #604 Grease + #575 Glass Pad	" "	"	"	"	38	2	"		3300	500	11'-2

PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
		• Requirement		.885 .865	1.012 .988	.885 .865	.100 .088									
[illegible]	Ti-155	Slight tears on legs and base at front and back ends.	Discard Pulled Out	.900	1.027	.898	.106 .105 .093	.893	1.016	.900	.105 .102 .095	.900	1.018	.903	.105 .102 .093	All Dies Showed some "Washing" and Deformation (Hot Flow).
[illegible]	"	Tears front 12" heavy scratches toward back.	"	.900	1.016	.903	.102 .103 .090	.898	1.015	.895	.105 .103 .093	.898	1.018	.905	.105 .106 .096	
29	"	Badly torn edges at back end, med. scratches	Die Plugged with Aluminum	.890	1.014	.903	.104 .105 .092	.880	1.025	.905	.112 .097 .085	.903	1.045	.923	.105 .125 .105	

GENERAL DATA

DATE : November 6, 1957
COMPANY : National Tube Div.
LOCATION: Gary, Indiana



NOMINAL DIMENSIONS
A - 0.875
B - 1.000
C - 0.875
D - 0.094

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 500
STEM DIAMETER 2.782"
EXTRUSION RATIO 27
CONTAINER DIAMETER 2-[illegible]/16"

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

MRB-C-5207

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)
30	Ti-155	6-1, 4x 2-3, 4"	1800	Same but not Argon.	34	None	Fisk #604 + Powdered #575 Glass	Aluminum Follower [illegible]	Flat Face 1/8" Land	Halcomb 218	500 F	30	2	Fast Application of Press Force		3200	457	11'-5-1/2"
[illegible]	"	"	1800	In container in Salt Pot with Argon.	32	"	Fisk #604 Grease	Fisk #604 Grease and Plumbago on Dies. Aluminum Follower used.	Flat Face .093" Land	"	"	30	1.5	"		3400	485	10'-8"
32	"	"	1750	Same but no Argon.	30	"	"	"	"	"	"	-	-	"		3200	457	8'-11"
[illegible]	"	"	1750	"	30	"	"	"	"	"	"	-	-	"		3500	500	11'-7"
[illegible]	"	"	1700	Same with Argon.	30	"	"	"	"	"	"	25	2	"		3250	[illegible]	11'-2"

PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
30	Ti-155	Slightly better than #29.	Die Plugged with Aluminum	.900	1.025	.900	.083 .100 .095	.895	1.009	.896	.089 .095 .084	.887	1.018	.895	.100 .105 .093	All Dies Showed some "Washing" and Deformation (Hot Flow) of Surface.
31	"	Inside - Good Outside - Scratched		.900	1.022	.898	.100 .098	.895	1.021	.890	.104 .104 .086	.900	1.025	.895	.120 .112 .081	
32	"		Discard Pulled Out	.900	1.013	.905	.099 .103 .090	.898	1.015	.900	.106 .108 .088	.900	1.022	.905	.112 .118 .100	
33	"	Good Surface		.895	1.013	.900	.100 .103 .090	.890	1.013	.893	.100 .103 .088	.890	1.015	.903	.100 .103 .096	
34	"	"		.900	1.014	.896	.103 .105 .085	.899	1.016	.895	.102 .106 .088	.904	1.022	.888	.078 .077 .083	

GENERAL DATA

DATE : November 6, 1957
COMPANY : National Tube Div.
LOCATION: Gary, Indiana

NOMINAL DIMENSIONS
A -
B -
C -
D -

CROSS SECTION VIEW

PRESS CAPACITY (TONS) ____
STEM DIAMETER ____
EXTRUSION RATIO ____
CONTAINER DIAMETER ____

TEST DATA OF EXTRUSION TRIALS AF33(600) [illegible]

[illegible]

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)
35	Ti-155	6-1/4 x 2-3/4"	1650	Same with Argon.	30	None	Fisk #604 Grease	No Aluminum Follower	Flat Face .093" Land	Halcomb 218	500	27	2	Fast Application of Press Force		3350	478	12' - 3-1/2"
36	"	"	1650	"	30	"	"	"	Flat Face 1/8" Land	"	"	27	2	"		3400	485	12'-7"
37	"	"	1650	"	30	"	"	"	Break-down +	"	"	-	-	" Failed to		3500	500	-
									Flat Face					Extrude				

PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
35	Ti-155	Fair Surface Pick-up Scratches		.895	1.020	.885	.102 .097	.885	1.015	.892	.095 .092	.876	1.016	.876	.090 .093	All Dies Exhibited
		toward back.					.087				.081				.065	some "Washing" and
36	"	Good Surface but Pick-up		.895	1.020	.904	.105 .102	.885	1.020	.902	.100 .095	.903	1.030	.904	.087 .085	Deformation (Hot
		Scratches toward Back.					.094				.092				.060	Flow) of Surface.

GENERAL DATA

DATE : November 6, 1957
COMPANY : National Tube Div.
LOCATION: Gary, Indiana

NOMINAL DIMENSIONS
A -
B -
C -
D -

CROSS SECTION VIEW

PRESS CAPACITY (TONS) ____
STEM DIAMETER ____
EXTRUSION RATIO ____
CONTAINER DIAMETER ____

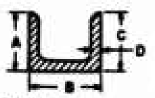
TEST DATA OF EXTRUSION TRIALS AF33(600) [illegible]

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)
38	Ti-155	6 1/4x 2 3/4"	1700	In container In salt pot	30	none	Fisk #604 grease	Fisk #604+ graphite	Flat Face 3/32" and	Halcomb 218	400/500	24	-	Press force applied slowly	Failed to Extrude			
				With Argon														
39	"	"	1700	"	34	"	"	"	"	"	"	34	-	"	"	"		"
40	"	8 1/4x 2 3/4"	1750	"	49*	"	"	"	"	"	"	29	3	*1700F for 30M., 1750F for 19M.	3300	3200		14'-9"
41	"	"	1750	"	54	"	"	10% additional graphite	"	"	"	24	3		3600	3600		14'-4"
42	"	"	1750	"	39	"	"	10% #575 glass in Fisk #604	"	"	"	67	2		3450	3450		14'-9"
43	"	"	1750	"	59	"	"	5% #575 glass in Fisk #604	"	"	"	25	2		3600	3600		14'-4
44	"	"	1750	"	54	"	Fisk #604 #575 glass	10% #575 glass Gr. in Fisk604	"	"	"	30	2		3600	3600		13'-3

PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
40	Ti-155	Tears at both front and back	Badly washed out pick-up on die	.897	1.015	.894	.105 .102	.895	1.014	.886	.108 .108	.893	1.022	.882	.098 .099	
		Lt. ridges in center	tongue				.088				.088				.097	
41	Ti-155	Front - OK Center-hvy. ridges	Badly washed out	.902	1.016	.895	.108 .106	.893	1.021	.897	.117 .108	.890	1.045	.883	.115 .112	
		Back-hvy. ridges and tears					.093				.098				.110	
42	Ti-155	Front - OK Back-bad scratches	Moderately washed	.887	1.019	.897	.102 .104	.885	1.017	.900	.100 .101	.886	1.004	.900	.099 .088	
		and tears on outer surface					.090				.094				.099	
43	Ti-155	Same as above	Moderately washed, pick-	.895	1.016	.888	.107 .100	.890	1.030	.888	.100 .106	.885	1.065	.875	.085 .070	Ridges on back and to hvy. for accurate
			up on tongue				.096				.106				.135	measurement
44	Ti-155	Same as above	Moderately washed	.905	1.025	.895	.100 .105	.900	1.020	.894	.105 .102	.895	1.022	.888	.106 .105	
							.095				.095				.094	

GENERAL DATA

DATE : 12-18-57
COMPANY : National Tube
LOCATION: Gary, Indiana



NOMINAL DIMENSIONS
A - 0.875
B - 1.000
C - 0.875
D - 0.094

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 500
STEM DIAMETER 2.782"
EXTRUSION RATIO 27
CONTAINER DIAMETER 2 15/16"

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT	Die Lubricant	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTR. LENGTH (FEET)
45	C1-155A	8¼ x 2¾"	1750	In container In salt pot With Argon	40	none	Fisk #604, #575Glass	10% #575 glass, Gr. in Fisk604	cast flat face	Peerless LCT-2	400/500	24	2		3600	3600		12'-5"
46	"	"	1750	"	43	"	Fisk #604	10% #575 glass in Fisk #604	Breakdown (two part)	Malcomb 218	"	31	-		Failed to Extrude			
47	"	"	1750	"	40	"	"	Same plus Graphite	Cast conical	Peerless LCT-2	"	28	2		3600	3600		12'-3"
48	C140AMo	6 x 3/4"	1750	"	36	"	"	"	Cast Flat face	"	"	32	2		3500	3500		8'-4
49	C140AMo	"	1800	"	40*	"	"	"	"	"	"	31	2	*1750F for 28M., 1800F for 12M.	3300	3300		8'-8"

PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
45	C1-155	Front - OK Back -bad scratches and tears on outer surface	Badly washed, Discard stuck	.914	1.044	.909	121 121 120	.908	1.039	.898	117 116 121	.892	1.049	.885	.075 .093 125	
47	C1-155	Same as above	Light scratches, No washout	.914	1.041	.910	122 120 125	.913	1.035	.905	111 116 118	.910	1.035	.890	105 105 120	
48	C140AMo	Front-OK Rear - Scratches	Same as above	.929	1.037	.915	121 115 120	.920	1.043	.915	120 113 120	.920	1.050	.914	125 117 120	Cross-section Consistent Throughout length
49	C140AMo	Light scratches and tears throughout	Same as above	.911	1.050	.910	123 119 122	.920	1.052	.911	125 115 120	.916	1.037	.903	123 117 120	

GENERAL DATA

DATE : 12-18-57

COMPANY : National Tube

LOCATION: Gary, Indiana

NOMINAL DIMENSIONS

A -
B -
C -
D -

CROSS SECTION VIEW

PRESS CAPACITY (TONS) ________

STEM DIAMETER ________

EXTRUSION RATIO ________

CONTAINER DIAMETER ________

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTR. LENGTH (FEET)
50	C140AMo	6 x 2 3/4"	1700	In container In salt bath With Argon	56*	none	Fisk #604	10% #575 glass in Fisk #604 Plus Graphite	Cast Flat face	Peerless LCT-2	400/500	31	2	*1800F for 30M., 1700F for 26M.	3400	3400		8'-5
51	"	"	1650	"	75*	"	"	Same plus 1/8" disc of #575 glass	"	"	"	45	2	*1800F for 5M., 1700F for 44M., 1650F for 26M.	3200	3200		7'-11
52	"	8¼ x 2¾"	1650	"	53*	"	"	Fisk #604 Plus Graphite	"	"	"	26	-	*1700F for 16M., 1650F for 37M.	Failed to Extrude			
														(Slow application of press force)				

PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
50	C130AMo	Very light scratches and tears throughout	Light scratches No washout	.913	1.040	.912	123 115 110	.913	1.042	.911	121 114 114	.918	1.042	.916	123 116 111	
51	C130AMo	Same as above	Same as above	.914	1.052	.908	120 131 120	.913	1.051	.908	116 127 117	.918	1.054	.910	120 124 115	

GENERAL DATA

DATE : 12-18-57

COMPANY : National Tube

LOCATION: Gary, Indiana

NOMINAL DIMENSIONS

A -
B -
C -
D -

CROSS SECTION VIEW

PRESS CAPACITY (TONS) ________

STEM DIAMETER ________

EXTRUSION RATIO ________

CONTAINER DIAMETER ________

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

MRO-C-5207

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT	Die Lubricant	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)	WATER QUENCH
53	T1-155A	6-1/8"	1750	Salt Bath: Argon 10 cfh	32	575 Glass Pad	Fisk #604	Graphite on Die Face	Flat Face	Cast Hi-Tungsten	400	30	3		850	850	119	8'-3"	Front
54	"	7-7/8"	"	" "	33	Pad of Al & Glass	Fisk & 15% Glass	" "	"	"	"	15	2		1800	1800	252	7'-8"	Front
55	"	8"	"	" "	31	575 Glass Pad	" "	" "	"	"	600	15	2		2250	2250	315	12'-7"	Front
56	"	8-1/8"	1700	" "	40*	"	" "	" "	"	"	500	18	2	*15 min. 1750, bal. 1700	2250	2250	315	12'-11"	Front
57	"	8-1/8"	1650	" "	31*	"	" "	" "	"	"	550	17	2	*11 min. 1700, bal. 1650	3100	3100	434	12'-11"	Front
58	"	8-1/8"	1650	" "	31	"	" "	" "	"	"	600	17	2		3300	3300	462	9'-5"	None
59	"	8-3/16"	1650	" "	30	"	" "	" "	"	"	600	13	2		3300	3300	462	11'-8"	None
60	"	8-3/16"	1650	" "	30	"	" "	" "	"	"	600	15	2		3300	3300	462	12'-5"	None
61	"	8-3/16"	1650	" "	32	"	" "	" "	Conical	"	900	20	4		3300	3300	462	12'-4"	None

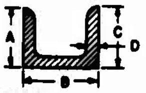
PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
53	T1-155A	Lt. Ridges all along	OK-use on the next push	905	1031	905	105 118	907	1038	908	110 114	895	1039	906	110 122	Butt end shows good flow.
54	"	Ridges; Badly torn edges	OK-use on the next push	883	1040	900	095 114	880	1037	892	100 117	900	1040	900	110 120	Butt-folding; flow not so good as #53.
55	"	75% torn edges Ridges	Discard on die Die removed	885	1040	903	080 120	900	1040	905	100 115	900	1041	903	110 115	Butt folds; slight shear; dropped temp.
56	"	Feathered edges, Ridges	OK	905	1050	895	093 110	910	1032	900	100 110	910	1041	888	115 120	Butt folding.
57	"	Lead - fair, Trail - Ridges	OK	895	1035	888	090 115	910	1040	895	103 113	915	1043	907	111 117	Lost locating Pin; Butt-good flow.
58	"	Lead - Good, Bal-ridges,torn	Pick-up and washout. 2nd	895	1050	915	072 090	907	1035	910	100 105	915	1040	905	106 118	Butt - evidence of shear cone.
59	"	Lead - fair, Bal.-ridges	Washout - removed. 2nd	892	1040	895	085 105	892	1038	898	099 110	903	1017	900	093 115	Butt-dev. shear; Sec. sheared off.
60	"	Light ridges throughout	Sec. stuck in Die. 1st.	905	990	915	100 127	900	1030	910	105 115	908	1045	915	115 120	Butt - shows good flow.
61	"	Ridges throughout	Center sec. out	925	1080	938	092 103	911	1059	905	087 115	912	1061	902	112 115	Butt-good flow, section sheared off.

GENERAL DATA

DATE : February 28, 1958

COMPANY : National Tube Division

LOCATION: Gary, Indiana



NOMINAL DIMENSIONS
A - .875
B -1.000
C - .875
D - .094

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 500

STEM DIAMETER 2.782"

EXTRUSION RATIO 27

CONTAINER DIAMETER 2-15/16"

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

MRO-C-5207

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT	Die Lubricant	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)	WATER QUENCH
62	T1-155A	8-1/4"	1650	Salt Bath; Argon 10 cfh	48	"Cast Iron" Glass	Fisk & 15% Gl	Graphite	Conical	Cast Hi-Tungsten	550	15	2		3550	3550	497	12'-4"	None
63	"	8-3/8"	"	" "	41	No Pad	"	No Graphite	"	"	550	18	2		3300	3300	462	11'-10"	None
64	"	8-3/8"	"	" "	44	" "	"	" "	"	"	600	20	2		2900	2900	406	13'-2"	None
65	"	8-3/8"	"	" "	31	" "	"	" "	Flat Face	"	-	-	-	Sticker	3300	3300	462	-	-
66	"	8-1/8"	"	" "	33	" "	"	Fisk on Die	"	"	-	-	-	Sticker	3300	3300	462	-	-
67	"	8-3/8"	"	" "	31	575 Glass Pad	"	" "	"	"	-	-	-	Sticker	3400	3400	476	-	-
68	C135AMO	7"	"	" "	31	" "	"	Graphite on Die Face	"	"	-	-	-	Sticker	3400	3400	476	-	-
69	"	7-1/16"	1700	" "	31*	" "	"	" "	"	"	600	23	3	15 min. at 1650 bal.1700	3100	3100	434	10'-10"	None
70	"	7-5/8"	"	" "	30	3KB Pad Glass	"	" "	"	"	600	23	3		2750	2750	385	12'-2"	None

PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
62	T1-155A	Ridges	Discard stuck in die - out.	920	1063	923	090 109	925	1061	921	115 116	915	1055	920	120 123	
63	"	Light ridges throughout	Slight washout	898	1058	925	091 119	900	1063	932	118 125	915	1060	931	121 125	Lubr. cont. only; Butt - Shear cone.
64	"	Ridges 1/3 way to end.	Same die as #63	893	1051	905	065 115	915	1064	918	083 115	925	1065	915	100 105	Butt - more than #63 Lbr. cont. only
65	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sticker Extr. 1"
66	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sticker Extr. 1-1/2"
67	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sticker Extr. 1-1/2"
68	C135AMO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Sticker Extr. 1"
69	"	Glass all along Ridges	OK-no washout 2nd use	916	1035	918	110 115	880	1032	921	113 115	840	1039	915	110 115	Butt - fair flow pattern
70	"	Fair	OK-no washout 1st use	880	1035	872	110 120	895	1033	895	102 108	905	1040	905	105 110	Butt - fair flow; glass covered

GENERAL DATA

DATE : February 28, 1958

COMPANY : National Tube Division

LOCATION: Gary, Indiana

NOMINAL DIMENSIONS
A - .875
B -1.000
C - .875
D - .094

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 500

STEM DIAMETER 2.782"

EXTRUSION RATIO 27

CONTAINER DIAMETER 2-15/16"

TEST DATA OF EXTRUSION TRIALS AF33(600) [illegible]

PUSH NO.	MATERIAL	BILLET DIM.	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT	CONTAINER LUBRICANT	Die Lubricant	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH (FEET)	QUENCH
71	C135AMO	7-3/4"	1700	Salt Bath Argon 10 cfh	30	3KB Glass Pad	Fisk & 15% Gl.	Graphite	Conical	Cast Hi Tungsten	600	17	3		2600	2600	364	9'-11"	Front
72	"	7-7/8"	"	" "	30	"	"	"	"	"	600	17	3		3300	3300	462	13'-/"	Front
73	"	7-13/16"	"	" "	31	Solid Al Disc	"	"	Flat Face	"	600	20	-	Sticker	3400	3400	476	-	-
74	"	9-3/8"	"	" "	30	3KB Glass PAD	"	"	"	"	600	22	3		3300	3300	462	15'-1"	None

PUSH NO.	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	EXTRUSION SECTION DIMENSIONS												REMARKS
				FRONT				CENTER				END				
				A	B	C	D	A	B	C	D	A	B	C	D	
71	C135AMO	Fair surface	OK - slightly washed	925	1085	914	100 121	931	1080	910	105 130	930	1085	912	120 129	Butt - fair flow; sheared off
72	"	Ridges	Pick-up; Die removed. 2nd	918	1095	930	070 085	908	1100	905	073 095	900	1095	895	100 105	Fair flow; sheared off. Inaccurate dimen.
73	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	because of ridges. Sticker Extr. 1-1/2"
74	"	Ridges	OK	895	1014	892	095 110	905	1030	903	110 118	910	1039	905	110 115	Fair flow; Cannot mike accurately - Ridges.

GENERAL DATA

DATE : February 28, 1958

COMPANY : National Tube Division

LOCATION: Gary, Indiana

NOMINAL DIMENSIONS

A - .875
B - 1.000
C - .075
D - .094

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 500

STEM DIAMETER 2.782"

EXTRUSION RATIO 27

CONTAINER DIAMETER 2-15/16"

PART II EXTRUSION TRIAL
DATA SHEETS

H. M. HARPER COMPANY

MRD-C-[illegible]

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

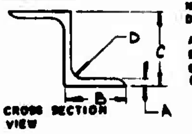
USH NO	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSFER TIME (SEC)	EXTR. TIME (SEC)		STARTING BREAK TIME P.S.I	END PRESSURE READING P.S.I	MAX PRESS ON BILLET (PSI)	MAX FORCE ON BILLET (TONS)	EXTRUSION LENGTH (FEET)
1	4140	$3\frac{7}{8}$ x 4	2260F	60 CYCLE INDUCTION	5MIN 50SEC	SCRAP GLASS	1100 GLASS		5192 X 2	M2 RC 50-52	300	20	7.8						21
2	4140	$3\frac{7}{8}$ x 4	2250	"	5MIN 45SEC	"	"		5192 X 2	M2 RC 50-52	400	25	6.0						19
3	4140	$3\frac{7}{8}$ x 4	2200	"	5MIN 45SEC	"	"		5192 X 1	M2 RC 50-52	350	20		STICKER					
4	4140	"	2240	"	5MIN 55SEC	"	"		5192 X 2	M2 RC 50-52	350	15	6.6						20
5	4140	"	2250	"	4MIN 10SEC	"	"		5192 X 1	M2 RC 54-56	350	15	8.4						26
6	4140	"	2250	"	4MIN 10SEC	"	"		5192 X 2	M2 RC 54-56	300	20		STICKER					
7	Ti-155A	"	1850	"	4MIN 50SEC	3KB	X-375		5192 X 1	M2 RC 54-56	400	20		STICKER	2000	2000	144000	920	
8	Ti-155A	"	2060	"	5MIN 55SEC	3KB	3KBA		5192 X 2	M2 RC 54-56	400	15		STICKER	2080	2080	152000	955	
9	Ti-155A	"	2200	"		3KB	3KBA		5192 X 2	M2 RC 54-56	400	20		STICKER	2100	2100	153000	965	

EXTRUSION SECTION DIMENSIONS

USH NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
1	4140	FAIR	ERODED BEYOND REUSE	.090	.550	I	1/8	.116	.580	I	1/4	.125	.670	I	3/16	I - BAD TWIST
2	4140	POOR	"	.090	.510	I	I	.119	.540	I	I	.137	.630	I	I	B-ONE LEG DID NOT FILL FOR SIX FEET I-BAD TWIST
3	4140	STICKER														
4	4140	FAIR	ERODED BEYOND REUSE	.090	.375	I	I	.103	.490	I	I	.141	.640	I	I	I - BAD TWIST
5	4140	GOOD	ERODED BEYOND REUSE	.090	.600	.760	1/8	.100	.610	.780	1/8	.05	.645	.740	1/4	
6	4140	STICKER														
7	Ti-155A	STICKER														
8	Ti-155A	STICKER														
9	Ti-155A	STICKER														

GENERAL DATA

DATE : 10-10-57
COMPANY : H.M HARPER
LOCATION : MORTON GROVE ILL.



