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REPORT NO: FGT-2727
DATE: 16 January 1962

STAINLESS STEEL SANDWICH PANEL BRAZING - DEVELOPMENT TESTS OF

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Contract No. [illegible](657)-[illegible]

62-2-3

GENERAL DYNAMICS | FORT WORTH

Department 6
FWP 1999-9-54

CONVAIR
A DIVISION OF GENERAL DYNAMICS CORPORATION
(FORT WORTH)

TEST F-4696
MODEL B-58

REPORT FGT-2727
DATE 1/19/61

TITLE

STAINLESS STEEL SANDWICH PANEL BRAZING - DEVELOPMENT TESTS OF -

SUBMITTED UNDER
AF33(600)-36200

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NO. OF PAGES 276
NO. OF DIAGRAMS

REVISIONS

NO.	DATE	BY	CHANGE	PAGES AFFECTED

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Table | Page

STAINLESS STEEL SANDWICH PANEL BRAZING -

DEVELOPMENT TESTS OF -

INTRODUCTION:

A. SCOPE OF REPORT:

The problems encountered during the development and production application of the stainless steel sandwich panel brazing program were numerous and varied widely in scope. This report represents an effort to compile all the data obtained by the Metallurgical Laboratory of the Engineering Test Laboratories relative to stainless steel sandwich panel brazing. This work was accomplished under Test Request F-4696 from May 1954 through December 1959.

Since the investigations reported herein were so diversified in nature, this report consists of several independent sections arranged in systematic order under the various subject headings. The subject material reported in these sections are the results of investigations previously not formally reported. In most instances this material had been furnished to interested departments in the form of memoranda or loose data sheets.

Section I of this report concerns investigations relating to the structural materials used in brazed, honeycomb, sandwich panels. Section II contains material pertaining to the brazing alloy investigations and methods used in brazing the structural members of the sandwich panels. In instances where several investigations were conducted on related items, the items are arranged under a common heading. The discussion section of each individual report is treated separately; however, the introductory remarks and conclusions are combined for the group as a whole.

B. HISTORY OF SANDWICH PANEL BRAZING

In order to provide some clarification and background on the material reported herein, a brief chronological summary of the sandwich panel brazing program is included in this section.

The decision to use brazed sandwich panel structures on the B-58 was made in March 1953. The major advantage in the use of a sandwich type structure was the possibility of obtaining a high-strength, light-weight part. The panels proposed for use on the B-58 also required stability in the 600 F to 900 F temperature range. This requirement eliminated the use of a bonded structure and for all practical purposes made the development of brazed panels the logical method.

A basic honeycomb sandwich panel consists of the following three components:

1. A core section, made from thin gage metal foil strips (less than 0.003" thick) which are tack welded together in such a manner that round, square or hexagonal cells are formed. See Figure 1.

2. Facing sheets or skins which are fastened to both sides of the honeycomb core so that the open ends of the core are covered. The core cells then run perpendicularly to the facing sheets. The core to skin attachment is performed by brazing.

3. Edge members are necessary in most cases. These are heavier metal strips around the panel perimeter in the form of a Z or U. The edge members are subsequently used to fasten the sandwich panel in place on the airplane. The strips are brazed in position at the same time that the skins are brazed to the core.

After the decision to use brazed sandwich panel structures had been made, an initial engineering survey was initiated and the first test panel was brazed at Convair in April 1953. In November of the same year, test panel contracts were given to various outside producers. Although almost all of the developmental research concerning sandwich panel brazing was accomplished by Convair, a large percentage of all production type sandwich panels has been brazed by outside manufacturers. The major purpose of the test panel contracts was to allow these producers to determine their costs in brazing sandwich panels in accordance with Convair specifications.

Original plans called for the development of both a low and a high temperature brazing procedure. The low temperature method specified a brazing range of 1300 F to 1750 F. It was to provide panels for use at operating temperatures to 600 F. The high temperature process called for a brazing temperature above 1750 F and the panels brazed by this process were for use at temperatures to 900 F.

The low temperature brazing development program was begun in April 1954. The high temperature program was started in November 1954. H.E.M. #H35.0001 with enclosure A, dated April 28, 1954, covers the proposed low temperature panel brazing program. This was revised and superseded on July 28, 1955 by enclosure B to include the high temperature development program.

In the interval between the issuing of H.E.M. #H 35.0001 enclosure A and enclosure B, considerable research and development work was accomplished. Brazing alloy investigations, heat treat cycle development, and general furnace brazing procedures were investigated. Published reports covering work done during this period in the Engineering Test Laboratories are abstracted in Section III of this report. See references 2-7 of Section III covering FGT-1340, MR 54-5, FTDM-1415, FGT-1347, FGT-1363, and FGT-1362.

It was recognized in July 1955 that the low temperature process was objectionable for two reasons.

1. Operating temperatures were limited to 600 F.
2. Panels brazed by this process had high susceptibility to corrosion because of brazing alloy flux entrapment within the panel.

Consequently, although some panels brazed by this process were tested on the engine test stand, this method was gradually discontinued. The major effort was then directed toward the high temperature process.

17-7PH stainless steel was chosen as the basic material for use with both the low and high temperature processes. Initial work however was accomplished with "C" condition material and later changed to annealed with added heat treatment. It was found that braze cycle would not produce the CH properties of 17-7PH. Results of preliminary evaluation tests on the heat treatment of 17-7PH steel were reported in FGT-1153 published in November 1953. An abstract of this report appears as reference 1 of Section III in this report. Section A and B list 17-7PH heat treat results which were previously reported only in data sheet form. The heat treat results given under B were used to determine the original high temperature brazing cycle.

The brazing alloy used in connection with the low temperature cycle was Easy-Flo #3. This alloy has a nominal composition of 50% Ag, 15-1/2% Cu, 15-1/2% Zn, 16% Cd, and 3% Ni. It melts at 1170 F and flows above 1270 F. This process was used only during the test panel development program and so is of historic interest only.

The brazing alloy first adopted for use with the high temperature brazing program was 85% Ag-15% Mn alloy. This alloy melts at 1745 F. A brazing temperature of 1820 F was used on most of the panels brazed with the Ag-Mn alloy. This alloy was used on test and production panels until July 1957. It was replaced because of its poor corrosion resistance. See Sections IIA, IIB, IIC, and IID of this report for further information.

In developing a brazing process for 17-7PH stainless steel panels of acceptable quality, three major prerequisites were found to be necessary:

1. A rigid brazing form of desired contour for use during the brazing operation.

2. An inert or reducing atmosphere during the brazing cycle.

3. A means of providing intimate contact between the various detail parts of the panel during brazing.

Initial sandwich panel brazing was carried out by the use of matched steel brazing forms placed on both sides of the panel being brazed. The entire assembly was placed in a steel brazing retort and processed under a hydrogen atmosphere. Many test panels were brazed using this procedure. However, the entire procedure was changed, item by item, as the brazing program progressed.

In December 1954 a vacuum envelope method was introduced which replaced the top brazing form in July 1955. This method consisted in placing the panel to be brazed on top of a single braze form and encasing both items in a welded stainless steel envelope. The cover sheet of the brazing envelope consisted of a 0.012" thick, steel diaphragm sheet. By reducing the pressure inside the envelope below atmospheric pressure, the sandwich panel was forced down against the brazing form. Thus, contact between the detail parts of the panel could be maintained during brazing. This method, in addition to eliminating the need for matched sets of brazing forms, was more effective in equalizing the pressure on the various panel parts when slight discrepancies were present in the mating of the panel details.

In April 1955 graphite was substituted for steel as the brazing form material. This step was advantageous because graphite has a much lower coefficient of expansion than does steel and therefore is less subject to dimensional change upon heating. Section I comments on the effect of graphite on 17-7PH steel.

As previously mentioned, the first test panels were brazed under a hydrogen atmosphere. Mixtures of hydrogen and air containing from 4% - 74% hydrogen by volume at room temperature are explosive. In August 1955 good brazes were obtained using sodium tetraborate flux in an argon atmosphere. Because of the safety hazard connected with the use of hydrogen, argon used in conjunction with this flux was adopted in October 1955.

In June 1955, a tack brazing method was first used in assembling panel parts for brazing. It can be readily understood from Figure 1 that the various panel parts must be in a definite position during the brazing operation. By tack brazing the panel parts together, while they were clamped in a holding fixture, the panels could be pre-assembled for brazing.

During the remainder of 1955 and through 1956, the brazing program changed from the test phase into the production phase. In December 1955 Fiberfrax insulation was introduced. The primary constituent of Fiberfrax is aluminum oxide. The product is manufactured in sheet form and is available in several thicknesses. It proved an ideal insulating material for the panel brazing process. Use was made of this material to insulate the panel brazing packages so that more even heating could be obtained on the sandwich panels during brazing.

X-ray radiological methods and flash testing were both developed as test procedures for determining over-all panel quality in 1956. Also, butt-welding standards for joining thin sheet material used as panel facings were set up during this period.

Concurrently with the development of the brazing technology, the configurations of the various structural panel parts for the airplane were determined. These configurations can be roughly classified into three types: 1) Flat panels of uniform thickness, 2) contoured or curved panels, and 3) wedge panels.

The brazing of flat panels offered no particular problems. This cannot be said for the contoured and wedge type panels. Test panels of both these types were brazed during 1955. In both, the flow characteristics of the brazing alloy presented problems.

The brazing alloy flow in the contour type panel was caused by gravitational forces moving the brazing alloy from high to low regions in the panel. The flow problem was evaded in brazing contoured production panels by reducing the panel size and thereby reducing the amount of curvature present. Several investigations were carried out on possible methods of controlling this type of brazing alloy flow. Tests regarding brazing alloy modifications are reported in Section II H, II-I, and II J of this report. Section II Q describes a zone brazing procedure for controlling alloy flow.

In wedge shaped panels the problem was caused by brazing alloy flow into the core capillaries or core nodes of the thicker core regions. This decreased the amount of brazing alloy available to form the skin-to-core braze fillets. Results of tests on brazing alloy flow in thick core sections are given in Section II N and II O of this report.

Late in 1956 investigations were conducted by the Manufacturing Research & Development Department and the Engineering Test Laboratories regarding the purity of the argon atmosphere in the sandwich panel during brazing. Until this time, the brazing package had been purged by flowing argon through the brazing retort for a set period prior to brazing. Testing showed that in the flow type purge the argon passed around the sandwich panel and rarely penetrated into the core region. It was further found that alternately evacuating the brazing retort and filling it with argon gas would provide purging action on the entire panel. This method of cyclic purging was adopted in January 1957.

At the same time the cyclic method was adopted for purging panels, the two tube brazing retort was introduced. The second tube served as the argon inlet and permitted passing a limited amount of argon through the retort during brazing. The flowing argon acted as a carrier gas to remove foreign gases evolved by the graphite during brazing. The use of flowing argon plus the cycle purging technique produced a noticeable improvement in the quality of brazed sandwich panels.

In April 1957 the use of stainless steel type 3-10 core was discontinued. In designating core material, the first digit indicates the diameter of the core cell in sixteenths of an inch. The last two digits indicate the thickness of steel foil used in the core in ten-thousandths of an inch. Both type 3-10 and 3-15 core had been used in panels prior to this time. The use of type 3-10 core was discontinued because it sometimes collapsed during brazing. Investigations of factors affecting the strength of 17-7PH steel core material are presented in Sections I F, I G, and I H of this report.

During the spring of 1957 a problem of contamination in the corner region of brazed sandwich panels was investigated. It was concluded that the contamination was caused by the presence of oxygen and carbon in the brazing atmosphere. The method of admitting argon into the brazing retort was modified to ensure that a positive pressure was maintained in the argon lines during the entire brazing cycle. Section I J presents the results of tests performed by the ETL on the causes of corner contamination. Later in 1957 this problem was virtually eliminated by adoption of the vapor barrier or picture frame concept into the brazing package. This modification was developed by the Manufacturing Research & Development Department.

In July 1957 a sterling silver plus 0.2% lithium alloy was adopted to replace the Ag-Mn brazing alloy. This step was taken in order to provide increased corrosion resistance in the brazed panels. Section II E presents results of the preliminary survey on the Ag-Cu-Li alloys conducted by the ETL. The preliminary heat treat data for use with Ag-Cu-Li are given in Section I C.

Several brazing problems arose or were accentuated with the adoption of Ag-Cu-Li as the brazing alloy. The brazing alloy flow problems, mentioned in a preceding paragraph, continued to be troublesome. The problem of voids in brazed edge member joints became increasingly acute. Section II L and II M discuss this problem. Eventually, it was found that by exercising closer control in the forming of the edge member detail parts this problem could be virtually eliminated.

Until the summer of 1958 no appreciable corrosion attack on Ag-Cu-Li brazed panels was observed. At this time, an oxidized region was observed in Ag-Cu-Li fillets after exposure at temperatures above 550 F. Investigation showed that this condition did not seriously affect panel strength after 300 hours at 700 F. See Section II E and the abstract listed under Section III reference 12. There have been a few indications that Ag-Cu-Li brazed panels do undergo corrosion phenomena of a electrochemical nature. These indications have not been sufficiently pronounced to cause serious concern.

In March 1959 the standard heat treat cycle for brazed panels was simplified by the elimination of the 1400 F conditioning step. The use of a 1650 F brazing temperature for the Ag-Cu-Li brazing alloy made elimination of this step feasible. Test results listed in Section I D were the basis for this change. The possibility of eliminating the -20 F transformation treatment is being investigated at the present time. This work is being done under a separate test request and the results will be reported separately.

This sequence of events completes the development of the stainless steel brazing program until the present time. Seemingly, the sandwich panels brazed with the Ag-Cu-Li alloy are adequate to perform their intended function. The effect that future increased operational requirements will have on brazed panel is still an unknown quantity.

STAINLESS STEEL SANDWICH PANEL BRAZING -

DEVELOPMENT TESTS OF -

PURPOSE:

To develop procedures for brazing 17-7PH stainless steel sandwich panels and to determine the cause of and remedies for difficulties that arose during the fabrication of sandwich panels.

TEST PROCEDURES, SPECIMENS AND EQUIPMENT

This item is intended to explain the procedures followed in obtaining the test data and other information presented in this report.

TENSILE TESTS:

The standard flat specimen used in ETL for tensile tests at room temperature is shown in Figure 2. Baldwin universal machines with capacity of 5000, 60,000, and 120,000 lbs. were used for tensile testing. The specimens were usually held in position by Templin grips. In some instances, a clevis and pin arrangement was employed. The specimen for tensile tests at elevated temperatures is similar to that of Figure 2. It is provided with holes in the ends for loading with a pin.

In tensile testing, the load was usually specified in pounds per minute at a rate which would break the specimen within 2 to 3 minutes. Unless otherwise stated, the elongation was measured on a 2" reduced section. The yield strength was calculated from the stress-strain curve for a .2% offset.

The accuracy of elongation measurements, especially of thin sheet having relatively low ductility, is often questioned. This subject is discussed briefly at the end of this statement on test procedures.

A notched tensile specimen for sheet is shown in Figure 3. This specimen was used in some tests for which the results are given in Item I,D of this report.

FATIGUE TESTS:

The standard flat specimen used for fatigue tests in axial tension-tension is shown in Figure 4. All the fatigue tests were carried out on Sonntag SF-1-U universal fatigue testing machines.

LAP SHEAR TESTS:

Figure 5 (a and b) shows two types of lap shear specimens. The double lap shear type of Figure 5-a affords even loading but is troublesome to prepare properly. This specimen was used mainly in the tests for which data are given in this report. The single lap shear specimen of Figure 5-b is objectionable because its geometry results in eccentric loading. The specimen shown in Figure 6 (AWS) type specimen, is the one presently used for shear tests. Although the single and double lap shear specimens more nearly represent the load conditions imposed on edge member sections of sandwich panels, it is felt the new specimen given a more accurate value for the shear strength of the brazing alloy.

X-RAY EQUIPMENT:

The X-ray diffraction and fluorescence analyses mentioned in this report were made on Norelco equipment. The diffraction patterns were obtained by either film or electronic recording methods.

METALLOGRAPHY:

Ordinarily, the specimens for metallography were sectioned in the desired manner and mounted in bakelite. The surface to be examined was ground flat on an abrasive belt (180 grit). Further grinding was done on 0 through 0000 metallographic papers. Final finishing was effected on an 8" lap wheel using a suspension of diamond dust (1 micron) in kerosene as the abrasive agent.

Visual examination was made and photomicrographs were taken on a Bausch and Lomb Research Metallograph. This apparatus affords magnifications of 50X to 2000X. Photomacrographs were taken with a Bausch and Lomb macro camera.

SPECIMEN FROM PANELS:

Specimens cut from brazed honeycomb sandwich panels were tested in accordance with the procedures set forth in Convair Specification FMS-0036.*

ELONGATION:

Elongation as determined in the tensile test is commonly regarded as a measure of ductility. In general, the percent elongation may be expected to decrease with decreasing cross-sectional area of the

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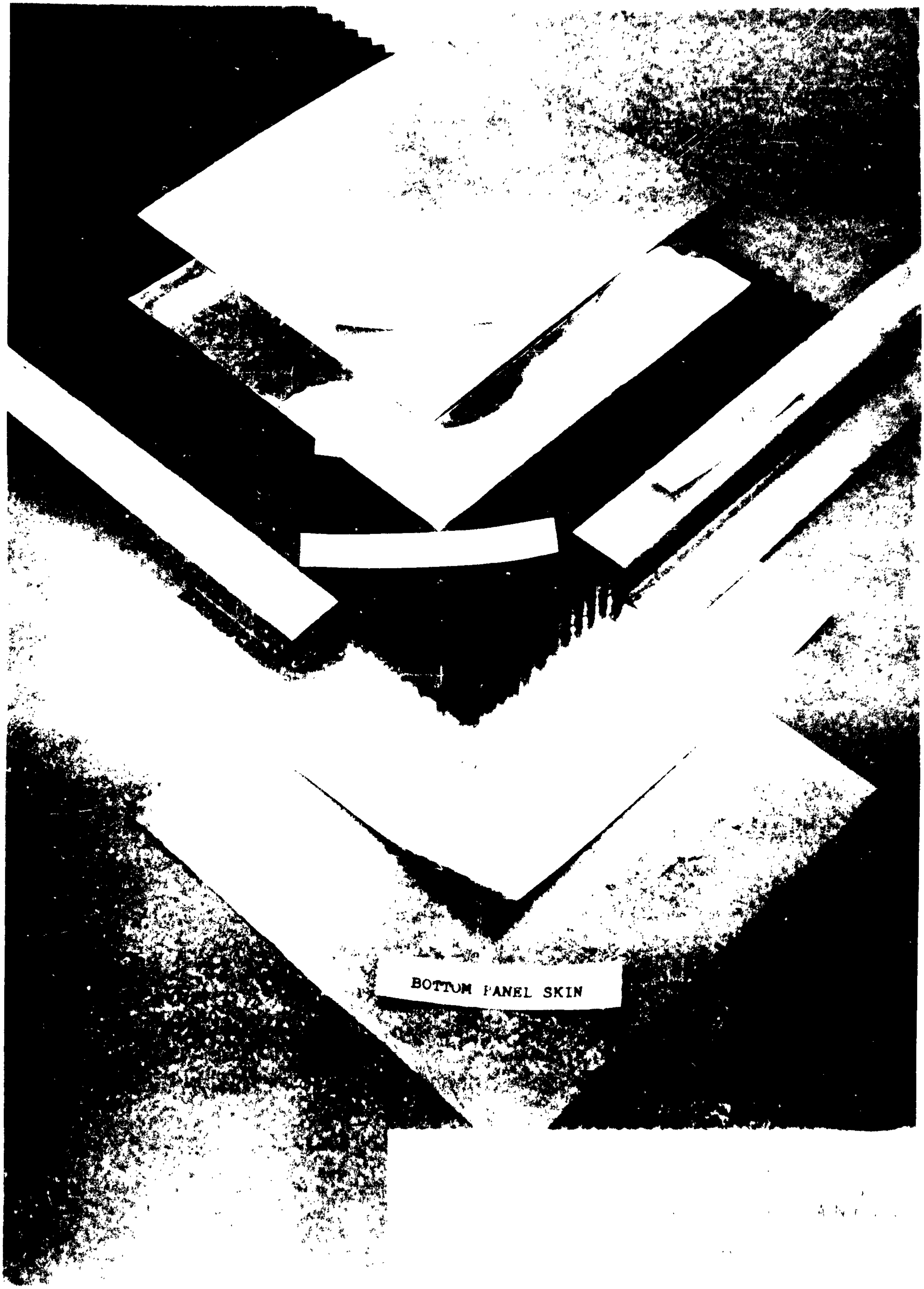
*See Supplemental Sheet S-1.

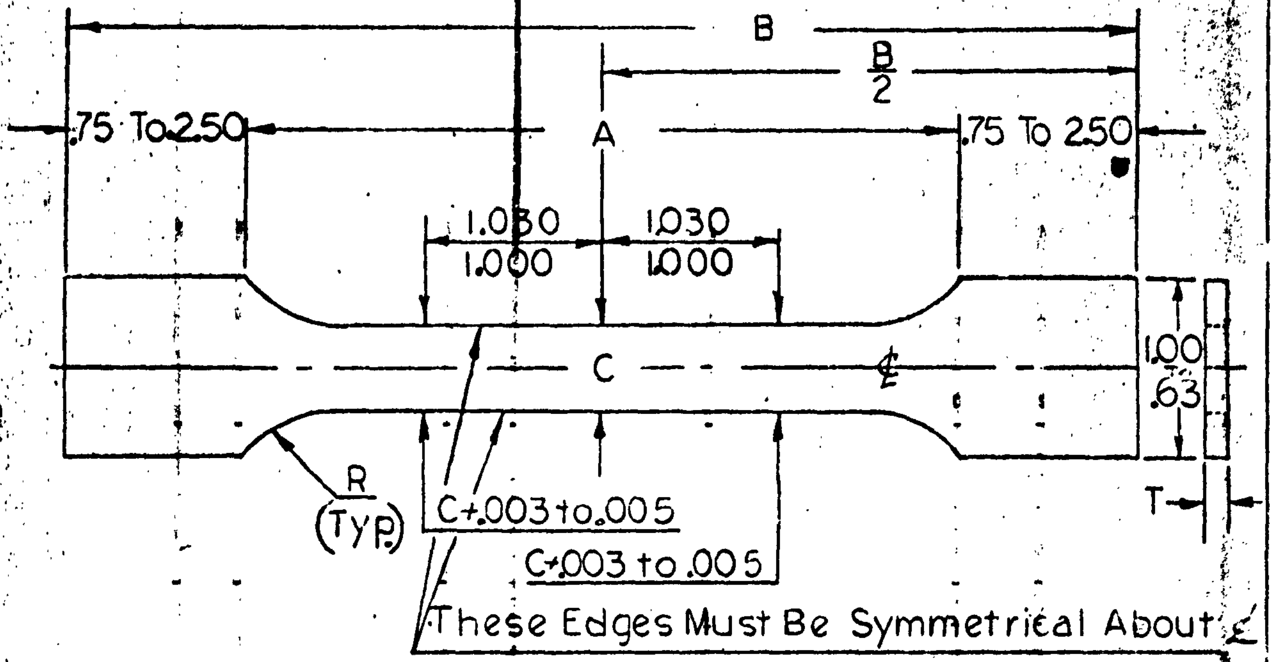
specimen for a given length of reduced section. This does not necessarily apply to all thicknesses, areas, and materials. Templin (Proc. ASTM, Vol. 26, Part II, 1926, pp 376-398) has discussed the effect of cross-section on elongation. In practice, the accuracy and meaning of the elongation measurement becomes questionable for sheet specimens in alloys of low ductility and light gages. Heat-treated 17-7PH steel sheet, in thicknesses of say .025" or less, is an example.

The tensile tests carried out in connection with the development of sandwich panels were mainly on sheet specimens .005" .008", and .010" thick. For numerous specimens the elongations obtained were low or marginal. The question arose as to whether the low values were due to the composition of the material, the heat treatment, or some variable in the testing procedure. In some cases improper preparation of the specimens was the cause, e.g., when failure consistently occurred toward one end of the reduced section. Such tests were usually repeated. In other cases the reasons for erratic or low values were not apparent. In summary, an investigation for determining a reliable procedure for measuring the ductility of thin sheet in 17-7PH steel seems to be warranted.



BOTTOM PANEL SKIN

DIAGRAM SHEET FW 12-1-47



1. Unless otherwise specified tolerances are as follows:
   Linear dimensions - .xx ± .03 .xxx ± .010
2. T = Material stock thickness
3. Polish edges of reduced section longitudinally with 0 grade emery paper.
4. Material to be as specified.
5. Grain direction to be longitudinal unless otherwise specified.

Dash No	A	B	C	R (Min)
-8	4.00	9.00	.500	1.00
-9	2.75	4.25	.500	.25
-10	4.00	9.00	.250	1.00
-11	2.75	4.25	.250	.25

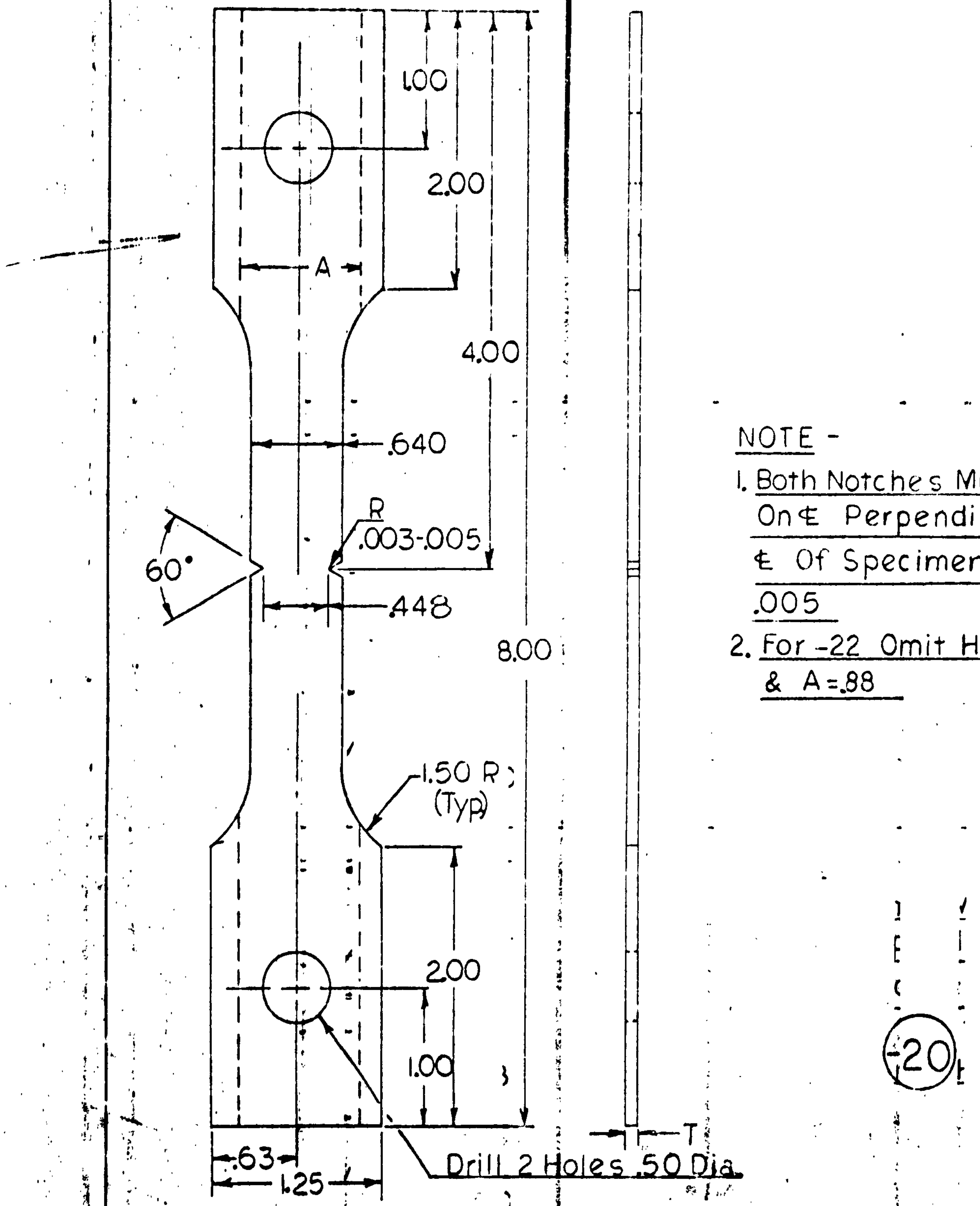
DRAWN R Catley
CHECKED
ENG.
PROJECT

TENSILE
TEST SPECIMEN—FLAT

CONSOLIDATED VULTEE AIRCRAFT CORPORATION
FORT WORTH DIVISION • FORT WORTH, TEXAS

FTJ-10940
Scale-Full

FIGURE 2



NOTE -

1. Both Notches Must Be On ℄ Perpendicular To ℄ Of Specimen Within .005
2. For -22 Omit Holes & A = .88

MAT'L.		H TREAT		
TOL.	0.0 ±	0.00 ± .030	0.000 ± .005	ANG. ±
DRAWN	R. Cathey	APPROVED		
CHECKED		DATE	8/18/59	

NOTCHED TENSILE SPECIMEN — SHEET

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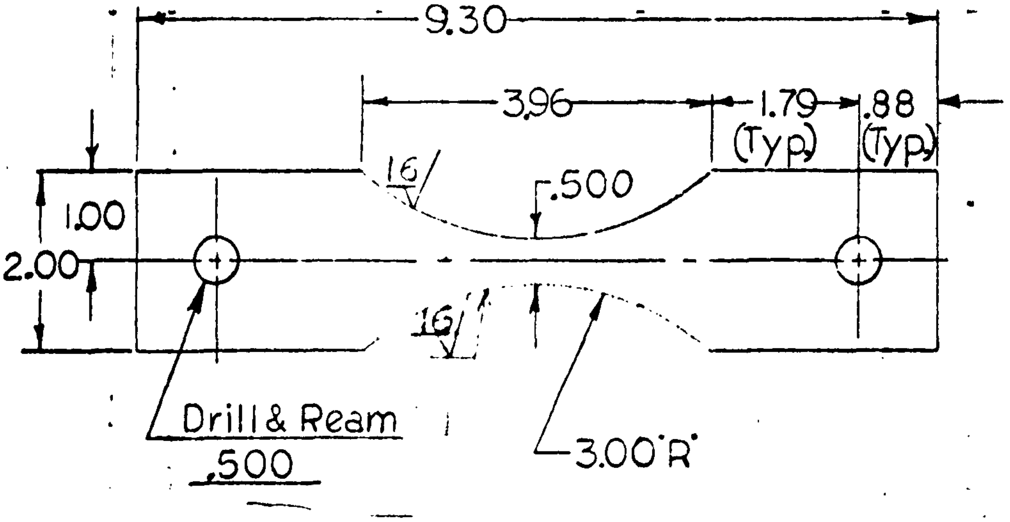
(FORT WORTH)

DRAWING FORM

DEPT. 24
FW-82-6-64

TOOL NO.
FTJ 10940
REPLACES

FIGURE 3



NOTE:

Center Holes On Line Of Symmetry Through Specimen

$K_t = 1.036$

Ref. AIA Fatigue Hdbk. 3.32-16 No. 15

MAT'L.		H'TREAT		
TOL.	0.0 ±	0.00 ± .030	0.000 ± .010	ANG. ±
DRAWN		APPROVED		
CHECKED		DATE		

FATIGUE SPECIMEN

CONVAIR
A DIVISION OF GENERAL DYNAMICS CORPORATION
(FORT WORTH)

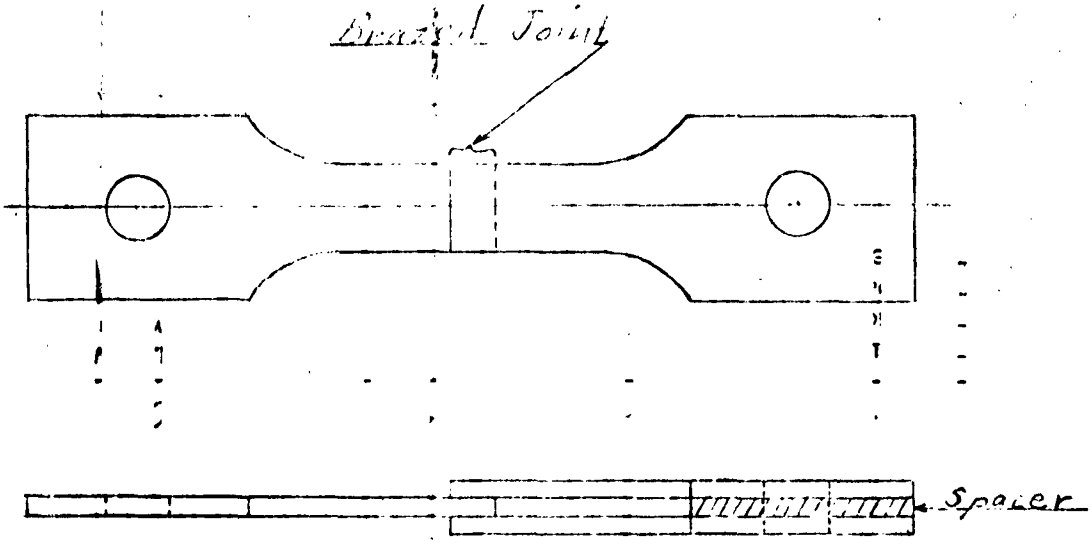
DRAWING FORM
DEPT. 24
FW-32-4-64

TOOL NO.
FTJ-10940-71

REPLACES

FIGURE 4

a. Double Lap-shear Specimen



b. Single Lap-shear Specimen

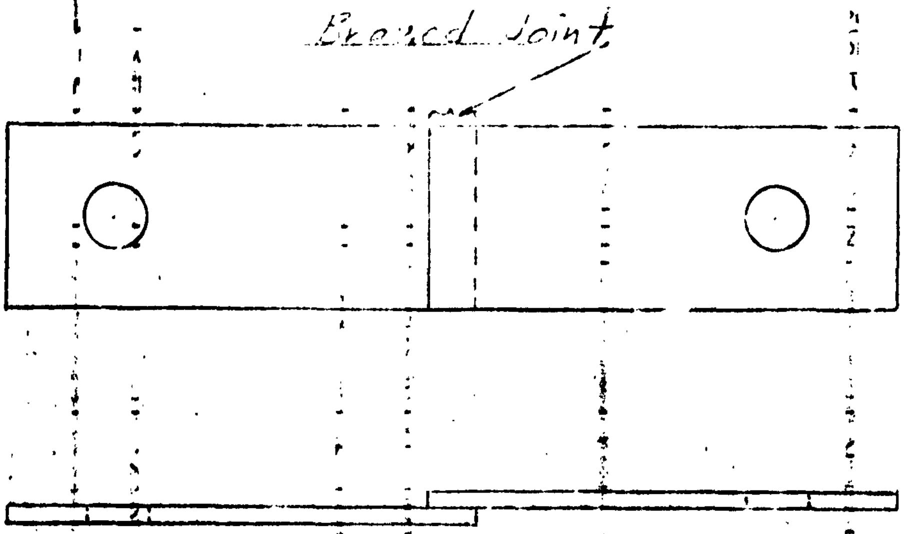


FIGURE - 5

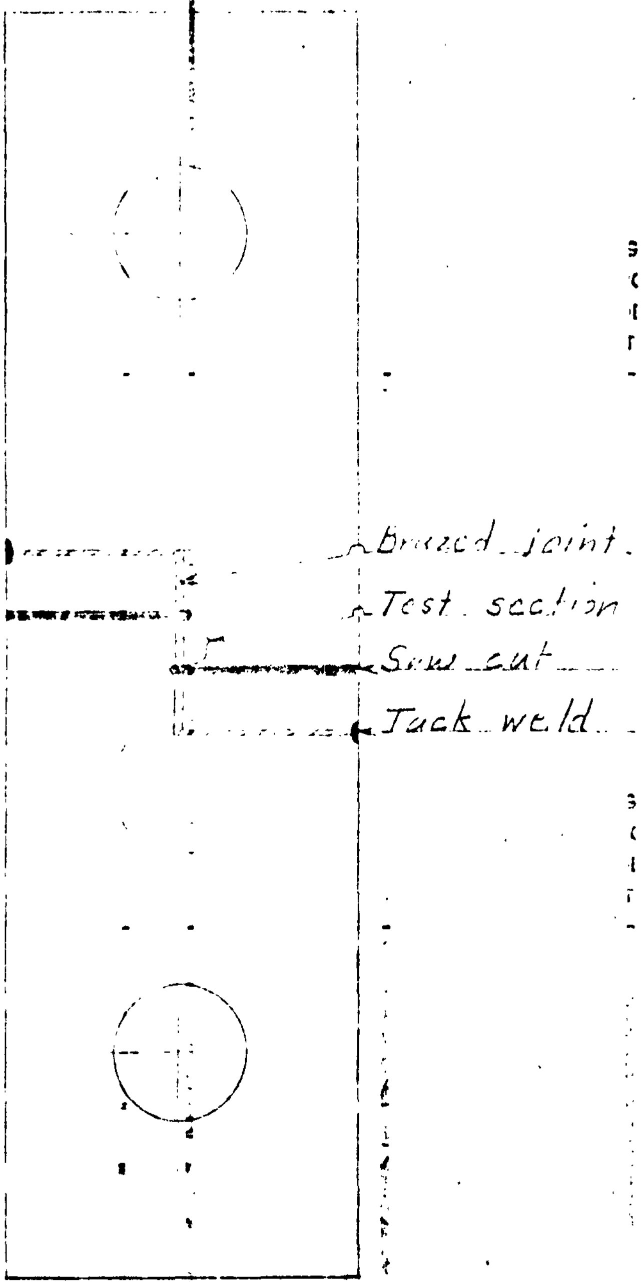


FIGURE - 6

SECTION I - STUDIES CONCERNING MATERIALS USED IN SANDWICH PANELS

17-7PH STAINLESS STEEL

HEAT TREATMENT

ITEM A - INITIAL HEAT TREAT RESPONSE STUDIES ON 17-7PH STEEL

During 1954-1956, several investigations were conducted on the heat treatment characteristics of 17-7PH steel. The results of this work were not published or reported by memoranda. They are summarized here. These results represent test data which were either not directly applicable or utilized in the development of any particular heat treatment subsequently adopted for production.

The investigations fall into two categories. These are: (1) Determination of the tensile properties of 17-7PH steel obtained by heat treatments corresponding to various brazing cycles; and (2) measurements of the dimensional changes in this steel caused by heat treatment. All tests were performed on sheet stock. All heat treatments, except transformation and some coolings as indicated in tables or figures, were carried out in argon.

The results of some tensile tests, mostly on .005", .008", and .020" thick material, are listed in Tables IA-I through IA-VI. In each table, the heat treatment is given. The tensile data are not presented in graphical form.

Tables IA-I and IA-II give the tensile values obtained on specimens which had received heat treatments similar to the Armco RH 1050. The time at the conditioning temperature was varied for specimens of Table IA-I. As shown, holding for 30 to 90 minutes at 1750 F gave satisfactory tensile properties. Table IA-II makes evident that holding for 10 minutes or 60 minutes at the transformation temperature, -100 F, gave satisfactory properties except for the .085" thick sheet. Both the tensile yield and ultimate strengths of this sheet were below the minima of Convair specification FSZ-4-046. One set of .085" thick specimens of Table IA-IV just met the specification as to strengths. Perhaps, both sets of specimens had been taken from one lot of sheet which was sensitive to the cooling rate and did not properly respond to the heat treatments.

The heat treatment, H.T. -3, given in Tables IA-III, IA-IV, and IA-V corresponds to the Armco TH 1050 treatment with certain variations. The data appear to show that the transformation temperature of +54 F gave more consistent results than did the lower temperatures. Also, the elongations were generally higher for transformation at +54 F. From the data of Table IA-V, aging at 950 F gave higher strength values and lower elongations than aging at 1050 F. The elongation of the .005" thick sheet aged at 950 F was exceptionally low.

The heat treatment, H.T. -4, given in Table IA-IV afforded acceptable tensile properties without a conditioning step. The reason why this type of treatment was not investigated further is not apparent. One explanation may be that the primary concern, at the time this work was in process, was high strength rather than high elongation. Subsequent experience has proven that adequate elongation is more difficult to maintain than high strength, especially in thin sheet. This refers to specification values.

Table IA-VI gives the tensile properties of .010" thick sheet in 17-7PH steel, processed with two sandwich panels during brazing. The table shows the brazing cycles. In both cases, the material placed at one end of the brazing retort acquired acceptable tensile properties, but material placed at the opposite end had low ultimate strength. This indicates the presence of a temperature gradient, presumably reflecting its most adverse effects during the aging operation.

Figures IA-1, IA-3, and IA-5 show curves indicating the progression in cooling small batches of tensile specimens of 17-7PH steel from three different temperatures to 1100 F. The results of tensile tests on material cooled as depicted in these figures are plotted in Figures IA-2, IA-4, and IA-6, respectively. Other details of the heat treatment are given in the latter figures.

As shown in Figures IA-2, IA-4, and IA-6, sheet specimens .005", .008", and .020" thick were heated to 2100, 2000, and 1900 F, and then cooled and aged. For each of these temperatures, the tensile properties are plotted against the time held at the shelving or conditioning temperature of 1700 F.

As may be seen from the above figures, there are appreciable variations in the tensile properties depending on several factors. These are the temperature to which heated, the time at the conditioning temperature, and the thickness of the sheet. The following pattern is apparent as concerns the effect of increasing time at the conditioning temperature: For the highest heating temperature, 2100 F, the strengths increase and the elongation tends to decrease. For the intermediate temperature, 2000 F, both the strength and the elongation tend to remain at about the same levels of values. For the lowest heating temperature, 1900 F, the strengths decrease and the elongation increases.

The three figures (IA-2, IA-4, and IA-6) show that the tensile yield and ultimate strengths were high for all treatments. In ten of twenty-seven instances the elongation was below the specified minimum. Poor elongation was pronouncedly characteristic of the .008" sheet. Examination of the graphs indicates that two combinations of heating temperature and time of conditioning produced acceptable elongation values for all three thicknesses.

Figures IA-7, IA-8, and IA-9 show the effects of the shelving (conditioning) temperature and cooling time from this temperature on the tensile properties of 17-7PH steel sheet, aged at 1050 F. The details of the heat treatment are given in the figures. Three thicknesses of sheet were tested, viz., .005", .008", and .020". Except with the .005" sheet no definitive pattern of effects on all properties was developed. For this thickness the general trend was toward higher tensile properties as the conditioning temperature was decreased from 1700 to 1400 F. The effect of the shelving time was most marked and consistent as concerns the elongation, the shorter time giving the higher values. As to the .008" and .020" thick sheet, the general trend was toward higher strengths with decreasing shelving temperatures. The elongation developed for the .008" sheet tended to decrease with decreasing temperature of shelving for the shorter exposure. For the longer exposure, the pattern was scrambled. Shelving temperatures and times had minor effect on the elongation of the .020" sheet.

Figures IA-10, IA-11, and IA-12 show the effects of the shelving temperature and cooling time on the tensile properties of 17-7PH steel sheet, aged at 1075 F. The effects are more or less comparable to those resulting from aging at 1050 F, but obvious divergencies may be noted. The ultimate strengths for the aging at 1075 F tended to level off or decrease a little with decreasing shelving temperature for the longer time of holding. They increased for the shorter time. The yield strengths increased for both the short and long times but much more markedly with the former. The elongation tended to increase for the .005" and .008" sheet for both short and long times with decreasing shelving temperature, but that of the .020" sheet decreased. Both .005" and .008" sheet, aged at 1050 and 1075 F, had marginal or low tensile yield and ultimate strengths with acceptable elongation. The .020" sheet acquired satisfactory strengths with both aging temperatures but marginal elongation on aging at 1050 F.

Figures IA-13 through IA-19 show the effects of the aging temperature, on the tensile properties of 17-7PH steel sheet, following a variety of heating and cooling treatments. Three thicknesses of sheet were treated, viz., .005", .009", and .020". The aging temperatures were 1050, 1075, and 1100 F. Full details of the treatments are given in the figures. The general pattern of the graphs is this: Both the tensile yield and ultimate strength decrease and the elongation increases with increasing aging temperature for the three thicknesses.

The effects of the combined treatments (heating, cooling, and aging) are readily apparent from the graphs of Figures IA-13 through IA-19. Irrespective of the treatment, all the tensile yield and ultimate strengths were above the specification minima except in four instances. With the treatment given in Figure IA-16, the ultimate strengths were below the minima for all the thicknesses of sheet aged at 1100 F. With the treatment of Figure IA-19, the ultimate strength was below for the .020" sheet aged at 1100 F. Both the strengths and the elongations were above the specification minima for all thicknesses, with the prior treatment of Figures IA-17 and IA-18, on aging at 1100 F.