NOMINAL DIMENSIONS
A -.062±.006
B -.675±.009
C -.750±.010
D -.125±.015

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 1050
STEM DIAMETER $3\frac{15}{16}$
EXTRUSION RATIO 102 TO 1
CONTAINER DIAMETER 4 INCH

MRD-C-[illegible]

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

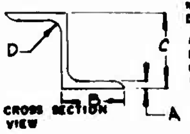
USH NO	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSFER TIME (SEC)	EXTR. TIME (SEC)		STARTING BREAK THRU P.S.I	END PRESSURE READING P.S.I	MAX PRESS ON BILLET (PSI)	MAX FORCE ON BILLET (TONS)	EXTRUSION LENGTH (FEET)
10	Ti-155A	$3\frac{7}{8}$ x 4"	2320	60 CYCLE INDUCTION	7MIN 35SEC	SCRAP	1100		5192 X-1	M2 RC 52-54	400	20	6.0		1760	2040	149000	935	25
11	Ti-155A	"	2320	"	7MIN 36SEC	"	"		5192X-2	"	"	"	"		2060	1860	150000	945	22

EXTRUSION SECTION DIMENSIONS

USH NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
10	Ti-155A	POOR BAD DIE LINES	ERODED BEYON REUSE CRACKED	.062	.610	.760	1/8	.075	.633	.780	3/16	.107	.645	.800	1/4	B-ONE LEG DID NOT FILL FOR FIVE FEET.
11	Ti-155A	"	"	.074	.600	—	3/16	.113	.615	—	1/4	.294	.660	—	1/2	B-ONE LEG DID NOT FILL FOR SIX FEET C-BAD TWIST

GENERAL DATA

DATE : 10-10-57
COMPANY : H.M. HARPER CO
LOCATION : MORTON GROVE ILL



NOMINAL DIMENSIONS
A -.062±.006
B -.625±.009
C -.750±.010
D -.125±.015

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 1050
STEM DIAMETER $3\frac{15}{16}$
EXTRUSION RATIO 102 TO 1
CONTAINER DIAMETER 4 INCH

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

NO	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSFER TIME (SEC)	EXTR. TIME (SEC)		STARTING BREAK THRU P.S.I.	END PRESSURE PSI	MAX PRESS ON BLT (PSI)	MAX FORCE ON BLT (TONS)	EXTRUSION LENGTH (FEET)
12	4140	3⅞×4	2200	60 CYCLE INDUCTION	8MIN 30SEC	SCRAP	1100		5/92X2	M2 RC 50 52	400	20	6		1600	2040	149,000	935	15
13	TI-155A	"	1900	"	8MIN 39SEC	3KB	3KB		5/92X2	M2 RC 52 54	400	22	6		2050	1720	149,500	940	22
14	TI-155A	"	1900	"	8MIN	3KB	3KB		5/92X1	M2 RC 50 52	400	23	6		1720	1800	131,000	825	18
15	TI-155A	"	1870	"	7MIN 47SEC	3KB	3KB		5/92X2	STAR J RC 61	500	20	6		1920	2000	146,000	915	18
16	TI-155A	"	1900	"	8MIN	606 FISKE GREASE	606 FISKE GREASE		5/92X1	M2 RC 54 56	400	25		STICKER	2100	2100	153,000	960	
17	TI-155A	"	2050	"	7MIN 39SEC	606 FISKE GREASE	606 FISKE GREASE		5/92X2	STAR J RC 61	400	22	3		1700	2100	153,000	960	7
18	TI-155A	"	1930	"	7MIN 32SEC	3KB	3KB		5/92X1	STAR J RC 61	400	21	5.4		1500	1740	127,000	795	20

EXTRUSION SECTION DIMENSIONS

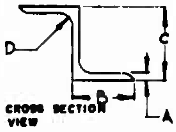
NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT				CENTER				END				REMARKS
				A	B	C	D	A	B	C	D	A	B	C	D	
12	4140	FAIR HAS DIE LINES	ERODED BEYOND REUSE CRACKED	.085	.600	I	$\frac{1}{8}$	.100	.610	.800	$\frac{3}{16}$	.147	.615	I	$\frac{1}{2}$	
13	TI-155A	TWIST BAD DIE LINES	"	.109	.655	.625	$\frac{1}{4}$	.117	.625	.675	$\frac{1}{2}$	.117	.635	.715	$\frac{1}{2}$	B-ONE LEG DID NOT FILL AT START OF EXTRUSION
14	"	TWIST BAD DIE LINES	"	.091	.512	.780	$\frac{1}{4}$	.087	.568	.787	$\frac{1}{2}$	.132	.609	—	$\frac{1}{2}$	C- BAD TWIST
15	"	TWIST DEEP DIE LINES	"	.078	.532	.711	$\frac{1}{4}$	.080	.651	.731	$\frac{1}{2}$	.130	.550	.809	$\frac{1}{2}$	
16	"	STICKER														
17	"	VERY BAD SURFACE	WASHED BADLY												←	NO DIM. COULD BE MEASURED DUE TO VERY BAD SURFACE
18	"	TWIST BAD SURFACE	ERODED BEYOND REUSE	.079	.569	.775	$\frac{1}{4}$	.105	.588	.774	$\frac{1}{2}$	.112	.732	.784	$\frac{1}{2}$	

GENERAL DATA

DATE : 10-21-57

COMPANY : H.M. HARPER CO

LOCATION : MORTON GROVE ILL



CROSS SECTION VIEW

NOMINAL DIMENSIONS
A -.062 ± .006
B -.625 ± .009
C -.750 ± .010
D -.125 ± .015

PRESS CAPACITY (TONS)	1030
STEM DIAMETER	3 3/16
EXTRUSION RATIO	102 TO 1
CONTAINER DIAMETER	4 INCH

MRD-C-5207

TEST DATA OF EXTRUSION TRIALS AF 33 (600) 34098

PUSH NO	MATERIAL	BILLET TEMP. °F	BILLET DIM.	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT	EXTRUSION PRACTICE	DIE DESIGN	DIE MATERIAL R C	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		START P.S.I.	END MAX. PRESSURE READING	MAX. PRESSURE ON BILLET (PSI)	MAX. FORCE ON BILLET (TONS)	EXTRUSION LENGTH (FEET)
19	Ti-155A	1940°F	3 7/8"-4"	60 CYCLE INDUCTION	6.55	3KB	3KBA	STANDARD PRACTICE THROTTLE VALVE 7/16 OPEN	5192 X1	HALCOMB 218 Rc 50-52	200°F	17	9.00		1880	2400	175000	1100	24
20	↓ (a)	1960°F	↓	↓	7.15	↓	↓	THROTTLE VALVE 9/16 OPEN	5192 X1	ALUMINUM OXIDE INSERT	↓	17		STICKER	2400	STICKER	175000	1100	
21	↓ (a)	2050°F	↓	↓	7.15	↓	↓	THROTTLE VALVE 5/8 OPEN	5192 X3	M2 Rc 54-56	↓	15	4.80		1840	2360	172000	1080	40
22	↓	2000°F	↓	↓	7.10	(b)	↓	THROTTLE VALVE FULL OPEN	5192 X1	CHROME CARBIDE INSERT	↓	14	5.40		1960	2300	162000	1050	48
23	MS 821	2000°F	↓	↓	7.25	(b)	↓	IMPACT	5192 X3	M2 Rc 54-56	↓	14		STICKER	2400	STICKER	175000	1100	
24	Ti-155A (a)	2200°F	↓	↓	10.06	(b)	↓	"	5192 X3	M2 Rc 54-56	↓	17	2.40		1520	1600	117000	735	16
25	↓	2160°F	↓	↓	9.80	3KB	↓	"	5192 X3	M2 Rc 54-56	↓	15	1.20		1800	2400	175000	1100	25
26	↓	2150°F	↓	↓	9.60	↓	↓	"	5192 X1	M2 Rc 54-56	↓	18	1.20		1700	1600	124000	780	16
27	↓	2060°F	↓	↓	7.32	↓	↓	"	5192 X1	M2 Rc 54-56	↓	13	1.20		1720	1680	126000	790	15

STANDARD PRACTICE - RAM BROUGHT TO BILLET WITH 150 TONS. UPON CONTACT BALANCE OF EXTRUSION FORCE IS APPLIED

EXTRUSION SECTION DIMENSIONS

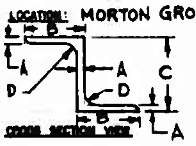
PUSH NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT A	FRONT B	FRONT C	FRONT D	CENTER A	CENTER B	CENTER C	CENTER D	END A	END B	END C	END D	REMARKS
19	Ti-155A	ATTACHED SHEET	FILLETS WASHED	1·.070 2·.000 3·.067	1·.187 2·.000	.580	1·1/8 2·1/32	1·.060 2·.061 3·.061	1·.424 2·.447	.764	1·1/8 2·3/32	1·.069 2·.060 3·.064	1·.570 2·.616	.766	1·5/32 2·1/8	
20	↓	↓	SHROUD CRACKED INSERT CRACKED													STICKER
21	↓	↓	FILLET WASHED	1·.070 2·.000 3·.105	1·.193 2·.000	.591	1·1/16 2·1/16	1·.065 2·.070 3·.060	1·.487 2·.380	.801	1·1/8 2·1/16	1·.065 2·.069 3·.058	1·.429 2·.467	.858	1·1/8 2·1/16	
22	↓	↓	INSERT FILLET CHIPPED	1·.061 2·.000 3·.056	1·.380 2·.000	.596	1·1/32 2·1/16	1·.060 2·.062 3·.060	1·.250 2·.270	.769	1·1/8 2·1/16	1·.063 2·.060 3·.061	1·.619 2·.617	.735	1·1/8 2·1/16	ONLY 12' HAD ALL 3 LEGS FILLED
23	MS 821	↓	DIE CRACKED FILLETS WASHED													
24	Ti-155A	↓	DIE CRACKED FILLETS WASHED	1·.107 2·.125 3·.089	1·.492 2·.601	.791	1·C 2·1/8	1·.108 2·.112 3·.070	1·.540 2·.660	.802	1 C 2 3/16	1·.107 2·.106 3·.091	1·.647 2·.634	.816	1 C 2 3/16	a- Billets coated with 1100 glass slurry before heating
25	↓	↓	FILLETS WASHED	1·.110 2·.085 3·.090	1·.297 2·.315	.772	1·1/16 2·1/8	1·.070 2·.100 3·.093	1·.504 2·.596	.862	1·1/16 2·1/8	1 C 2 C 3 C	1 C 2 C	C	1 C 2 C	b- Die coated with 1100 glass slurry- pad not used
26	↓	↓	DIE CRACKED FILLETS WASHED	1·.060 2·.088 3·.081	1·.615 2·.615	.785	1·1/8 2·1/16	1·.093 2·.120 3·.100	1·.611 2·.630	.798	1·3/16 2·1/8	1 C 2 C 3 C	1 C 2 C	C	1 C 2 C	c- surface too rough to measure
27	↓	↓	DIE CRACKED FILLETS WASHED	1·.099 2·.106 3·.120	1·.610 2·.595	.823	1·1/8 2·1/16	1·C 2·C 3·C	1·C 2·C	C	1 C 2 C	1 C 2 C 3 C	1 C 2 C	C	1 C 2 C	

GENERAL DATA

DATE: 12-20-57

COMPANY: H.M. HARPER CO.

LOCATION: MORTON GROVE, ILL.



CROSS SECTION VIEW

NOMINAL DIMENSIONS
A —.062 ±.006
B —.625 ±.009
C —.750 ±.010
D —.125 ±.015

PRESS CAPACITY (TONS)	1100
STEM DIAMETER	3 15/16
CONTAINER DIAMETER	4 INCH
EXTRUSION RATIO	102 TO 1

MRD-C-5207

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

PUSH NO	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT	EXTRUSION PRACTICE	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		START PSI	END MAX PRESSURE READING	MAX PRESS ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH (FEET)
28	Ti-155A	3 7/8-4	2050	60 CYCLE INDUCTION	7.39	3KB	3KBA	IMPACT	5192X1	ALUMINUM OXIDE INSERT	400	15	1.20		1920	1840	140000	880	21
29	↓	↓	2150	↓	7.50	FISKE 604A GREASE	FISKE 604A GREASE	↓	5192X2	STAR J	↓	11	1.20		1600	1800	131000	925	12
30	↓	↓	1800	↓	5.92	↓	↓	↓	5192X1	HALCOMB 218 Rc 50-52	↓	9		STICKER	2500	—	181000	1140	
31	↓	↓	2150	↓	7.61	↓	↓	↓	5192X1	ZIRCONIUM OXIDE INSERT	↓	9		STICKER	2600	—	189000	1190	
32	↓	↓	2160	↓	8.50	↓	↓	↓	5192X2	CHROME CARBIDE INSERT		11	1.20		2200	2140	161000	1010	30

EXTRUSION SECTION DIMENSIONS

PUSH NO	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT A	FRONT B	FRONT C	FRONT D	CENTER A	CENTER B	CENTER C	CENTER D	END A	END B	END C	END D	REMARKS
28	Ti-155A	ATTACHED SHEET	SHROUD CRACKED INSERT SPLIT	.060 .073 .076	[illegible] .646	.778	1/16 1/8	.041 .057 .059	C	C	C	C	C	C	C	
29	↓	↓	FILLETS BROKE OUT													BADLY SCORED DIMENSION CHECK NOT POSSIBLE
30	↓	↓	DIE CRACKED FILLETS WASHED													2ND PUSH WITH DIE STICKER
31	↓	↓	SHROUD CRACKED INSERT SPLIT													STICKER
32	↓	↓	INSERT SPLIT													BADLY SCORED DIMENSION CHECK NOT POSSIBLE

(a) BILLETS COATED WITH 1100 GLASS PRIOR TO HEATING

(b) DIE COATED WITH 1100 GLASS + NO GLASS PAD USED

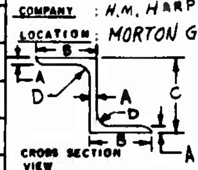
(c) DIMENSIONS NOT MEASURABLE DUE TO ROUGH SURFACE

GENERAL DATA

DATE: 12/20/57

COMPANY: H.M. HARPER CO.

LOCATION: MORTON GROVE, ILL.



CROSS SECTION VIEW

NOMINAL DIMENSIONS:
A -.062 ±.006
B -.625 ±.009
C -.750 ±.010
D -.125 ±.015

PRESS CAPACITY (TONS)	1050
STEM DIAMETER	3 15/16
EXTRUSION RATIO	102 TO 1
CONTAINER DIAMETER	4 INCH

MRC-C-5207

TEST DATA OF EXTRUSION TRIALS AF 33(600) 34098

RUN No	MATERIAL	BILLET DIM.	BILLET TEMP °F	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT	EXTRUSION PRACTICE	DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		START P.S.I	END MAX PRESSURE READING	MAX PRESS ON BLLT (PSI)	MAX FORCE ON BLLT (TONS)	EXTRUSION LENGTH (FEET)
33	4140	3⅞-4	2100	60 CYCLE INDUCTION	5.40	SCRAP GLASS	1100	REGULAR	5192X1	M2 Rc-54-56	200	18	7.2		2380	2360	173000	1090	40
34	(a)	↓	2140	↓	6.00	"	↓	↓	5192X2	M2 Rc-54-56	↓	14	10.2		1500	2320	169000	1060	12
35	(a)		2100		5.90	"			5192X3	M2 Rc-54-56		18	6.0		1900	2340	170000	1070	24
36	(a)		2220		5.90	"			5192X1	M2 Rc-54-56		17	8.4		2000	2320	169000	1060	40
37			2120		4.23	(b)			5192X3	M2 Rc-54-56		15	—	STICKER	2400	—	175000	1100	—
38	(a)		2160		4.85	6600			5192X2	M2 Rc-54-56		15	6.6		2000	2380	173000	1090	29

(a) BILLETS COATED WITH 1100 GLASS

(b) DIE COATED WITH 1100 GLASS + NO GLASS PAD USED.

(C) DIMENSIONS NOT MEASURABLE DUE TO ROUGH SURFACE.

X1 Die = 25° Conical entry with substantial bearing

X2 Die = Double angle, large conical entry with short bearing at end of die

X3 Die = Flat face design with ⅛ radius

EXTRUSION SECTION DIMENSIONS

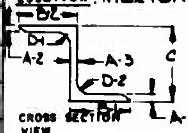
RUN No	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION	FRONT A	FRONT B	FRONT C	FRONT D	CENTER A	CENTER B	CENTER C	CENTER D	END A	END B	END C	END D	REMARKS
33	4140	ATTACHED SHEET	DIE CRACKED FILLETS WASHED	[illegible]	[illegible]	361	[illegible]	[illegible]	[illegible]	465	[illegible]	[illegible]	[illegible]	635	[illegible]	
34	↓	↓	↓	[illegible]	[illegible]	C	[illegible]	[illegible]	[illegible]	545	[illegible]	[illegible]	[illegible]	547	[illegible]	
35				[illegible]	[illegible]	655	[illegible]	[illegible]	[illegible]	790	[illegible]	[illegible]	[illegible]	906	[illegible]	
36				[illegible]	[illegible]	625	[illegible]	[illegible]	[illegible]	450	[illegible]	[illegible]	[illegible]	615	[illegible]	
37																STICKER
38				[illegible]	[illegible]	780	[illegible]	[illegible]	[illegible]	741	[illegible]	[illegible]	[illegible]	760	[illegible]	

GENERAL DATA

DATE : 12-20-57

COMPANY : H.M. HARPER CO.

LOCATION : MORTON GROVE



CROSS SECTION VIEW

NOMINAL DIMENSIONS

A .062±.006

B .625±.009

C .780±.010

D .125±.015

PRESS CAPACITY (TONS) 1100

STEM DIAMETER 3 13/16

EXTRUSION RATIO 102 TO 1

CONTAINER DIAMETER 4 INCH

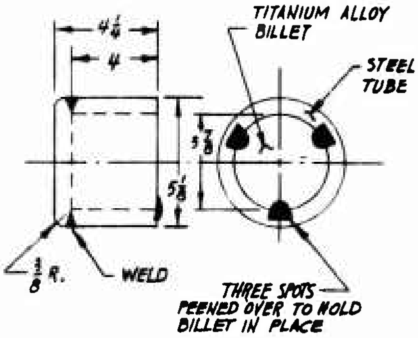
MRC-C-5207

TEST DATA OF EXTRUSION TRIALS AF 33 (600) 34098

RUN No	MATERIAL Ti-155A	BILLET TEMP. °F	BILLET DIM.	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT		DIE DESIGN	DIE MATERIAL RC	DIE TEMP °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)	RAM SPEED	START PRESSURE	END MAX. PRESSURE READING	MAX. PRESSURE ON BILLET (PSI)	MAX. FORCE ON BLLT (TONS)	EXTRUSION LENGTH (FEET)
39	CANNED BILLETS	2000	SEE	ELECTRIC FURNACE	55	5 OZ. SCRAP GLASS	1100 GLASS	WITH ⅛" SECTION THICKNESS	5192X1	M2 Rc 50-52	500	12	4	1" PER SEC.	2120	2400	99000	1100	22
40	SEE SKETCH BELOW	1940	SKETCH BELOW	↓	50	↓	↓		"	↓	↓	14	3	↓	3000	3160	131000	1450	15
41		1870	↓		40				"			15	3		3260	3500	144000	1600	14
42		1850			40				5192X2			20	3		3560	3360	147000	1630	14

No DIMENSIONAL CHECKS POSSIBLE

RUN No	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION
39		SURFACE TORN STEEL + Ti SEPARATED	DIE CRACKED DEFORMED SLIGHTLY
40		FIRST 8' Ti - LAST 7' CLAD HAS SOME	↓
41		SECTIONS COMPLETELY CLAD. STEEL	
42		PEELING IN SOME AREAS	



REMARKS

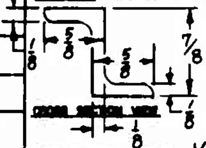
BILLET OVERHEATED

GENERAL DATA

DATE: 1-31-58

COMPANY: H.M. HARPER

LOCATION: MORTON GROVE, ILL.



NOMINAL DIMENSIONS

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 1650

STEM DIAMETER 5 ⅛ INCH

CONTAINER DIAMETER 5 5/16 INCH

EXTRUSION RATIO 100 TO 1

TEST DATA OF EXTRUSION TRIALS AF 33 (600) 34098

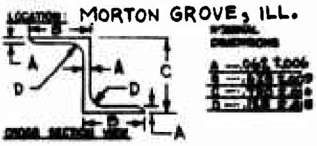
PUSH No	MATERIAL	BILLET TEMP. °F	BILLET DIM.	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT	EXTRUSION PRACTICE	DIE DESIGN	DIE MATERIAL R C	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		START PSI	END, MAX. PRESSURE READING	MAX. PRESSURE ON BILLET (PSI)	MAX. FORCE ON BILLT (TONS)	EXTRUSION LENGTH (FEET)	FEET PER SEC.
44	Ti 155A	1950	3 7/8"X4"	60 CYCLE INDUCTION	21	3KB	3KBA	THROTTLE 7/16 OPEN	5192X1	HALCOMB 218 Rc 50-52	1000	24		STICKER	2400		176000	1100		
45	"	2000	"	"	22	"	"	THROTTLE 1/2 OPEN	DIE USED FOR PUSH 44		1000	20	8.0		2040	2300	168000	1055	35	4.37
46	"	2050	"	"	19	"	"	"	5192X1	CARPENTER T.K. Rc 52-54	1000	19	7.2		1700	2320	169000	1060	38	5.28
47	"	2030	"	"	21	8 oz. 3KB FRIT 50-100 MESH	"	"	5192X1	PEERLESS A Rc 50-52	900	21	8.4		2060	2340	170000	1070	22	2.62
48	"	2050	"	"	19	4 oz. 3KBA FRIT 200 MESH	"	"	5192X1	CARPENTER T.K. Rc 52-54	1000	19	6.6		1620	2320	169000	1060	20	3.03
49	"	2050	"	"	19	3KB	"	"	5192X3 SHROUD ONLY	M2 Rc 52-54	400	20	6.0		1320	2320	169000	1060	11	1.83
50	"	2050	"	"	19	"	"	"	5192X3 INSERT	SILICON CARBIDE 1/2 THICK	1300	19		STICKER	2340		170000	1070		
51	"	2100	"	"	20	"	"	"	DIE USED FOR PUSH 50		1300	20		STICKER	2380		173000	1090		
52	"	2100	"	"	21	"	"	"	5192X3 INSERT	SILICON CARBIDE 1/2 THICK	1300	20	3.3		2420	2460	180000	1130	9	2.72

EXTRUSION SECTION DIMENSIONS

PUSH No	MATERIAL	EXTRUSION SURFACE FINISH	DIE CONDITION		FRONT A	FRONT B	FRONT C	FRONT D	CENTER A	CENTER B	CENTER C	CENTER D	END A	END B	END C	END D	REMARKS
44	Ti 155A																
45	"			1 2 3	.067 .000 .059	.332 .000	.768	1/8 .000	.100 .000 .050	.568 .000	.780	1/8 .000	.122 .092 .131	.480 .525	.705	1/8 5/16	
46	"			1 2 3	.061 .000 .000	.343 .000	.596	1/4 .000	.147 .000 .093	.583 .000	.735	5/16 .000	.072 .065 .073	.665 .650	.760	3/8 1/4	
47	"			1 2 3	.047 .000 .140	.638 .000	.755	*	.054 .070 .083	.560 .567	.755	*	.058 .074 .087	.623 .584	.808	*	* FILLETS NOT MEASURABLE DUE TO SCORES
48	"			1 2 3	.067 .061 .069	.571 .378	.758	5/64 1/8	.071 .068 .083	.610 .612	.773	3/32 5/32	.085 .078 .101	.685 .690	.796	3/32 5/32	LAST 8 FEET BADLY SCORED
49	"			1 2 3													BADLY SCORED, DIMENSION CHECK IMPOSSIBLE
50	"			1 2 3													INSERT ONLY HEATED TO 1300°F WITH HAND TORCH
51	"			1 2 3													INSERT ONLY HEATED TO 1300°F WITH HAND TORCH
52	"	BADLY SCORED CANNOT MEASURE	DEFORMED CONSIDERABLY														INSERT ONLY HEATED TO 1300°F WITH HAND TORCH

GENERAL DATA

DATE: 3-7-58
COMPANY: H.M. HARPER CO.
LOCATION: MORTON GROVE, ILL.



PRESS CAPACITY (TONS) 1100
STEM DIAMETER 3 13/16
CONTAINER DIAMETER 4 INCH
EXTRUSION RATIO 102 TO 1

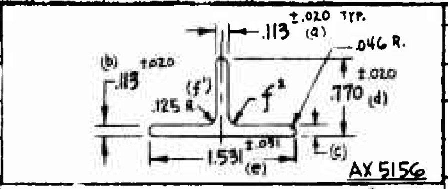
TEST DATA OF EXTRUSION TRIALS AF 33 (600) 34098

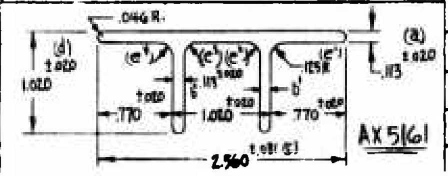
PUSH No	MATERIAL	BILLET TEMP. °F	BILLET DIM.	HEATING CONDITION	HTG TIME (MIN)	BILLET LUBRICANT	CONTAINER LUBRICANT	EXTRUSION PRACTICE	DIE DESIGN	DIE MATERIAL R C	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)		START PSI	END MAX. PRESSURE READING	MAX. PRESSURE ON BILLET (PSI)	MAX. FORCE ON BILLT (TONS)	EXTRUSION LENGTH (FEET)	FEET PER SEC.
43	Ti 155A	1950	3 7/8"X4"	60 CYCLE INDUCTION	24	3KB	3KBA	STANDARD	5156	M2 Rc 52-54	800	20	3.1		1320	1460	106000	670	8	2.56
53	MS821	2100	3 7/8"X8"	"	21	3KB	"	THROTTLE 1/2" OPEN	5156	M2 Rc 52-54	800	18	6.2		1220	2220	163000	1020	25	4.03
54	"	2000	"	"	19	2 PADS 3KB	"	"	5156	M2 Rc 52-54	800	19	7.4		1540	2220	163000	1020	24	3.24
55	"	2000	"	"	20	2 PADS 3KB	"	"	5161	M2 R 52-54	800	20	3.6		1400	2340	170000	1070	12	3.33

DIM'S. FOR	NOM.	TOL.	RECORDED DIMENSIONS TEST 43 (AX5156)			RECORDED DIMENSIONS TEST 53 (AX5156)			RECORDED DIMENSIONS TEST 54 (AX5156)		
AX5156			FRONT	CENTER	END	FRONT	CENTER	END	FRONT	CENTER	END
HEIGHT (d)	.770	±.020	.770	.790	.811	.746	.809	.837	.810	.835	.814
WIDTH (e)	1.531	±.031	1.477	1.521	1.576	1.583	1.541	1.489	1.546	1.543	1.489
LEG THICKNESS (a)	.113	±.020	.117	.118	[illegible]	.121	.120	.117	.126	.130	.126
LEG THICKNESS (b)			.118	.121	.126	[illegible]	.119	.136	.119	.124	.140
LEG THICKNESS (c)			.122	.121	.120	.118	.133	.133	.123	.120	.137
FILLET RADIUS f¹	.125	±.031	.125	.125	.125	.125	.125	.125	.125	.156	.125
FILLET RADIUS f²			.125	.125	.125	.171	.171	.171	.125	.156	.171

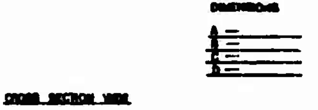
DIMS. FOR	NOM.	TOL.	RECORDED DIMENSIONS TEST 55 (AX5161)		
AX 5161			FRONT	CENTER	END
HEIGHT (d)	1.020	±.020	1.068	1.057	.997
WIDTH (C)	2.560	±.031	2.649	2.661	2.681
LEG THICKNESS (a)	.113	±.020	.126	.128	.133
(b¹)	.113	±.020	.124	.126	.136
(b²)	.113	±.020	.126	.126	.128
FILLET RADII (e¹)	.125	±.031	.125	.125	.140
(e²)			.125	.125	.156
(e³)			.125	.125	.187
(e⁴)			.125	.125	.125

PUSH No	MATERIAL	FINISH	
43	Ti 155A		
53	MS821		
54	"		
55	"		





DATE: MARCH 7, 1958
COMPANY: H.M. HARPER CO.
LOCATION: MORTON GROVE, ILL.