The effects of the various heat treatments, given in Figures IA-13 through IA-19, on the elongations of the 17-7PH steel sheet specimens are of interest. Of 63 average elongation values in total, 35 were below the specification minima or 56%. Of 21 average elongation values for .005" thick sheet, 10 were below the specification minimum. Of 21 average values for .009" sheet, 11 were below the minimum. Finally, of 21 values for .020" sheet, 14 were below the minimum.

Figure IA-20 shows an S/N curve for .008" thick sheet in 17-7PH steel, tested in tension-tension fatigue. An R factor of .25 was used. The material was heat treated with a modified Armco TH 1050 procedure. The endurance limit was determined as 106 ksi.

The test data from which the graphs of Figures IA-1 through IA-20 were plotted are no longer available. The values plotted for the tensile properties are the averages of tests on three specimens.

The measurements of the dimensional changes, in 17-7PH steel sheet or three thicknesses, caused by different heat treatments are listed in Tables IA-VII through IA-X. Each table gives the heat treatments used. As shown, the steel specimens grew somewhat during heat treatment through the transformation step. Then, they contracted a little on aging. The final result was growth.

For some unknown reason, the over-all growth of the .005" thick sheet was predominantly greater than that of the .008" or .020" material. Omitting those instances where the growth of two or three thicknesses was the same, the frequency of most growth for the .005" sheet was 6.5 times that of the .008" and 4.3 times that of the .020" sheet. The amount of contraction occurring during aging was generally greater with increasing temperatures. Also, the data showed that the specimens conditioned at 1700 F developed about 12% more over-all growth on the average than those conditioned at 1400 F.

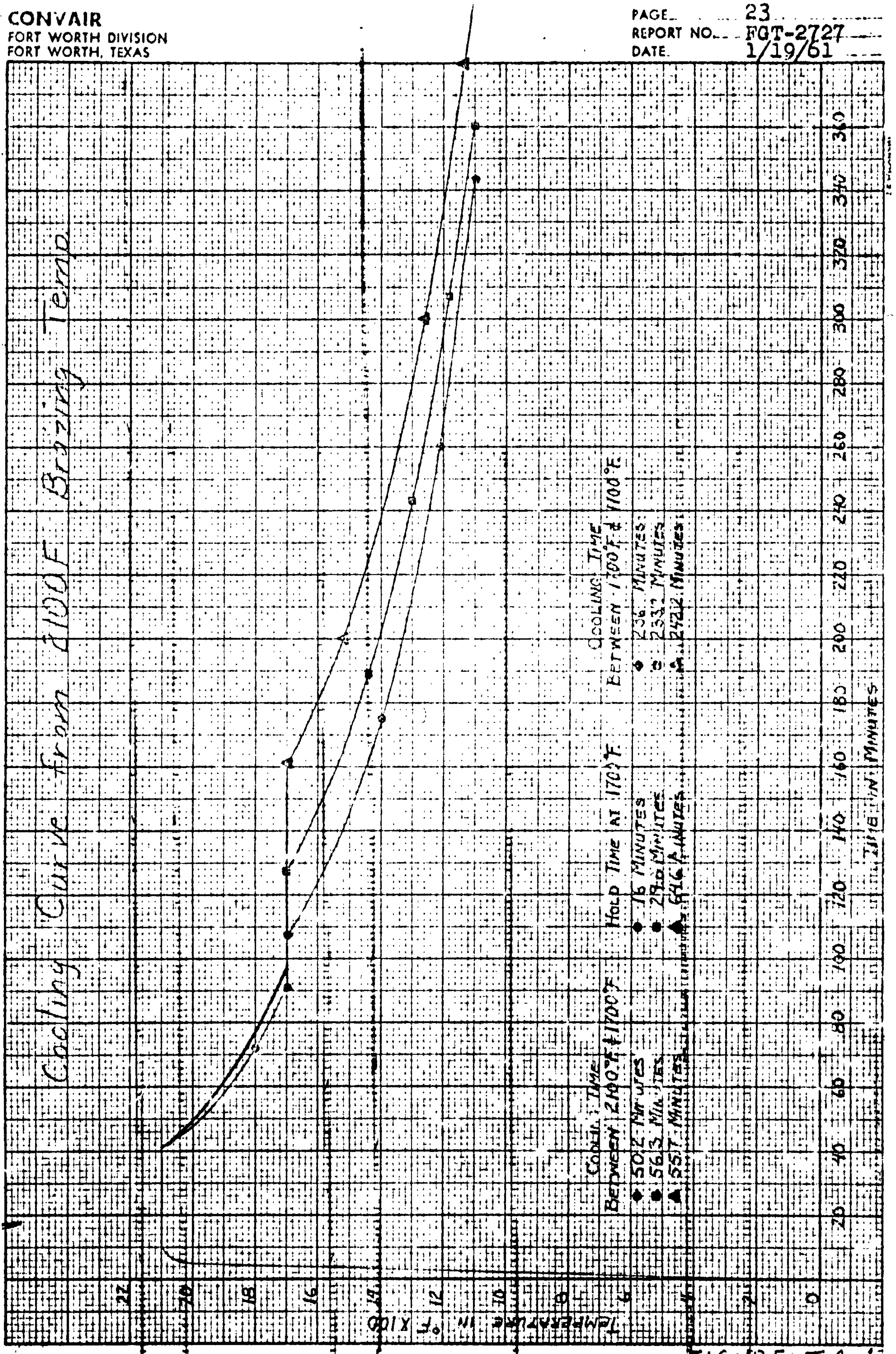

Cooling Curve from 2100F Brazing Temp
TEMPERATURE IN °F X100
22
20
18
16
14
12
10
8
6
4
2
0
TIME IN MINUTES
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
COOLING TIME
BETWEEN 2100°F & 1700°F
◆ 50.2 MINUTES
● 56.3 MINUTES
▲ 55.7 MINUTES
HOLD TIME AT 1700°F
◆ 16 MINUTES
● 29.0 MINUTES
▲ 64.6 MINUTES
COOLING TIME
BETWEEN 1700°F & 1100°F
◆ 236 MINUTES
○ 233.2 MINUTES
▲ 242.2 MINUTES

FIGURE: IA-1

Effect of Holding Time at 1700F on 17-7PH Steel

H.T. — Heated to 2100F & held 30 min.
Cooled as shown in Figure IA-1
Transformed at -20F
Aged at 1050F for 90 min.

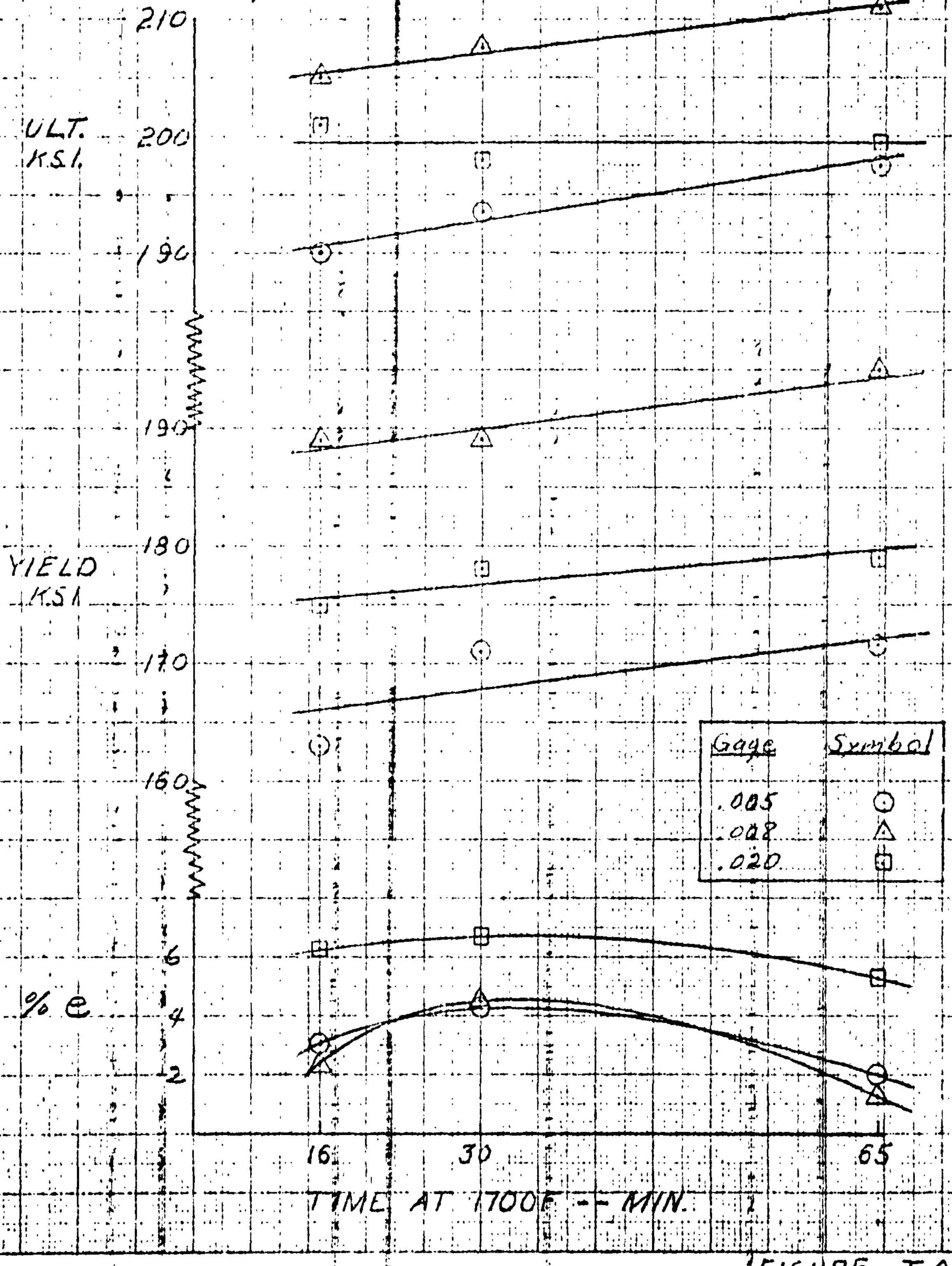
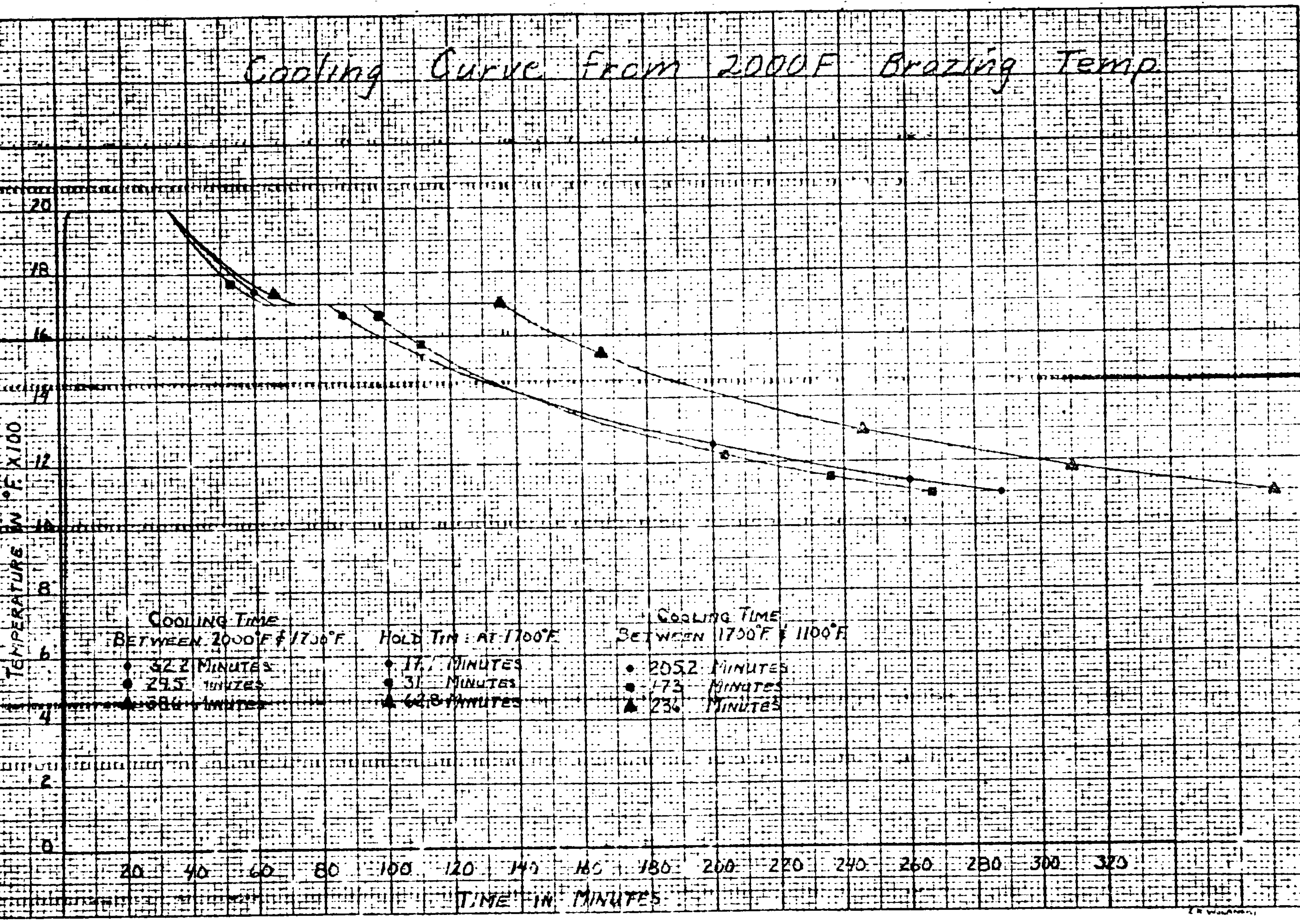


FIGURE: IA-2



Cooling Curve From 2000F Brazing Temp

COOLING TIME BETWEEN 2000°F & 1700°F	HOLD TIM : AT 1700°F	COOLING TIME BETWEEN 1700°F & 1100°F
◆ 32.2 MINUTES	◆ 17.1 MINUTES	● 2052 MINUTES
● 29.5 MINUTES	● 31 MINUTES	■ 173 MINUTES
▲ 38.4 MINUTES	▲ 62.8 MINUTES	▲ 234 MINUTES

FIGURE: IA-3

Effect of Holding Time at 1700F on 17-7PH Steel

H.T — Heated to 2000F & held 30 min.
Cooled as shown in Figure IA-3
Transformed at -20F
Aged at 1050F for 90 min.

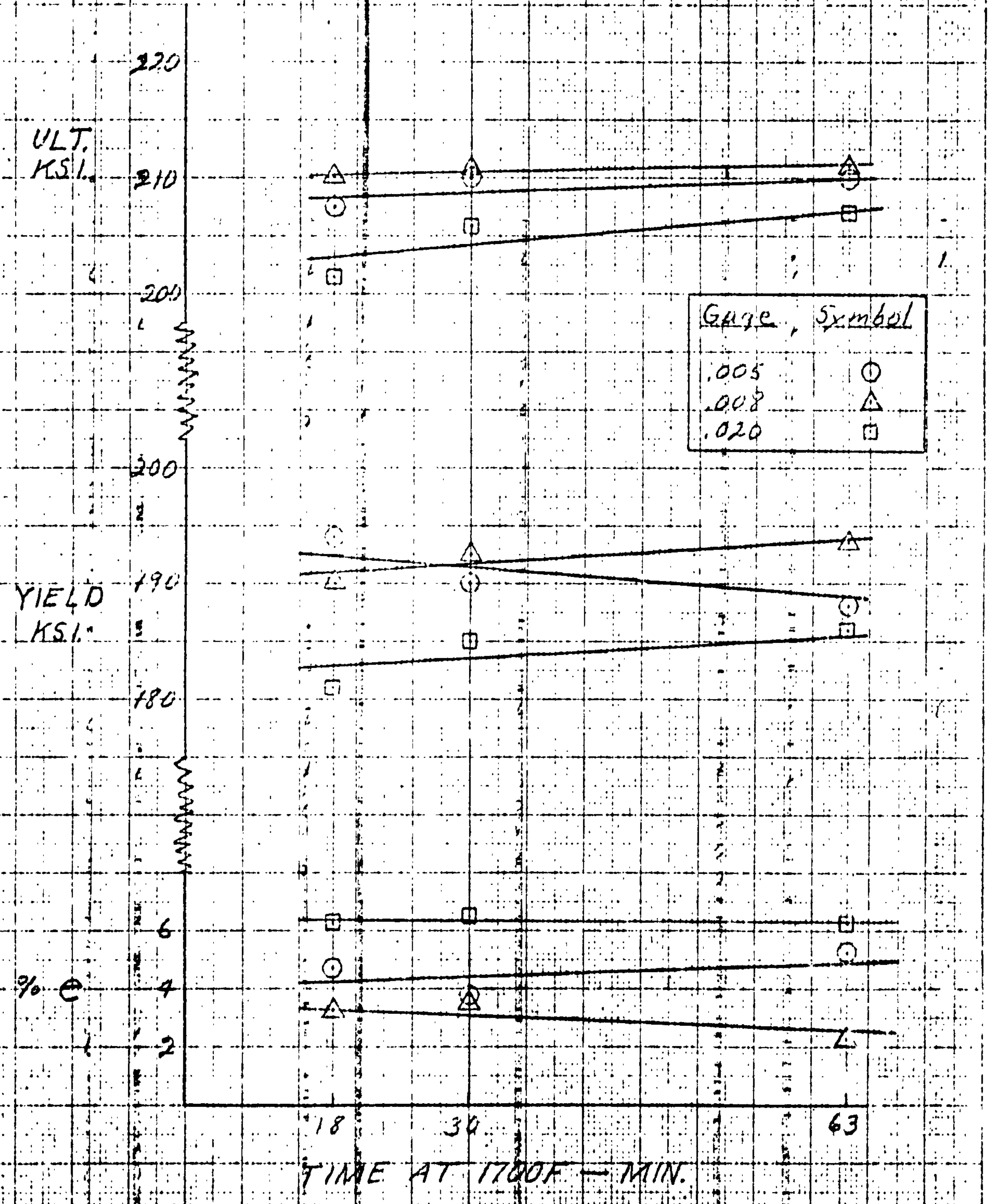


FIGURE: IA-4

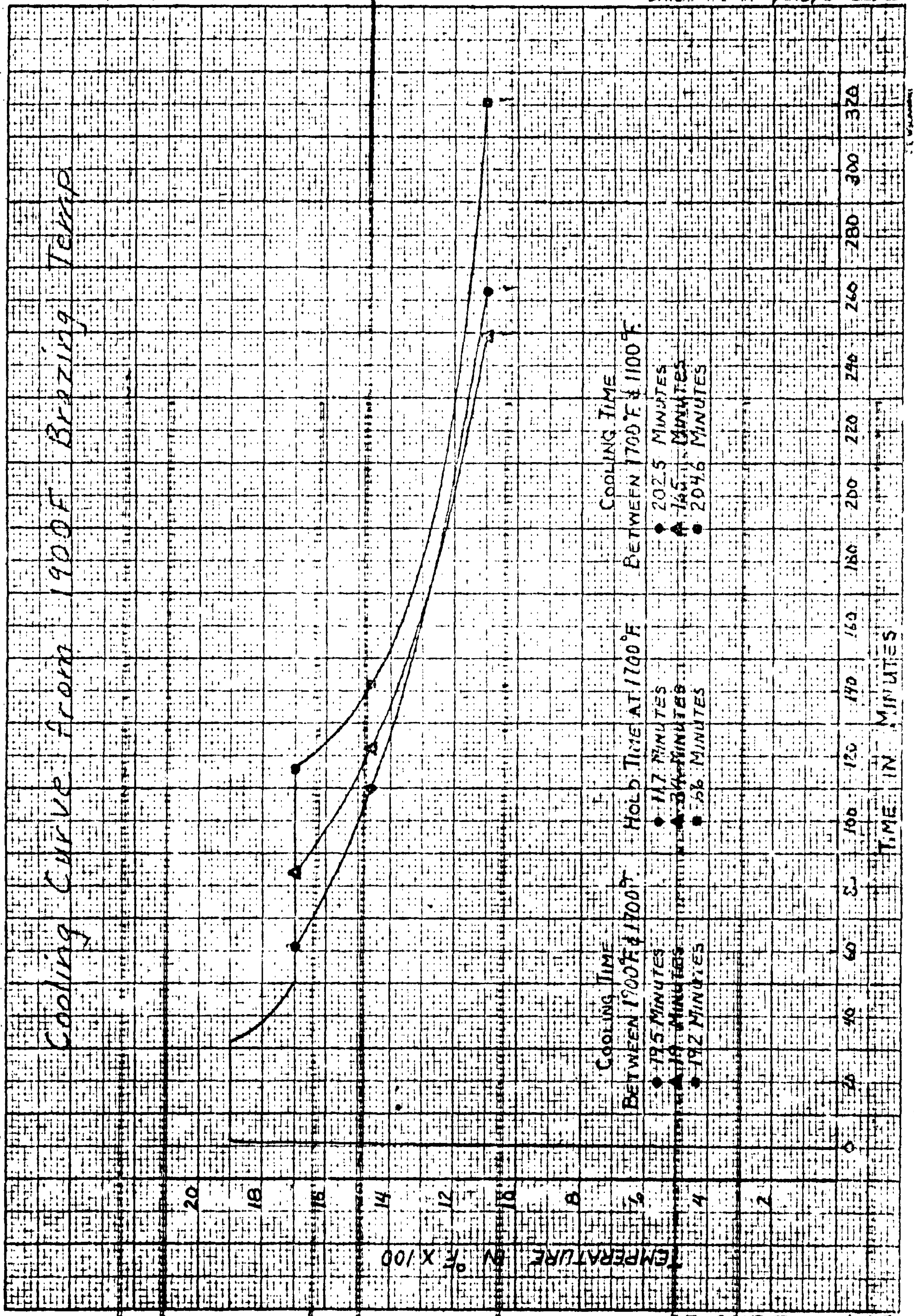
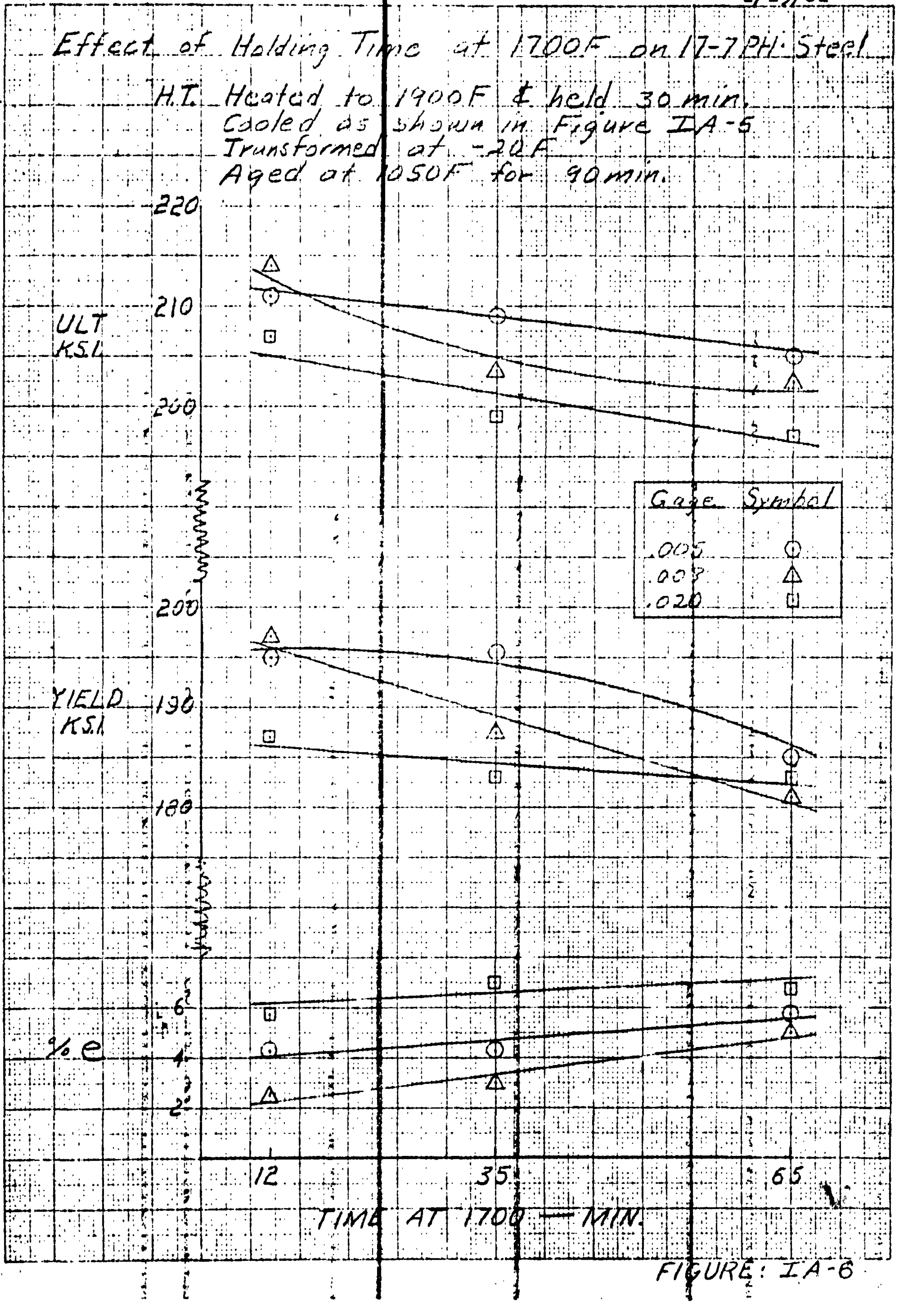