PRESS CAPACITY (TONS) 1100
STEM DIAMETER 3 13/16
CONTAINER DIAMETER 4 INCH
EXTRUSION RATIO 102 TO 1

PART III EXTRUSION TRIAL DATA SHEETS

BABCOCK AND WILCOX COMPANY

TEST DATA OF EXTRUSION TRIALS AF33(600) 34099

Push No.	Billet Material	Billet Size	Billet Temp °F	Billet Coating	Heating Method	Htg Time (Min)	Billet Lubricant	~~Container Lubricant~~ Shape	Container Temp.	Die Lubricant	Die Temp	Die ~~Design~~ Number	Die Material R C	Extr. Pract-ice	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading TONS	Max.** Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
83	4340	4"×6"	2300	Salt Bath	Salt Bath	30	335-14	1/8" T	600°F	Ground window glass Pads	600	2	Peerless A RC 48-52	Full Lub.	29		702	122,000		13'6"
84	18-8	"	"	"	"	35	335-14	"	"	"	400	6	"	"	28		1080	188,500		14'6"
85	4340	4"×10"	"	"	"	45	335-14	"	"	"	"	7	"	"	32		540	94,300		21'8"
86	18-8	"	"	"	"	60	335-14	"	"	"	"	8	"	"	32		840	146,000		21'6"
87	7Al 4Mo	4"×6"	1600	318 A	Electric Furnace	61	318	1½" Round	"	*318 Glass Pads	"	—	Brighton Alloy	"	45		760	132,500		8'
88	7Al 4Mo	"	"	"	"	62	318	1½" Round	"	"	"	—	"	"	39		838	146,000		3'
89	7Al 4Mo	"	"	"	"	58	318	¼" T	"	"	900	26	Braeburn "T" Alloy	"	39		1080	188,600		STICKER
90	7Al 4Mo	4"×4"	1750	"	"	110	318	1/8" T	"	"	"	9	Peerless A RC 48-52	"	35		1080	188,500		"
91	7Al 4Mo	4"×6"	"	"	"	120	318	¼" T	"	"	"	26*	Braeburn "T" Alloy	"	30		648	113,000		6'

* Repaired by tack welding after cracking into 3 sections during Push 89

** Based on 4 5/16" container

Extrusion Section Dimensions

Push No	Extrusion Surface and Straightness	Die Condition After Extrusion	Front A	Front B	Front C	Front D	Center A	Center B	Center C	Center D	End A	End B	End C	End D	Remarks
83	Lubrication broke down on interior corners - die marks	Some wear along interior corners													
84	Edge lubrication broke down after 3' was extruded	Die wear as above. Die cracked													
85	Same as 83	Slight wash at interior corners													
86	Lack of lubrication on interior surfaces otherwise OK	Die wear along interior corners Die cracked													
87	Some die marks along length	Very slight die wash													SURFACE GENERALLY ROUGH
88	Same as 87	Same as #87													" " "
89	——	Die cracked No extrusion													STICKER
90	——	No Extrusion													STICKER
91	Surface Fairly Rough	Slight Die Wash													Small breaks in form of Herring bone marks. Surface between marks fairly smooth

General Data

Date: December 19, 1958

Company: Babcock + Wilcox

Location Beaver Falls, Pa.

Nominal Dimensions

A

B

C

D

Cross Section View

Press Capacity (Tons) 1080

Stem Diameter 4 1/16"

Container Diameter 4 5/16"

Extrusion Ratio VARIABLE

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp °F	Billet Coating	Heating Method	Htg Time (Min)	Billet Lubricant	Container Lubricant	Container Temp. °F	Die Lubricant	Die Temp °F	Die ~~Design~~ Number	Die Material R C	Extru. Practice	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max.** Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
92	7Al 4Mo	4"×4"	1800	#85	Electric Furnace	50	Ground Window Glass	1/8" T	600	(1) 3KB	900°	3	Peerless A RC 48-52	Scalp	32		948	161,500		6'10"
93	7Al 4Mo	4"×4"	1800	#85	"	60	"	"	"	(1) "	"	4	"	"	30		784	152,600		7'3"
94	7Al 4Mo	4"×5"	1800	#65	"	80	"	"	"	(2) "	"	10	"	"	* 8		958	152,600		9'

(1) - 1" thick glass pad used.

(2) - 5/8" thick glass pad used. Note how A+B extrusion dimensions are constricted and C+D increased due to excess glass in 1" pads (Pushes 92,93)

* Billet heated in can and transported to run down table in can.

** Based on 4" scalping dummy block

Extrusion Section Dimensions

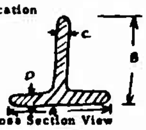
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Front A	Front B	Front C	Front D	Center A	Center B	Center C	Center D	End A	End B	End C	End D	Remarks
92	Surface fairly good Stem wavy for last 2 feet	Die cracked Very slight die wear.	1.976	1.726	.153	.124 .135					1.877	1.787	.192	.127 .116	
93	Surface good Waviness worse	Die cracked Some die wear.	1.775	1.672	.180	.129 .130					1.883	1.727	.194	.101 .129	
94	No waviness. Glass plugged part of orifice Surface OK except for front + back.	Very slight die wear.	1.922	1.739	.112	.112 .113					1.939	1.762	.117	.117 .120	

General Data

Date: December 19, 1958

Company: Babcock and Wilcox Beaver Falls, Pa.

Location



Cross Section View

Nominal Dimensions

A 2.000

B 1.750

C .125

D .125

Press Capacity (Tons) 1080

Stem Diameter 4 1/16

Container Diameter 4 5/16

Extrusion Ratio 27:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp. °F	Billet Coating	Heating Method	Htg Time (Min)	Billet Lubricant	Extrusion Practice	Container Temp. °F	Die Lubricant (2)	Die Temp °F	Die Design	Die Material R C 48-52	Die No.	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
95	4340	6"	2300	Salt	Salt Bath	35	335-14	Full Lub.	600	GWG-1"	400	T	LCT-2	3	-	.15			523	-
96	4340	10"	2300	Salt	"	40	335-14	"	600	"	400	T	LCT-2	3	-	.30			643	-
97	18-8	6"	2300	Salt	"	43	335-14	"	600	"	400	T	P.A.	21R	-	.35			910	-
98	18-8	10"	2300	Salt	Ind.	60	335-14	"	600	GWG-1/2"	400	T	P.A.	9	8	.40			635	-
99	C135*	4 3/4"	1800	85	Elect. Fce	120	GWG	Scalp	600	3KB-1/2"	900	T	P.A.	22	33	.15			935	6'9"
100	"	4 3/4"	1800	85	"	127	"	Scalp	600	3KB-1/2"	900	T	P.A.	17	35	.15			850	6'11"
101	"	5"	1800	85	"	135	"	Scalp	600	" (1)	900	T	LCT-2	12	40	.35			962	9'0"
102	"	5 1/2"	1800	85	" **	60	"	Scalp	600	" (1)	900	T	LCT-2	24	20	.30			988	13'2"
103	"	5 1/2"	1800	85	" **	65	"	Scalp	600	"	900	T	P.A.	20	15	.55			1040	11'8"

*Forged ** Canned Extrusion section dimensions (see Table II) (1) Minus 40 mesh glass, others, -14 mesh glass (2) 1/2" pads used for pushes 98 thru 103 contained 1/4" tee orifice in pad

Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion (See Table IV)	Remarks on Butt Ends
95	-	Moderate Die Wash	
96	-	"	
97	-	"	
98	-	"	
99	Smooth surface Good straightness	Very slight die wash	Front face not completely retarded in scalping. Slight back end lamination.
100	Smooth surface Straightness OK	No Wear	Same as above. Severe back end seams.
101	Good surface Wavy	"	Same as above. Very severe back end seams.
102	Smooth surface Straightness OK	Slight die wash	Square front butt face. Severe back end seam and suck in.
103	Smooth surface Fair straightness	Slight die wash one inside corner only	Same as above

GENERAL COMMENTS

Thinner (3/8 to 1/2") flat glass pads with 1/4" tee openings proved very effective in producing the finest continuous film of clear glass ever observed at any of the previous trials. On two pushes, this effective glass lubrication resulted in dies without wear, pickup, deformation or any evidence of prior use after a sand blast cleanup On the other three titanium alloy pushes, wear was limited to light scratches, or deformation at the radii of the tee. The effectiveness of the glass lubrication is considered primarily due to the thinness of the pad although the influence of die temp. (or pad temp) has not been determined. The 1/4" tee openings in the glass pad eliminate any early clogging of the die orifices which produces undersize section dimensions in the first few feet of extrusion.

Cast electric discharge machined dies were used. A new die design proved successful in eliminating breakage during extrusion. The dies were confined in a thin tapered shell which permitted the restriction of the conical container opening to be transferred to the die.

General Data

Date: January 16, 1959

Company: Babcock & Wilcox Company
Beaver Falls, Pa.

Location

Nominal Dimensions
A
B 2,000"
C .125"
D 1,750"
E .125"
F .125"

Cross Section View

Press Capacity (Tons) 1080
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 27:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp. °F	Billet Coating	Heating Method	Htg Time (Min)	Billet Lubricant	Extrusion Practice	Container Temp. °F	Die Lubricant	Die Temp.	Die Design	Die Material R C 48-52	Die No.	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
104	4340	6"	2300	85	Induction	-	335-14	Full Lub	600	GWG	400	T	LCT-2	3					1100	-
105	18-8	6"	2300	85	"	-	"	"	"	"	"	"	P.A.	22	15	-			880	-
106	4340	10"	2300	85	"	-	"	"	"	"	"	"	P.A.	21R	15	.25			825	-
107	C-135 Forged	6"	1800	85	Electric Fce	95	GWG	Scalp	"	3KB 1/2"	900	"	P.A.	7	35	.25			935	10'6"
108	"	8"	1800	85	"	143	"	"	"	"	"	"	P.A.	19	60	1.60			1100	2'7"
109	C-135 Cast	4"	1800	85	"	149	"	"	"	"	"	"	LCT-2	14	25	.15			853	5'9"
110	"	6"	1800	85	"	96	"	"	"	"	"	"	P.A.	16	30	-			850	10'5"
111	C-135 Forged	6"	1800	85	Elec.Fce & Induct.	10 + Ind.	"	"	"	"	"	"	LCT-2	23	8	.30			935	8'4"
112	"	6"	1800	85	"	"	"	"	"	"	"	"	P.A.	16	8	-			1100	-

Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion (see Table IV)	Remarks on Butt Ends
104	-	-	Square front butt
105	-	Deformed - but not scored or washed	
106	-	Badly washed	
107	Good surface Fair straightness	Light deformation No wear	Square front face. Back end suck in and slight back end defect.
108	Fair surface and straightness	Light deformation some wear and scores	Partial sticker
109	Surface OK Good straightness	Severe scores and pickup	Square front face. Partial shear cone. No back end defect.
110	Good surface and straightness	No deformation Light wear	Square front face. Complete shear cone. Severe seams & laminations.
111	Surface OK Good straightness	No deformation Light scores	Square front face. Slight suck in. No back end defects. Good butt.
112	Sticker	No deformation Little wear	

GENERAL COMMENTS

A new replacement stem was found to be bent about 1/16 after several pushes. Reversing the stem 180° overbent the stem in the direction in which it was originally bent. The stem was again reversed 180° and the container was offset about 1/64 to correct for the tendency of the stem to bend. About 8 extrusion trials were conducted after this change and at the end of the day's trials, the bent condition of the stem had not aggravated further.

Results of this day's trials were again as impressive as those of January 9. Although for reasons not yet established, the glass films were not as clear, heavy or continuous as on January 9, extrusion surface was good. Dies may not have been as well protected as during previous trial (1/16/59); but this will be determined in future inspection since at the end of the day's trials, four dies still had to be removed from the butts. (Sectional dies are being designed to overcome this difficulty). Slight die wear which occurred across the entrance radius did not generally affect the die bearing

General Data

Date: January 23, 1959

Company: Babcock & Wilcox Company

Location Beaver Falls, Pa.

Cross Section View

Nominal Dimensions

A ______
B 2.002"
C .125"
D 1.750"
E .125"
F .125"

Press Capacity (Tons) 1080
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 27:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp. °F	Billet Coating	Heating Method	Htg Time (Min)	Extrusion Practice	Container Lubricant	Container Temp.	Die Lubricant	Die Temp. °F	Die Design	Die Material R C 48-52	Die No.	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
113	C-135 Forged	8"	1800	85	Electric Fce*	136	GWG	Scalp	600	3KB1/2"	900	T	P.A.	19	13	.40			1045	15'4"
114	"	6"	1800	85	"	73	318	Full Lub	"	"	"	T	LCT-2	15	35	.40			990	10'3"
115	"	6"	1800	85	"	83	318	"	"	"	"	"	LCT-2	14	30	.30			990	11'4"
116	"	6"	1800	85	"	36	318	"	"	"	"	"	LCT-2	10	40	.30			839	10'9"
117	"	6"	1800	85	"	45	318	"	"	"	"	"	LCT-2	1	40	.30			908	11'6"

*Canned

Push No.	Extrusion Surface and Straightness	(See Table IV) Die Condition After Extrusion	Remarks on Butt Ends
113	Good surface and Straightness	Light deformation Some pickup & scores	Square front face. Slight suck in. No back end defects. Good butt.
114	Surface OK Fair straightness	Slight deformation Slight wear	Rounded front face with light flow lines. No shear or suck in. Good butt.
115	Surface OK Very Wavy	Same as Push 109	Rounded front face with lines from shear due to partial scalping.
116	Rough surface Good straightness	No deformation Light score line	
117	"	Scored	

GENERAL COMMENTS (Contd)

surface or the extruded surface. Several dies were used twice during the day's trials and were reusable after the second push. Dies which were used for steel extrusion could not be considered reusable due to slight wash or deformation at the radii of the tee. It may also be desirable to re-electric discharge machine the orifices of the dies used for titanium extrusion to eliminate slight constrictions (.001 or .002) which occur (generally near the radii of the tee).

General Data

Date: January 23, 1959

Company: Babcock & Wilcox Company

Location Beaver Falls, Pa.

Cross Section View

Nominal Dimensions

A ______
B 2.002"
C .125"
D 1.750"
E .125"
F .125"

Press Capacity (Tons) 1080
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 27:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp. °F	Billet Coating	Heating Method *	Htg Time (Min)	Billet Lubricant	Extrusion Practice	Container Temp. °F	Die Lubricant	Die Temp °F	Die No.	Die Material R C	Die Lub Shape	Billet Trans. Time (Sec.)	Extr. Time (Sec.) ***	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
118	18-8	10"	2300	85	EL1800 Ind2300	63	335-14	Full Lub	550 - 600	GWG	200	13		1/2"	20				***	3'4"
119	18-8	10"	2300	85	"	95	"	"	"	"	"	2		"	"					20'1"
120	7A1-4Mo Forged	6"	1800	"	EL Furn Argon	80	GWG		"	3KB	900	28		"	12					1'6"
121	7A1-4Mo Cast	"	"	"	"	101	"	Scalp	"	"	"	20		"	12	10				10'1"
122	7A1-4Mo Forged	"	"	"	"	78	318	Full Lub	600 - 650	"	"	29		"	15					11'9"
123	"	"	"	318-XW	"	86	"	"	"	"	"	28		"	15					11'1"
125	6A1-4V Forged	"	"	85	"	95	GWG	Scalp	"	"	"	12		"	15					10'5"
126	"	8"	"	"	"	110	"	"	"	"	"	32		"	15					-
124	7A1-4Mo Cast	6"	"	318-XW	"	65	318	Full Lub	"	***	"	28		1/4"	15					11'2"

* All Titanium Billets Canned **Scored Orifice - Not Completely Through ***Recording Equipment Not Functioning Properly

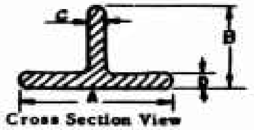
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Extrusion Section Dimensions Front A	Front B	Front C	Front D	Center A	Center B	Center C	Center D	End A	End B	End C	End D	Remarks
118	Fairly good Some roughness	Slight wash - OK													Partial sticker Not hot enough
119	"	Internal corners washed otherwise OK	2.000	1.746	.125	.123	1.974	1.734	.123	.125	1.988	1.742	.118	.119	-
120	Rough edges Fairly smooth	OK													Partial sticker
121	Rough 3' front end rest very smooth	Die washed - internal corner	1.927	1.717	.108	.113	1.985	1.753	.115	.114	1.976	1.752	.112	.113	" "
122	Herringbone very slight die marks	Die washed - some pick-up	1.943	1.981	.121	.119	1.963	1.886	.124	.125	2.022	1.646	.127	.126	Lamination along edge
123	Herringbone-slight die marks-smooth	Die wear	2.016	1.776	.125	.125	2.030	1.781	.126	.125	2.021	1.780	.124	.125	No laminations
125	Some die marks good surface	CK	2.008	1.772	.122	.119	2.004	1.780	.126	.125	2.002	1.773	.126	.123	
126	-	Extruded only in center some wear													Sticker - used 1/16" orifice die by mistake
124	Herringbone Die marks - pick-up	OK	2.004	1.781	.123	.123	2.002	1.770	.124	.123	2.032	1.982	.124	.123	Lamination

General Data

Date: 5-22-59

Company: Babcock and Wilcox

Location Beaver Falls, Pa.



Cross Section View

Nominal Dimensions
A 2.000
B 1.750
C .125
D .125

Press Capacity (Tons) 1100
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 28:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp. °F	Billet Coating	Heating Method *	Htg Time (Min)	Billet Lubricant	Extrusion Practice	Container Temp. °F	Die Lubricant	Die Temp °F	Die No.	Die Material R C	Die Lub Shape	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
127	6Al-4V Forged	6"	1800	85	El Furn Argon	78	318	Full Lub	600-650	3KB	900	30		1/4"	15	.75			814	11'0"
128	6Al-4V Forged	8"	"	318-XW	"	81	"	"	"	"	"	5		"	"	1.50			"	16'1"
130	7Al-4Mo Cast	10"	"	"	"	85	"	"	"	"	"	30		3/8"	"	"			1036	19'10"
131	"	"	"	"	"	51	3KB		"	"	"	28		"	"	-			-	-
129	"	"	"	"	"	50	318		"	"	"	-		"	"	-			-	-

* All Billets Canned

Extrusion Section Dimensions

Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Front				Center				End				Remarks
			A	B	C	D	A	B	C	D	A	B	C	D	
127 q	Slight die pick-up Herringbone-Smooth	Washed-some pick-up	[illegible]	[illegible]	[illegible]	[illegible]	2.004	1.772	[illegible]	.125	2.047	1.772	[illegible]	.127	Laminated
128	No pick-up - slight die marks -B.E.	Severe wash	[illegible]	[illegible]	.122	.130	2.01	[illegible]	.123	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Not laminated
130	Bad pick-up F.E. die marks	Washed - some pick-up	1.780	1.702	[illegible]	[illegible]	[illegible]	1.704	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Laminated
131	-														Sticker - broke stem
129	-														

General Data

Date: 5-22-59

Company: Babcock and Wilcox

Location Beaver Falls, Pa.

Cross Section View

Nominal Dimensions

A 2.000
B 1.750
C .125
D

Press Capacity (Tons) 1100
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 28:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material (1)	Billet Size	Billet Temp °F	Billet Coating	Heating Method Canned	Htg Time (Min)	Billet Lubricant	Billet Radius	Container Temp. °F	Die Lubricant	Die Temp °F	Die No.	Die Material R C	Die Lub Shape	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
133	6Al-4V	5"	1750	Spray 318-XW	Elect. Furnace	174	318	1/2"	575	3KB	900	33		1/2" flat	25	2.5			756	7'7"
134	"	5"	"	"	"	210	"	"	595	"	"	24		1/2" flat	20	2.5			810	8'4"
135	"	8"	"	"	"	90	"	"	700	"	"	2		1/2" flat	20	3			810	14'8"
136	"	10"	"	"	"	100	"	"	600	"	"	22		3/4" cone w1/2" T opening	20	3.5			864	20'10"
137	"	10"	"	"	"	124	"	"	610	"	"	23		"	18	3			756	20'11"
138	"	4"	"	"	"	87	"	"	675	"	"	31		"	20	3			1013	(2)
140	7Al-4Mo	8"	1800	"	"	82	"	"	670	"	"	34		"	23	2.5			783	15'10"
141	"	6"	"	"	"	97	"	"	710	"	"	18		"	20	2.75			837	11'9"
144	"	6"	"	None	"	107	"	3/4"	720	"	"	35		"	20	2.5			864	12'

(1) Billets polished with emery cloth to these surface readings - Side - 40-80 microinches RMS
Face - 30-100 " "

All trials with full lubrication practice

(2) .062 opening die used for this push, all other pushes with .125 die.

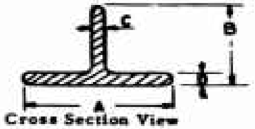
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Extrusion Section Dimensions Front A	Front B	Front C	Front D	Center A	Center B	Center C	Center D	End A	End B	End C	End D	Remarks
	The extruded shapes showed good straightness with little twist and no waviness. A general improvement over previous trials (see Table for surface readings.	All dies showed evidence of wear although some dies are reusable. All bearing surfaces were marked to at least a light degree and no bearing surfaces were unmarked as had been experienced in previous trials. The marking of the bearing surface indicates some breakthru of the protective glass film.													

General Data

Date: 5-22-59

Company Babcock and Wilcox

Location Beaver Falls, Pa.



Cross Section View

Nominal Dimensions

A 2.000
B 1.750
C .125
D .125

Press Capacity (Tons) 1100
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 28:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material C135-AMo	Billet Size 4"dia x	Billet Temp.	Billet Coating	Heating Method (Can)	Htg Time (Min)	Billet Lubricant	Container Lubricant	Container Temp. °F	Die Lubricant Shaped Pads	Die Temp. °F	Die Design 2 Piece	Die Material #		Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
145	Cast	7-3/4"	1800	85	STD	(1)	318	None	600	3KB	900	Tee	3		30	-		171,000	1100	-
146	"	"	"	"	"	"	"	"	"	"	"	"	34		20	1.50		118,500	765	18'8"
147	"	"	"	"	Double	"	"	"	"	"	"	"	39		(2)	2.00		119,300	770	18'16"
148	"	"	"	"	"	"	"	"	"	"	"	"	33		(2)	-*			-*	19'2"
149	"	"	"	383A	STD	"	383	"	"	383	"	"	37		20	-*			-*	17'8"
150	"	"	"	"	"	"	"	MoS_2	"	"	600	"	36		15	1.50		89,200	575	17'8"
151	"	"	"	"	"	"	318	"	"	3KB	"	"	38		15	1.50		113,000	727	18'2"
152	"	"	"	"	Double	"	"	"	"	383	200	"	35		(2)	1.75		136,600	881	17'6"
153	"	"	"	"	"	"	"	"	"	"	"	"	35		(2)	1.50		118,700	766	18'7"

(1) 1 Hour, 20 minutes minimum to 1 hour, 45 minutes maximum

(2) Effectively zero due to double container transfer method

*Recording equipment not functioning properly

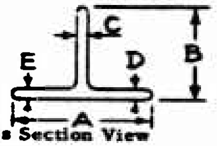
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Extrusion Section Dimensions												Remarks
			Front				Center				End				
			A	B	C	D	A	B	C	D	A	B	C	D	
145	See "Results"	-													Sticker
146		Good													
147		Bad local wash at top of Tee, one spot of pick-up.													Bad Lamination
148		Some wash and scoring at interior corners													Bad Lamination
149		Some scoring along Tee Upright													
150		Slight Scoring													
151		Some pick-up, bad wash at outside of Tee leg													
152		Good													
153		Still good, local wash started by defect in Ti													

General Data

Date: 2/12/60

Company: Babcock & Wilcox Co.

Location Beaver Falls, Pa.



Cross Section View

Nominal Dimensions

A 2.000"
B 1.750"
C .125"
D .125"
E. .125"

Press Capacity (Tons) 1100
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 28:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material C135 AMo	Billet Size 4" Dia. x	Billet Temp °F	Billet Coating	Heating Method (Can)	Htg Time (Min)	Billet Lubricant	Container Lubricant	Container Temp. °F	Die Lubricant	Die Temp. °F	Die Design 2 Piece	Die Material R C #		Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
154	Cast	7-3/4"	1800	85	Std.	(1)	318	MoS_2	600	3KB	200	Tee	36		15	1.50		118,700	766	18'5"
155	"	"	"	"	"	"	"	"	"	"	Cold	"	37		10	3.00		148,500	958	18'9"
160	"	10"	"	"	"	"	"	"	"	"	Room Temp	"	33		10	3.00		131,700	850	23'6"
161	Forged	"	"	"	"	"	"	"	"	"	"	"	34		15	5.00		154,400	996	23'9"

(1) 1 Hour, 20 Minutes minimum to 1 Hour, 45 Minutes maximum.

Extrusion Section Dimensions

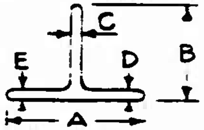
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Front				Center				End				Remarks
			A	B	C	D	A	B	C	D	A	B	C	D	
154	See "Results"	Fairly good, pick-up at interior corner													
155		Bad scoring along Tee Bottom & Upright, No Wash													
160		Bad wash, interior corners, pick-up on tee upright													
161		Severe wash on interior corners, some wash all over													Bad Lamination

General Data

Date: 2-12-60

Company: Babcock & Wilcox Co.

Location Beaver Falls, Pa.



Cross Section View

Nominal Dimensions

A 2.000"
B 1,750"
C .125"
D .125"
E .125"

Press Capacity (Tons) 1100
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 28:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material Forged	Billet Size Lgth	Billet Temp. °F	Billet Coating	Heating Method (can)	Htg Time (Min)	Billet Lubricant	Container Lubricant	Container Temp. °F	Die Lubricant	Die Temp °F	Die Design 2-piece	Die Material R C	Die No.	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
162	7Al 4Mo Ti	7 1/2"	1800	85	Std.	109	318	None	675	3KB 1/2" Thick	600	Tee		35	20.4	3.0		171,000	1080	14'1"
163	"	7 1/2"	"	"	"	132	"	"	620	"	600	"		53	21.0	2.4		120,000	750	14'5"
164	"	7 1/2"	"	"	"	138	"	"	605	"	800	"		57	18.6	2.4		111,000	700	19'
165	"	7 1/2"	"	"	"	148	"	"	590	"	"	"		55	19.8	2.4		111,000	700	14'9"
166	"	7 1/2"	"	"	"	98	3KB	"	575	3/8" Thick	"	"		50	22.2	2.0		102,000	650	14'2"
167	"	7 1/2"	"	"	"	90	"	MoS_2	560	"	"	"		46	22.8	2.4		142,000	900	15'2"
168	"	7 1/2"	"	"	"	93	"	None	535	"	"	"		49	14.2	2.0		111,000	700	14'11"
169	"	7"+1/2" ti nose	"	"	"	108	318	"	530	"	"	"		41	18.6	2.2		80,000	500	16'
170	"	7 1/2"	"	"	"	97		"	530	"	"	x"		56	21.6	1.8		96,000	600	14'10"

Extrusion Section Dimensions

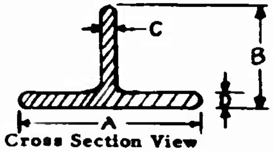
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Front				Center				End				Remarks
			A	B	C	D	A	B	C	D	A	B	C	D	
162	See Results	See Table IV - Evaluation of Die Performance													SEE TABLE V
163	"	"													
164	"	"													
165	"	"													
166	"	"													
167	"	"													
168	"	"													
169	"	"													
170	"	"													

General Data

Date: 29 September 1960

Company: Babcock and Wilcox

Location: Beaver Falls, Pa.



Cross Section View

Nominal Dimensions

A 2.000"
B 1.750"
C .125"
D .125"
E .125"

Press Capacity (Tons) 2500 Ton
Stem Diameter 4 1/16"
Container Diameter 4 3/16
Extrusion Ratio 25:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material Forged	Billet Size	Billet Temp. °F	Billet Coating	Heating Method (Can)	Htg Time (Min)	Billet Lubricant	Container Lubricant	Container Temp °F	Die Lubricant	Die Temp °F	Die Design 2-Piece	Die Material R C	Die No.	Billet Trans. Time (Sec.)	Extr. Time (Sec)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext Lgth (Ft.)
171	7Al 4Mo Ti	7 1/2"	1800	85	Std	103	3KB	None	545	3KB 3/8" Thick	800	Tee		59	21.6	2.2		142,000	900	16'11"
172	"	"	"	"	"	102	318	None	525	318	"	"		60	22.2	2.2		111,000	700	15'6"
173	"	"	"	"	"	90	318	None	575	3KB	"	"		42	20.4	1.6		102,000	600	14'10"
174	"	"	"	"	"	90	318	None	605	Glass Wool Pad	"	"		51	15.6	1.5		102,000	600	14'5"
175	"	"	"	"	"	97	3KB	None	635	3KB	"	"		58	16.8	1.6		102,000	600	15'11"

Extrusion Section Dimensions

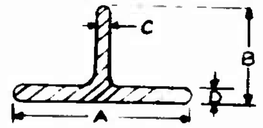
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Front				Center				End				Remarks
			A	B	C	D	A	B	C	D	A	B	C	D	
171	See Results	See Table IV - Evaluation of Die Performance													SEE TABLE V
172	"	"													
173	"	"													
174	"	"													
175	"	"													

General Data

Date: 29 September 1960

Company: Babcock & Wilcox

Location: Beaver Falls, Pa.



Cross Section View

Nominal Dimensions

A 2.000"
B 1.750"
C .125"
D .125"
E .125"

Press Capacity (Tons) 2500
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 25:1

PART III EXTRUSION TRIAL
DATA SHEETS

COMPTOIR INDUSTRIEL d'ETIRAGE el PROFILAGE de METAUX

TEST DATA OF EXTRUSION TRIAL

PUSH NO.	MATERIAL	Length BILLET DIM. inches	BILLET TEMP. °F	HEATING CONDITION	HTG. TIME (MIN.)	BILLET LUBRICANT			DIE DESIGN	DIE MATERIAL RC	DIE TEMP. °F	BILLET TRANSF. TIME (SEC)	EXTR. TIME (SEC)	Ram Speed inches/sec.	MAX. PRESSURE READING	MAX. PRESS ON BLLT. (PSI)	MAX. FORCE ON BLLT. (TONS)	EXTRUSION LENGTH ~~(FEET)~~ inches
1	4340	5.7	2200	Salt bath	14	[illegible]			U	Hot work die steel	Not heated	Less than 10 seconds		9.1	25	113,000	525	82
2	4340	5.7	2200	"	10	"			L	"	"			8.6	27	121,500	565	109
3	4340	5.7	2200	"	10	"			Z	"	"	"		8.8	31	140,000	650	174
4	4340	5.7	2200	"	11	"			U	"	"	"		8.6	25.5	115,000	535	84
5	Ti 6-4	5.7	1740	Coated with glass and heated in electric furnace	47	"			U	"	"	"		9.8	24.5	111,000	516	88
6	Ti 6-4	4.9	1740		47	"			L	"	"	"		10.3	25	113,000	525	100
7	Ti 6-4	5.7	1740		47	"			Z	"	"	"		9.2	29.5	133,000	618	170
8	Ti 6-4	5.7	1740	"	37	"			U	"	"	"		10.0	24.5	111,000	516	88
9	Ti 6-4	4.9	1740	"	43	"			L	"	"	"		9.1	24	109,000	506	101
10	Ti 6-4	5.7	1740	"	36	"			Z	"	"	"		8.3	28	126,000	586	169

All Billet Diameters – 2.36" All dies sectional flat face design

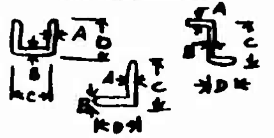
PUSH NO.	MATERIAL	Microinch, RMS EXTRUSION SURFACE FINISH FRONT	BACK	DIE CONDITION	EXTRUSION SECTION DIMENSIONS FRONT A	B	C	D	CENTER A	B	C	D	END A	B	C	D	REMARKS
1	4340	100-175	125-190	Reusable	.101 .103	.094	1.013	.873 .879					.100 .103	.094	1.012	.880 .880	
2	4340	125-160	120-135	Reusable	.100	.099	1.008	1.015					.098	.098	1.008	1.012	
3	4340	75-125	80-115	Reusable	.066	.062	.757	.619					.065	.060	.759	.618	
4	4340	150	140	Reusable	.100 .103	.094	1.009	.880 .878					.099 .103	.093	1.010	.880 .876	
5	Ti 6-4	125-275	175-375	Reusable	.102 .103	.092	1.014	.878 .878					.102 .101	.089	1.017	.875 .878	
6	Ti 6-4	175-185	150-225	Reusable	.099	.103	1.004	1.012					.099	.104	1.002	1.011	
7	Ti 6-4	110-150	150-450	Washed out	.066	.073	.768	.616					.068	.094	.765	.628	
8	Ti 6-4	175-275	110-175	Reusable	.103 .103	.090	1.018	.878 .878					.102 .102	.091	1.023	.879 .877	
9	Ti 6-4	200-250	175	Ti Pickup	.098	.102	1.012	1.005					.099	.104	1.012	1.007	
10	Ti 6-4	75-200	200-550	Washed out	.064	.071	.770	.624					.066	.101	.765	.627	

GENERAL DATA

DATE : 4/23/58

COMPANY : Comptoir Industriel d'Etirage et Profilage de Metaux

LOCATION: Persan, France



NOMINAL DIMENSIONS

A -
B -
C -
D -

CROSS SECTION VIEW

PRESS CAPACITY (TONS) 440 Vertical

STEM DIAMETER -

EXTRUSION RATIO U 19:1 L 26:1 Z 40:1

CONTAINER DIAMETER 2.44"

Test Data of Comptoir Extrusion Trials

General Data

Material: Ti 7-4
Container Diameter: 2.44"
Die Material: Hot work die steel
Press Capacity: 440 tons (vertical press)
Billet Diameter: 2.36"

Push No.	Date	Die No.	Ext. Ratio	Temp °F	Heating Time Min.	Condition	Ram Speed in/sec.	Pressure Reading psi/10^3	Pressure on Billet (tons)
11	10/7	○16.5	14.1/1	1650	57	Coated	6-1/2	154/117	360/273
12	10/7	○12.5	24.5/1	1650	55	with	8	181/133	422/310
13	10/9	○12.5	24.5/1	1700	40	glass	6	130/112	303/262
14	10/9		24.6/1	1700	45	and	?	161/121	375/282
15	11/13	○12.9	23/1	1750	55	heated	5	112/106	261/247
16	11/13	L 2253	23/1	1750	56	in	4-1/2	175/121	408/282
17	11/13	L 2306	45/1	1750	60	electric	3	154/140	360/326
18	11/13	○12.9	23/1	1700	47	furnace	4-1/4	175/130	408/303
19	11/13	L 2255	23/1	1700	48		sticker	188	440
20	11/13	○12.9	23/1	1650	52		3	168/145	392/338
21	11/13	L 2253	23/1	1650	54		3-1/2	171/152	400/354
22	11/14	L 2253	23/1	1700	50		4-1/2	134/125	312/292

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No	Billet Material (1)	Billet Size	Billet Temp -F	Billet Coating Glass	Heating Method	Htg Time (Min)	Billet Lubricant Glass	Container Lubricant	Container Temp. °F	Die Lubricant Glass	Die Temp	Die Design	Die Material R C (2)	Extr. Speed ft / sec	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading (psi)	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	E- Lgth (Ft.)
23 T	Ti 7Al/4Mo	4-3/4" x 8"	1800	E71	Elec. furnace	70	E71	MoS2 Grease	200	E71	Room	2326(1)	MTC	11.5	13	2.2	1940	116,000	1130	25.2
24 T	"	"	1800	E71	"	73	E71	"	200	E71	Room	2326(2)	MTC	12.3	11	2.1	2080	119,000	1210	25.8
25 ⊓	"	4-3/4" x 9"	1800	E71	"	97	E71	None	200	E71	Room	2327(1)	RDS	15.0	12	1.6	2405/ 1765	136,000/ 106,000	1400/ 1030	24
26 ⊓	"	"	1800	E71	"	103	E71	None	200	E71	Room	2327(3)	RDS	16.1	12	1.6	2480/ 1720	149,000/ 103,000	1440/ 1000	25.8
27 T	"	4-1/2" x7-1/2	1800	E71	"	117	E71	can.bil.carbon E71 between	200	E71	Room	2326(1)	MTC	19.8	19	1.0	1540/ 1495	102,500/ 99,500	890/ 870	19.8
28 T	"	"	1800	E71	"	90	E71	MoS2 Grease	200	E71	Room	2326(1)	MTC	9.9	17	2.4	1930	115,000	1125	23.8
29 T	"	"	1800	E71	"	95	E71	can.bil carbon + E71	200	E71	Room	2326(2)	MTC	10.5	12	2.0	1420	94,500	830	21.0
30 ⊓	"	"	1800	E71	"	102	E71	can. bil. st. + E71	200	E71	Room	2327(2)	RDS	9.1	17	2.2	1465	97,500	855	20.1

(1) All billet material was forged, annealed stock

(2) RDS is 9% Tungsten Hot Work Steel
MTC is 5% Chrome Tool Steel (AJAX T-1)

Extrusion Section Dimensions

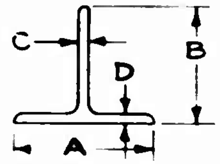
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Front A	Front B	Front C	Front D	Center A	Center B	Center C	Center D	End A	End B	End C	End D	Remarks
23	Scores near the end-Slight twist.	Slight die pick-up	2.050	1.790	.122 .134	.130 .150	2.052	1.790	.124 .128	.130 .147	2.039	1.803	.125 .122	.125 .138	
24	Slight scores near end-Slight twist.	Very slight die pick-up	1.865	1.785	.124 .131	.130 .142	2.039	1.803	.126 .126	.130 .146	2.050	1.803	.127 .110	.129 .145	
25	Good surface-very slight score near end. Very poor straightness on last 6 feet.	Very slight die pick-up.	2.551 1.511 .694 .539	.874 .878	.118 .120	.118	2.722 1.327 .678 .776	.886 .890	.111 .116	.114	2.870 1.535 .732 .752	.874 .886	.111 .118	.115	A partial shell remained in the liner due to poor container lubrication. This caused poor flow conditions.
26	Scores all along becoming more severe near end together with die wear.	Very severe die pick-up and wear.	2.761 1.535 .732 .729	.882 .890	.119 .118	.116	2.693 1.515 .780 .776	.878 .890	.120 .119	.113	2.942 1.526 .780 .776	.882 .894	.117 .119	.112	
27	Scores very severe near the end.	Severe pick-up and grooves at the end.	2.039	1.790	.129 .138	.133 .151	2.053	1.803	.129 .110	.133 .147	2.050	1.810	.128 .108	.132 .138	Billet was pushed thru can which remained in liner.
28	Good surface with 2 light scores which are barely discernible.	Slight wear lines	1.993	1.755	.120 .128	.122 .136	2.020	1.770	.121 .127	.121 .133	2.016	1.782	.123 .124	.119 .133	
29	Scratches on the base along 5 ft from front end - a few hollow defects near discard due to excess of glass drawn along by metal flow.	Severe wear lines.	2.007	1.762	.129 .128	.130 .140	2.028	1.882	.128 .127	.128 .141	2.028	1.770	.134 .128	.126 .140	"
30	A few hollow defects on the edges along the bar due to excess of glass drawn along by metal flow. No pickup scoring.	Severe die wear probably due to extrusion tearing near end of extrusion.	2.441 1.510 .569 .588	.870 .873	.115 .111	.107	2.600 1.533 .686 .698	.866 .881	.113 .121	.115	2.823 1.540 .752 .768	.870 .877	.112 .122	.109	"

General Data

Date: 9/7/59, 9/19/59, 10/3/59

Company: C.I.E.P.M.-Persan (France)

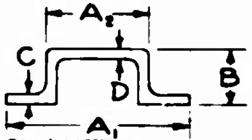
Location



Cross Section View

Nominal Dimensions

A 2.000
B 1.750
C .125
D .125



Cross Section View

Nominal Dimensions

A 2.75-1.50
B .875
C .125
D .125

Press Capacity (Tons) 1650
Stem Diameter 4.850"
Container Diameter 4.970"

Extrusion Ratio	39/1	36/1	34/1	32 1
Nos.	1, 2, 6	3, 4	5, 7	8

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp. °F	Billet Coating Glass	Heating Method	Htg Time (Min)	Billet Lubricant Glass	Container Lubricant	Container Temp. °F	Die Lubricant Glass	Die Temp	Die Design	Die Material R C	Extr Speed ft/sec.	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading (psi)	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext Lgth (Ft.)
31	Ti 7A1/4Mo	4-3/4" x 8"	1800	E71	Elec. furnace	57	E71	MoS2 Grease	240	E71	Room	2326(1)	RDS	11.8	15	2	1940	116,000	1130	23.5
32	"	"	1800	E71	"	66	E71	"	240	E71	Room	2326(2)	MTC	15.5	13	1.5	1940	116,000	1130	23.2
33	"	4-3/4" x 9"	1800	E71	"	65	E71	"	240	E71	Room	2326(1)	MTC	6.1	13	4.5	2080	125,000	1210	27.2
34	"	"	1800	E71	"	70	E71	"	240	E71	Room	2326(1)	RDS	17.6	18	1.5	2000	120,000	1160	26.4

Extrusion Section Dimensions

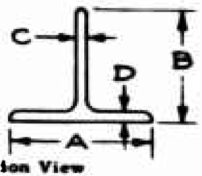
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion		Front				Center				End				Remarks
				A	B	C	D	A	B	C	D	A	B	C	D	
31	Uniformly smooth surface throughout with few light score lines starting in middle.	Very little pick-up. Reused for #12.	1 2	1.980	1.792	.128 .139	.125 .135	2.027	1.783	.127 .120	.123 .135	2.060	1.783	.126 .118	.123 .130	
32	Same as #9	Pick-up marks and light die wear lines.	1 2	2.048	1.775	.132 .134	.125 .136	2.048	1.783	.127 .116	.124 .136	2.042	1.780	.129 .120	.124 .128	
33	Same as above except more light score lines and one score aggravated by more severe pick-up.	Pronounced pick-up marks and light die wear lines.	1 2	2.020	1.803	.126 .132	.126 .135	2.030	1.792	.121 .112	.124 .134	2.040	1.780	.121 .119	.124 .133	
34	Most aggravated pick-up scoring of the four pushes. Surface between groups of score lines remains smooth.	See die surface in Figure 21	1 2	2.040	1.788	.127 .140	.126 .137	2.030	1.788	.123 .120	.122 .134	2.043	1.788	.122 .119	.122 .130	

General Data

Date: 10/30/59

Company: C.I.E.P.M., Persan, France

Location



Nominal Dimensions
A 2.000
B 1.750
C .125
D .125

Cross Section View

Press Capacity (Tons) 1650
Stem Diameter 4.850
Container Diameter 4.970
Extrusion Ratio 39:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp. °F	Billet Coating (glass spray)	Heating Method	Htg Time (Min)	Billet Lubricant	Container Lubricant	Container Temp. °F	Die Lubricant (glass pad)	Die Temp.	Die Design	Die Material R C	Extr Speed ft/sec	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading (psi)	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
35	Ti 7Al/4Mo	2 3/8 x 3 1/2 to 5" long	1800	E71	Elec. furnace	24		MoS2 Grease	750	E71 (200)	Room	2253(3)	MTC	9.2	Approx. 3.0 Seconds	0.8	2830	125,500	293	7.35
36	"		1800	E71	"	23		No	750	* E71 (140)	Room	2253(5)	"			Sticker	3980	175,000	410	Sticker
37	"		1800	C105	"	28		MoS2 Grease	750	E71 (100)	Room	2253(4)	"	10.9		0.8	3770	167,000	390	8.7
38	"		1800	E71	"	24		"	750	(40/ E71 100)	Room	2253(1)	"	9.4		0.7	3150	140,000	328	6.55
39	"		1800	E71	"	22		"	750	E71 (200)	Room	2253(2)	"	12.8		0.6	2640	117,000	273	7.7
40	"		1800	E71	"	22		"	750	(1) E71 (200)	Room	2253(6)	"	12.3		0.8	3770	167,000	390	9.85
41	"		1800	C105	"	25		"	750	(2) E71 (200)	Room	2253(5)	"	23.3		0.3	2640	117,000	273	7.0
42	"		1800	C105	"	21		"	750	(3) E71 (200)	Room	2253(2)	"	22.7		0.35	2640	117,000	273	7.95

*Powder only - No pad used

(1) Numerous steel chips placed near orifice opening in glass pad. Presumably ejected prior to break-through.

(2) Few steel chips placed 3/8 from orifice opening in glass pad into small hole 1/8" deep.

(3) Same as in 2 except steel chips on one leg and emery grain on other leg.

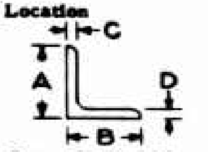
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Extrusion Section Dimensions Front A	B	C	D	Center A	B	C	D	End A	B	C	D	Remarks
35	Light to moderate score	Very shallow pick-up pits.													
36	Sticker	Sticker													
37	No score lines	Very light die wear lines. No pick-up marks.													
38	No score lines														
39	No score lines	No record. Die reused for Push No. 20.													Push No. 19 - The pit in the die was caused 1/2" from the butt end as a result of extruding chilled material. This can be avoided by leaving a reasonable butt thickness (1/2").
40	Moderate score lines	Moderate pick-up pits.													
41	No score lines	Deep pick-up pits on one leg (see Remarks).													
42	Severe score lines	Severe pick-up pit and lines on all four surfaces.													

General Data

Date: November 16, 17, 1959

Company: CIEPM

Location



Cross Section View

Nominal Dimensions

A 1.000 ± .012
B 1.000 ± .012
C .094 ± .006
D .094 ± .006

Press Capacity (Tons) 440
Stem Diameter 2.3"
Container Diameter 2.45"
Extrusion Ratio 25.2

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp.	Billet Coating (glass spray)	Heating Method	Htg Time (Min)	Billet Lubricant	Container Lubricant	Container Temp.	Die Lubricant	Die Temp	Die Number	Die Material R C	Ext. speed ft/sec.	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext Lgth (Ft.)
43 (1)	Ti 7/4	58 mm (2.3")	980°C 1795°F	1st coat - C105 2nd coat - C240	Elec. furnace	92		MoS2 Grease	400°C 750°F	6240 (40-100)	Room	6	MTC 5% Cr	18.2		.5		109,000	280	8.6
44 (1)						23				"		3		6.3		1.3		129,000	332	8.6
45 (1)						30				"		1		6.7		.9		113,500	290	5.8
46						28				"		4		8.1		.7		106,000	272	5.9
47						24				E 71 (40-100)		5		7.5		.6		121,000	310	4.7
48						26				"		5		17.0		.3		112,000	288	4.9
49						24				"		3		5.4		.8		118,000	303	4.6
50						23				"		5						129,000	332	6.5

(1) Pure titanium discs were used in front of these extrusion billets

Extrusion Section Dimensions

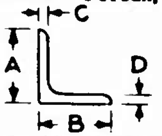
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Front				Center				End				Remarks
			A	B	C	D	A	B	C	D	A	B	C	D	
43	Catastrophic scoring	Beyond salvage													Extruded with titanium plate in front of the billet
44	Deep groove at front of extrusion disappears at back end.	No pick-up pits													"
45	Severely scored	Severe pick-up pits													"
46	Severely scored	Shallow pick-up pits													Extruded with approach speed - No delay.
47	Good surface - No scores	No pick-up pits													
48	Good surface - Two light score lines.														
49	Good surface No scores														
50	Good surface - Two score lines														

General Data

Date: November 23, 1959

Company: CEFILAC

Location Persan, France



Cross Section View

Nominal Dimensions

A 1.010"
B 1.010
C .095"
D .095

Press Capacity (Tons) 440
Stem Diameter 2.3"
Container Diameter 62 mm (2.45")
Extrusion Ratio 25.2

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp °F	Billet Coating Glass	Heating Method	Htg Time (Min)	Billet Lubricant Glass	Container Lubricant	Container Temp °C	Die Lubricant Glass	Die Temp	Die Design	Die Material R C	Extr. Speed ft/sec.	Billet Trans. Time (Sec)	Extr. Time (Sec.)	Max Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
51	Ti 7Al/4Mo	4-3/4 x 8"	1800	E71	Elec. furnace	70	E71	MoS2 Grease	100	E71	Room	2326(4)	MTC	9.0	16	2.9	2150	128,500	1250	26.2
52						77						2326(5)		9.3	14	2.8	2080	124,500	1210	26
53						64						2326(5)		12.4	13	2.1	2080	124,500	1210	26

Extrusion Section Dimensions

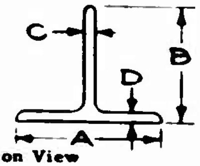
Push No.	Extrusion Surface and Straightness *	Die Condition After Extrusion		Front				Center				End				Remarks
				A	B	C	D	A	B	C	D	A	B	C	D	
			1			.130	.130									
		Die Nr 4 Dimensions	2			.134	.134									
51	Pickup scores in the last 1/3 of the bar.	Slight die pick-up, groove on one end	1	2.005	1.752	.122	.123	2.040	1.783	.119	.124	2.035	1.790	.124	.122	
			2			.138	.131			.126	.132			.125	.132	
			3				.124				.122				.121	
			4				.135				.134				.128	
		Die Nr 5 Dimensions	1			.128	.128									
			2			.134	.134									
52	Pickup scores in the last 1/3 of the bar.	Slight die pickup	1	2.050	1.700	.124	.126	2.050	1.792	.122	.123	2.045	1.780	.120	.119	
			2			.140	.136			.128	.135			.126	.133	
			3				.127				.121				.123	
			4				.138				.135				.138	
53	Very severe scores on the last 2/3 of the bar.	In this second use of Die #5, pickup became very severe on all die bearing surfaces.	1	2.020	1.780	.127	.123	2.050	1.803	.122	.124	2.050	1.792	.119	.123	
			2			.140	.131			.126	.135			.124	.131	
			3				.126				.123				.120	
			4				.137				.135				.129	

General Data

Date: November 24, 1959

Company C.I.E.P.M., Persan, France

Location



Cross Section View

Nominal Dimensions

A 2.000
B 1.750
C .125
D .125

Press Capacity (Tons) 1650
Stem Diameter 4.850
Container Diameter 4.970
Extrusion Ratio 39/1

* Extrusions 51, 52, 53 had the typically smooth surface obtained with glass lubrication. In comparison with extrusions 23-34, these three pushes were somewhat more scored and twisted.