Cooling Curve from 1900F Brazing Temp
TEMPERATURE IN °F X 100
20
18
16
14
12
10
8
6
4
2
TIME IN MINUTES
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
COOLING TIME
BETWEEN 1900°F & 1700°F
● 19.5 MINUTES
▲ 19 MINUTES
● 19.2 MINUTES
HOLD TIME AT 1700°F
● 11.7 MINUTES
▲ 34 MINUTES
● 56 MINUTES
COOLING TIME
BETWEEN 1700°F & 1100°F
● 202.5 MINUTES
▲ 145 MINUTES
● 204.6 MINUTES

FIGURE: IA-5

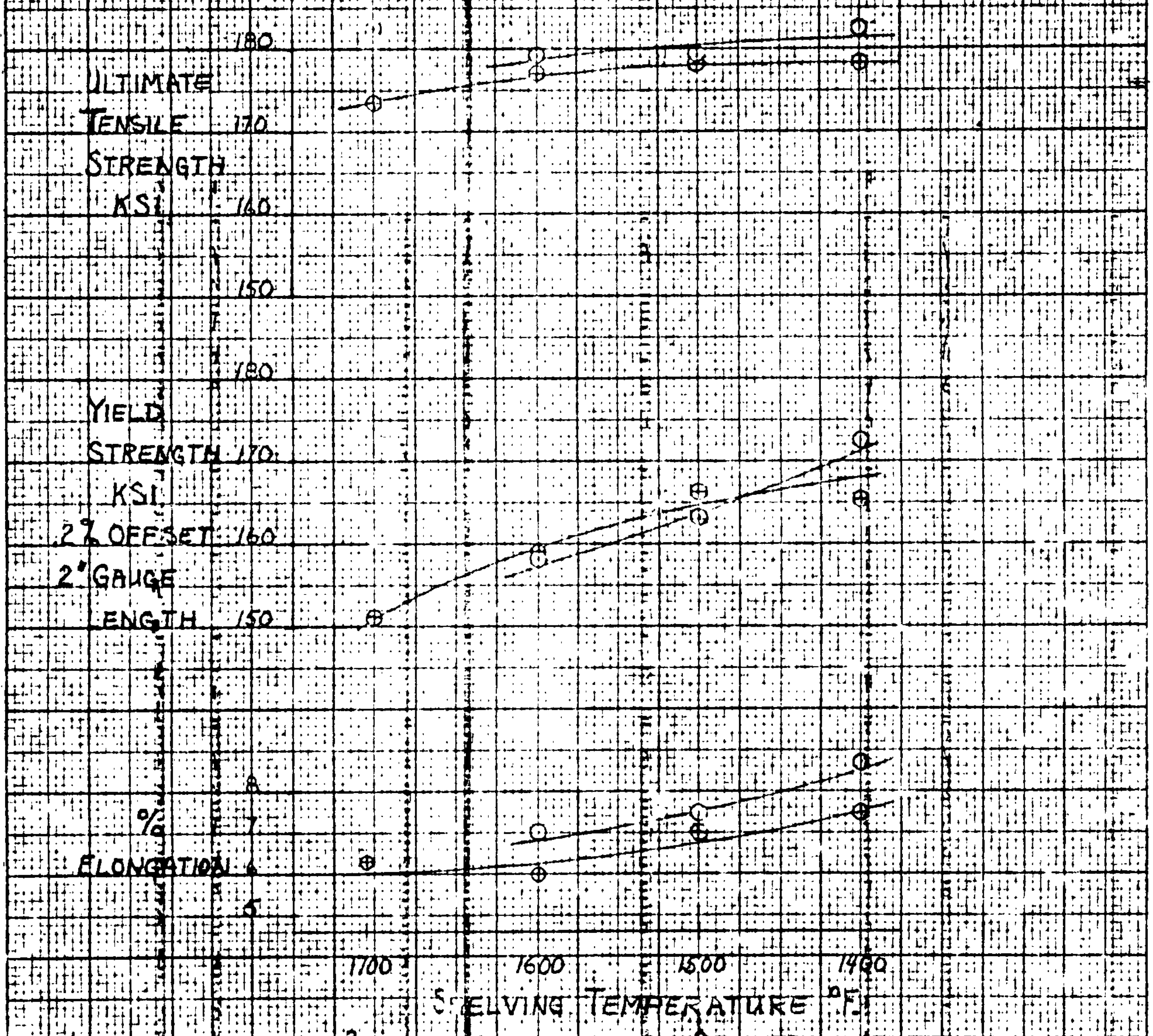


Effect of Holding Time at 1700F on 17-7PH Steel

H.T. Heated to 1900F & held 30 min.
Cooled as shown in Figure IA-5
Transformed at -20F
Aged at 1050F for 90 min.

FIGURE: IA-6

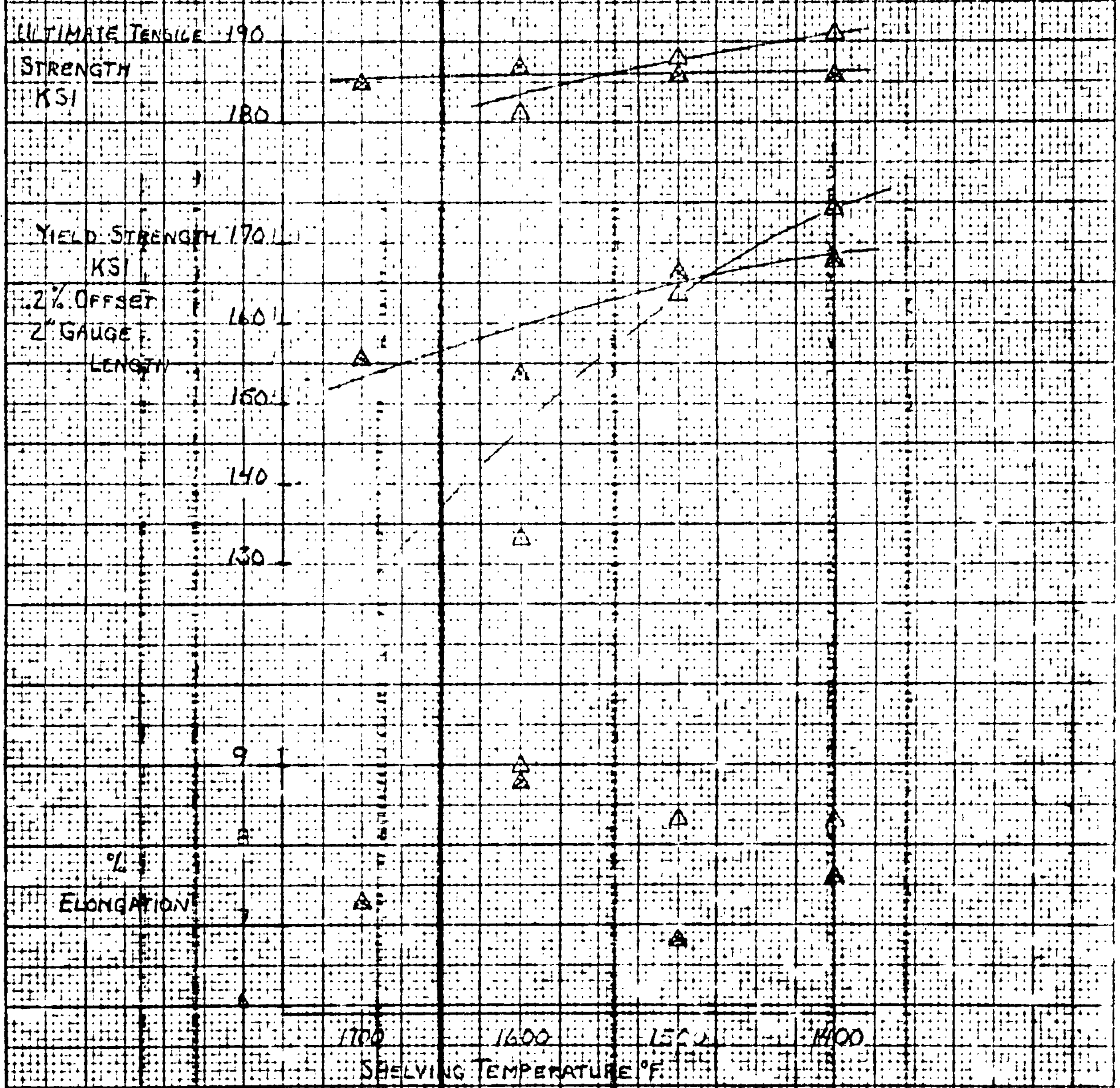
EFFECT OF VARIOUS SHELVING TEMPERATURES AND COOLING TIMES BETWEEN THE SHELVING TEMPERATURES AND 1100°F ON THE MECHANICAL PROPERTIES OF 17-7PH STAINLESS STEEL .005 IN. GAUGE. HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1700°F FOR .5 HRS, FURNACE COOLED TO THE SHELVING TEMPERATURE[1], HELD AT SHELVING TEMPERATURE[2], ~~COOLED FROM THE SHELVING TEMPERATURE TO 1100°F~~ IN MINUTES[3] THEN COOLED TO ROOM TEMPERATURE, FOLLOWED BY A -20°F COOL. AGED AT 1050°F FOR 90 MINUTES.



1. SHELVING TEMP.	2 HELD AT SHELVING TEMP.	3. TIME BETWEEN SHELVING TEMP. & 1100°F.
⊕ 1700°F	60 MIN.	210 MIN.
⊖ 1600°F		62 "
⊖ 1500°F		58 "
⊖ 1400°F		58 "
⊕ 1600°F		220 "
⊕ 1500°F		225 "
⊕ 1400°F		220 "

FIGURE: TA-7

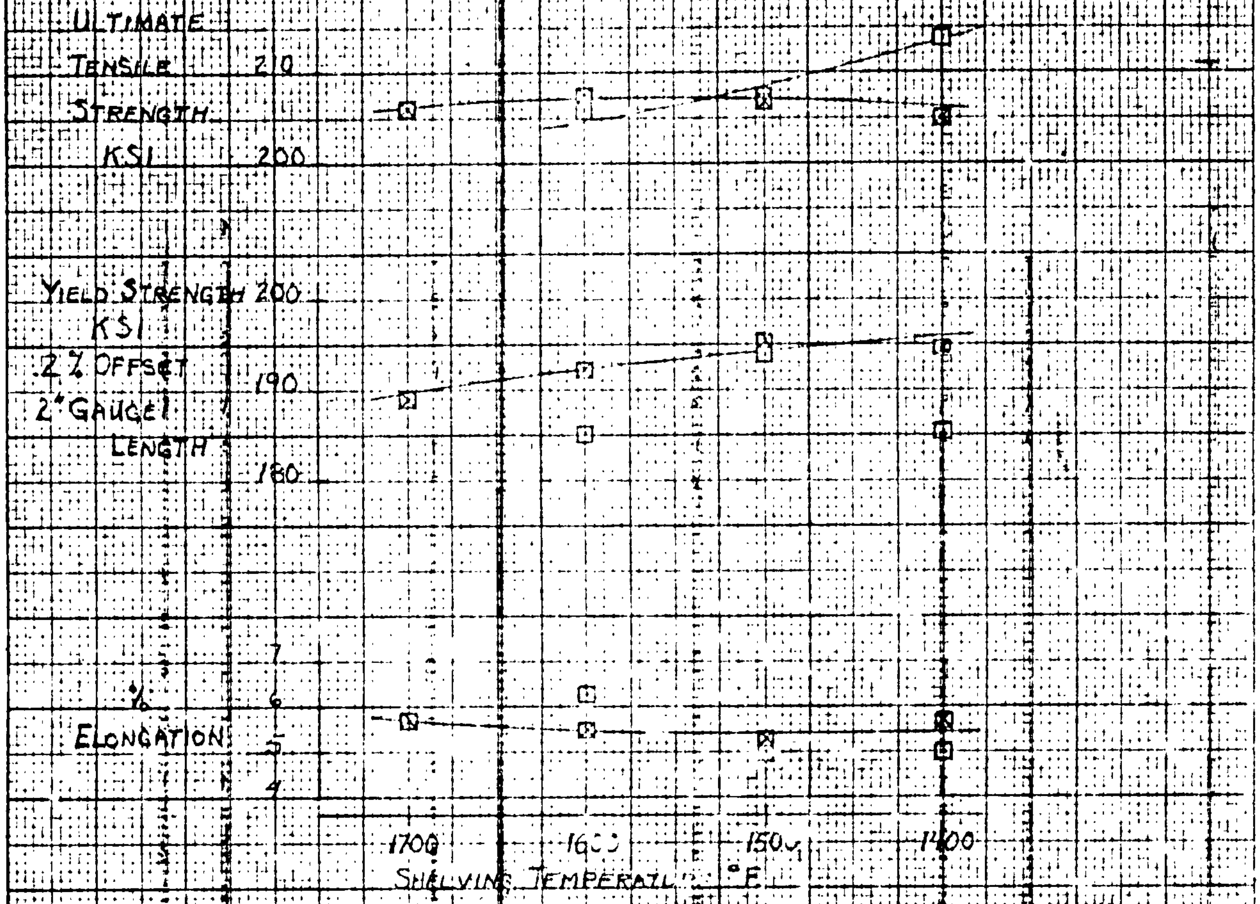
EFFECT OF VARIOUS SHELVING TEMPERATURES AND COOLING TIMES BETWEEN THE SHELVING TEMPERATURE AND 1100°F ON THE MECHANICAL PROPERTIES OF 17-7PH STAINLESS STEEL .008 IN. GAUGE, HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1900°F FOR .5 HRS.; FURNACE COOLED TO THE SHELVING TEMPERATURE [1]; HELD AT SHELVING TEMPERATURE [2]; ~~COOLED FROM THE SHELVING TEMPERATURE TO 1100°F IN MINUTES~~ [3]; ~~THEN COOLED TO~~ ROOM TEMPERATURE; FOLLOWED BY A -20°F COOL; AGED AT 1050°F FOR 90 MINUTES.



1. SHELVING TEMP.	2. HELD AT SHELVING TEMP	3. TIME BETWEEN SHELVING TEMP. & 1100°F
△ 1600°F	60 MINUTES	52 MINUTES
△ 1500°F		58
△ 1400°F		58
▲ 1700°F		210
▲ 1600°F		220
▲ 1500°F		225
▲ 1400°F		220

FIGURE TA-8

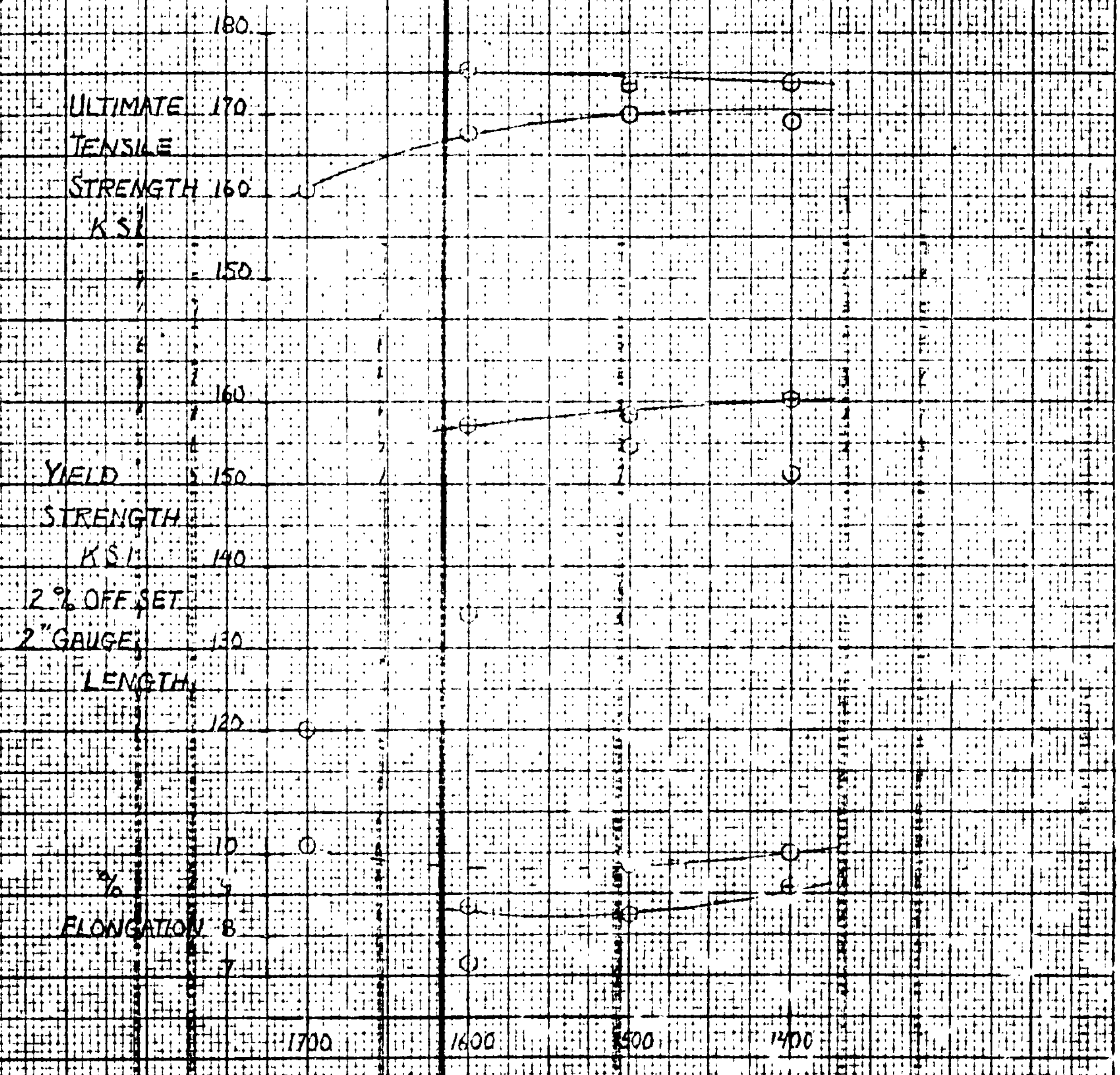
EFFECT OF VARIOUS SHELVING TEMPERATURES AND COOLING TIMES BETWEEN THE SHELVING TEMPERATURES AND 1100°F ON THE MECHANICAL PROPERTIES OF 17-7 PH STAINLESS STEEL .020 IN. GAUGE HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1900°F FOR .5 HRS, FURNACE COOLED TO THE SHELVING TEMPERATURE[1] - HELD AT SHELVING TEMPERATURE[2] - COOLED FROM THE SHELVING TEMPERATURE TO 1100°F IN MINUTES[3] THEN COOLED TO ROOM TEMPERATURE FOLLOWED BY A -20°F COOL. AGED AT 1050°F FOR 90 MINUTES.