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material	Billet Size	Billet Temp. °F	Billet Coating	Heating Method	Htg Time (Min)	Billet Lubricant	Container Lubricant	Container Temp. °F	Die Lubricant	Die Temp	Die Design	Die Material R C		Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
54	Ti 7/4	2.36 x 5.31"	1800	C105	Salt Bath	30	None	MoS2	750	E-71	Room	One 1 Pc.	42.8		9	0.75		172,000	368	9.8 ft.
55	"	2.36 x 5.43"	"	"	Elec. Furnace	43	-	-	"	C-105	"	2 (1P)	41		3.5	0.9		177,000	373	10.2
56	"	2.36 x 5.28"	"	"	"	33	-	-	"	E-71	"	5 (2P)	43.3		3	0.5		125,000	264	10.1
57	"	2.36 x 5.24"	"	"	"	30	-	-	"	E-71	"	6 (2P)	43		3	1.0		158,000	334	10.2
58	"	2.36 x 5.39"	"	"	"	30	-	-	"	C-105	"	7 (2P)	42.6		2.5	0.5		133,000	280	10.2
59	"	2.36 x 5.31"	"	"	"	37	-	-	"	E-71	"	11 (2P)	46		4.6	1.0		176,000	370	10.9
60	"	2.36 x 5.31"	"	"	"	30	-	-	"	C-105	"	10 (2P)	45.3		4	0.6		163,000	343	10.4
61	"	2.36 x 5.31"	"	"	"	45	-	-	"	C-105	"	3 (1P)	44		3	?		186,000	392	7.0
62	"	2.36 x 5.19"	"		"	35	C-80	-	"	C-105	"	12 (2P)	44.6		12	0.6		163,000	343	11.2

Extrusion Section Dimensions

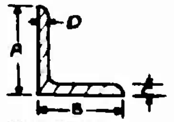
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Front				Center				End				Remarks
			A	B	C	D	A	B	C	D	A	B	C	D	
54	See Results	Slight wear of the inlet radius on the outside legs.													
55	"	More severe wear than in #1 - some pick-up.													
56	"	Inlet radius completely worn out - some pick-up.													
57	"	Same as Die No. 3													
58	"	Similar to No. 2													
59	"	Inlet radius completely washed out -consid. wear.													
60	"	Slight wear - Some pick-up.													
61	"	Heavy wear of inlet radius - heavy pick-up.													
62	"	Numerous die pick-up - slight wear.													

General Data

Date: July 11, 1960

Company: CEFILAC

Location Persan, France



Cross Section View

Nominal Dimensions
A 1.000
B 1.000
C .094
D .094

Press Capacity (Tons) 400
Stem Diameter 2.36"
Container Diameter 2.44"
Extrusion Ratio 25:1

PART IV EXTRUSION TRIAL
DATA SHEETS

BABCOCK AND WILCOX COMPANY

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material Forged	Billet Size 4" Dia Length	Billet Temp.	Billet Coating	Heating Method (can)	Htg Time (Min)	Billet Lubricant	Container Lubricant	Container Temp. °F	Die Lubricant	Die Temp °F	Die Design	Die Material	Die No.	Total Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
176	7A14Mo Ti	8"	1800°F	#85	Std.	125	3KB	None	800	3KB	600	2-piece Tee	M-36	56	78	4 1/2		152,000	966	15'1"
177	"	"	"	"	"	140	318	"	"	3KB	800	"	"	47	72	3 1/4		131,000	826	16'1"
178	"	"	"	"	"	161	318	"	"	Glass Wool	"	"	"	44	67	3 1/4		140,000	879	16'1"
179	"	"	"	"	"	181	3KB	"	"	3KB	"	"	"	41	57	4		146,000	919	16'3"
180	"	"	"	"	"	99	318	"	"	3KB	"	"	"	49	50	3		127,000	800	16'5"
181	"	"	"	"	"	94	318	"	"	Glass Wool	"	"	"	54	48	3 3/4		125,000	787	15'9"
182	Cast	8 7/16	"	"	"	85	318	"	"	"	"	"	"	43	50	3 1/4		133,000	840	17'0"
183	Forged	8 1/2"	"	A-50	"	93	318	"	900	3KB	"	"	"	48	50	3		117,000	735	16'9"
184	"	8 1/2"	"	DAG261	"	88	318	"	"	3KB	"	3-piece Tee	Peerless A	2	54	3 1/2		125,000	787	19'9"

Extrusion Section Dimensions

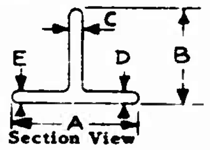
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Front				Center				End				Remarks
			A	B	C	D	A	B	C	D	A	B	C	D	
176	See Results	See Table II - Evaluation of Die Performance													See Table II
177	"	"													
178	"	"													
179	"	"													
180	"	"													
181	"	"													
182	"	"													
183	"	"													

General Data

Date: 24 May 1961

Company: Babcock & Wilcox

Location Beaver Falls, Pa.



Cross Section View

Nominal Dimensions

A 2.000"
B 1.750"
C .125"
D .125"
E .125"

Press Capacity (Tons) 2500
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 28:1

TEST DATA OF EXTRUSION TRIALS AF33(600) 34098

Push No.	Billet Material Forged	Billet Size	Billet Temp. °F	Billet Coating	Heating Method (can)	Htg Time (Min)	Billet Lubricant	Container Lubricant	Container Temp. °F	Die Lubricant	Die Temp °F	Die Design	Die Material R C	Die No.	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure Reading	Max. Pressure on Billet (psi)	Max. Force on Billet (Tons)	Ext. Lgth (Ft.)
185	7A1 4Mo Ti	8"	1800	#85	Std.	91	318	None	800	Glass Wool (54 grams)	800	2-piece Tee	Ceramic Coated M-36	X	45	3 1/2		144,000	905	20'7"
186	"	8"	1800	#85	Std.	102	3KB	None	"	3KB	"	3-piece Tee	Peerless A	4	45	3		146,000	918	23'10"
187	"	7 1/2"	1800	#85	Std.	88	318	None	"	Glass Wool (54 grams)	"	"	"	1	58	3		128,000	813	19'8"

Extrusion Section Dimensions

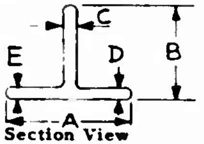
Push No.	Extrusion Surface and Straightness	Die Condition After Extrusion	Front				Center				End				Remarks
			A	B	C	D	A	B	C	D	A	B	C	D	
185	See Results	See Table II - Evaluation of Die Performance													
186	"														Incomplete fill-out of extrusion.
187	"														Complete fill-out of extrusion.

General Data

Date: 24 May 1961

Company: Babcock and Wilcox

Location Beaver Falls, Pa.



Cross Section View

Nominal Dimensions

A 2.000
B 1.750
C .093
D .093
E .093

Press Capacity (Tons) 2500
Stem Diameter 4 1/16
Container Diameter 4 3/16
Extrusion Ratio 38:1

TEST DATA OF EXTRUSI 'RIALS AF33(600) 34098

Push No.	Billet Material Forged	Billet Size 4" Dia Length	Billet Temp	Billet Coating	Heating Method Argon Atm.	Htg Time (Min)	Billet OD Lubricant (Glass)	Die Lubricant (Glass Pad)	Container Temp. °F	Die Coating (Ceramic)	Die Temp °F	Die Design "Tee" & Size	Die Material R C	Die No.	Billet Trans. Time (Sec.)	Extr. Time (Sec.)	Max. Pressure on Billet (PSI)	Peak Force on Billet Ton	Average Force on Billet (Tons)	Ext Lgth (Ft.)
188	7Al-4Mo Ti	8"	1800°F	#85	Electric Furnace	94	318-14 mesh	3KB-14 mesh	800	none	800	2-Piece .125"	M-36	40	48	4	128,000	814	748	15' 2"
189	"	"	"	"	"	111	"	3KB-14	800	"	800	3-Piece .092"	P. A.	31	54	3 1/2	133,000	840	761	22' 6"
190	"	"	"	"	"	113	"	3KB-14	800	Alumina	800	3-Piece .092"	P. A.	33	52	2 3/4	133,000	840	761	24' 8"
191	"	"	"	"	"	124	"	3KB-40	900	none	1000	2-Piece .125"	M-36	45	54	3	113,000	708	669	15' 4"
192	"	"	"	"	"	90	"	3KB-40	900	"	"	3-Piece .092"	P. A.	39	50	3	121,000	761	735	22' 10"
193	"	"	"	"	"	84	"	3KB-14 R(1) 1 G. W. Pad	900	"	"	2-Piece .125"	M-36	52	63	3	127,000	800	715	14' 4"
194	"	"	"	"	"	85	"	3KB-14 R 2 G. W. Pads	900	"	"	3-Piece .092"	P. A.	41	69	2 3/4	138,000	866	761	20' 10"
195	"	"	"	"	"	45	"	3KB-14 R 3 G.W. Pads	900	"	"	3-Piece .092	P. A.	43		3 1/4	138,000	866	791	20' 8"
196	"	7 1/2"	"	"	"	64	"	3KB-14 R 3 G.W.Pads	1000	Alumina	"	3-Piece .092"	P. A.	36	58	3	125,000	787	748	21' 0"
197	7Al 4Mo Ti	8"	1800°F	#383 A	Electric Furnace	90	318 - 14	3KB - 14	1000	none	1000	3 piece .125"	P. A.	32	54	3	117,000	735	708	16' 11"
198	"	8	"	"	"	80	"	3KB - 14R 3G. W. Pads	"	"	"	3 piece .092"	"	44	60	3	117,000	735	695	18' 9"
199	"	7 1/2	"	"	"	65		PULL OFF	LINE UP											
200	"	8	"	#85	"	65	318 - 14	3KB - 14R 3G. W. Pads	1000	none	1000	3 piece .092"	P. A.	53	60	2 1/2	128,000	813	721	18' 10"
201	"	7 1/2	"	"	"	52	"	"	"	Chrome oxide	"	"	"	37	48	3	142,000	892	715	19' 1"
202	"	7 3/4	"	"	"	60	"	"	"	alumina	"	"	"	34	52	2 3/4	113,000	708	628	22' 2"
203	"	5	"	"	"	55	"	"	"	none	"	3 piece .062"	"	42	49	2 1/4	133,000	840	787	17' 6"
204	"	5	"	"	"	75	"	"	"	Chrome oxide	"	"	"	38	54	2 1/3	121,000	761	735	16' 7"

G.W. (glass wool pads)

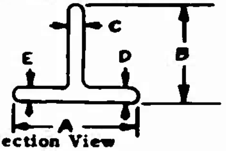
P. A. Peerless "A" - 9% Tungsten Tool Steel
M-36 6% Tungsten Tool Steel

General Data

Date: November 27, 1961

Company: Babcock & Wilcox

Location: Beaver Falls, Pa.



Cross Section View

Nominal Dimensions

A 2.000
B 1.750
C .093
D .093
E .093

Press Capacity (Tons) 2,500
Stem Diameter 4 1/16"
Container Diameter 4 3/16"
Extrusion Ratio 38:1

Results of Group No. 18 Extrusion Trial Conducted at the Babcock and Wilcox Co.
on June 5, 1962, AF33(600)-34098 Part IV - Heat No. D1252 7Al-4Mo Ti

Push No.	Billet		Extrusion Length	Billet Heating Time	Die Pad	Die Size	Die Matl.	Die No.	Results
	Lgth	Wt							
205	7 3/4"	16#	20'1"	80 min.	T cut orifice	.092"	PA-UC* 3 piece	205	1. Good glass coverage along entire length. No glass build-up on front end. Severe scoring approx. 9' from back end on bottom and top of flange section. 2. Full extrusion fill-out at breakthru. 3. Fairly straight extrusion. Some twist 4. Billet discard lost below the press 5. Die showed slight wear, bottom section damaged by cut-off saw. Slight wash in corner section at top of stem
206	7 3/4"	16#	sticker	88 min.	T cut orifice	.092"	PA-Al 3 piece	206	Cover was dislodged from billet carrier can during billet transfer to extrusion press which resulted in some billet cooling. This condition combined with lower press pressure due to improper setting of pressure pump recycling resulted in a sticker. Approximately 3" of extruded material passed thru $A120_3$ coated die partially destroyed the $Al_2 0_3$ coating. Die material remained undisturbed.
207	7 3/4"	16#	18'8"	106 min.	T cut orifice	.092"	PA-UC 3 piece	207	Good glass coverage over entire lgth of extrusion. Scoring on bottom of flange and right radius corresponding to die wear. Clear surface on bottom flange corresponds to scalping of discard in that area. Some scoring on bottom flange about 10' from back end, wavy pattern of stem element. Complete extrusion fill-out at front end peak breakthru pressure 1100 tons. Discard showed lamination at bottom flange

*PA = Peerless "A" Steel
UC = Uncoated Die
Al = Alumina Coated

Push	Billet		Extrusion	Billet	Die	Die	Die	Die	Results
No.	Lgth	Wt	Length	Heating Time	Pad	Size	Matl.	No.	
207 (continued)									portion. Good glass coverage - wrinkles on billet and extrusion surface over the lamellar flow pattern. Dies: galling in right radius and deep wear on bottom flange - slight wear on all surfaces.
208	7 3/4"	16#	sticker	-	T orifice	.092"	PA-Al 3 piece	208	Sticker - no material passed thru die - possibility of glass blockage of die - remedy was to open up tee orifice in glass wool pad - alumina die coating and die material undisturbed.
209	7 3/4"	16#	17'7"	-	enlarged T orifice 2 glass wool pads	.092"	PA-Cr plated .005"	209	Tee orifice of glass wool pad opened up 1/2" wide. Complete extrusion fill-out at breakthru - no glass buildup. Glass coverage very light and green coloration due to reaction with chromium plated die radii lubrication. Some scoring 3' from back end. Discard - uniform matl flow - good glass coverage on discard. Die does not iron out wrinkled billet skin on discard. Dies - heavy wash on bottom land section - chrome plating was depleted as indicated by copper sulphate test. The chrome reacted with glass lubricant and protected die surface to some degree.

Push No.	Billet		Extrusion Length	Billet Heating Time	Die Pad	Die Size	Die Matl.	Die No.	Results
	Lgth	Wt							
210	7 3/4"	16#	21'	-	same as 209	.092"	PA Ni 3 piece	210	Fair to good glass coverage entire extrusion length. Ragged breakthru at front end and 1100 tons peak pressure indicated some difficulty at breakthru. Some scoring on right stem approx. 10' from front end. Discard - shows uniform metal flow and good glass coverage. Wrinkles on billet butt was not ironed out as it passed through die area. Die - Difficult to tell condition of glass covered die; however, die washed along the entire bottom flange surface. Nitrided die material not acceptable. Some wash in stem corners.
211	7 3/4"	1#	18'2"	-	Same as 209	.092"	Pa Ni Cr 3 piece	211	1125 ton peak pressure and jagged breakthru front end of extrusion - good glass coverage over entire length - green glass coloration due to reaction of glass lubricant with die chrome plating. Scoring approximately 5' from front end on bottom flange-good glass coverage in radii. Discard similar to that experienced in push 210. Die stem area good. Some wash in corners - severe wash in flange area and depletion of chrome plating in most of die land area.

Push No.	Billet		Extrusion Length	Billet Heating Time	Die Pad	Die Size	Die Matl.	Die No.	Results
	Lgth	Wt							
212	7 3/4"	16#	17'9"	-	same as 209	.092"	PA Al* 3 piece	212	Good glass coverage entire length of extrusion. No scoring on bottom flange. Good surface in terms of smoothness and no scoring on surface. Sharp corners. 1100 ton breakthru pressure and complete fill-out of FE. Discard showed good glass coverage - no glass in left radius. Billet skin wrinkles were smoothed out as they passed thru alumina die. Die - alumina coating spalled in land area, but die material undisturbed. Good die.
213	7 3/4"	16#	22'4"	-	same as 209	.092"	PA Al 3 piece	213	Complete glass coverage over entire extrusion length, twist approx. 7' from back end of extrusion. Complete extrusion fill-out at breakthru at 1050 tons pressure. Discard showed good glass coverage and ironing out of billet skin wrinkles as it passes thru die orifice. Alumina coating was removed from die land area. The underlying die metal remained undisturbed. (see Fig. 8).
214	7 3/4"	16#	16'7"	-	same as 209	.098"	Rex AA 1 piece	214	Fair coverage along entire length of extrusion. Complete extrusion fill-out at breakthru at 1075 tons peak pressure. Fairly straight extrusion length some twist. Dummy block expanded and scored liner. Left radius dry at breakthru. Extrusion length was laminated 7' from front end. Severe scoring at lamination 4' from front end. Severe scoring at laminated and scalped billet and extreme radius wash on right side of discard. Die stem shows some wear - top of flange area & right radius severely washed with closing in of radii area. Die matl was heat treated to a hardness of Rc 58. (Fig. 9)

*Rex AA = 18% tungsten steel
PA = Peerless "A" Steel
Al = Alumina Coated Dies

Push No.	Billet Lgth	Billet Wt	Extrusion Length	Billet Heating Time	Die Pad	Die Size	Die Matl	Die No.	Results
215	5 3/4"	12#	21'	-	granular pad - T orifice and 3 glass wool pads	.062"	PA UC* 3 piece	215	Good glass coverage of FE. Partial coverage towards BE - incomplete extrusion fill-out of the first 10' from FE at 1100 tons peak pressure. Left flange incomplete fill out (1/8"short) along entire length due to die blockage. Dimensional variation from front to back end indicated both incomplete fill-out at FE and die wear. The billet discard was scalped with the extrusion butt severely scored and scalloped. The die was slightly worn in bottom flange area with areas of wash near the corners - overall die condition fair.
216	5 3/4"	12#		-	granular pad - 1 glass wool ring	.062"	PA Cr 3 piece	216	One glass wool pad was used to prevent die blockage at breakthru. However, this was not the case. The entire stem section of the die orifice was blocked; only the flange section extruded at 1075 ton peak pressure. The billet discard was severely laminated which might be attributed to excessive chilling of the billet surface during the O.D. glass application. The die surface of the bottom flange and radii were severely washed.
217	5 3/4"	12#	sticker	-	same as 216 - glass pad orifice opened to 1/2"	.062"	PA Ni-Cr 3 piece	217	Heated billet was rolled through O.D. glass once in an attempt to reduce billet surface chilling. Only 5' of extrusion flange came thru die orifice. Stem did not extrude. Die showed severe wash of area in contact with extrusion section.

*PA = Peerless "A" Steel; UC = Uncoated
Cr = Chrome Plated Die

Push No.	Billet		Extrusion Length	Billet Heating Time	Die Pad	Die Size	Die Matl	Die No.	Results
	Lgth	Wt							
218	6"	12#	40' of flange	-	same as 217	.062"	PA Al* 3 piece	218	Delay handling time in billet transfer in removal of transfer can from furnace. Incomplete fill of extrusion at 1075 tons peak pressure. Flange area extruded to a width of 1". Glass die blockage at FE was dislodged approximately 4' from BE as evidenced by fill-out of the tee cross section. Non-uniform metal flow and scalping was evidenced on the discard. Severe die wash of the bottom flange section was experienced. A glass/graphite O. D. lubricant was used in an attempt to facilitate breakthrough.
219	5 3/4"	12#	18'2"	-	glass ring & 3 glass wool pads	.062"	PA Al 3 piece	219	The precut tee orifice granular glass die pad was replaced with a 1/2" wide granular glass ring backed up with 3 glass wool die pads having expanded tee orifice openings. The O. D. lubricant was changed to a glass/graphite mixture to facilitate breakthrough - complete extrusion fill-out at FE at a peak pressure of 1030 tons. Glass coverage good for first 10' of extrusion,- ran out of glass in radii areas towards BE with some pick up. Scoring on extrusion stem area. Extrusion had one complete twist along its length. Die had a buildup of glass on the flange section. Some wash in radii areas (see Figs. 10 and 11). Die matl undisturbed. Discard showed uniform metal flow with fair glass coverage.

* PA-Al = Alumina Coated Peerless "A" Steel Die

TEST DATA OF TITANIUM ALLOY EXTRUSION TRIALS AF33(600) 34098

Conducted at the Babcock & Wilcox Co. on July 24, 25, 1962

Push No.	Billet Material (Forged) Heat No.	Billet Size 4" Dia. Length	Billet Temp. °F	Billet Coating (Glass)	Billet Weight	Htg Time Actual	Billet Lubricant (Glass)	Die Pad Lubricant (Glass)*	Die Pad Temp. °F	Aluminum Die Coating Thickness	Die Temp. °F	Die Design Tee Opening	Die Material	Die No.	Billet Trans. Time (Sec.)	Extr. Length Ft-In	Tons Peak Extrusion Force	Tons Average Extrusion Force
220	7AL-4Mo D-1252	6½	1800°F	85	13.1	85	318-14 MESH	3KB-14 MESH Ring + 34W PADS	Room	.008	1000	3 PIECE 1/16"	PEERLESS A 9% TUNGSTEN	235	60	21-5	950	902
221	"	"	"	"	"	"	"	"	"	.028	"	"	"	1**	"	-	925	-
222	"	"	"	"	"	"	"	"	"	008	"	"	"	236	42	-	"	-
223	"	"	"	"	"	90	"	"	1000°	"	"	"	"	237	55	-	1100	-
224	"	"	"	"	"	155	"	"	Room	.019	"	"	"	206**	63	19-11	"	1000
225	"	"	1825	"	"	160	"	"	"	.004	"	"	"	219**	40	17-9	735	603
226	6AL 4VA D 3025	7	1750/1800	"	13.8	"	"	"	1000°	015	"	"	"	224	36	23-6	1300	1000
227	"	"	"	"	"	145	"	"	Room	.008	"	"	"	225	43	22 5	900	800
228	4AL-3Mo/V D 3269	"	"	"	14 0	6c	"	"	Room	"	"	"	"	230	38	16-9	850	775
229	"	"	"	"	"	"	"	"	1000°	"	"	"	"	231	48	17-7	775	675
230	7AL-4Mo D 1252	6½	1800	E 71	13.1	75	E-71-B	E 71A OPEN T PAD + 2GW PADS	"	"	"	"	"	238	"	18 8	700	650
231	"	6	"	"	12.1	65	"	E-71B OPEN T + 34W. PADS	"	025	"	"	"	6**	42	22-1	950	825
232	"	"	"	"	"	60	318-14 MESH	E-71A RING + 34W PADS	"	.008	"		"	239	49	21-0	900	"
233	"	"	"	"	"	60	E 71-B	"	"	"	"	"	"	240	44	19 3	825	775
234	6AL-4VA D-3025	7	1750/1800	E-71B	13.8	55	318	3KB-14 MESH RING + 34W PADS	"	.022	"	"	" "	212**	38	26-4	875	800
235	"	"	"	85	"	50	E-71B	E-71 RING + 3GW PADS	"	.008	"	"	"	226	42	"	900	"
236	"	"	1800	E-71B	"	60	"	"	"	"	"	"	"	227	–	25-2	825	775
237	"	"	"	85	"	"	"	E 71B RING + 34W PADS	"	.019	"	"	"	208**	40	–	"	810
238	"	"	"	"	"	75	"	E-71 RING + 34W PADS	Room	"	"	"	"	213**	44	26-1	925	825
239	"	"	"	"	"	80	318-14 MESH	3KB RING + 3GW. PADS	"	.008	"	"	"	229	42	25-4	755	675
240	4AL 3Mo/V D-3269	"	"	"	14.0	"	"	"	1000°	.030	"	"	"	5**	48	23-11	650	600
241	"	"	"	"	"	95	"	E 71 RING + 34W PADS	"	.019	"	"	"	220**	53	25-9	"	"
242	"	"	"	"	"	70	"	3KB RING + 34W PADS	"	004	"	"	"	231**	43	34-0	"	"
243	"	"	"	E-71B	"	"	E-71-B	E-71 RING + 34W. PADS	"	.008	"	"	"	232	"	17-3	"	"
244	"	"	"	85	"	75	318-14 MESH	3KB-14 MESH + 34W. PADS	"	"	"	"	"	233	36	20-11	475	450
245	"	"	"	"	"	60	318 14 MESH 10% 7 [illegible]	"	"	"	"	"	"	234	41	23-4	505	500

* G. W. = Glass Wool

** Dies used in previous extrusion trial.

	Discard (a)		Glass Coverage (b)					Die Material Condition (c)		
Push	Metal Flow	Glass Cover-age	Front	Middle	Back	Extrus. Length	Die No.	Wear	Wash	Remarks
220	Scalped	Good	Good	Good	Good	21' 5"	235		3, 6	Extrusion section of discard fractured in press, therefore it was not necessary to use the cut off wheel for discard separation. Good breakthrough. Glass run out in radii 10 feet from front end.
221	Full Flow	Sticker				13"	221	Good		Thick layer of die coating spalled off die surface - plugging the die port - Extrusion necked down and broke after 12 inches of extrusion
222		Sticker				3"	236	Good		Good breakthrough first 3 inches of extrusion
223	Full Flow	Good	Good	Good	Good	21"	237	Good		Sticker - Good breakthrough - Extrusion broke after 21", no necking in break area.
224	Laminated	Good	Good	Fair	Fair	19' 11"	206	Good		Billet heat soak temperature raised to 1825°F with a long heat soak time. The fiber glass string holding the glass wool pad to the granular glass die pad was removed and the glass wool pad orifice enlarged. Die used previously
225	Full Flow	Good	Good	Good	Good	17' 9"	219	Die Material undisturbed		3" left on billet discard - press just stopped after 17'9" were extruded. Die pad heated to 1000°F. Some twist to extruded shape. Die used previously

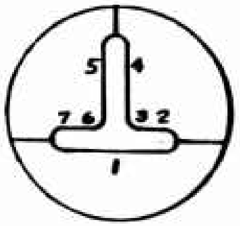
(a) Discard

Good: Uniform metal flow
Fair: Uneaqual metal flow
Poor: Scalped condition - interior metal forming extrusion surface

(b) Glass Coverage

Good: Uniform glass film
Fair: Streaky glass coverage - some bare spots
Poor: Dry areas indicating no glass coverage

(c) Die Material Condition



	Discard (a)		Glass Coverage (b)					Die Material Condition (c)		
Push	Metal Flow	Glass Cover-age	Front	Middle	Back	Extrus. Length	Die No.	Wear	Wash	Remarks
226	Full Flow	Good	Good	Good	Good	23' 6"	224	None	6	Pad heated to 1000°F. Some twist to shape. Radii ran out of glass lubricant after 10', some galling in radii. Slight wash in die radius position No. 6
227	Scalped	Good	Good	Good	Good	22' 5"	225	None	Some wash 3, 6	Glass run out in radii after 5 feet. Some glass build up on front end. Extrusion laminated 6 feet from back end. Build up of glass on extrusion die approaches. Possible mechanical reaction between glass and alumina coating
228	Scalped	Good to Fair	Good	Fair	Poor	16' 9"	230	None	Radii wash 3, 6	Laminated extrusion at back end. Severely scored surface at the back end. Some glass pick-up on land.
229	Scalped	Good Dry in radii	Good	Good	Good	17' 6"	231		Some	Good breakthrough - Die pad heated to 1000°F. Glass run out in radii after 10' from front end.
230	Full Flow	Fair	Fair	Fair	Fair	18' 8"	238	Some wear 3, 6	None	Very light glass film along entire extrusion length: O.D. glass lubricant pick-up very poor on E-71 coated hot billet surface. Dry radii - transparent glass film. Good breakthrough
231	Scalped	Fair	Good	Fair	Fair	22' 11"	6	Excellent-coating spalled off leaving a tenacious thin alumina coating on the die surface		Transparent glass coating as compared to the blue opaque hue experienced with the 85-318 glass system. Fair break-through slightly pointed

Push	Metal Flow	Glass Cover-age	Front	Middle	Back	Extrus. Length	Die No.	Wear	Wash	Remarks
232	Full Flow	Poor	Poor	Poor	Poor	21'	239	Die in good shape. No wash experienced in radii		Although there was adequate glass on the billet discard, poor glass coverage was experienced along the entire extrusion length. Some scoring at back end of extrusion length.
233	Full Flow	Fair	Fair	Fair	Fair	19' 3"	240	No die wear. Some glass build up		Very light transparent glass coating with areas of black patches along entire extrusion length. Some scoring and streaks of dry areas were experienced indicating partial glass coverage
234			Poor	Poor	Poor		212	None	None	Good breakthrough. Poor glass pick-up of 318 O.D. glass using an E-71 glass coated billet. Severe scoring along extrusion length accompanied by tearing of left flange segment 10' from front end.
235	Full Flow	Good	Good	Good	Good	26' 4"		Severe radii wash and die wear overall die surface		Rogged breakthrough condition. Some twist and scoring along bottom flange area. Good glass pick-up of E-71 O.D. glass on a No. 85 glass coated billet.
236	Full Flow	Fair	Good	Fair	Fair	25' 2"		Slight at No 6		Lightly streaked glass coating at front end, some scoring on flange and stem after 10' from front end. Fairly straight as-extruded section. Straight extrusion in terms of less twist has been experienced with the E-71 glasses A E-71 glass coated billet does not pick up O.D. lubricating glass as well as the 85 glass.

Push	Metal Flow	Glass Cover-age	Front	Middle	Back	Extrus. Length	Die No.	Wear	Wash	Remarks
237	Full Flow	Good	Good	Good	Good	3' sticker	208	None	None	Poor breakthrough and severe scoring on first three feet of extruded product indicated there was some change in extrusion procedure. This was first push of Second Day of Trials
238	Scalped	Good	Good	Good	Good	26' 1"		None	None	Areas of dry patches along extrusion length and in radii. Heating time increased to 90 minutes at 1800°F to prevent sticker from occurring.
239	Full Flow	Good	Good	Good	Good	25' 4"	229	Heavy All areas except #1	Heavy	Glass run out 6' from front end at the radii areas. Severe scoring at back end of extrusion corresponds to severe die wear and wash
240	Scalped	Fair	Good	Fair	Fair	23'11"	5	None	None	Lamination on extrusion length corresponds to area where billet was scalped. Right radius showed lack of glass lubricant along entire extrusion length - some scoring
241	Scalped	Fair	Good	Good	Good		220	None	No. 3	Extrusion showed some scoring along back sections. Good glass coverage with the No. 85 - E-71 glass combination
242	Scalped	Poor	Fair	Poor	Poor	34'	223		1, 3, 6	Incomplete extrusion fill-out. Good glass coating on billet surface. Application of rolled on O.D. glass coating was satisfactory. Glass run-out on stem, flange and radii areas.

Push	Metal Flow	Glass Coverage	Front	Middle	Back	Extrus. Length	Die No.	Wear	Wash	Remarks
243	Full Flow	Poor	Fair	Poor	Poor	17' 3"	232		Some wash 3, 4, 5, 6, 7	Temperature raised from 1800-1850°F with this alloy. Lubricating glass run out and heavy scoring was experienced at back end.
244	Full Flow	Fair	Good	Good	Fair	20'11"	233		Good die Some wash out portion No. 3	Run-out of glass in radii and bottom flange portion corresponding to die wash in radii. Very straight extrusion. 10% graphite by weight added to 318 O.D. glass lubricant.
245	Full Flow	Good	Good	Good	Good	23' 4"	234	None	Slight wash in radii portion 3 and 6	10% Graphite added to 318 O.D. glass lubricant. Extrusion was extremely straight, no twist was experienced. Radii area dry after 10' of extrusion.

PART IV EXTRUSION TRIAL
DATA SHEETS

BATTELLE MEMORIAL INSTITUTE

DATA FOR EXTRUSION OF 0.125-INCH C-135A Mo TEE SECTION
FOLLOWING B & W LUBRICATION PRACTICE(a,b)

Test No.	Die No.	Billet Heating Time, min.	Extrusion Pressure, psi		Length Extruded, in.	Surface Finish, avg. micro in.(c)				Extruded Quality
						Front		Rear		
			Breakthrough	Runout		Flange Top	Stem	Flange Top	Stem	
1	40	10	104,000	-	-	-	-	-	-	Sticker
2	43	11	96,000	-	-	-	-	-	-	Sticker
3	44	10	83,000	68,000	50	280/500	-	330/460		Good die fill--good glass coverage
10	34	12	68,000	65,000	42	260/440		60/380	280/420	Good die fill--good glass coverage

(a) Extrusion temperatures as follows: Billet -1800 F
Container - 900 F
Die & Dummy -1000 F

Billet size was 3-1/8-inch diameter x 4-1/4 inches long. All billets heated by induction under an argon atmosphere.

(b) B & W practice consisted of 3KB glass pad+glass wool as die lubricant, 85 glass billet coating, and 318 container lubricant. 3KB glass ring measured 3/8-inch thick x 3" OD x 2" ID. Glass wool weights varied from 5-15 grams.

(c) Surface finish given as range of values and indicates the general surface condition.

DATA FOR EXTRUSION OF 0.093-INCH C-135AMo TEE SECTIONS WITH E71-BASE GLASSES(a)

Test Number	Die(b) Number	Lubricant			Billet Heating Time min.	Extrusion Pressure(d), 1000 psi		Length Extruded, inches	Surface Finish, Average microinches(e)				Extruded Quality	
		Billet Coating	Container	Die(c)		Initial	Runout		Front		Rear		Glass Coverage	Die Fill
									Flange Top	Stem	Flange Top	Stem		
17	8-2	E71A	E71A	E71A	10	68	78	58	280/450	--	220/420	--	Fair	Poor
20	8-3	E71A	E71	E71A	12	66	65	55	180/260	--	250/320	--	Fair	Very good
30	8-5	E71A	E71B	E71A	9	87	78	49	140/280	350/420	215/285	230/280	Very good	Very good
25	9-1	E71	E71A	E71A	8.5	67	66	51	320/480	--	370/480	--	Good	Fair
9	5-1	E71	E71	E71A	10	65	67	60	290/450	--	240/500	--	Poor	Poor
14	6-2	E71	E71B	E71A	12	67	68	58	220/320	--	190/320	--	Fair	Fair
16	7-2	E71B	E71A	E71A	10	72	72	55	130/240	--	170/300	--	Fair	Very good
21	7-3	E71B	E71	E71A	10	65	72	55	200/310	320/460	300/380	--	Good	Very good
31	4-5	E71B	E71B	E71A	9	96	78	49	140/260	240/290	165/210	240/260	Good	Fair
23	7-4	E71	E71A	E71	10	68	63	48	200/360	--	240/300	240/310	Fair	Good
5	1-1	E71	E71	E71	14	85	82	72	400/540	--	260/500	--	Good	Very poor
28	5-2	E71	E71B	E71	10	82	70	52	400/460	400/560	280/360	260/340	Good	Fair
11	6-1	E71B	E71A	E71	10	66	65	57	250/410	--	210/440	--	Good	Poor
8	4-1	E71B	E71	E71	12	60	66	61	280/380	--	260/370	--	Good	Very poor
29	9-2	E71B	E71B	E71	11	75	68	51	340/450	280/520	200/340	250/300	Fair	Fair
24	8-4	E71A	E71A	E71	9	63	57	51	360/480	--	300/440	--	Fair	Poor
6	2-1	E71A	E71	E71	14	88	77	78	260/420	--	310/410	--	Good	Very poor
13	8-1	E71A	E71B	E71	10	73	73	59	230/380	--	280/490	--	Very good	Poor
27	6-5	E71B	E71A	E71B	9	72	60	53	340/460	--	350/400	--	Good	Very poor
19	4-3	E71B	E71	E71B	14	62	62	55	220/360	--	280/400	--	Poor	Very good
12	7-1	E71B	E71B	E71B	10	68	70	58	300/430	290/380	290/330	--	Good	Poor
26	4-4	E71A	E71A	E71B	9	73	70	52	340/440	240/460	360/510	250/520	Good	Very poor
22	6-4	E71A	E71	E71B	11	57	68	60	420/700	--	260/340	--	Good	Very poor
32	7-5	E71A	E71B	E71B	9	80	75	53	320/440	330/520	300/350	280/390	Good	Very poor
18	6-3	E71	E71A	E71B	14	65	67	57	200/380	--	200/450	--	Poor	Very good
7	3-1	E71	E71	E71B	12	75	70	66	360/520	--	340/520	--	Good	Poor
15	4-2	E71	E71B	E71B	12	57	66	55	300/420	--	140/290	--	Good	Very good

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(a) Extrusion temperatures as follows: Billet - 1800 F; Container - 900 F; Die & Dummy - 1000 F. All billets heated by induction under an argon atmosphere . Billet size was 3-1/8-inch diameter x 4-1/4-inches long.

(b) First number is die number - second number signifies how many times die has been used.

(c) Glass pads measured 3" diameter x 3/8" (OD) thick with 10° entry taper. Tee slot in pad was 0.2-inch wide.

(d) In extrusions where runout pressure exceeded initial pressure, incomplete die fill occurred at the start of extrusion.

(e) Surface finish given as a range of values and indicates the general surface condition.

DATA FOR EXTRUSION OF 0.093-INCH C-135 AMo TEE SECTIONS WITH E71-BASE GLASSES (Series 2)(a)

Test Number	Die Number	Billet(b) Size Diam., inches	Billet(b) Size Length, inches	Billet Heating Time minutes	Lubricant Billet Coating	Lubricant Container	Lubricant Die(c)	Extrusion Pressure, psi Breakthrough	Extrusion Pressure, psi Runout	Length Extruded, inches	Extruded Quality
35	5	3-1/8	8	12	E71	E71B	E71B	57,000	70,000	110	Poor die fill-edges torn Severe surface scoring
36	6	3-1/8	8	15	E71B	E71B	E71	136,000	106,000	122	Ditto
37	8	3-1/8	8	14	E71B	E71B	E71A	125,000	116,000	60	"
38	4	3-1/8	4-1/4	12	E71B	E71B	E71A	Stuck		--	--

(a) Extrusion temperatures as follows:
Billet - 1800 F
Container - 900 F
Die & Dummy - 1000 F

All billets heated by induction under an argon atmosphere.

(b) Billet surfaces centerless ground to 30 microinch finish.

(c) Glass pads measured 3-inch diameter x 3/8" (OD) thick with 10° entry taper. Tee slot in pad was 0.2-inch wide.

CONDITIONS AND DATA FOR EXTRUSION OF 0.063-INCH C-135 AMo
TEE SECTIONS USING E71-BASE GLASSES - SERIES 3(a)

					Die Glass Variables					Extrusion Pressure, 1000 psi				Surface Finish, Average microinches(f)					Extruded Quality		
														Front		Rear					
Test No.	Die No.(b)	Billet Coating(c)	Cont. Lubr.	Die Glass	Mesh Size	Pad Shape and Size(d)	Temp. F	Number Glass Wool Pads(e)	Billet Heating Time minutes	Initial	Runout	Test No.	Length Extruded, inches	Flange Top	Stem	Flange Top	Stem	Typical Over-all Finish	Glass Coverage	Die Fill	General Comments
									High Viscosity Die Glass												
39	2-1	E71B+D	E71B	E71A	100	Tapered ring	80	1	10	99	84	39	--	Severe	Scoring	--	--	--	Fair	Poor	Glass plugged die, extrusion badly torn-scrapped
45	8-1	E71B+D	E71B	E71A	100	Ditto	80	3	10	104	79	45	133	100/160	180/420	130/230	180/390	230	Good	Poor	
40	1-1	E71B+D	E71B	E71A	100	"	80	1	10	82	67	40	116	130/300	130/270	150/230	90/220	150	Fair	Poor	Very good extrusion
42	5-1	E71B+D	E71B	E71A	325	"	80	1	14	92	71	42	123	260/380	90/260	200/380	130/290	180	Fair	Poor	
43	4-1	E71B+D	E71B	E71A	20	"	80	1	16	92	77	43	105	160/320	85/390	150/210	90/580	230	Good	Good	
52	11-1	E71	E71B	E71A	100	"	80	3	13	82	66	52	120	75/220	60/160	130/170	80/220	130	Fair	Fair	Very good extrusion
41	12-1	E71B+D	E71B	E71A	100	Shaped Pad	80	0	10	82	66	41	129	180/440	150/450	170/340	170/580	300	Fair	Poor	Die plugged, pad stem tear
54	10-1	E71B+D	E71B	E71A	100	Shaped Pad (1/2 inch thick)	1000	0	15	89	66	54	119	260/340	180/360	210/350	190/380	220	Fair	Good	
55	8-2	E71B+D	E71B	E71A	100	Shaped Pad	1000	1	14	89	67	55	115	100/160	60/300	60/150	75/160	140	Good	Very good	Very good extrusion
									Normal Viscosity Die Glass												
44	3-1	E71B+D	E71B	E71	100	Tapered ring	80	1	11	89	73	44	127	190/420	200/360	140/330	100/310	200	Fair	Fair	
51	2-2	E71B+D	E71B	E71	100	Ditto	80	3	16	69	56	51	114	180/500	140/290	70/150	100/220	180	Fair	Fair	Stem edge tears in middle of extrusion
									Low Viscosity Die Glass												
56	5-2	E71D	E71B	E71B	100	Shaped Pad	1000	1	17	97	73	56	114	70/260	70/170	95/190	70/140	140	Fair	Very good	Very good extrusion
53	3-2	E71B+D	E71B	E71B	100	Tapered ring	80	3	--	87	53	53	123	260/490	60/180	90/200	120/260	160	Fair	Poor	
57	1-2	E71D	E71B	E71B	100	Shaped Pad	1000	1	15	77	63	57	112	140/230	60/100	130/260	80/200	140	Fair	Good	Very good extrusion
									Republic - B&W Die Glass												
46	7-1	E71B+D	E71B	3KB	14	Flat ring	80	3	12	85	71	46	121	160/360	130/250	170/250	160/280	200	Good	Good	
48	6-1	85	318	3KB	14	Ditto	80	3	14	--	--	48	138	80/290	100/360	210/500	300/500	240	Fair	Fair	
49	7-2	85	318	3KB	14	"	80	3	--	89	76	49	121	180/300	160/380	140/540	160/600	220	Fair	Poor	

CONDITIONS AND DATA FOR EXTRUSION OF 0.063-INCH C135AMo TEE SECTIONS - SERIES 4[(a)]

Test No.	Die No.(b)	Billet Length, inches	Lubricants				Temperatures, F			Billet Heating Time, minutes	Extrusion Pressure, 1000 psi	
			Billet Coating	Container	Die							
					Glass(c)	Glass Wool(d)	Billet	Container	Die & Dummy		Initial	Runout
58	11-2	4-1/2	85	E71B + graphite	E71	Econoline	1800	700	1000	21	--	--
59	10-2	4-1/2	85	Ditto	E71	Econoline	1825	700	1000	37	--	--
60	5-3	3-1/4	85	"	E71	Econoline	1850	750	1000	20	123	82
61	12-2	3-1/4	85	"	E71	E71A	1850	750	1000	18	110	75
62	7-3	3-1/4	85	"	E71	TWF	1850	750	1000	20	91	72
63	2-3	4-1/2	85	"	E71A	563	1850	750	1000	31	107	72
64	2-4	4-1/2	85	318 + graphite	3KB	3KB	1800	800	1000	21	85	68
65	10-3	4-1/2	E71	E71B + graphite	E71	E71A	1800	800	1000	18	92	72
66	11-3	4-1/2	E71	Ditto	E71A	TWF	1800	800	1000	22	91	72

(a) Billets were heated by induction under an argon atmosphere. All billets were 3-1/8-inch diameter with centerless ground surfaces (30 microinch finish).

(b) The first number is the die number; the second number signifies how many times the die has been used.

(c) All glass rings were 3-inch diameter x 3/8-inch thick at the O.D.

(d) Glass wool pads were 3-inch diameter x 1-inch thick with a 1-3/4-inch equilateral triangular opening.

Test No.	Length Extruded, inches	Surface Finish Average Microinches(e)				Typical Over-all Finish	Extruded Quality		
		Front		Rear			Glass Coverage	Die Fill	General Comments
		Flange Top	Stem	Flange Top	Stem				
58	--	--	--	--	--	--	--	--	Sticker
59	--	--	--	--	--	--	--	--	Sticker
60	75	100/130	60/180	130/210	90/220	120	Fair	Fair	Localized scoring right stem area
61	96	150/300	70/220	150/250	130/220	165	Good	Poor	Bad stem tear at front end
62	74	100/250	90/180	180/300	100/400	140	Good	Good	Localized severe scoring
63	96	130/300	70/300	120/250	70/220	150	Good	Poor	Severe tears at front end-die plugged
64	100	180/340	80/240	80/320	110/240	160	Good	Fair	Poor stem fill
65	108	200/360	140/290	180/300	150/400	200	Fair	Poor	Severe tearing at front end-die plugged
66	93	160/380	100/150	190/410	100/270	170	Poor-Fair	Good	Higher billet temperature (1850°F) necessary for better glass coverage

(e) Surface finish given as a range of values indicating the general surface condition in each location. Typical surface finish is given to indicate over-all finish of the entire extruded section.

TEST DATA OF EXTRUSION TRIAL CONDUCTED AT BABCOCK AND WILCOX COMPANY
ON 2 MAY 1963 - PART V GROUP 1. MATERIAL 6Al4V TITANIUM ALLOY (FORGED STOCK)

PUSH NO.	HEAT NO.	BILLET LENGTH	BILLET WGT.	BILLET COATING	BILLET TEMP.	HEATING TIME MIN.	BILLET TRANSFER TIME (SECS.)	OD LUB.	DIE GLASS	DIE GLASS CONFIGURATION	DIE NO.	DIE ORIFICE	SHAPE NO.	BILLET CONFIG.	REMARKS
251	D4050	6 3/4	13.5	85	1800	67	33	E71B	E71	Ring + 30W pads	8C	093	677	Convex Face	Extrusion broke off - striated and grooved surface - poor glass coverage on discard and on extrusion - titanium pickup on die - force seemed high.
252						72	43	E71B	E71	Ring + 30W pads	8K	093	677	Convex Face	Striated and grooved surface - heavy glass coating on die - some titanium pickup on die - billet glass coating appeared dull - back of tee shape looked good - force still high.
253						75	34	318	3KB	Ring + 30W pads	8B	093	677	Convex Face	Extrusion good - slight striation in radius - good glass coverage - good flow on discard - die appeared good (no wash) - die coating stood up - lower force reflected normal operation.
254	↓	↓	↓			74	37	318	3KB	Ring + 30W pads	8H	093	677	Convex Face	Extrusion good - good glass coverage on extrusion - heavy glass coating on die - low force.
255	D2449	9 1/4	18.5			77	43	E71B	E71	Dished Pad	Multi Port #1	093	678	Flat Face	Sticker - approximately 2' extruded - probably chilled billet.
256						98	38	E71B	E71	Dished Pad	Multi Port #2	093	678	Flat Face	Sticker - approximately 2' extruded - may be due to long length.
257	↓	↓	↓				PULLED OFF LINE							Flat Face	Pulled off line - will use shorter billet.
258	D4050	6 3/4	13.5			90	31	318	3KB	Dished Pad	Port #3	093	678	Convex Face	Extruded shapes fair - nose indicated poor breakthrough - possibly due to convex face.
259						75	UNKNOWN	E71B	E71	Ring + 30W pads	7K	062	676	Convex Face	Score mark on one side - titanium pickup on die on same side as score mark - E71B - E71 glass combination not lubricating properly.
260						81	34	318	3KB	• •	7H	062	676	•	Good surface on extrusion - die looked good - discard looked good except for lap which did not get into extrusion - will use 318-3KB glass for balance of trial.
261						75	28	318	3KB	• •	7C	062	676	•	Good extrusion - slight scoring due to some pickup - no scalp on discard.
262						33	30	•	•	• •	8A	093	677	•	Sticker - 2" extruded - billet coating appeared darker than others coming out of furnace.
263						74	28	•	•	• •	8K	093	677	•	Good extrusion - scalp again noted on discard but did not get to die.
264						63	32	•	•	• •	7J	062	676	•	Score mark on extrusion leg - die looked good - discard looked good but again had lap condition (scalp).
265	↓					69	29	•	•	• •	7E	062	676	•	Badly scored extrusion on bottom - die looked good - discard scalped - extended into shape - noted stem on press tooling was bent upwards.
266	D3025					87	31	•	•	• •	7A	062	676	•	Ripple on left flange - discard scalped badly extending into shape.
267	↓	↓	↓	↓	↓	79	42				Multi Port #1A	093	678	•	Good shapes - no scalping on discard - good glass coverage and metal flow.

TEST DATA OF EXTRUSION TRIAL CONDUCTED
AT BABCOCK AND WILCOX COMPANY ON 12 JULY 1963 - PART V - GROUP 2
MATERIAL TI-6AL-4V (FORGED STOCK)

PUSH NO.	HEAT NO.	BILLET LENGTH (IN)	BILLET WGT (LBS)	BILLET COATING	BILLET TEMP. (°F)	HEATING TIME (MIN)	BILLET TRANSFER TIME (SECS)	OD LUB.	DIE GLASS	DIE GLASS CONFIG.	DIE NO.	DIE ORIFICE (IN)	SHAPE NO.	BILLET CONFIG.
268	D4044	7 1/4	14.5	85	1800	88	50	318	3KB	Ring + 3 glass wool pads	8A	093	677	Convex Face
269	↓	↓	↓	↓	↓	92	38	↓	↓	↓	8B	↓	↓	↓
270	↓	↓	↓	↓	↓	103	48	↓	↓	↓	8M	↓	↓	↓
271	↓	↓	↓	↓	↓	102	45	↓	↓	↓	8K	↓	↓	Convex Face 2 1/4 D Nose
272	↓	6 3/4	13.5	↓	↓	84	36	↓	↓	↓	7A	063	676	Convex Face
273	↓	↓	↓	↓	↓	82	38	↓	↓	↓	7M	↓	↓	↓
274	↓	↓	↓	↓	↓	75	42	↓	↓	↓	7AA	↓	↓	↓
275	D3025	↓	↓	↓	↓	72	43	↓	↓	↓	7J	↓	↓	Convex Face 2 1/4 D Nose
276	D4044	7	14	↓	↓	75	34	↓	↓	Dished Pad	1	093	678	Flat Face
277	↓	↓	↓	↓	↓	87	42	↓	↓		2	↓	↓	↓
278	↓	↓	↓	↓	↓	95	43	↓	↓		3	↓	↓	↓
279	↓	↓	↓	↓	↓	103	38	↓	↓		4	↓	↓	↓
280	↓	9	18	↓	1850	87	42	↓	↓		5	↓	↓	↓
281	D3025	↓	↓	↓	↓	98	37	↓	↓		6	↓	↓	↓

REMARKS

Lamination appeared on first discard (Push 268). Coating skid rails on which glassed billet is placed with #85 glass slurry eliminated laminations on balance of pushes. Dies were holding up for approximately 10' to 14' of extrusion and then washing out in the fillet radius. Shapes had good surface finish for the first 10' to 14' with scoring starting at that point and becoming progressively worse toward the back of the shape. Washing of the fillet radius in the dies consistently occurred and areas of die wash corresponded to areas of scoring on the shapes. Heavy die wash is attributed to an inadvertent light coating of ceramic on fillet radius (under 0.005") due to ceramic spray technique. Good dimensional uniformity of thickness dimensions along the entire length of the shapes indicates ceramic coating on the lands of the stem and flange were holding up.