1 SHELVING TEMP.	2 HELD AT SHELVING TEMP.	3 TIME BETWEEN SHELVING TEMP. & 1100°F
□ 1600°F	60 MINUTES	63 MINUTES
□ 1500°F		58
⊞ 1400°F		58
⊞ 1700°F		210
⊞ 1600°F		220
⊞ 1500°F		225
⊞ 1400°F		220

FIGURE: TA-9

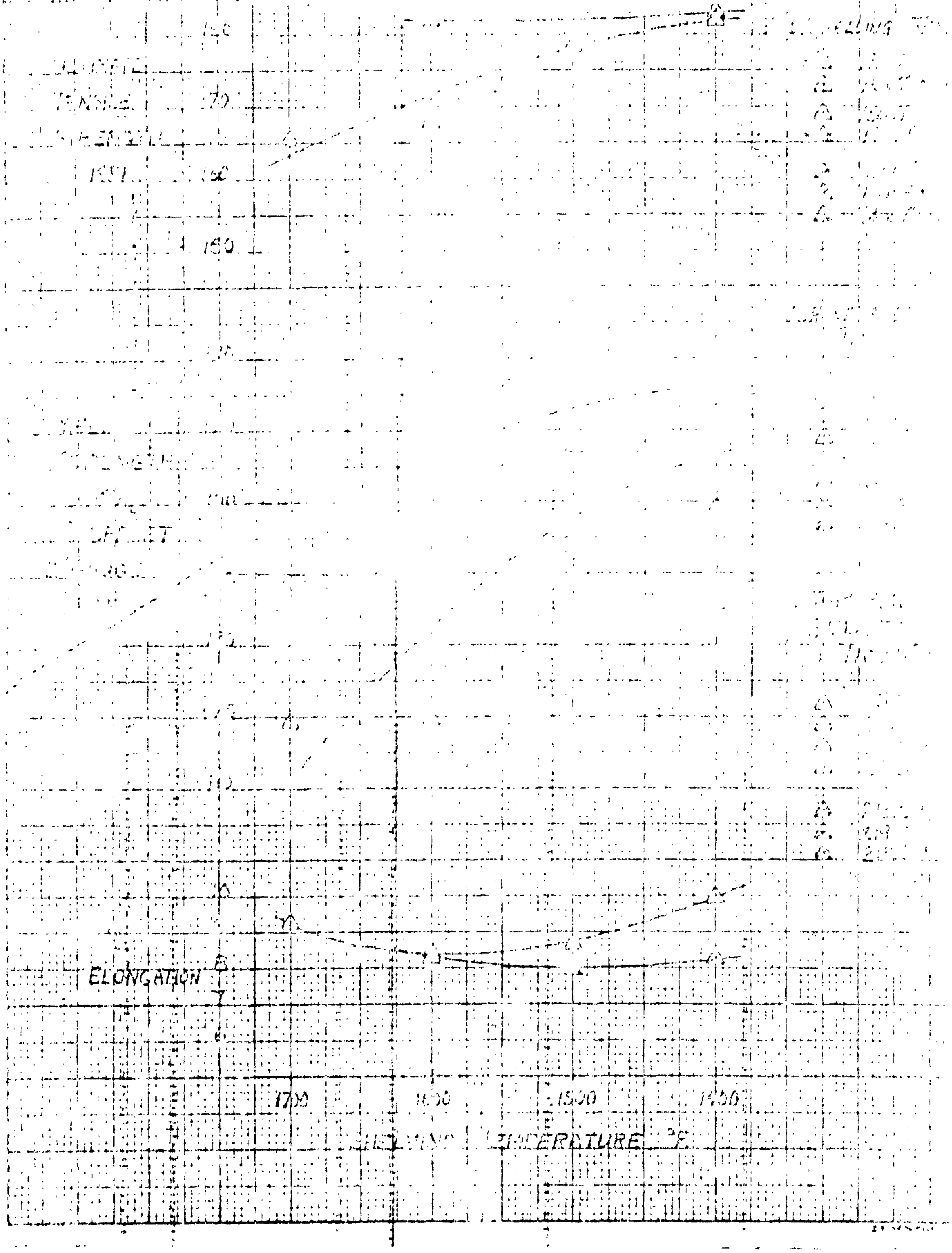
EFFECT OF VARIOUS SHELVING TEMPERATURES AND COOLING TIMES BETWEEN THE SHELVING TEMPERATURES AND 1100°F ON THE MECHANICAL PROPERTIES OF 17-7PH STAINLESS STEEL .005 IN. GAUGE HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1900°F FOR .5 HRS., FURNACE COOLED TO THE SHELVING TEMPERATURE¹, HELD AT SHELVING TEMPERATURE², COOLED FROM THE SHELVING TEMPERATURE TO 1100°F IN MINUTES³. THEN COOLED TO ROOM TEMPERATURE FOLLOWED BY A -20°F COOL. AGED AT 1075°F FOR 90 MINUTES.



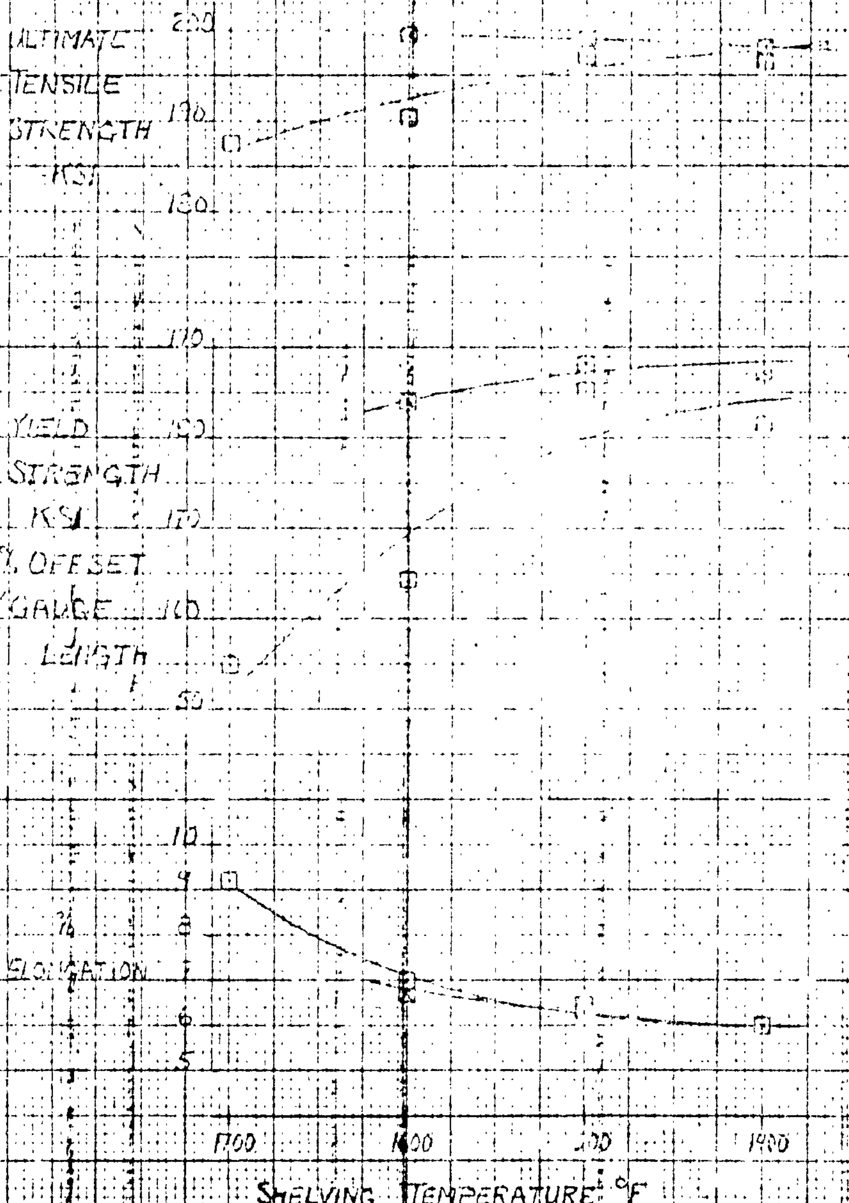
	1. SHELVING TEMP	2. HELD AT SHELVING TEMP	3. TIME BETWEEN SHELVING TEMP & 1100°F
○	1700°F W/ 16.8 MIN.	59.8 MIN.	53.6 MIN.
○	1600°F W/ 45.2	52.5	46.3
○	1500°F W/ 42.8	1.8	60.0
○	1400°F W/ 69.6	4.3	56.6
⊕	1600°F W/ 43.0	0.6	210.2
⊕	1500°F W/ 60.0	1.8	219.3
⊕	1400°F W/ 69.8	3.6	219.6

FIGURE TA-10

EFFECT OF VARIOUS [illegible] AND CLEANING TIMES BETWEEN THE SHELVING TIME [illegible] NORMAL FROM THE [illegible] SHELVING [illegible] 100 [illegible] AS FOLLOWS: [illegible] HEAT AT [illegible] FOR [illegible] TO THE SHELVING TEMPERATURE [illegible] HELD AT SHELVING TEMPERATURE [illegible] FROM THE SHELVING TEMPERATURE TO [illegible] IN [illegible] TO ROOM TEMPERATURE; FOLLOWED [illegible]

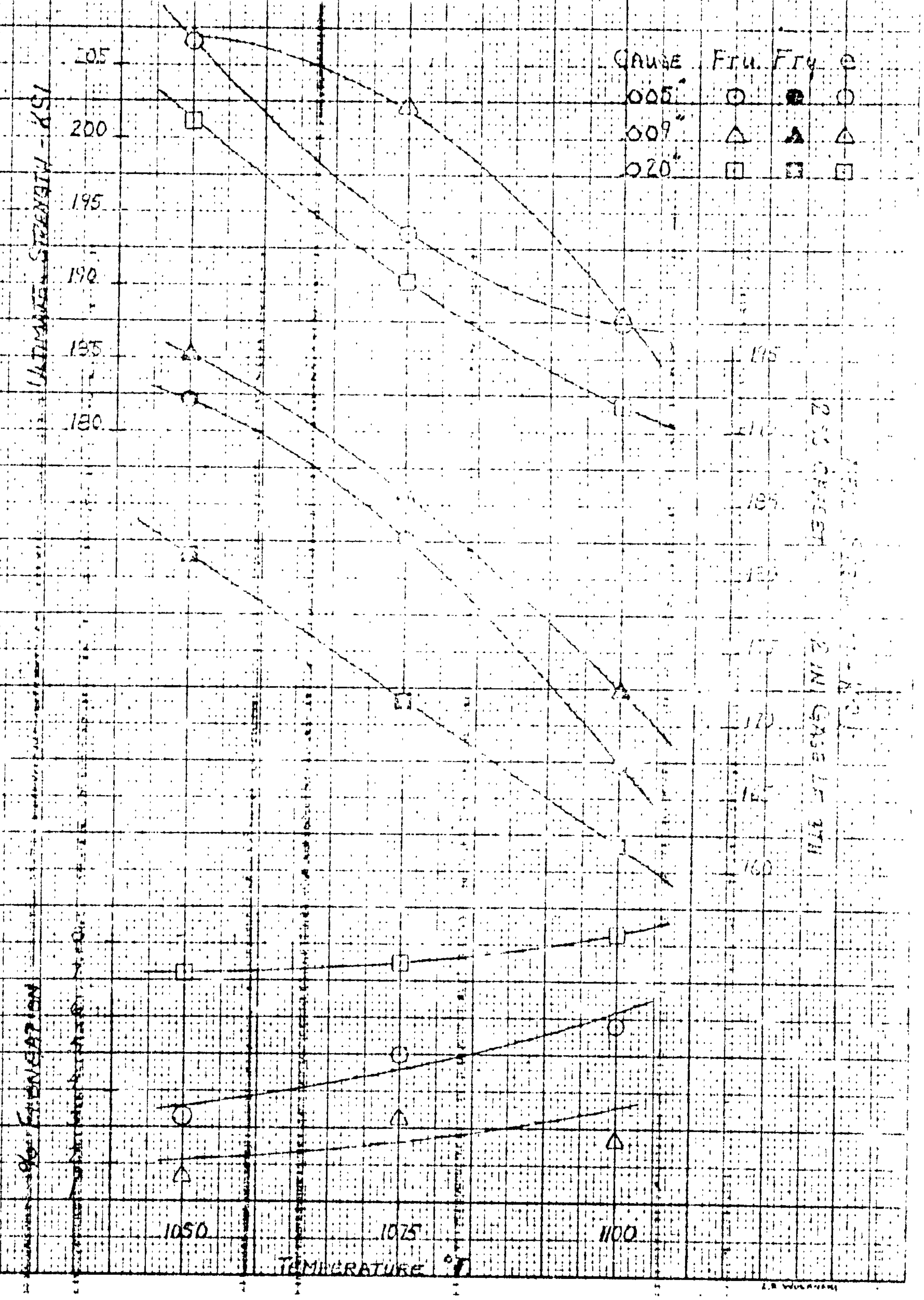


EFFECT OF VARIOUS SHELVING TEMPERATURES AND COOLING TIMES BETWEEN THE SHELVING TEMPERATURES AND 1100 F ON THE MECHANICAL PROPERTIES OF 17 [illegible] STAINLESS STEEL .020 IN. GAUGE, HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1900°F FOR .5 HRS., FURNACE COOLED TO THE SHELVING TEMPERATURE, HELD AT SHELVING TEMPERATURE², COOLED FROM THE SHELVING TEMPERATURE TO 1100°F IN MINUTES³; THEN COOLED TO ROOM TEMPERATURE; FOLLOWED BY A -20°F COOL, AGED AT 1075°F FOR 90 MINUTES.

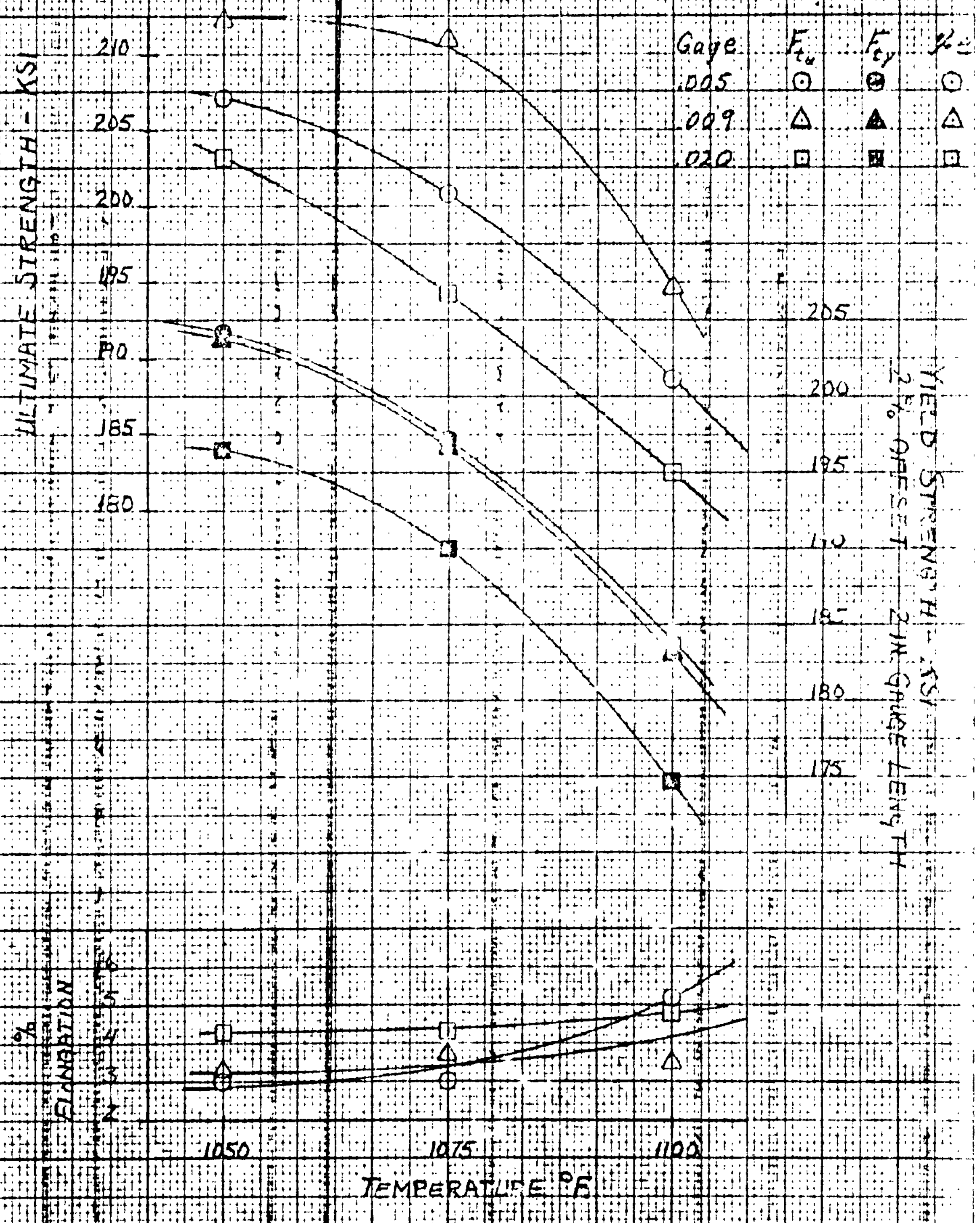


1. SHELVING TEMP		2. HELD AT SHELVING TEMP	3. TIME BETWEEN SHELVING TEMP & 1100°F
☐	1700°F IN 11.8 MIN	59.8 MIN.	53.6 MIN.
☐	1600°F IN 45.2 "	62.5 "	56.3 "
☐	1500°F IN 42.8 "	61.3 "	60.0 "
☐	1400°F IN 69.6 "	64.3 "	56.6 "
☒	1600°F IN 42.0 "	60.6 "	210.2 "
☒	1500°F IN 66.0 "	61.5 "	219.8 "
☒	1400°F IN 69.0 "	62.6 "	219.6 "

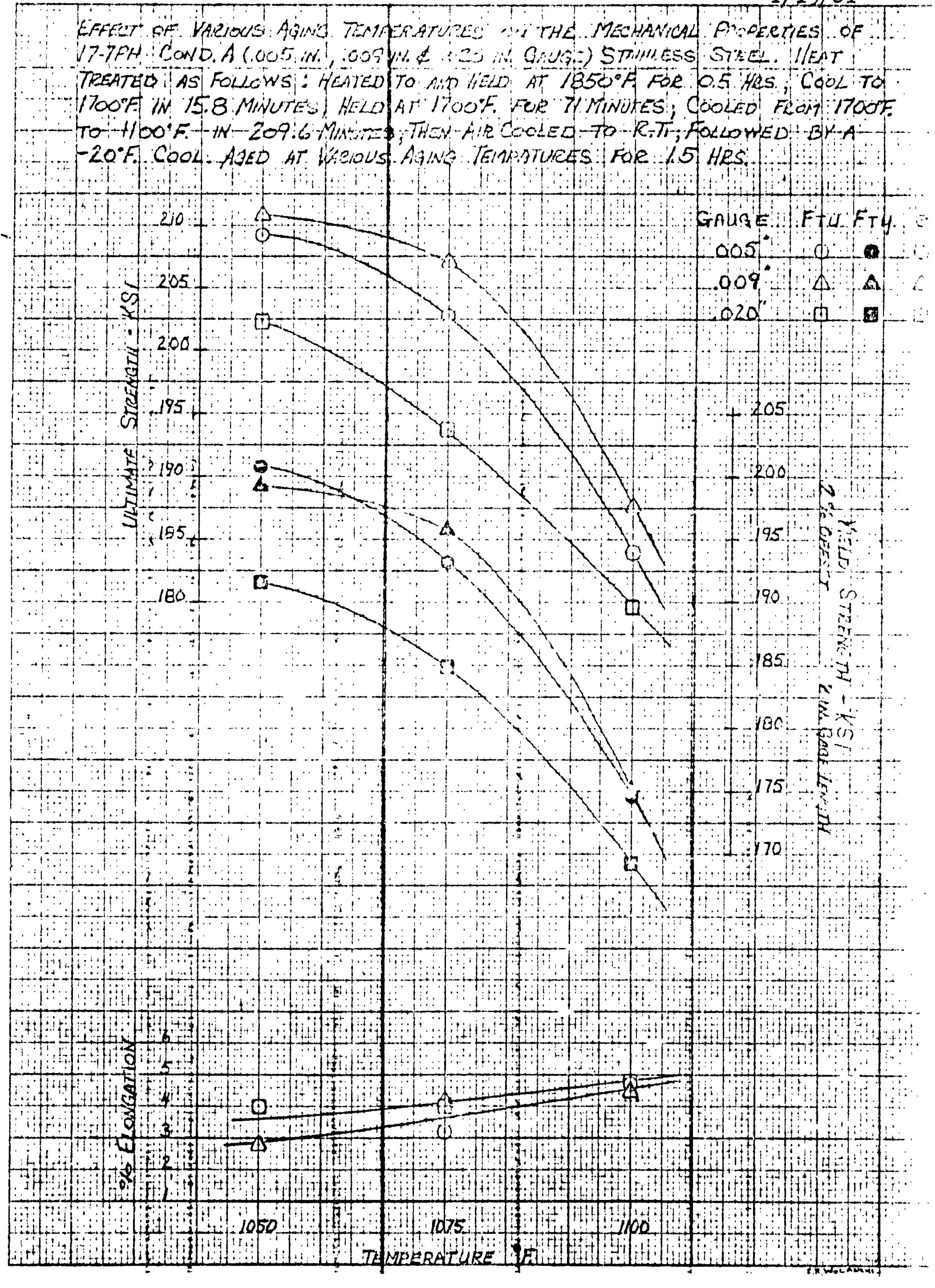
Effect of Various Aging Temperatures on the Mechanical Properties of 17-7PH Cond. A (.005 in., .009 in. & .020 in. Gauge) Stainless Steel. Heat Treated as Follows: Heated to and Held at 1900°F for 0.5 Hrs.; Cool to 1700°F in 21 Minutes; Held at 1700°F for 69.5 Minutes; Cooled from 1700°F to 1100°F in 199.2 Minutes; Then Air Cooled to R.T.; Followed by a -20°F Cool. Aged at Various Aging Temp. for 1.5 Hrs.



EFFECT OF VARIOUS AGING TEMPERATURES ON THE MECHANICAL PROPERTIES OF 17-7PH COND. A (.005 IN., .009 IN. & .020 IN. GAUGE) STAINLESS STEEL HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1850°F FOR 0.5 HRS; FURNACE COOL FROM 1850°F TO 1400°F IN 80 MINUTES. HELD AT 1400°F FOR ~~93.8 MINUTES, AIR COOL FROM 1400°F TO 175°F IN 19 MINUTES.~~ FOLLOWED BY A 0°F COOL. AGED AT VARIOUS AGING TEMPERATURES FOR 1.5 HRS.