NOTE: FINAL EXTRUSION TRIAL DATA SHEET (PUSH # 282-297)IS LISTED ON PAGE 146

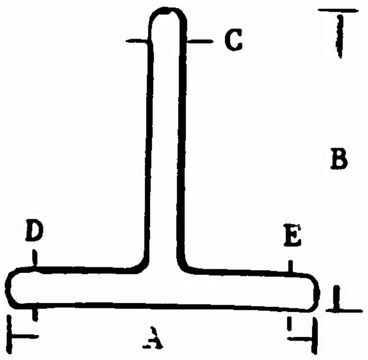
APPENDIX B

Dimensional Measurements of Warm Drawn Shapes

Table B-1

DIMENSIONAL SURVEY OF STARTING 64E12 EXTRUSIONS

AS EXTRUDED



Distance in Feet

Extrusion 260 - 20 feet

	F	2	4	6	8	10	12	14	16	18	20	E
A	1.675	1.713	1.720	1.729	1.738	1.734	1.735	1.741	1.737	1.742	1.746	1.745
B	1.455	1.494	1.522	1.541	1.559	1.557	1.556	1.567	1.563	1.570	1.571	1.574
C	0.058	0.058	0.060	0.060	0.060	0.061	0.061	0.061	0.062	0.062	0.063	0.063
D	0.063	0.064	0.064	0.066	0.067	0.067	0.066	0.067	0.066	0.066	0.066	0.066
E	0.059	0.062	0.061	0.062	0.062	0.067	0.061	0.063	0.063	0.063	0.063	0.063
F	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64
G	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64

Extrusion 261 - 16 feet, 8 inches

	F	2	4	6	8	10	12	14	E
A	1.752	1.750	1.743	1.730	1.732	1.729	1.716	1.702	1.687
B	1.570	1.567	1.563	1.565	1.554	1.545	1.530	1.511	1.487
C	0.058	0.059	0.060	0.060	0.060	0.060	0.059	0.059	0.060
D	0.061	0.061	0.061	0.061	0.061	0.060	0.060	0.060	0.059
E	0.064	0.064	0.064	0.064	0.064	0.063	0.063	0.063	0.063
F	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64
G	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64

Table B-1 (Con't)

Extrusion 264 - 20 feet

	F	2	4	6	8	10	12	14	16	18	E
A	1.643	1.681	1.715	1.721	1.721	1.726	1.731	1.741	1.737	1.739	1.740
B	1.443	1.462	1.500	1.503	1.518	1.538	1.556	1.570	1.567	1.570	1.571
C	0.067	0.067	0.068	0.067	0.069	0.067	0.068	0.068	0.068	0.068	0.068
D	0.062	0.062	0.063	0.063	0.064	0.064	0.063	0.064	0.064	0.064	0.064
E	0.060	0.061	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
F	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64
G	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64

Extrusion 266 - 20 feet

	F	2	4	6	8	10	12	14	16	18	E
A	1.693	1.698	1.714	1.722	1.725	1.729	1.729	1.733	1.733	1.733	1.735
B	1.380	1.403	1.431	1.447	1.471	1.486	1.509	1.530	1.549	1.561	1.567
C	0.052	0.054	0.054	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
D	0.059	0.061	0.062	0.063	0.064	0.064	0.064	0.064	0.065	0.065	0.065
E	0.056	0.056	0.056	0.058	0.058	0.059	0.059	0.059	0.059	0.058	0.058
F	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64
G	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64

Extrusion 290 - 16 feet, 8 inches

	F	2	4	6	8	10	12	14	E
A	1.725	1.753	1.796	1.803	1.813	1.809	1.811	1.812	1.815
B	1.631	1.632	1.642	1.644	1.654	1.650	1.652	1.657	1.658
C	0.073	0.071	0.071	0.071	0.073	0.071	0.071	0.072	0.073
D	0.076	0.076	0.077	0.078	0.079	0.079	0.079	0.080	0.080
E	0.068	0.068	0.069	0.069	0.070	0.070	0.070	0.071	0.072
F	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64
G	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64

Table B-1 (Con't)

Extrusion 292 - 20 feet

	F	2	4	6	8	10	12	14	16	18	E
A	1.719	1.746	1.772	1.776	1.777	1.780	1.782	1.784	1.786	1.786	1.788
B	1.521	1.537	1.578	1.603	1.610	1.618	1.627	1.630	1.631	1.630	1.637
C	0.059	0.058	0.059	0.060	0.060	0.060	0.060	0.060	0.059	0.059	0.060
D	0.073	0.074	0.075	0.075	0.075	0.076	0.076	0.078	0.078	0.078	0.080
E	0.069	0.069	0.068	0.070	0.071	0.072	0.072	0.073	0.073	0.073	0.073
F	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64
G	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64	9/64

Extrusion 294 - 13 feet, 7 inches

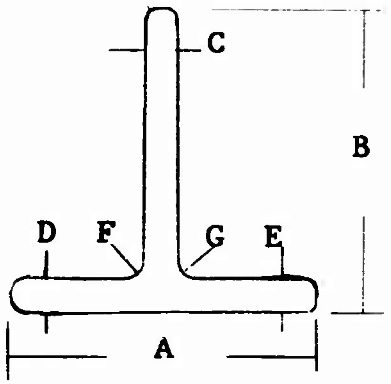
	F	2	4	6	8	10	12	E
A	1.768	1.792	1.807	1.805	1.817	1.819	1.821	1.821
B	1.617	1.634	1.644	1.641	1.650	1.653	1.658	1.653
C	0.067	0.067	0.068	0.068	0.069	0.069	0.069	0.069
D	0.064	0.065	0.066	0.067	0.067	0.068	0.069	0.069
E	0.068	0.070	0.071	0.071	0.072	0.073	0.073	0.073
F	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64
G	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64

Extrusion 295 - 18 feet, 3 inches

	F	2	4	6	8	10	12	14	16	E
A	1.728	1.794	1.794	1.798	1.799	1.800	1.801	0.807	1.804	1.814
B	1.638	1.642	1.643	1.647	1.647	1.648	1.650	1.650	1.653	1.660
C	0.058	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.060
D	0.068	0.068	0.068	0.069	0.069	0.070	0.070	0.069	0.071	0.071
E	0.068	0.069	0.069	0.069	0.069	0.069	0.069	0.070	0.070	0.071
F	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64
G	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64	11/64

Table B-2

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER FIRST WARM DRAW PASS 0.065 or 0.075in.



Distance in Feet

Extrusion 260 - 17 feet, 10 inches

	F	2	4	6	8	10	12	14	16	E
A	1.685	1.734	1.750	1.750	1.754	1.755	1.758	1.761	1.750	1.752
B	1.454	1.545	1.586	1.598	1.612	1.615	1.620	1.617	1.615	1.618
C	0.056	0.059	0.060	0.059	0.060	0.060	0.059	0.059	0.059	0.060
D	0.062	0.063	0.064	0.063	0.066	0.064	0.065	0.064	0.063	0.063
E	0.058	0.060	0.061	0.062	0.062	0.061	0.061	0.061	0.061	0.061

Extrusion 261 - 16 feet, 9 inches

	F	2	4	6	8	10	12	14	E
A	1.763	1.761	1.745	1.729	1.727	1.723	1.724	1.700	1.696
B	1.588	1.602	1.580	1.558	1.556	1.550	1.545	1.513	1.515
C	0.058	0.059	0.058	0.058	0.059	0.058	0.058	0.058	0.059
D	0.059	0.059	0.059	0.060	0.059	0.060	0.059	0.059	0.059
E	0.063	0.062	0.063	0.063	0.063	0.063	0.063	0.063	0.063

Table B-2 (Con't)

Extrusion 264 - 19 feet, 11 inches

	F	2	4	6	8	10	12	14	16	18	E
A	1.667	1.713	1.723	1.725	1.731	1.735	1.742	1.745	1.745	1.741	1.743
B	1.453	1.515	1.526	1.534	1.558	1.571	1.591	1.596	1.598	1.593	1.596
C	0.063	0.066	0.066	0.066	0.065	0.065	0.066	0.067	0.067	0.067	0.066
D	0.058	0.061	0.061	0.062	0.063	0.062	0.062	0.063	0.063	0.063	0.063
E	0.060	0.062	0.061	0.061	0.061	0.061	0.061	0.062	0.062	0.062	0.062

Extrusion 266 - 16 feet, 6 inches

	F	2	4	6	8	10	12	14	E
A	1.706	1.720	1.740	1.752	1.750	1.750	1.743	1.754	1.754
B	1.384	1.448	1.493	1.520	1.538	1.557	1.576	1.602	1.660
C	0.058	0.054	0.054	0.054	0.054	0.054	0.055	0.055	0.055
D	0.062	0.062	0.063	0.063	0.063	0.064	0.063	0.064	0.063
E	0.056	0.057	0.057	0.058	0.059	0.058	0.058	0.058	0.058

Extrusion 290 - 15 feet, 6-1/2 inches

	F	2	4	6	8	10	12	14	E
A	1.737	1.764	1.791	1.790	1.796	1.793	1.790	1.789	1.785
B	1.665	1.665	1.671	1.671	1.680	1.671	1.671	1.675	1.658
C	0.066	0.064	0.064	0.063	0.063	0.062	0.061	0.061	0.061
D	0.069	0.069	0.068	0.068	0.067	0.068	0.067	0.067	0.066
E	0.064	0.064	0.064	0.063	0.063	0.063	0.062	0.062	0.062

Table B-2 (Con't)

Extrusion 292 - 17 feet, 5-1/2 inches

	F	2	4	6	8	10	12	14	16	E
A	1.724	1.766	1.778	1.790	1.792	1.798	1.798	1.801	1.793	1.796
B	1.523	1.563	1.598	1.625	1.640	1.658	1.667	1.673	1.678	1.662
C	0.058	0.059	0.058	0.058	0.059	0.061	0.059	0.059	0.061	0.064
D	0.070	0.071	0.072	0.073	0.073	0.074	0.075	0.076	0.075	0.076
E	0.067	0.069	0.069	0.069	0.070	0.073	0.071	0.072	0.070	0.071

Extrusion 294 - 13 feet, 6-1/2 inches

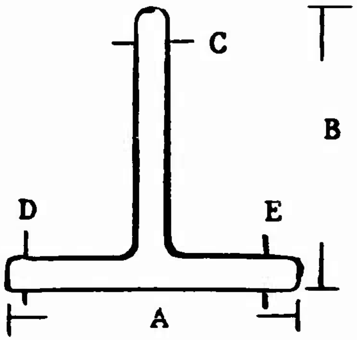
	F	2	4	6	8	10	12	E
A	1.774	1.813	1.821	1.830	1.832	1.833	1.838	1.838
B	1.631	1.671	1.680	1.690	1.698	1.703	1.710	1.708
C	0.065	0.068	0.066	0.066	0.067	0.068	0.067	0.068
D	0.063	0.065	0.065	0.066	0.066	0.067	0.067	0.067
E	0.067	0.069	0.070	0.071	0.071	0.071	0.071	0.071

Extrusion 295 - 18 feet, 3 inches

	F	2	4	6	8	10	12	14	16	E
A	1.744	1.805	1.810	1.811	1.813	1.820	1.821	1.816	1.819	1.829
B	1.653	1.668	1.670	1.675	1.680	1.684	1.686	1.694	1.695	1.695
C	0.056	0.057	0.057	0.057	0.057	0.057	0.058	0.058	0.058	0.059
D	0.063	0.066	0.067	0.067	0.067	0.067	0.067	0.068	0.069	0.069
E	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.058	0.058	0.059

Table B-3

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER 1st WARM DRAW PLUS HOT STRETCH STRAIGHTEN



Distance in Feet

Extrusion 260 - 17 feet, 9-3/4 inches

	F	2	4	6	8	10	12	14	16	E
A	1.695	1.731	1.747	1.747	1.753	1.757	1.753	1.758	1.751	1.756
B	1.478	1.545	1.586	1.598	1.608	1.612	1.616	1.621	1.609	1.615
C	0.055	0.057	0.059	0.058	0.059	0.059	0.059	0.059	0.058	0.059
D	0.061	0.064	0.064	0.063	0.064	0.064	0.064	0.064	0.064	0.064
E	0.058	0.059	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061

Extrusion 261 - 16 feet, 8-1/2 inches

	F	2	4	6	8	10	12	14	E
A	1.768	1.759	1.744	1.727	1.725	1.720	1.723	1.705	1.687
B	1.604	1.600	1.584	1.563	1.553	1.552	1.547	1.517	1.494
C	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.056	0.055
D	0.059	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058
E	0.062	0.062	0.061	0.062	0.061	0.061	0.061	0.060	0.061

Table B-3 (Con't)

Extrusion 264 - 19 feet, 11 inches

	F	2	4	6	8	10	12	14	16	18	E
A	1.662	1.712	1.719	1.720	1.728	1.733	1.738	1.741	1.743	1.741	1.742
B	1.457	1.520	1.530	1.533	1.565	1.581	1.596	1.598	1.601	1.599	1.598
C	0.061	0.065	0.065	0.065	0.065	0.065	0.066	0.066	0.066	0.066	0.066
D	0.059	0.060	0.061	0.061	0.062	0.061	0.061	0.061	0.061	0.061	0.061
E	0.058	0.061	0.060	0.060	0.061	0.061	0.060	0.060	0.061	0.061	0.060

Extrusion 266 - 16 feet, 6 inches

	F	2	4	6	8	10	12	14	E
A	1.703	1.719	1.739	1.750	1.748	1.749	1.742	1.753	1.752
B	1.400	1.445	1.490	1.514	1.531	1.553	1.580	1.597	1.612
C	0.053	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.055
D	0.051	0.061	0.062	0.062	0.062	0.062	0.062	0.062	0.062
E	0.056	0.056	0.057	0.056	0.057	0.057	0.057	0.057	0.057

Extrusion 290 - 15 feet, 6-1/4 inches

	F	2	4	6	8	10	12	14	E
A	1.738	1.772	1.783	1.785	1.793	1.788	1.791	1.788	1.785
B	1.663	1.665	1.665	1.667	1.671	1.669	1.667	1.679	1.653
C	0.063	0.062	0.061	0.062	0.061	0.060	0.060	0.060	0.059
D	0.067	0.067	0.067	0.067	0.067	0.066	0.065	0.064	0.064
E	0.062	0.062	0.062	0.062	0.062	0.061	0.061	0.060	0.060

Table B-3 (Con't)

Extrusion 292 - 16 feet, 3-1/4 inches

	F	2	4	6	8	10	12	14	E
A	1.727	1.763	1.775	1.786	1.789	1.794	1.796	1.799	1.793
B	1.526	1.563	1.604	1.625	1.637	1.656	1.662	1.665	1.666
C	0.056	0.056	0.055	0.057	0.056	0.057	0.057	0.057	0.057
D	0.071	0.072	0.072	0.073	0.074	0.074	0.075	0.075	0.075
E	0.066	0.067	0.068	0.068	0.069	0.067	0.068	0.068	0.070

Extrusion 294 - 13 feet, 5-3/4 inches

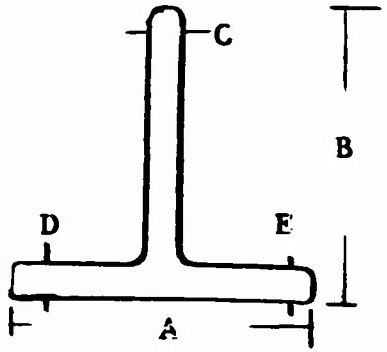
	F	2	4	6	8	10	12	E
A	1.773	1.809	1.817	1.827	1.829	1.830	1.835	1.833
B	1.649	1.680	1.680	1.691	1.700	1.702	1.709	0.711
C	0.064	0.065	0.065	0.066	0.066	0.066	0.066	0.066
D	0.062	0.063	0.064	0.064	0.064	0.065	0.065	0.066
E	0.066	0.068	0.069	0.069	0.069	0.070	0.070	0.070

Extrusion 295 - 18 feet, 2-3/8 inches

	F	2	4	6	8	10	12	14	16	E
A	1.738	1.803	1.807	1.808	1.812	1.816	1.821	1.813	1.816	1.826
B	1.660	1.683	1.678	1.675	1.683	1.682	1.687	1.695	1.699	1.694
C	0.055	0.056	0.056	0.056	0.056	0.056	0.057	0.057	0.057	0.057
D	0.066	0.066	0.066	0.067	0.067	0.067	0.068	0.068	0.068	0.068
E	0.066	0.067	0.066	0.067	0.067	0.067	0.068	0.068	0.068	0.068

Table B-4

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER
2nd WARM DRAW PASS 0.058in



Distance in Feet

Extrusion 260 - 10 feet, 3 inches

	F	2	4	6	8	E
A	1.685	1.728	1.736	1.755	1.761	1.754
B	1.499	1.557	1.586	1.610	1.623	1.620
C	0.055	0.056	0.055	0.054	0.053	0.053
D	0.059	0.061	0.060	0.059	0.058	0.058
E	0.056	0.058	0.058	0.058	0.058	0.056

Extrusion 261 - 15 feet, 8 inches

	F	2	4	6	8	10	12	14	E
A	1.758	1.756	1.732	1.726	1.716	1.715	1.713	1.697	1.675
B	1.624	1.612	1.581	1.569	1.560	1.555	1.544	1.524	1.506
C	0.054	0.054	0.053	0.054	0.053	0.052	0.052	0.050	0.051
D	0.056	0.057	0.056	0.055	0.055	0.055	0.055	0.054	0.055
E	0.057	0.058	0.057	0.057	0.056	0.056	0.056	0.055	0.055

Table B-4 (Con't)

Extrusion 264 - 8 feet

	F	2	4	6	E
A	1.647	1.661	1.670	1.677	1.676
B	1.459	1.508	1.523	1.531	1.548
C	0.058	0.058	0.057	0.057	0.056
D	0.056	0.057	0.056	0.057	0.057
E	0.056	0.057	0.057	0.056	0.056

Extrusion 266 - 15 feet, 10 inches

	F	2	4	6	8	10	12	14	E
A	1.699	1.728	1.745	1.753	1.756	1.756	1.718	1.755	1.758
B	1.404	1.478	1.509	1.530	1.553	1.574	1.582	1.604	1.622
C	0.051	0.052	0.052	0.052	0.052	0.051	0.049	0.051	0.050
D	0.058	0.059	0.059	0.059	0.058	0.058	0.058	0.057	0.057
E	0.054	0.055	0.055	0.054	0.054	0.054	0.053	0.053	0.053

Extrusion 290 - 16 feet

	F	2	4	6	8	10	12	14	E
A	1.723	1.754	1.770	1.768	1.777	1.775	1.782	1.785	1.784
B	1.660	1.666	1.670	1.678	1.672	1.670	1.680	1.664	1.672
C	0.056	0.055	0.055	0.055	0.055				
D	0.060	0.060	0.059	0.059	0.059				
E	0.058	0.058	0.056	0.056	0.056				

Table B-4 (Con't)

Extrusion 294 - 14 feet, 4 inches

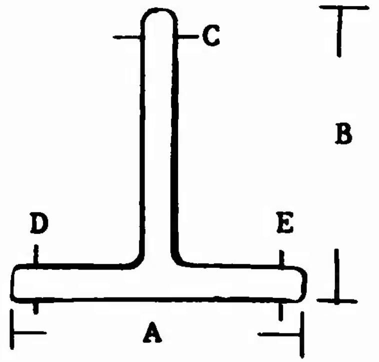
	F	2	4	6	8	10	12	E
A	1.760	1.780	1.788	1.794	1.796	1.805	1.826	1.836
B	1.641	1.664	1.671	1.677	1.681	1.689	1.699	1.717
C	0.057	0.056	0.056	0.055	0.055	0.055	0.054	0.054
D	0.059	0.058	0.058	0.058	0.056	0.056	0.057	0.057
E	0.060	0.059	0.059	0.058	0.058	0.059	0.058	0.057

Extrusion 295 - 16 feet, 10 inches

	F	2	4	6	8	10	12	14	E
A	1.801	1.819	1.822	1.823	1.832	1.827	1.827	1.827	1.777
B	1.698	1.690	1.693	1.683	1.694	1.679	1.673	1.673	1.691
C	0.055	0.053	0.053	0.052	0.052	0.052	0.051	0.050	0.050
D	0.062	0.061	0.061	0.060	0.059	0.059	0.058	0.058	0.057
E	0.061	0.061	0.061	0.060	0.059	0.058	0.058	0.058	0.057

Table B-5

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER 2nd WARM DRAW TO 0.058in PLUS HOT STRETCH STRAIGHTEN



Distance in Feet

Extrusion 260 - 8 feet, 9 inches

	F	2	4	6	8	E
A	1.727	1.737	1.757	1.760	1.755	1.753
B	1.543	1.578	1.611	1.618	1.622	1.618
C	0.055	0.054	0.054	0.053	0.053	0.053
D	0.060	0.060	0.059	0.058	0.058	0.058
E	0.057	0.057	0.057	0.057	0.056	0.056

Extrusion 261 - 15 feet, 3 inches

	F	2	4	6	8	10	12	14	E
A	1.764	1.748	1.729	1.720	1.715	1.700	1.690	1.677	1.690
B	1.628	1.603	1.593	1.569	1.556	1.545	1.532	1.508	1.520
C	0.054	0.054	0.053	0.052	0.052	0.052	0.052	0.051	0.052
D	0.055	0.055	0.055	0.055	0.054	0.054	0.054	0.054	0.054
E	0.058	0.057	0.056	0.056	0.056	0.055	0.054	0.054	0.055

Table B-5 (Con't)

Extrusion 264 - 8 feet, 3 inches

	F	2	4	6	E
A	1.637	1.662	1.670	1.676	1.674
B	1.474	1.508	1.523	1.533	1.543
C	0.056	0.056	0.056	0.056	0.055
D	0.056	0.056	0.056	0.056	0.055
E	0.055	0.056	0.055	0.055	0.055

Extrusion 266 - 14 feet

	F	2	4	6	8	10	12	E
A	1.704	1.720	1.742	1.745	1.749	1.743	1.737	1.747
B	1.452	1.479	1.550	1.535	1.545	1.574	1.592	1.610
C	0.050	0.050	0.051	0.051	0.050	0.049	0.050	0.050
D	0.053	0.058	0.058	0.058	0.057	0.057	0.057	0.057
E	0.054	0.054	0.055	0.053	0.054	0.055	0.054	0.054

Extrusion 290 - 15 feet, 7 inches

	F	2	4	6	8	10	12	14	E
A	1.718	1.760	1.762	1.761	1.768	1.769	1.766	1.780	1.772
B	1.672	1.670	1.663	1.660	1.665	1.662	1.663	1.655	1.661
C	0.056	0.054	0.054	0.053	0.053	0.053	0.053	0.052	0.052
D	0.059	0.059	0.058	0.058	0.058	0.057	0.057	0.056	0.056
E	0.056	0.056	0.056	0.055	0.055	0.055	0.055	0.054	0.054

Table B-5 (Con't)

Extrusion 294 - 14 feet

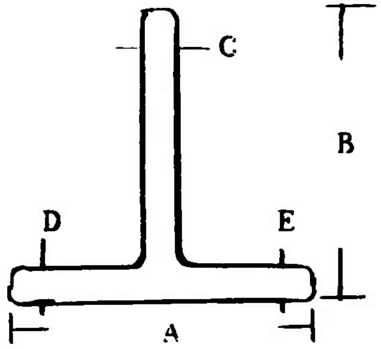
	F	2	4	6	8	10	12	E
A	1.764	1.775	1.779	1.787	1.789	1.800	1.823	1.836
B	1.646	1.661	1.664	1.671	1.680	1.688	1.708	1.723
C	0.056	0.054	0.054	0.054	0.053	0.053	0.053	0.053
D	0.058	0.057	0.056	0.056	0.055	0.056	0.056	0.056
E	0.059	0.059	0.058	0.058	0.058	0.058	0.057	0.057

Extrusion 295 - 15 feet, 1 inch

	F	2	4	6	8	10	12	14	E
A	1.823	1.818	1.819	1.820	1.825	1.817	1.816	1.813	1.825
B	1.712	1.703	1.692	1.680	1.680	1.675	1.661	1.667	1.681
C	0.053	0.052	0.052	0.051	0.050	0.050	0.050	0.049	0.051
D	0.060	0.060	0.060	0.059	0.058	0.058	0.057	0.057	0.057
E	0.062	0.060	0.060	0.060	0.059	0.058	0.057	0.056	0.057

Table B-6

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER THIRD WARM DRAW TO 0 053in



Distance in Feet

Extrusion 260 - 6 feet, 7 inches

	F	2	4	6	E
A	1.720	1.765	1.779	1.787	1.768
B	1.545	1.581	1.609	1.612	1.619
C	0.053	0.052	0.051	0.050	0.050
D	0.055	0.054	0.053	0.053	0.052
E	0.054	0.053	0.052	0.052	0.052

Extrusion 261 - 14 feet, 3 inches

	F	2	4	6	8	10	12	E
A	1.760	1.744	1.720	1.718	1.713	1.695	1.687	1.678
B	1.630	1.620	1.583	1.583	1.569	1.562	1.549	1.533
C	0.052	0.051	0.050	0.050	0.049	0.049	0.049	0.048
D	0.054	0.053	0.053	0.052	0.052	0.052	0.051	0.050
E	0.055	0.054	0.053	0.052	0.052	0.052	0.051	0.051

Table B-6 (Con't)

Extrusion 264 - 8 feet, 7 inches

	F	2	4	6	8	E
A	1.629	1.654	1.664	1.663	1.661	1.670
B	1.464	1.525	1.537	1.552	1.554	1.563
C	0.054	0.053	0.053	0.052	0.051	0.051
D	0.052	0.052	0.052	0.052	0.051	0.051
E	0.051	0.052	0.052	0.052	0.051	0.051