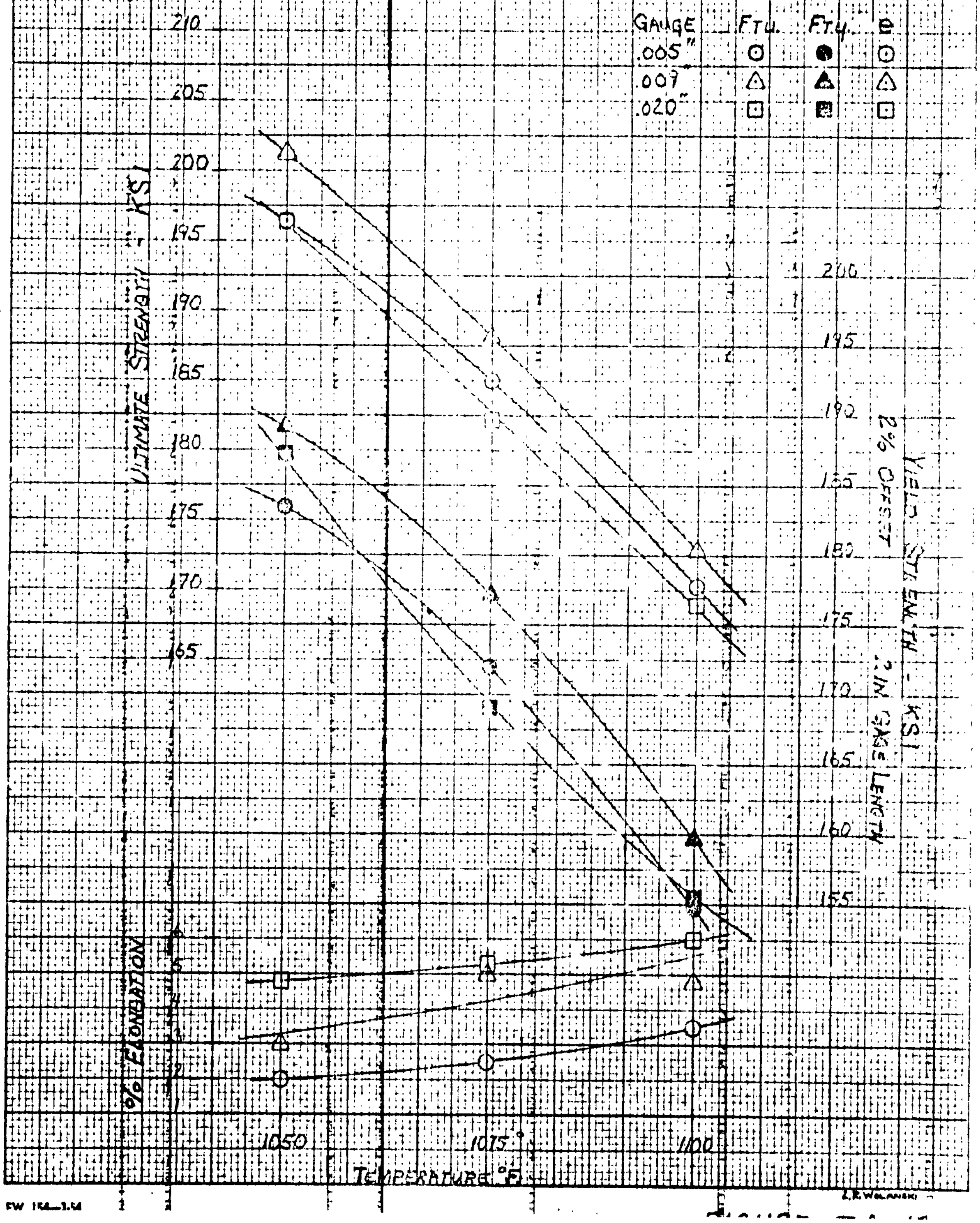


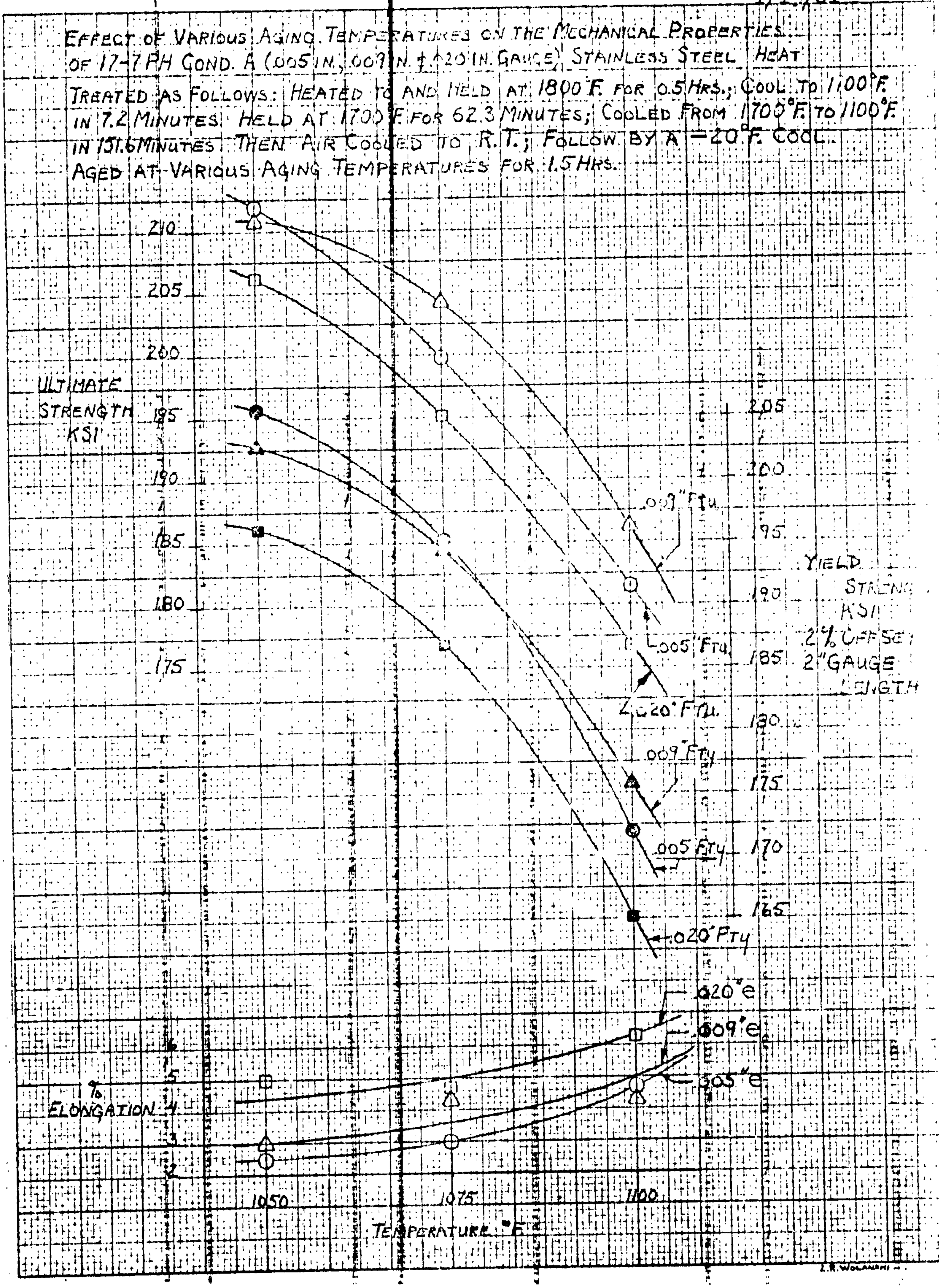
Z.R WOLANSKI



EFFECT OF VARIOUS AGING TEMPERATURES ON THE MECHANICAL PROPERTIES OF 17-7PH COND. A (.005 IN., .009 IN. & .020 IN. GAUGE) STAINLESS STEEL. HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1850°F FOR 0.5 HRS., COOL TO 1700°F IN 15.8 MINUTES, HELD AT 1700°F FOR 71 MINUTES; COOLED FROM 1700°F TO 1100°F IN 209.6 MINUTES; THEN AIR COOLED TO R.T.; FOLLOWED BY A -20°F COOL. AGED AT VARIOUS AGING TEMPRATURES FOR 1.5 HRS.

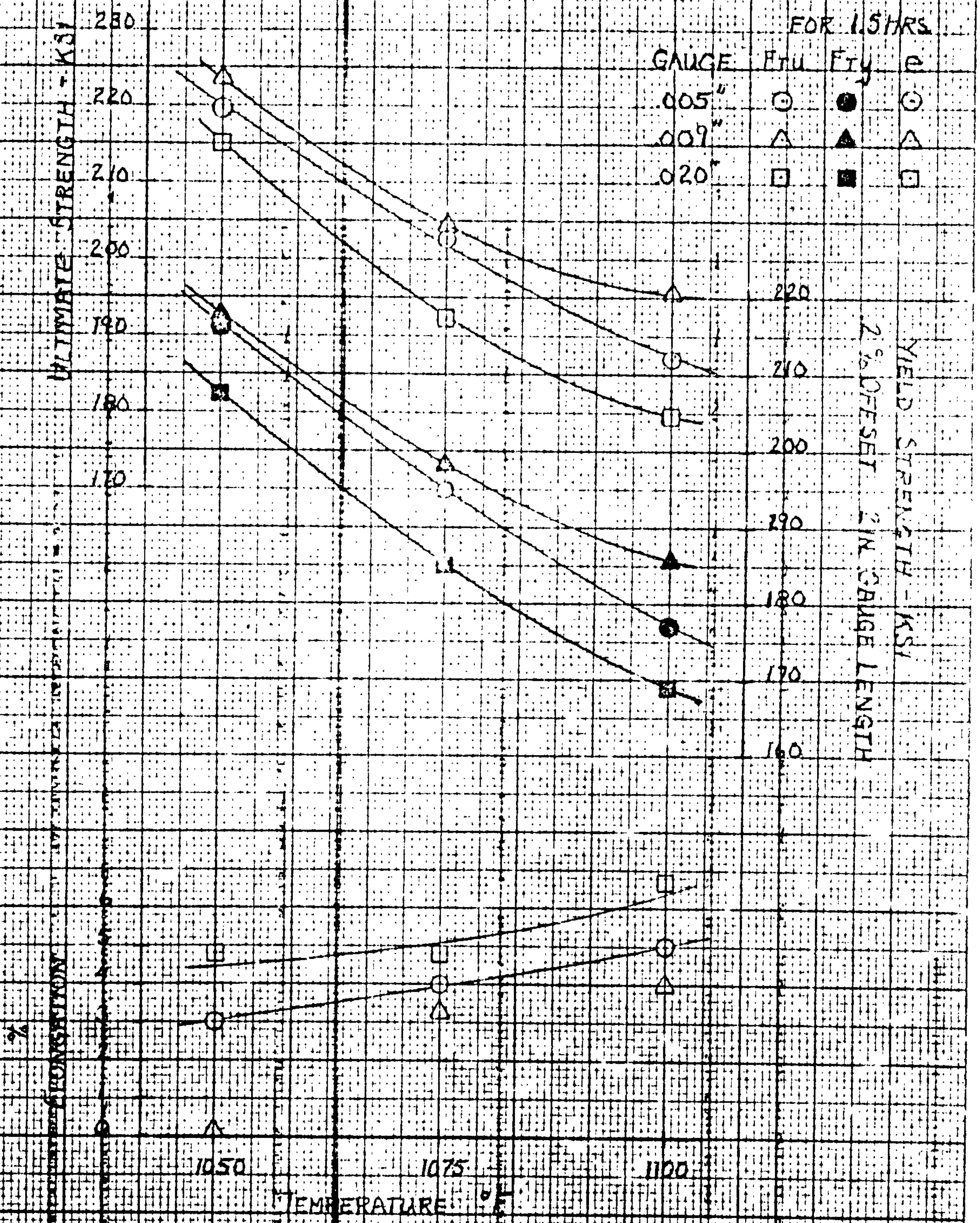
EFFECT OF VARIOUS AGING TEMPERATURES ON THE MECHANICAL PROPERTIES OF 17-7PH COND. A (.005 IN. .009 IN. & .020 IN. GAUGE) STAINLESS STEEL, HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1850°F FOR 0.5 HRS.; COOL TO 1700°F IN 16.5 MINUTES, HELD AT 1700°F FOR 60.5 MINUTES; COOLED FROM 1700°F TO 1100°F IN 210.2 MINUTES; THEN AIR COOLED TO R.T.; FOLLOWED BY A 0°F COOL; AGED AT VARIOUS AGING TEMP. FOR 1.5 HRS.

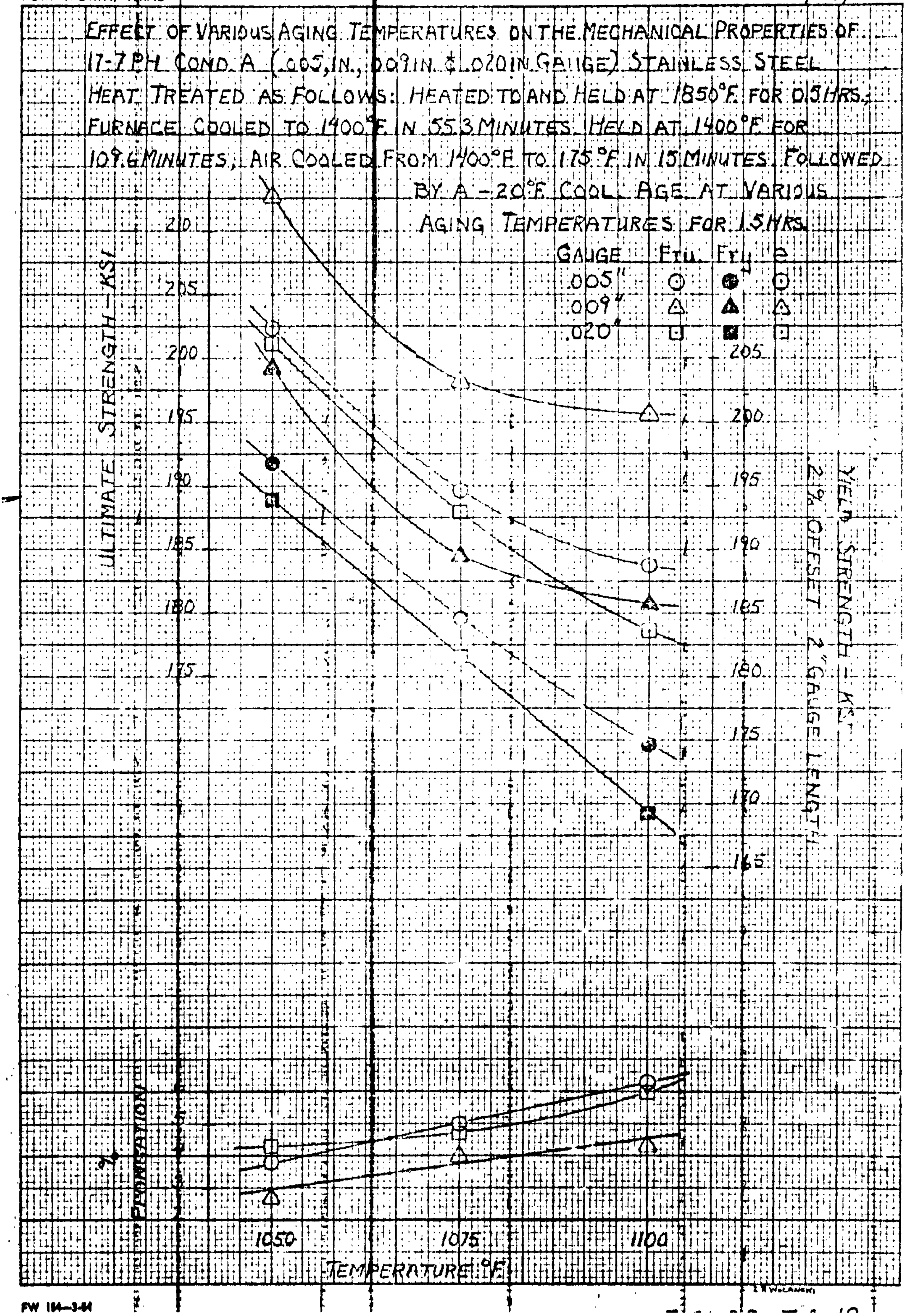




EFFECT OF VARIOUS AGING TEMPERATURES ON THE MECHANICAL PROPERTIES OF 17-7 PH COND. A (.005 IN., .009 IN. & .020 IN. GAUGE) STAINLESS STEEL HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1800°F. FOR 0.5 HRS.; COOL TO 1100°F. IN 7.2 MINUTES. HELD AT 1700°F. FOR 62.3 MINUTES; COOLED FROM 1700°F. TO 1100°F. IN 151.6 MINUTES. THEN AIR COOLED TO R.T.; FOLLOW BY A −20°F. COOL. AGED AT VARIOUS AGING TEMPERATURES FOR 1.5 HRS.

EFFECT OF VARIOUS AGING TEMPERATURES ON THE MECHANICAL PROPERTIES OF 17-7PH COND A (.005 IN. .009 IN. & .020 IN. GAUGE) STAINLESS STEEL HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1850°F FOR 0.5 HRS, FURNACE COOLED TO 1300°F IN 12 MINUTES HELD AT 1300°F FOR 96.8 MINUTES AIR COOLED FROM 1300°F TO 175°F IN 17.2 MINUTES FOLLOWED BY A -20°F COOL. AGED AT VARIOUS AGING TEMPERATURES FOR 1.5 HRS.





EFFECT OF VARIOUS AGING TEMPERATURES ON THE MECHANICAL PROPERTIES OF 17-7PH COND. A (.005 IN., .009 IN. & .020 IN. GAUGE) STAINLESS STEEL HEAT TREATED AS FOLLOWS: HEATED TO AND HELD AT 1850°F FOR 0.5 HRS.; FURNACE COOLED TO 1400°F IN 55.3 MINUTES. HELD AT 1400°F FOR 109.6 MINUTES; AIR COOLED FROM 1400°F TO 175°F IN 15 MINUTES FOLLOWED BY A -20°F COOL. AGE AT VARIOUS AGING TEMPERATURES FOR 1.5 HRS.

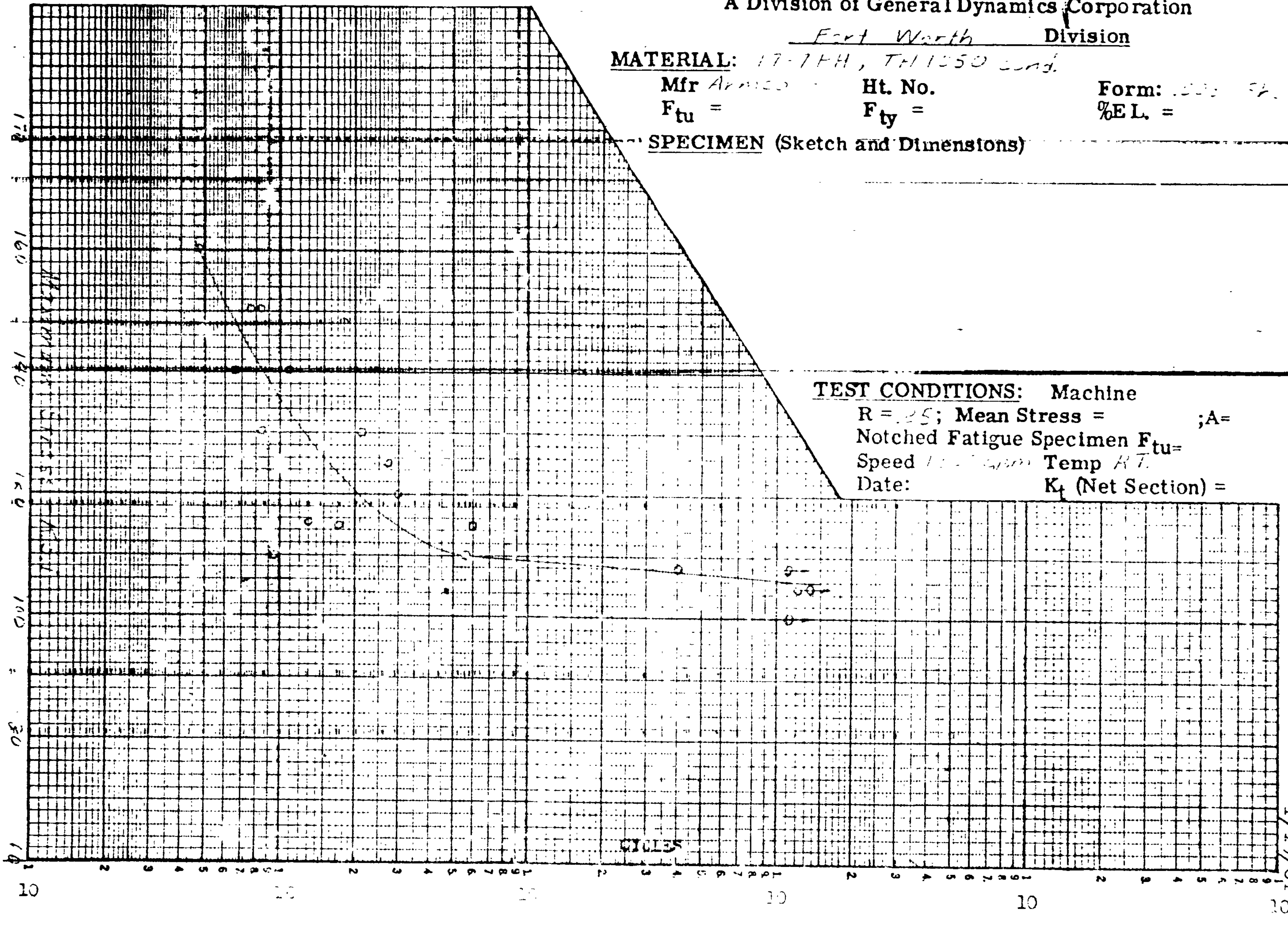
GAUGE	Ftu	Fty	e
.005"	○	●	○
.009"	△	▲	△
.020"	□	■	□

CONVAIR
A Division of General Dynamics Corporation
Fort Worth **Division**

MATERIAL: 17-7PH, TH1050 Cond.
Mfr Armco **Ht. No.** **Form:** [illegible]
F_{tu} = **F_{ty} =** **%E L. =**

SPECIMEN (Sketch and Dimensions)

TEST CONDITIONS: Machine
R = .25; **Mean Stress =** ;A=
Notched Fatigue Specimen **F_{tu}=**
Speed [illegible] **Temp** R.T.
Date: **K_t (Net Section) =**



CONVAIR—FORT WORTH

TABLE IA-I

TABULATION SHEET 0.005, 0.008, & 0.010 GAGE 17-7PH STEEL TENSILES

SAMP NO	HEAT TREAT	GRAIN DIR	0.005 GAGE F_{ty}-ksi	0.005 GAGE F_{tu}-ksi	MAT'L %e	0.008 GAGE F_{ty}-ksi	0.008 GAGE F_{tu}-ksi	MAT'L %e	0.020 GAGE F_{ty}-ksi	0.020 GAGE F_{tu}-ksi	MAT'L %e
141	1A	Long.	187.7	195.2	4.0	205.9	210.9	4.0	193.3	200.9	5.0
142			190.7	192.8	4.0	203.4	209.6	4.0	196.4	202.1	5.0
143			182.3	194.3	3.0	203.4	209.7	4.0	199.3	221.1	5.0
156			177.4	185.2	5.5	189.6	206.8	4.0	188.0	192.5	5.0
157			179.3	196.9	6.0	197.4	217.5	5.0	185.1	194.2	6.0
158			177.0	[illegible]	5.0	190.5	202.9	4.5	188.1	197.1	5.0
AVERAGE			184.1	[illegible]	[illegible]	193.9	201.1	4.2	191.0	[illegible]	5.[illegible]
135	1B		184.1	[illegible]	2.0	194.0	203.0	4.0	190.4	[illegible]	[illegible]
136			183.7	[illegible]	6.0	197.7	[illegible]	[illegible]	193.3	[illegible]	5.5
137			[illegible]	[illegible]	4.0	[illegible]	[illegible]	5.0	192.3	[illegible]	[illegible]
159			[illegible]	[illegible]	5.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
160			[illegible]	[illegible]	6.5	[illegible]	[illegible]	4.5	188.0	[illegible]	[illegible]
161			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AVERAGE			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
138	1C		183.7	[illegible]	5.0	[illegible]	[illegible]	3.5	190.4	[illegible]	[illegible]
139			188.1	[illegible]	[illegible]	[illegible]	[illegible]	3.5	187.5	[illegible]	[illegible]
140			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.5	[illegible]	[illegible]	[illegible]
162			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.0	176.9	[illegible]	[illegible]
163			179.8	[illegible]	5.5	[illegible]	[illegible]	4.5	183.5	[illegible]	7.0
164			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.0	[illegible]	[illegible]	[illegible]
AVERAGE			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.2	[illegible]	[illegible]	[illegible]
132	1D		—	—	—	[illegible]	[illegible]	4.0	[illegible]	[illegible]	[illegible]
133			[illegible]	[illegible]	[illegible]	202.9	207.7	3.5	175.3	[illegible]	6.0
134			[illegible]	[illegible]	[illegible]	201.3	210.1	4.0	194.7	[illegible]	5.0
165			[illegible]	[illegible]	7.5	[illegible]	[illegible]	4.0	175.5	[illegible]	7.0
166			[illegible]	[illegible]	4.0	186.3	196.5	5.0	183.2	[illegible]	6.0
167			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.0	172.2	[illegible]	6.5
AVERAGE			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.1

H.T.-1
Heat to [illegible]F & hold [illegible] min.
Cool to [illegible]F & hold for — A 10 min.; B 30 "; C 60 "
Cool to -100F for 2 hrs.

CONVAIR—FORT WORTH 0.005, 0.008

TABULATION SHEET 0.020, 0.040, 0.063 & 0.085 -GAGE, 17-7PH STEEL TENSILES

TABLE IA-II

SAMP. NO	HEAT TREAT	GRAIN DIR	0.005 GAGE MAT'L			0.008 GAGE MAT'L			0.020 GAGE MAT'L		
			F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e
129	2A	Long.	175.0	188.5	9.0	193.5	204.6	5.5	186.5	196.6	6.5
130	↓	↓	177.7	189.5	8.0	193.8	205.0	5.5	185.7	196.3	7.0
131			178.0	187.7	7.0	195.8	207.2	5.0	185.2	196.7	7.5
AVERAGE			176.9	189.3	8.0	194.4	205.6	5.3	185.8	196.5	7.0
150	2B		176.2	187.5	6.5	197.7	207.0	6.0	190.0	199.[illegible]	6.5
151	↓	↓	178.5	188.3	8.0	192.5	207.0	6.0	191.6	[illegible]	7.5
152			178.5	190.2	7.0	191.0	207.0	5.0	191.1	[illegible]	7.0
AVERAGE			177.7	188.[illegible]	7.2	192.4	207.0	5.7	190.9	199.7	7.0

SAMP. NO	HEAT TREAT	GRAIN DIR	0.040 GAGE MAT'L			0.063 GAGE MAT'L			0.085 GAGE MAT'L		
			F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e
129	2A	Long.	173.0	187.2	9.5	172.9	193.3	11.0	122.3	172.7	15.0
130	↓	↓	169.0	185.2	[illegible]	[illegible]	[illegible]	10.5	121.0	[illegible]	15.0
131			170.1	181.3	[illegible]	[illegible]	[illegible]	[illegible]	102.3	[illegible]	[illegible]
AVERAGE			170.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	117.2	[illegible]	15.7
150	2B		175.5	186.1	9.0	177.3	195.1	11.0	142.2	[illegible]	15.0
151	↓	↓	175.2	185.3	[illegible]	176.7	193.3	10.0	145.7	178.2	15.0
152			174.3	[illegible]	[illegible]	[illegible]	192.5	9.0	144.1	172.4	[illegible]
AVERAGE			175.0	[illegible]	[illegible]	[illegible]	[illegible]	10.0	144.0	[illegible]	15.0

HT-2 Heat to 1750F & hold 20 min.
Cool to rm. temp. out of furnace
Cool to -100F and hold for
A. 10 min.
B. 60 min.
Age at 1050F for 90 min.

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TABLE IA-III

TABULATION SHEET 0.005, 0.008 & 0.020 GAGE 17-7PH STEEL TENSILES

SAMP. NO.	HEAT TREAT	GRAIN DIR.	0.005 GAGE MAT'L F_{ty}-ksi	0.005 GAGE MAT'L F_{tu}-ksi	0.005 GAGE MAT'L %e	0.008 GAGE MAT'L F_{ty}-ksi	0.008 GAGE MAT'L F_{tu}-ksi	0.008 GAGE MAT'L %e	0.020 GAGE MAT'L F_{ty}-ksi	0.020 GAGE MAT'L F_{tu}-ksi	0.020 GAGE MAT'L %e
49	3A	Long.	190.0	197.3	6.5	198.5	204.3	4.0	195.7	203.3	8.0
50			185.9	1939	6.0	201.3	205.6	4.0	195.2	2043	6.0
51			185.5	1930	6.0	204.3	207.6	4.0	196.5	2036	7.0
120			188.9	196.3	8.0	205.7	213.2	4.0	196.3	202.8	6.0
121			187.6	195.8	8.0	207.1	212.3	4.5	196.6	202.7	6.0
122			187.6	1955	8.0	207.2	212.7	5.0	1991	201.0	6.5
AVERAGE			187.6	1153	7.1	2035	[illegible]	4.[illegible]	1957	203.0	6.6
52	3B		1880	194.8	5.5	206.5	205.5	4.[illegible]	197.0	203.6	7.0
53			187.2	193.0	5.5	199.6	[illegible]	3.0	196.7	202.3	7.0
54			1880	197.3	5.5	197.4	[illegible]	3.0	197.1	2047	7.0
AVERAGE			187.7	[illegible]	5.5	[illegible]	[illegible]	3.[illegible]	197.3	[illegible]	7.0
55	3C		191.1	196.7	4.5	201.8	206.3	3.5	200.2	205.9	6.0
56			192.2	197.3	4.0	202.7	207.2	4.0	199.1	204.2	6.0
57			1914	[illegible]	3.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AVERAGE			191.6	1971	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
58	3D		[illegible]	[illegible]	4.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.0
59			191.9	197.4	[illegible]	201.1	207.3	3.5	2005	206.3	6.0
60			[illegible]	197.2	4.5	197.3	203.7	4.5	200.7	206.5	6.0
123			197.1	202.0	5.0	210.3	2158	4.0	2002	[illegible]	[illegible]
124			1959	201.3	4.5	211.9	216.1	4.5	199.7	[illegible]	5.0
125			1971	[illegible]	5.5	[illegible]	[illegible]	3.0	[illegible]	[illegible]	5.5
AVERAGE			1943	[illegible]	[illegible]	[illegible]	[illegible]	3.7	[illegible]	[illegible]	[illegible]
61	3E		191.4	197.5	4.0	197.7	203.6	5.0	198.7	204.2	7.0
62			191.2	197.4	3.0	201.0	206.7	4.5	200.9	205.7	6.0
63			193.3	[illegible]	3.5	192.0	2041	4.5	2000	2059	6.0
AVERAGE			193.6	194.2	3.5	199.9	204.8	4.7	199.9	205.3	6.3

H.T.-3
Heat to 1400F & hold 90 min.
Cool out of furnace to
Age at 1050F for 90 min.

A +54F
B +30F
C 0F
D -20F
E -50F

CONVAIR—FORT WORTH
TABULATION SHEET

TABLE IA-IV
0.005, 0.008, 0.020, 0.040, 0.063 & 0.085 GAGE, 17-7PH STEEL TENSILES

SAMP NO	HEAT TREAT	GRAIN DIR.	0.040 GAGE MAT'L			0.063 GAGE MAT'L			0.085 GAGE MAT'L		
			F_{ty}	F_{tu}	%e	F_{ty}	F_{tu}	%e	F_{ty}	F_{tu}	%e
120	3A	Long.	179.1	191.2	8.5	186.3	197.4	9.0	145.9	180.8	12.0
121	↓	↓	177.6	189.4	7.0	189.6	200.6	8.0	155.0	182.2	13.0
122			179.1	190.2	7.0	189.8	[illegible]	7.0	149.3	180.3	13.0
AVERAGE			178.6	190.3	7.5	188.6	200.7	8.3	150.1	181.1	12.7
123	3D		190.1	196.7	6.0	196.8	205.5	7.0	176.6	194.9	11.0
124	↓	↓	191.0	197.8	6.5	196.1	205.7	6.0	173.3	191.2	10.5
125			188.6	196.3	6.0	197.7	[illegible]	6.0	173.3	[illegible]	[illegible]
AVERAGE			189.9	196.9	6.2	[illegible]	[illegible]	6.3	174.4	[illegible]	10.7
SAMP NO	HEAT TREAT	GRAIN DIR.	0.005 GAGE MAT'L			0.008 GAGE MAT'L			0.020 GAGE MAT'L		
			F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e
144	4	Long.	177.7	[illegible]	6.0	182.7	197.6	6.0	167.6	[illegible]	6.5
145	↓	↓	176.4	185.9	5.5	182.7	197.6	5.0	166.7	[illegible]	7.0
146			176.4	[illegible]	5.0	184.1	[illegible]	5.5	177.1	[illegible]	[illegible]
AVERAGE			176.8	[illegible]	5.5	183.2	[illegible]	5.5	[illegible]	[illegible]	[illegible]

H.T.-3 Heat to 1400F & hold 90 min.
Cool out of furnace to:
A. +54F
D. -20F
Age at 1050F for 90 min.

HT-4. Load into fce. @ 1100F
Heat fce. to 1275F
Fce. cool from 1275F to 1100F
in 3 hours
Cool to rm. temp in air
Cool to -10F for 30 min.
Age at 1060F for 90 min.

CONVAIR—FORT WORTH

TABULATION SHEET 0.005, 0.010 & 0.020 GAGE, 17-7PH STEEL TENSILES

TABLE IA-V

SAMP NO	HEAT TREAT	GRAIN DIR	0.005 GAGE MAT'L			0.010 GAGE MAT'L			0.020 GAGE MAT'L		
			F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e
16	3A	Long.	202.0	208.0	4.0	192.6	200.6	6.0	195.8	205.3	6.0
17			—	—	—	189.2	197.2	8.0	200.1	207.5	5.5
18			202.0	209.3	5.0	185.6	197.6	5.0	194.6	203.6	5.0
19			200.8	206.5	4.0	191.5	198.4	6.0	197.4	205.9	5.0
20			205.6	214.7	4.0	189.7	195.7	5.0	195.0	204.5	5.0
AVERAGE			202.6	209.6	4.3	179.7	197.7	6.0	196.6	205.[illegible]	5.3
6	3A'		218.7	225.4	1.5	206.9	218.3	—	211.1	224.6	3.5
7			218.7	223.5	1.0	209.9	218.8	4.0	212.3	227.2	4.5
8			219.9	225.1	1.0	209.2	218.1	4.0	211.7	225.1	4.5
9			219.3	225.0	1.0	205.8	218.7	6.0	210.8	224.2	3.0
10			219.9	227.1	3.0	205.4	211.3	—	211.7	[illegible]	[illegible]
AVERAGE			219.4	225.2	1.5	202.4	[illegible]	4.7	211.5	[illegible]	[illegible]

H.T. -3A Heat to 1400F & hold 90 min.
Cool out of furnace to +54F
Age at 1050F for 90 min.

HT-3A' Heat to 1400F & hold 2 min.
Cool out of furnace to +54F
Age at 950F for 10 min.

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TABLE IA-VI

~~TABULATION~~ SHEET 17-7PH Steel - Tensiles - Processed With AgMn Test Panel.

SAMP. NO.	H.T.	GAGE	GUN & POSITION	YIELD KSI	ULT. KSI	%e
IA-1	I	0.010	1, end A	158.9	179.0	10.0
2	↓	↓	↓	162.0	181.0	10.0
3	↓	↓	↓	158.6	178.9	10.0
AVERAGE				159.8	179.6	10.0
IB-1	↓	↓	1, end B	178.6	195.1	8.0
2	↓	↓	↓	180.0	191.0	7.0
3	↓	↓	↓	179.2	190.3	6.0
AVERAGE				179.3	192.1	7.0
IIA-1	II	↓	2, end A	177.1	191.3	12.0
2	↓	↓	↓	171.3	183.4	9.0
3	↓	↓	↓	[illegible]	193.3	[illegible]
AVERAGE				177.5	[illegible]	[illegible]
IIB-1	↓	↓	2, end B	[illegible]	177.2	[illegible]
2	↓	↓	↓	[illegible]	[illegible]	[illegible]
3	↓	↓	↓	[illegible]	177.9	[illegible]
AVERAGE				[illegible]	[illegible]	[illegible]

H.T-I
Heated to 1800F in 85 min. - No holding time.
Cooled from 1800F to 1400F in 110 min - Held 90 min
Cooled from 1400F to 400F in 105 min.
Transformed at -23F
Aged at 1050F for 90 min.

HT-II
Heated to 1850F in 47 min. - No holding time
Cooled from 1850F to 1400F in 43 min. - Held 90 min.
Cooled from 1400F to 400F in 100 min.
Transformed at -25F
Aged at 1050F for 90 min.

CONVAIR — FORT WORTH

~~TABULATION SHEET~~

TABLE IA-VII

Dimensional Change in 17-7PH Steel During H.T.

Samp. No.	Nom. Gage	Heat Treat	Growth after -20 In/In	Contraction, Cold T-TH 1050 age	Contraction, Cold T-TH 1075 age	Contraction, Cold T-TH 1100 age	Overall Growth In/In
1	0.005	A	.0060	.0003			.0057
1	0.008		.0054	.0002			.0052
1	0.020		.0055	.0004			.0051
2	0.005		.0065		.0006		.0059
2	0.008		.0054		.0008		.0046
2	0.020		.0054		.0006		.0047
3	0.005		.0052			.0007	.0045
3	0.008		.0056			.0011	.0045
3	0.020		.0040			.0010	.0030
1	0.005	B	.0056	.0006			.0055
1	0.008		[illegible]	.0006			[illegible]
1	0.020		.0052	.0007			[illegible]
2	0.005		.0062		.0012		[illegible]
2	0.008		.0054		.0007		[illegible]
2	0.020		.0052		.0006		[illegible]
3	0.005		.0055			.0007	[illegible]
3	0.008		[illegible]			.0005	[illegible]
3	0.020		.0052			.0007	[illegible]

H.T.-A
Heat to 1300F and hold 30 min.
Cool to 1700F and hold 60 min.
Cool to 1100F in 150 min.
Air cooled to RT followed by -20F transformation.
Aged at temperature at head of column for 90 min.

H.T.-B
Heat to 1900F and hold 30 minutes
~~Coolnto~~ 1700F and hold 70 min.
Cool to 1100F in 200 min.
Air cool to RT followed by -20F transformation
Aged at temperature at head of column for 90 min.

CONVAIR — FORT WORTH

~~TABULATION SHEET~~

TABLE I A-VIII

Dimensional Change in 17-7PH Steel During H.T.

Samp. No.	Nom. Gage	Heat Treat	Growth after Transformation In/In.	Contraction, Cond I-TH 1050 age	Contraction, Cond I-TH 1075 age	Contraction, Cond I-TH 1100 age	Overall Growth In/In.
1	0.005	C	.0058	.0004			.0054
1	0.008		.0056	.0007			.0049
1	0.020		.0055	.0007			.0048
2	0.005		.0060		.0007		.0053
2	0.008		.0056		.0007		.0049
2	0.020		.0057		.0007		.0050
3	0.005		.0060			.0010	.0050
3	0.008		.0056			.0009	.0047
3	0.020		.0055			.0009	.0046
1	0.005	D	.0064	.0006			[illegible]
1	0.008		.0067	.0007			[illegible]
1	0.020		[illegible]	.0007			[illegible]
2	0.005		.0062		.0010		[illegible]
2	0.008		.0062		.0008		[illegible]
2	0.020		.0057		.0008		[illegible]
3	0.005		.0063			.0011	[illegible]
3	0.008		.0064			.0012	[illegible]
3	0.020		.0056			.0012	[illegible]

H.T.-C
Heat to 1750F and hold 30 min.
Cool to 1700F and hold 70 min.
Cool to 1100F in 200 min.
Air cool to R.T. then transformed at -20F
Age at temperature at top of column for 90 min.

H.T.-D
Heat to 1750 and hold 30 min.
Cool to 1700F and hold 60 min.
Cool to 1100F in 200 min.
Air cool to R.T. then transformed at 0F
Age at temperature at top of column for 90 min.

CONVAIR — FORT WORTH

TABLE IA-IX

~~TABULATION SHEET~~ Dimensional Change in 17-7PH Steel During H.T.

Samp. No.		Nom. Gage	Heat Treat	Growth after transformation In/in	Contraction, Cond T-TH 1050 age	1075 age	1100 age	Growth Overall In/in
1		0.005	E	.0049	.0005			.0044
1		0.008		.0049	.0005			.0044
1		0.020		.0050	.0006			.0044
2		0.005		.0050		.0002		.0048
2		0.008		.0049		.0006		.0043
2		0.020		.0048		.0004		.0044
3		0.005		.0050			.0011	.0039
3		0.008		.0049			.0009	.0040
3		0.020		.0050			.0005	.0045
1		0.005	F	.0064	.0010			.0054
1		0.008		.0052	.0010			.0042
1		0.020		.0057	.0010			.0047
2		0.005		.0052		.0010		[illegible]
2		0.008		.0050		.0009		.0041
2		0.020		.0052		.0010		[illegible]
3		0.005		.0052			.0010	[illegible]
3		0.008		[illegible]			.0010	[illegible]
3		0.020		.0051			.0011	[illegible]

H.T.-E
Heat to 1950F and hold 30 min.
Cool to 1400F in 50 min. then hold 90 min.
Air cool to R.T. then transformed at 0F
Age at temperature at top of column for 90 min.

H.T.-F
Heat to 1550F and hold 30 min.
Cool to 1400F in 55 min. then hold 110 min.
Air cool to R.T. then transformed at -20F
Age at temperature at top of column for 90 min.

CONVAIR—FORT WORTH

TABLE IA-X

~~TABULATION SHEET~~ Dimensional Change ~~in~~ 17-7PH Steel During H.T.

Samp. No.	Nom. Gage	Heat Treat	Growth after -20F In/In	Contraction, Cond. T-TH 1050 age	Contraction, Cond. T-TH 1075 age	Contraction, Cond. T-TH 1100 age	Overall Growth In/In.
1	0.005	G	.0052	.0006			.0046
1	0.008		.0052	.0006			.0046
1	0.020		.0055	.0007			.0048
2	0.005		.0058		.0012		.0046
2	0.008		.0052		.0008		.0044
2	0.020		.0052		.0008		.0044
3	0.005		.0054			.0013	.0041
3	0.008		.0050			.0010	.0040
3	0.020		.0053			.0011	.0042

HT-G Heat to [illegible]F and hold 30 min.
Cool to 1300F in 120 min then hold 100 min.
Air cool to RT then transform at -20F
Age at temperature listed in column above for 90 min.

HEAT TREATMENT

ITEM B - COMPARISON OF BRAZING CYCLES FOR HEAT TREATMENT OF 17-7PH STEEL SHEET BRAZED WITH 85:15 SILVER-MANGANESE ALLOY

An investigation was carried out beginning late in 1954 and extending into early 1956 to determine a satisfactory brazing cycle for 17-7PH steel sandwich panels using 85:15 silver-manganese alloy for brazing. The primary object was to develop data on which the optimum brazing cycle combining heat treatment could be based.

Standard tensile-test specimens were prepared from 17-7PH steel sheet, condition A, in the following nominal thicknesses: .005", .008", .020", .040", .063", and .080". The testing was mostly limited to the first three.

Several basic cycles of heat treatment were investigated. Certain variations as concerns cooling and aging were studied. The test data obtained, together with the heat treatments applied, are given in Tables IB-I to IB-VII.

Figure IB-I is a chart in which the tensile properties of .005", .008", and .020" sheet, heat treated according to different cycles, are compared. All the specimens were aged for 90 minutes at 1050 F. The test values were all above the minima specified for 17-7PH steel sheet of the three thicknesses. These minima were 150 ksi yield strength and 180 ksi ultimate strength with elongation of 3.5% for .005" and .008" thick sheet and 5.5% for .020" sheet.

With only one exception, Figure IB-I and the pertinent tables show that the .008" thick sheet had higher yield and ultimate strengths than the .005" and .020" materials for all heat treatments. The elongation of the .020" thick sheet was highest for these treatments. Also, the transformation temperature of -100 F conferred higher elongations for the three thicknesses than did the -20 F temperature.

Figure IB-2 shows the effect of aging temperature on the tensile properties of the three sheet materials. All were heat treated according to the cycle given in Table IB-I. The aging time was 90 minutes and the temperature was varied in the range 1050 to 1080 F. As may be seen, the yield and ultimate strengths decreased with increasing aging temperature. The slopes for the .005" and .008" materials are about the same, but the slope for the .020" sheet is considerably less steep. The elongation increased with increasing aging temperature for the .005" and .008" materials but decreased for the .020" sheet.

In Figure IB-3, the top graph shows the effect of time at the transformation temperature -100 F, for a given heat treatment, on the tensile strength of the three thicknesses of sheet. The middle graph shows the effect on the elongation. As is evident, the strength increases and the elongation decreases with increasing time at -100 F. The slopes for the strengths are practically parallel, but those for the elongations differ appreciably.