Extrusion 266 - 11 feet, 6 inches

	F	2	4	6	8	10	E
A	1.704	1.736	1.761	1.761	1.765	1.760	1.750
B	1.449	1.500	1.535	1.552	1.560	1.580	1.594
C	0.050	0.049	0.049	0.049	0.049	0.049	0.048
D	0.055	0.054	0.055	0.054	0.054	0.054	0.054
E	0.052	0.052	0.052	0.052	0.051	0.051	0.051

Extrusion 290 - Approx. 14 feet

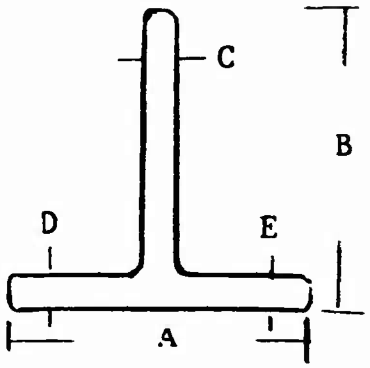
No dimensions taken

Extrusion 294 - 14 feet, 7 inches

	F	2	4	6	8	10	12	14	E
A	1.760	1.778	1.782	1.790	1.792	1.798	1.821	1.835	1.845
B	1.650	1.667	1.678	1.670	1.681	1.702	1.697	1.724	1.728
C	0.053	0.052	0.051	0.051	0.050	0.050	0.050	0.050	0.050
D	0.054	0.053	0.053	0.053	0.052	0.052	0.052	0.052	0.052
E	0.054	0.054	0.054	0.054	0.054	0.054	0.053	0.052	0.052

Table B-7

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER THIRD WARM DRAW TO 0.053in PLUS HOT STRETCH STRAIGHTEN



Distance in Feet

Extrusion 260 - 5 feet, 8-1/2 inches

	F	2	4	E
A	1.783	1.775	1.758	1.717
B	1.604	1.603	1.581	1.547
C	0.049	0.050	0.051	0.053
D	0.051	0.051	0.052	0.053
E	0.052	0.052	0.053	0.055

Extrusion 261 - 15 feet, 1-1/2 inches

	F	2	4	6	8	10	12	14
A	1.746	1.722	1.715	1.704	1.706	1.699	1.672	1.678
B	1.612	1.593	1.572	1.570	1.563	1.550	1.536	1.517
C	0.050	0.049	0.048	0.048	0.048	0.048	0.047	0.047
D	0.052	0.051	0.051	0.050	0.050	0.050	0.050	0.050
F	0.054	0.053	0.053	0.052	0.052	0.051	0.051	0.051

Table B-7 (Con't)

Extrusion 264 - 7 feet

	F	2	4	6	E
A	1.646	1.654	1.661	1.661	1.636
B	1.509	1.529	1.536	1.542	1.540
C	0.053	0.052	0.051	0.050	0.050
D	0.052	0.051	0.051	0.051	0.050
E	0.051	0.051	0.050	0.050	0.047

Extrusion 266 - 10 feet, 5 inches

	F	2	4	6	8	E
A	1.720	1.743	1.750	1.755	1.755	1.740
B	1.482	1.506	1.532	1.568	1.558	1.587
C	0.048	0.048	0.048	0.047	0.047	0.047
D	0.054	0.054	0.053	0.053	0.053	0.052
E	0.050	0.051	0.051	0.051	0.051	0.050

Extrusion 290 - 14 feet

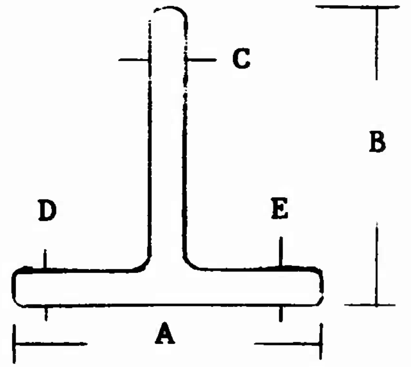
	F	2	4	6	8	10	12	E
A	1.776	1.770	1.767	1.758	1.762	1.762	1.770	1.776
B	1.652	1.657	1.638	1.640	1.646	1.650	1.637	1.662
C	0.050	0.049	0.048	0.048	0.048	0.047	0.047	0.048
D	0.050	0.050	0.049	0.049	0.048	0.048	0.048	0.049
E	0.050	0.052	0.051	0.052	0.050	0.051	0.050	0.050

Extrusion 294 - 14 feet, 1 inch

	F	2	4	6	8	10	12	E
A	1.760	1.772	1.776	1.783	1.783	1.796	1.818	1.841
B	1.654	1.656	1.660	1.666	1.678	1.681	1.693	1.728
C	0.050	0.050	0.049	0.049	0.049	0.049	0.048	0.048
D	0.052	0.051	0.051	0.051	0.051	0.051	0.050	0.050
E	0.054	0.053	0.053	0.053	0.052	0.052	0.051	0.050

Table B-8

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER FOURTH WARM DRAW TO 0.047in.



Distance in Feet

Extrusion 260 - 5 feet

	F	2	4	E
A	1.730	1.759	1.782	1.779
B	1.555	1.567	1.597	1.596
C	0.046	0.047	0.048	0.048
D	0.0485	0.0485	0.050	0.0485
E	0.047	0.048	0.050	0.0495

Extrusion 261 - 12 feet, 5-1/2 inches

	F	2	4	6	8	10	E
A	1.730	1.713	1.711	1.708	1.692	1.690	1.679
B	1.590	1.565	1.569	1.564	1.545	1.529	1.518
C	0.046	0.045	0.046	0.046	0.045	0.044	0.044
D	0.049	0.048	0.048	0.048	0.048	0.047	0.047
E	0.049	0.049	0.048	0.048	0.048	0.047	0.047

Table B-8 (Con't)

Extrusion 264 - 7 feet

	F	2	4	6
A	1.650	1.653	1.657	1.644
B	1.509	1.525	1.535	1.542
C	0.050	0.049	0.048	0.047
D	0.495	0.049	0.048	0.048
E	0.049	0.048	0.048	0.047

Extrusion 266 - 7 feet, 3-1/4 inches

	F	2	4	6	E
A	1.718	1.757	1.751	1.763	1.769
B	1.477	1.519	1.531	1.549	1.548
C	0.045	0.045	0.044	0.045	0.044
D	0.049	0.050	0.049	0.049	0.048
E	0.048	0.047	0.047	0.048	0.047

Extrusion 290 - 14 feet, 10-1/2 inches

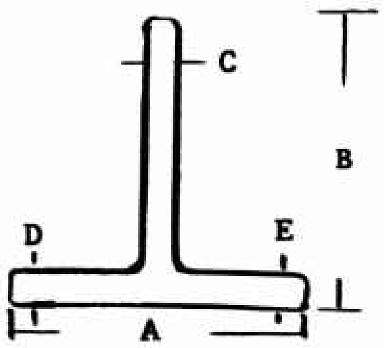
	F	2	4	6	8	10	12	E
A	1.776	1.773	1.770	1.770	1.768	1.764	1.765	1.770
B	1.647	1.651	1.640	1.633	1.640	1.637	1.634	1.655
C	0.049	0.048	0.047	0.046	0.046	0.046	0.046	0.045
D	0.048	0.048	0.047	0.047	0.047	0.047	0.046	0.046
E	0.050	0.049	0.049	0.048	0.047	0.047	0.047	0.046

Extrusion 294 - 13 feet, 7-1/2 inches

	F	2	4	6	8	10	12	E
A	1.772	1.776	1.784	1.784	1.795	1.815	1.831	1.844
B	1.644	1.642	1.651	1.660	1.662	1.671	1.697	1.718
C	0.046	0.045	0.045	0.045	0.045	0.044	0.043	0.044
D	0.048	0.047	0.046	0.046	0.046	0.046	0.045	0.046
E	0.047	0.046	0.047	0.047	0.047	0.046	0.046	0.045

Table B-9

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER FOURTH WARM DRAW TO 0.047in PLUS HOT STRETCH STRAIGHTEN



Distance in Feet

Extrusion 260 - 4 feet, 9-1/2 inches

	F	2	4	E
A	1.720	1.747	1.759	1.778
B	1.554	1.558	1.575	1.594
C	0.045	0.047	0.047	0.048
D	0.049	0.048	0.047	0.048
E	0.048	0.048	0.048	0.049

Extrusion 261 - 12 feet, 6 inches

	F	2	4	6	8	10	E
A	1.729	1.707	1.703	1.697	1.679	1.661	1.676
B	1.589	1.555	1.557	1.547	1.528	1.514	1.517
C	0.047	0.045	0.045	0.045	0.044	0.043	0.044
D	0.048	0.047	0.047	0.046	0.046	0.045	0.045
E	0.049	0.048	0.047	0.047	0.046	0.046	0.046

Table B-9 (Con't)

Extrusion 264 - 7 feet

	F	2	4	E
A	1.648	1.648	1.653	1.646
B	1.508	1.520	1.529	1.542
C	0.050	0.049	0.048	0.047
D	0.048	0.049	0.047	0.047
E	0.048	0.048	0.047	0.047

Extrusion 266 - 7 feet, 4 inches

	F	2	4	6	E
A	1.725	1.754	1.751	1.753	1.755
B	1.482	1.507	1.518	1.530	1.537
C	0.045	0.044	0.043	0.043	0.043
D	0.049	0.050	0.049	0.049	0.048
E	0.047	0.048	0.047	0.047	0.047

Extrusion 290 - 14 feet, 10-1/2 inches

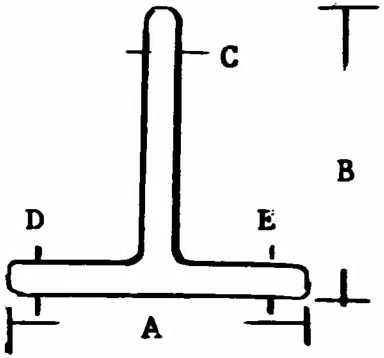
	F	2	4	6	8	10	12	E
A	1.777	1.766	1.762	1.760	1.764	1.758	1.764	1.760
B	1.650	1.643	1.627	1.627	1.627	1.627	1.622	1.646
C	0.047	0.046	0.046	0.045	0.045	0.045	0.045	0.045
D	0.048	0.047	0.047	0.046	0.046	0.046	0.045	0.045
E	0.049	0.048	0.048	0.048	0.047	0.047	0.046	0.046

Extrusion 294 - 12 feet, 6 inches

	F	2	4	6	8	10	E
A	1.819	1.795	1.780	1.777	1.776	1.767	1.770
B	1.691	1.657	1.648	1.648	1.636	1.634	1.642
C	0.043	0.043	0.044	0.044	0.044	0.044	0.046
D	0.045	0.046	0.046	0.046	0.046	0.047	0.047
E	0.045	0.045	0.045	0.045	0.045	0.046	0.047

Table B-10

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER FIFTH WARM DRAW TO 0.043in.



Distance in Feet

Extrusion 260 - 4 feet, 5-1/2 inches

	F	2	E
A	1.750	1.742	1.702
B	1.565	1.542	1.543
C	0.044	0.043	0.041
D	0.044	0.044	0.043
E	0.044	0.044	0.043

Extrusion 261 - 10 feet, 3 inches

	F	2	4	6	8	E
A	1.731	1.717	1.712	1.713	1.701	1.703
B	1.585	1.541	1.535	1.525	1.510	1.513
C	0.045	0.042	0.042	0.042	0.041	0.041
D	0.045	0.043	0.042	0.042	0.042	0.041
E	0.045	0.044	0.043	0.042	0.041	0.040

Table B-10 (Con't)

Extrusion 264 - 6 feet, 6 inches

	F	2	4	E
A	1.646	1.638	1.644	1.642
B	1.502	1.515	1.524	1.528
C	0.046	0.045	0.044	0.043
D	0.044	0.044	0.044	0.043
E	0.044	0.043	0.043	0.042

Extrusion 266 - 7 feet, 4 inches

	F	2	4	E
A	1.741	1.735	1.750	1.751
B	1.484	1.498	1.520	1.538
C	0.042	0.042	0.041	0.040
D	0.046	0.045	0.045	0.044
E	0.045	0.045	0.043	0.043

Extrusion 290 - 15 feet, 6 inches

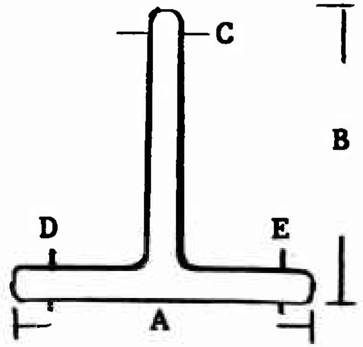
	F	2	4	6	8	10	12	14	E
A	1.779	1.774	1.773	1.768	1.771	1.764	1.766	1.763	1.761
B	1.644	1.635	1.618	1.620	1.623	1.617	1.616	1.634	1.636
C	0.045	0.044	0.043	0.043	0.042	0.042	0.041	0.041	0.041
D	0.046	0.046	0.045	0.044	0.043	0.043	0.043	0.042	0.043
E	0.046	0.045	0.045	0.044	0.043	0.043	0.043	0.042	0.043

Extrusion 294 - 12 feet, 10-3/4 inches

	F	2	4	6	8	10	E
A	1.825	1.803	1.795	1.783	1.783	1.773	1.768
B	1.693	1.652	1.645	1.645	1.635	1.631	1.642
C	0.043	0.043	0.042	0.042	0.041	0.041	0.041
D	0.044	0.044	0.044	0.044	0.044	0.044	0.043
E	0.044	0.044	0.043	0.044	0.044	0.043	0.042

Table B-11

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER FIFTH WARM DRAW TO 0.043in PLUS HOT STRETCH STRAIGHTEN



Distance in Feet

Extrusion 260 - 3 feet, 9-1/2 inches

	F	2	E
A	1.754	1.723	1.704
B	1.551	1.524	1.523
C	0.043	0.041	0.041
D	0.044	0.043	0.043
E	0.044	0.043	0.043

Extrusion 261 - 9 feet, 11 inches

	F	2	4	6	8	E
A	1.720	1.700	1.688	1.681	1.669	1.685
B	1.571	1.530	1.513	1.495	1.483	1.467
C	0.043	0.040	0.040	0.040	0.039	0.038
D	0.044	0.042	0.041	0.040	0.040	0.040
E	0.044	0.042	0.041	0.040	0.039	0.040

Table B-11 (Con't)

Extrusion 264 - 5 feet, 1-1/2 inches

	F	2	4	E
A	1.634	1.624	1.624	1.640
B	1.510	1.504	1.504	1.529
C	0.046	0.044	0.043	0.043
D	0.044	0.043	0.043	0.043
E	0.044	0.043	0.042	0.043

Extrusion 266 - 6 feet, 7-3/4 inches

	F	2	4	E
A	1.736	1.719	1.719	1.697
B	1.483	1.465	1.484	1.486
C	0.040	0.039	0.038	0.038
D	0.045	0.043	0.042	0.042
E	0.043	0.042	0.041	0.041

Extrusion 290 - 14 feet, 11 inches

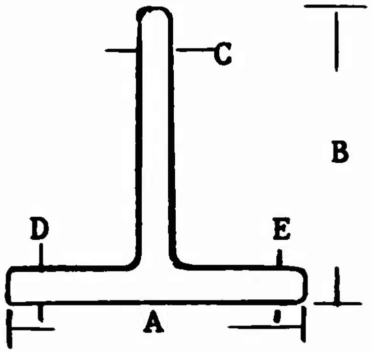
	F	2	4	6	8	10	12	14	E
A	1.777	1.766	1.761	1.756	1.764	1.757	1.758	1.751	1.751
B	1.634	1.630	1.614	1.617	1.622	1.611	1.607	1.612	1.641
C	0.043	0.043	0.042	0.041	0.041	0.041	0.040		
D	0.044	0.044	0.043	0.043	0.042	0.042			
E	0.046	0.045	0.044	0.043	0.042	0.042			

Extrusion 294 - 12 feet, 4-1/2 inches

	F	2	4	6	8	10	E
A	1.804	1.783	1.776	1.764	1.765	1.746	1.751
B	1.681	1.638	1.630	1.632	1.619	1.609	1.625
C	0.042	0.041	0.041	0.040	0.040	0.040	0.040
D	0.043	0.043	0.042	0.043	0.042	0.042	0.042
E	0.044	0.043	0.043	0.043	0.042	0.042	0.042

Table B-12

DIMENSIONAL SURVEY OF 64E12 EXTRUSIONS AFTER SOLUTION TREATING 1725F(15sec)WQ PLUS STRETCH-STRAIGHTEN AGING



Distance in Feet

Extrusion 261 - 8 feet, 4-3/4 inches

	F	2	4	6	E
A	1.698	1.698	1.677	1.657	1.610
B	1.535	1.519	1.501	1.473	1.426
C	0.040	0.038	0.038	0.037	0.035
D	0.042	0.040	0.039	0.037	0.036
E	0.041	0.040	0.039	0.037	0.036

Extrusion 264 - 5 feet, 2 inches

	F	2	4	E
A	1.630	1.613	1.611	1.627
B	1.504	1.490	1.489	1.524
C	0.046	0.043	0.041	0.043
D	0.044	0.042	0.041	0.043
E	0.042	0.042	0.041	0.041

Table B-12 (Con't)

Extrusion 266 - 6 feet, 6-1/2 inches

	F	2	4	E
A	1.726	1.714	1.682	1.690
B	1.484	1.460	1.451	1.477
C	0.041	0.038	0.036	0.037
D	0.044	0.042	0.040	0.039
E	0.044	0.042	0.040	0.039

Extrusion 290 - 13 feet, 8-3/4 inches

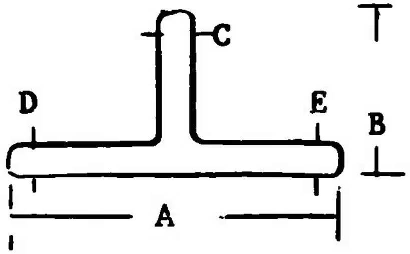
	F	2	4	6	8	10	12	E
A	1.775	1.761	1.759	1.762	1.758	1.750	1.752	1.751
B	1.629	1.629	1.625	1.622	1.615	1.614	1.625	1.619
C	0.042	0.041	0.041	0.040	0.040	0.039	0.039	0.039
D	0.043	0.042	0.041	0.041	0.040	0.040	0.039	0.039
E	0.044	0.043	0.042	0.042	0.041	0.040	0.040	0.040

Extrusion 294 - 11 feet, 4 inches

	F	2	4	6	8	10	E
A	1.808	1.784	1.774	1.765	1.766	1.741	1.735
B	1.669	1.642	1.633	1.633	1.620	1.601	1.600
C	0.040	0.040	0.039	0.039	0.039	0.038	0.038
D	0.042	0.041	0.041	0.041	0.041	0.040	0.040
E	0.042	0.041	0.041	0.041	0.041	0.040	0.040

Table B-13

DIMENSIONAL SURVEY OF 64E15 EXTRUSIONS AFTER WARM DRAW TO 0.080 INCHES AND HOT STRETCHER STRAIGHTEN



Distance in Feet

Extrusion 253M - 9 feet, 5-1/2 inches

	F	2	4	6	8	E
A	1.723	1.713	1.717	1.723	1.723	1.723
B	0.992	0.998	0.999	0.994	0.992	0.998
C	0.080	0.078	0.077	0.077	0.076	0.077
D	0.080	0.079	0.079	0.078	0.077	0.078
E	0.079	0.077	0.076	0.076	0.075	0.077

Extrusion 253D - 9 feet, 4 inches

A	1.728	1.719	1.723	1.723	1.735	1.744
B	0.978	0.989	0.996	0.991	0.987	0.995
C	0.081	0.079	0.079	0.078	0.078	0.079
D	0.080	0.077	0.079	0.078	0.078	0.079
E	0.079	0.077	0.077	0.077	0.076	0.077

Table B-13(Con't)

	F	2	4	6	8	10	12	14	16	18	E
Extrusion 254 - 20 feet, 9-1/2 inches											
A	1.740	1.725	1.715	1.721	1.715	1.709	1.715	1.703	1.698	1.698	1.692
B	0.998	0.991	0.991	0.995	0.987	0.993	0.988	0.980	0.982	0.993	0.985
C	0.081	0.080	0.079	0.079	0.077	0.077	0.077	0.076	0.076	0.075	0.075
D	0.081	0.080	0.079	0.079	0.078	0.078	0.078	0.077	0.077	0.077	0.076
E	0.079	0.078	0.078	0.077	0.077	0.076	0.076	0.075	0.075	0.075	0.075
Extrusion 263 - 21 feet, 5-1/4 inches											
A	1.724	1.722	1.721	1.723	1.720	1.722	1.722	1.721	1.721	1.721	1.722
B	0.991	0.992	0.990	0.993	0.992	0.988	0.988	0.988	0.986	0.985	0.984
C	0.079	0.078	0.077	0.077	0.076	0.076	0.076	0.076	0.075	0.075	0.074
D	0.082	0.081	0.081	0.080	0.080	0.080	0.079	0.079	0.079	0.079	0.079
E	0.081	0.080	0.079	0.079	0.078	0.078	0.078	0.078	0.078	0.077	0.077
Extrusion 282 - 22 feet, 11-1/2 inches											
A	1.745	1.803	1.799	1.800	1.797	1.799	1.805	1.804	1.805	1.821	1.825
B	0.984	1.012	1.015	1.014	1.018	1.027	1.030	1.030	1.029	1.041	1.045
C	0.080	0.079	0.079	0.078	0.078	0.078	0.078	0.078	0.078	0.077	0.077
D	0.079	0.080	0.080	0.080	0.079	0.079	0.079	0.079	0.079	0.079	0.079
E	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.078	0.078	0.078	0.078
Extrusion 284 - 21 feet, 8 inches											
A	1.750	1.752	1.762	1.755	1.751	1.755	1.753	1.756	1.757	1.757	1.761
B	0.973	0.966	0.970	0.968	0.962	0.960	0.960	0.955	0.962	0.950	0.944
C	0.078	0.077	0.077	0.076	0.076	0.075	0.075	0.075	0.075	0.074	0.074
D	0.084	0.083	0.082	0.081	0.081	0.081	0.081	0.081	0.080	0.080	0.079
E	0.082	0.081	0.081	0.080	0.079	0.079	0.079	0.079	0.078	0.077	0.077

Table B-13(Con't)

Extrusion 285 - 21 feet, 4 inches

	F	2	4	6	8	10	12	14	16	18	20	E
A	1.760	1.781	1.751	1.765	1.778	1.767	1.779	1.778	1.777	1.778	1.786	1.786
B	1.022	1.030	1.024	1.030	1.026	1.025	1.030	1.026	1.024	1.022	1.036	1.031
C	0.079	0.079	0.078	0.078	0.078	0.077	0.077	0.077	0.077	0.077	0.076	0.076
D	0.083	0.082	0.081	0.081	0.081	0.081	0.081	0.080	0.080	0.080	0.080	0.080
E	0.081	0.080	0.079	0.079	0.079	0.079	0.078	0.078	0.078	0.078	0.078	0.078

Extrusion 286 - 19 feet, 8-1/2 inches

A	1.778	1.776	1.770	1.765	1.764	1.760	1.761	1.766	1.770	1.780	1.787
B	0.988	0.986	0.993	0.985	0.987	0.972	0.974	0.975	0.970	0.970	0.980
C	0.079	0.078	0.078	0.078	0.077	0.077	0.077	0.076	0.076	0.076	0.076
D	0.084	0.084	0.084	0.084	0.083	0.083	0.082	0.082	0.082	0.081	0.081
E	0.078	0.078	0.078	0.077	0.077	0.077	0.076	0.076	0.076	0.076	0.076

Extrusion 288 - 21 feet, 10-1/8 inches

	F	2	4	6	8	10	12	14	16	18	E
A	1.741	1.741	1.741	1.741	1.735	1.742	1.740	1.744	1.742	1.746	1.755
B	0.995	1.000	1.003	1.002	1.000	1.006	1.009	1.006	1.004	1.005	1.009
C	0.080	0.080	0.080	0.079	0.078	0.078	0.078	0.078	0.078	0.077	0.077
D	0.077	0.079	0.079	0.078	0.078	0.077	0.077	0.077	0.077	0.077	0.077
E	0.080	0.080	0.080	0.079	0.079	0.078	0.078	0.078	0.078	0.077	0.077

Extrusion 289 - 22 feet, 6-1/2 inches

	F	2	4	6	8	10	12	14	16	18	20	E
A	1.764	1.745	1.759	1.771	1.762	1.760	1.775	1.755	1.761	1.762	1.757	1.759
B	1.011	1.000	1.005	1.015	1.017	1.007	1.012	1.000	1.001	0.999	0.995	0.998
C	0.080	0.079	0.079	0.078	0.078	0.077	0.077	0.077	0.077	0.076	0.076	0.076
D	0.081	0.080	0.080	0.080	0.079	0.079	0.079	0.078	0.079	0.079	0.079	0.078
E	0.080	0.080	0.079	0.079	0.079	0.079	0.079	0.078	0.078	0.078	0.078	0.077

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1 January 1957 - 31 October 1963,
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Contract AF33(600)-34098
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Unclassified Report

UNCLASSIFIED

1. Titanium Alloys
2. Extrusion
3. Materials
4. Physical Metallurgy
5. Warm Drawing of Shapes
6. Heat Treatment

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Republic Aviation Corporation
Manufacturing Research,
Farmingdale, New York
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A variety of structural shapes such as angles, channels, zees, hats and tees were extruded in the following alloys: Ti-155A, MS 821, Ti-7Al-4Mo, Ti-4Al-3Mo-1V, and Ti-6Al-4V

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