The bottom graph in Figure IB-3 shows the effect of the transformation temperature, for a given heat treatment, on the elongation of the three thicknesses of sheet. For both the .005" and .020" materials the trend of values was upward with increasing temperature. For the .008" sheet the trend was downward. The elongation values for the .008" and .020" sheet did not all lie close to the straight line indicating the trend.

The test data obtained in this investigation were analyzed to determine whether they afforded information on which the optimum brazing cycle could be based. For this purpose maximum yield and strength values together with elongations above the specified minima were selected from the results for each heat treatment as set forth in the tables. Likewise, the maximum elongations together with acceptable yield and strength values were similarly chosen. For both sets of maxima, the corresponding heat treatment was noted. The data of Table IB-VI were not included because the material was in the solution annealed, A, condition prior to transformation and aging. The data is included to show that annealed material cannot be hardened without the conditioning step. The values selected from Tables IB-I to IB-V and IB-VII were rated numerically, and the results are scored in Table IB-VIII.

Patterns of sorts are apparent in both the upper and lower sections of Table IB-VIII. First, the thickness of sheet is a factor affecting the properties conferred by a particular heat treatment. This is thought to be associated with the percentage of reduction in rolling to finished thickness after annealing.

Second, treatments entailing the 1400 F conditioning step are not necessary for developing the best or an acceptable combination of tensile properties. Third, the Armco TH 1050 treatment, or some cycle involving cooling from 1750 F or a higher temperature followed by transformation at -100 F and then aging at 1050 F, yields a good combination of properties. None of this is to suggest that the optimum brazing cycle for 17-7PH steel sandwich panels has been worked out as a result of the investigation summarized here.

Comp[illegible] Various
Heat [illegible] Cycles

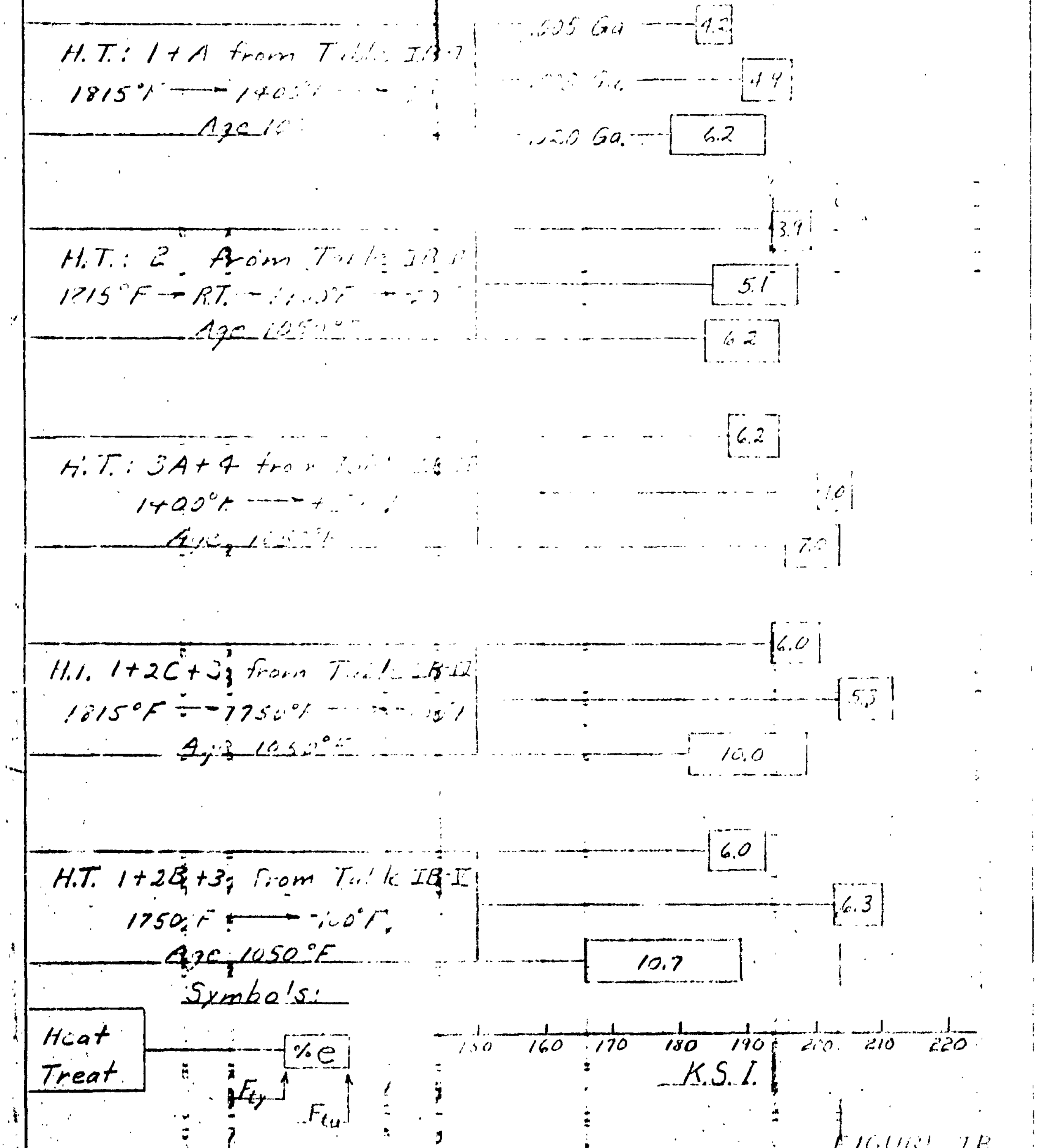

FIGURE IB

F_{tu}, F_{ty} & %e vs Age Temperature
From Heat Treat #1 Table II

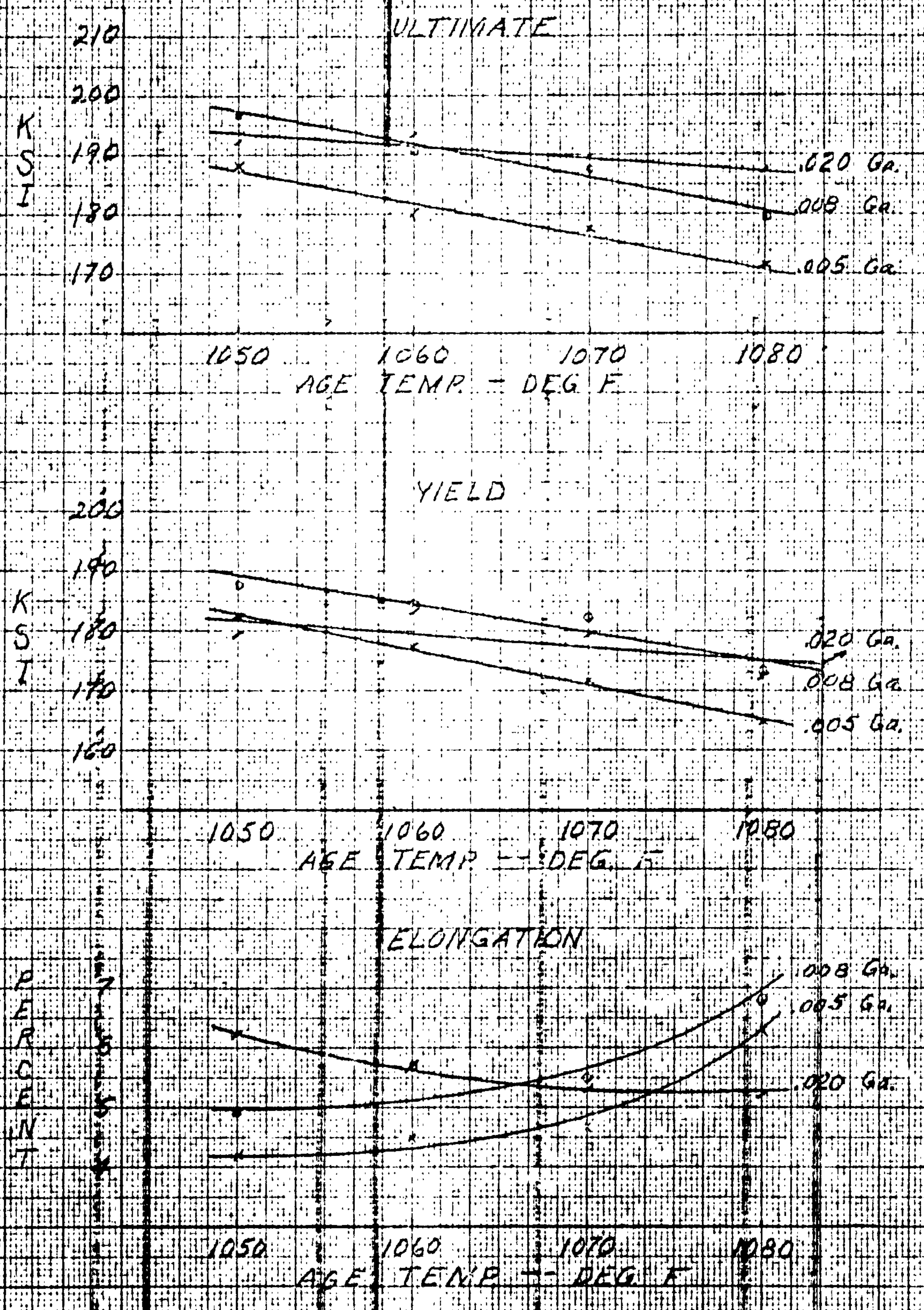

FIGURE - IB-2

Effect of Transformation Time & Temperature on 17-7PH

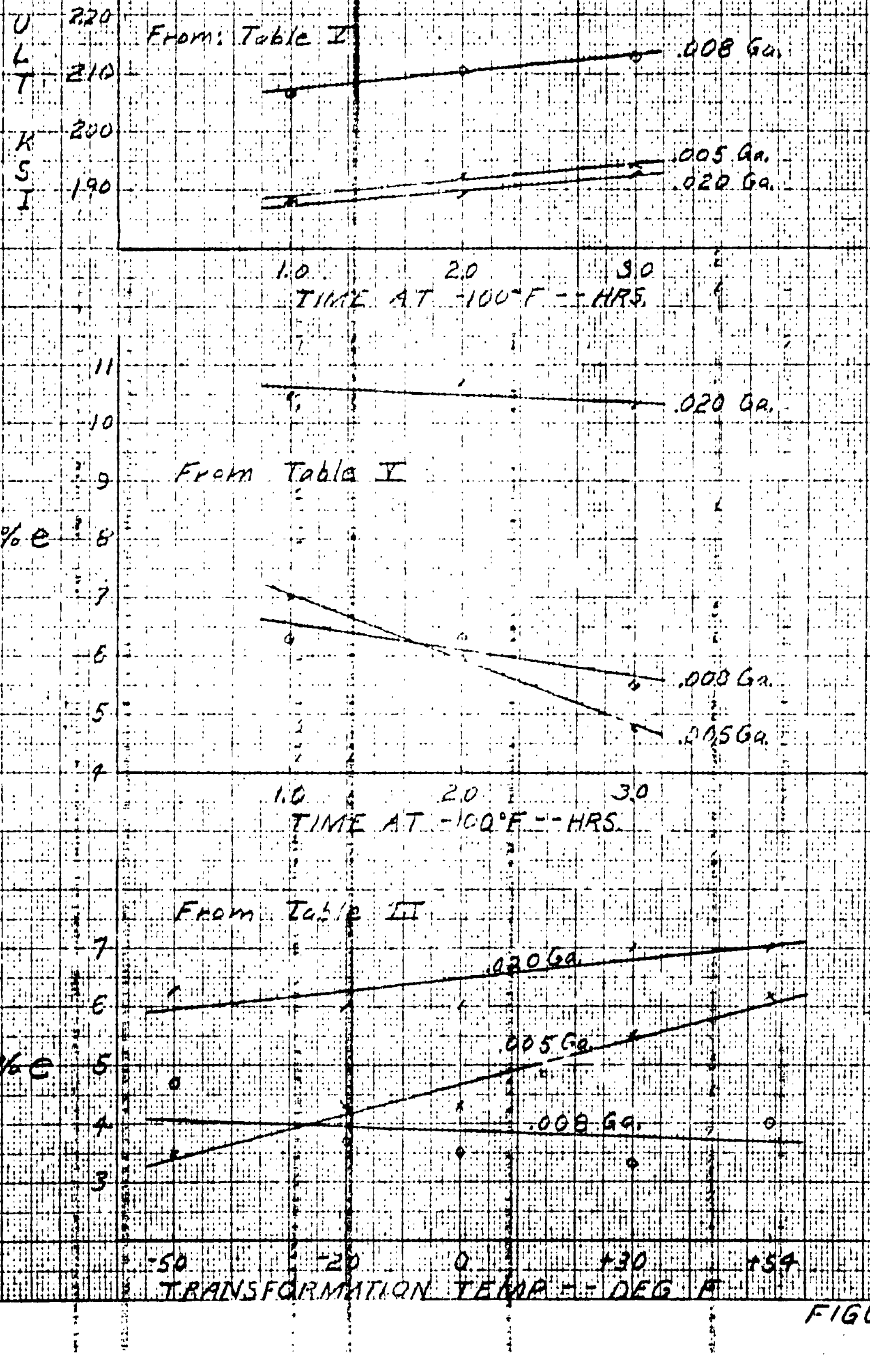

FIGURE: IB

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TABLE IB-I

TABULATION SHEET 17-7PH Stainless Steel-0.005, 0.008 & 0.020 Gage Tensiles

SPEC. NO.	GRAIN DIR	H.T.		0.005 GAGE Fty-ksi.	0.005 GAGE Ftu-ksi.	0.005 GAGE %e	0.008 GAGE Fty-ksi.	0.008 GAGE Ftu-ksi.	0.008 GAGE %e	0.020 GAGE Fty-ksi.	0.020 GAGE Ftu-ksi.	0.020 GAGE %e
46	Long.	1+A		182.3	188.1	4.5	187.3	195.7	5.0	176.0	191.0	6.0
47				180.3	186.4	4.0	185.2	195.7	—	174.5	187.9	5.0
48				185.5	192.3	4.5	181.2	192.4	4.5	173.6	[illegible]	2.0
16				180.7	186.3	—	191.0	196.4	5.0	182.7	193.[illegible]	5.0
17				183.7	185.2	4.0	187.2	196.5	5.0	181.5	[illegible]	5.5
18				183.6	189.7	4.0	190.9	196.6	5.0	171.9	[illegible]	[illegible]
AVG.				182.7	188.0	4.2	[illegible]	[illegible]	4.9	[illegible]	[illegible]	[illegible]
19		1+B		171.0	172.2	—	185.3	191.3	6.0	182.2	[illegible]	[illegible]
20				[illegible]	[illegible]	5.0	[illegible]	188.7	5.5	184.2	[illegible]	[illegible]
21				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.5	[illegible]	[illegible]	[illegible]
AVG.				171.7	[illegible]	[illegible]	184.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		1+C		172.2	[illegible]	[illegible]	[illegible]	[illegible]	5.5	[illegible]	[illegible]	[illegible]
[illegible]				171.3	177.6	[illegible]	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]
[illegible]				172.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AVG.				171.8	177.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25		1+D		165.1	171.6	[illegible]	172.5	172.7	7.0	[illegible]	[illegible]	[illegible]
26				164.6	171.5	7.0	178.0	[illegible]	7.0	[illegible]	[illegible]	[illegible]
27				164.8	[illegible]	[illegible]	[illegible]	[illegible]	5.5	[illegible]	[illegible]	5.5
AVG				[illegible]	171.6	6.3	[illegible]	[illegible]	[illegible]	173.5	[illegible]	[illegible]

H.T.:

Heat to 1215°F & hold 15 min.
Fce. cool to 1400°F in 90 min. & hold 90 min.
Cool to R.T. in 300 min.
Cooled to -20°F & hold 60 min.
Age at:
A. 1050°F for 90 min.
B. 1060°F " " "
C. 1070°F " " "
D. 1080°F " " "

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TABULATION SHEET 17-7 P.H. Stainless Steel - 0.005, 0.008 & 0.020 Gage Tensiles

TABLE I-II

SPEC. NO.	GRAIN DIR	H.T.	0.005 GAGE Fty-ksi	0.005 GAGE Ftu-ksi	0.005 GAGE % e	0.008 GAGE Fty-ksi	0.008 GAGE Ftu-ksi	0.008 GAGE % e	0.020 GAGE Fty-ksi	0.020 GAGE Ftu-ksi	0.020 GAGE % e
1S	Long.	2	194.7	198.6	3.0	192.4	202.2	6.0			
2S			197.8	203.0	4.0	188.1	199.0	6.0			
3S			194.9	198.4	3.0	190.3	201.7	6.0			
4S			198.6	202.6	4.0	192.2	204.0	6.5	N		
5S			192.7	202.8	4.5	186.8	203.1	6.5		O	
6S			196.2	202.3	4.5	195.1	205.4	4.5		T	
7S			198.8	202.0	4.0	193.7	202.6	5.5			
8S			197.6	202.0	4.0	188.3	202.0	5.5			
9S			200.8	206.6	4.0	188.1	202.5	4.0		R	
10S			196.6	202.3	4.0	186.4	202.4	5.5			U
11S			[illegible]	[illegible]	4.0	191.6	[illegible]	5.0			N
12S			198.5	202.1	5.0	192.7	205.1	[illegible]			
13S			195.7	201.6	4.0	191.3	203.5	5.5			
14S			175.3	201.7	4.0	193.5	205.5	[illegible]			
15S			193.5	192.7	4.5	192.9	202.5	5.0			
16S			192.1	197.7	3.0	192.1	205.5	[illegible]			
112			195.3	199.5	2.5	187.8	[illegible]	5.0	183.1	[illegible]	5.5
113			192.4	202.6	2.0	182.2	[illegible]	5.0	182.9	[illegible]	5.5
114			199.9	202.3	2.0	[illegible]	183.7	6.0	182.3	[illegible]	[illegible]
43			169.6	185.3	6.7	165.5	173.0	7.0	176.6	[illegible]	7.0
44			167.1	183.9	6.5	152.7	182.5	9.0	177.1	181.3	7.5
45			165.4	184.2	7.5	163.6	182.6	5.5	163.5	182.2	7.0
73			[illegible]	202.8	2.5	175.7	188.2	6.5	186.1	196.5	6.5
74			197.5	202.6	3.5	179.0	191.0	4.5	185.1	197.4	5.5
75			198.7	202.1	3.0	177.0	193.3	5.0	182.8	195.2	6.5
76			194.1	199.0	3.5	181.3	194.0	5.0	182.5	[illegible]	6.0
77			192.4	202.8	3.0	184.5	193.5	4.0	187.2	194.6	5.5
72			193.3	203.0	3.0	182.9	192.6	4.5	182.8	[illegible]	6.0
AVERAGE			193.9	199.6	3.9	185.2	197.7	5.3	183.9	[illegible]	6.2

H.T. 2:
(1) Heat to 1315°F & hold 15 min.
(2) Cool to R.T. in 200 min.
(3) Reheat to 1900°F & hold 90 min.
(4) Cool to R.T. in [illegible] min.
(5) Cool to -20°F & hold 60 min.
(6) Age at 1050°F for [illegible]

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TABLE IB-II

TABULATION SHEET- 17-7 PH Stainless Steel - 0.005, 0.008 & 0.020 Gage Tensiles

SPEC NO	GRAIN DIR	H.T.		.005 GAGE			.008 GAGE			.020 GAGE		
				F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e
49	Long.	3A+4		190.0	194.7	6.5	198.5	204.3	4.0	195.7	203.3	7.0
50				185.9	197.3	6.0	201.3	205.6	4.0	195.2	204.3	6.0
51				185.5	193.0	6.0	201.3	207.1	4.0	196.5	202.1	7.0
AVG				187.1	195.0	6.2	200.4	205.7	4.0	195.8	203.1	7.0
52		3B+4		188.0	194.7	5.5	200.5	205.5	4.0	197.0	203.6	7.0
53				177.2	193.0	5.5	199.6	206.2	3.0	196.7	203.3	7.0
54				182.0	194.3	5.5	197.4	203.3	3.0	197.1	[illegible]	7.0
AVG				182.4	194.0	5.5	199.5	205.0	[illegible]	[illegible]	[illegible]	7.0
55		3C+4		191.1	[illegible]	3.5	201.7	206.3	3.5	200.9	[illegible]	[illegible]
56				[illegible]	[illegible]	[illegible]	202.4	[illegible]	4.0	197.1	[illegible]	[illegible]
57				[illegible]	[illegible]	[illegible]	200.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AVG				[illegible]	197.1	[illegible]	201.5	206.5	[illegible]	[illegible]	[illegible]	[illegible]
58		3D+4		192.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
59				191.4	197.8	[illegible]	201.7	207.3	3.5	209.5	[illegible]	[illegible]
60				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.5	200.7	[illegible]	[illegible]
AVG				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
61		3E+4		191.4	197.5	4.0	197.7	203.6	5.0	198.2	204.3	7.0
62				191.2	197.4	3.0	201.0	206.7	4.5	200.9	205.1	6.0
63				[illegible]	197.7	2.5	197.0	204.1	4.5	200.0	[illegible]	[illegible]
AVG				187.6	[illegible]	2.5	199.9	204.8	4.7	[illegible]	[illegible]	6.3

H.T. 3 - Heat to 1400°F & hold 90 min.
Cool in air to:
A. +54°F
B. +30°F
C. 0°F
D. -20°F
E. -50°F
4 Age at 1050°F for 90 min.

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TABLE IB-IV

TABULATION SHEET 17-7PH Stainless Steel - 0.005, 0.008 & 0.020 Gage Tensiles

SPEC. NO.	GRAIN DIR	H.T.	0.005 GAGE F_{ty}-ksi	F_{tu}-ksi	%e	0.008 GAGE F_{ty}-ksi	F_{tu}-ksi	%e	0.020 GAGE F_{ty}-ksi	F_{tu}-ksi	%e
79	Long	1+2A+3	188.7	192.3	6.0	193.1	201.7	4.5	NONE	187.0	10.5
80	↓	↓	188.5	189.7	5.0	193.5	202.6	5.5	175.9	187.8	10.0
81	↓	↓	182.3	187.5	6.0	187.7	198.0	5.0	168.1	186.2	10.0
AVG			186.5	189.8	5.7	191.4	200.2	5.0	172.0	187.0	10.2
82	↓	1+2B+3	192.9	197.6	6.0	202.3	210.6	5.5	167.3	184.9	10.0
83	↓	↓	192.0	197.1	5.0	202.6	211.9	6.0	183.8	194.5	9.0
84	↓	↓	193.6	198.3	5.0	199.9	[illegible]	6.0	167.9	[illegible]	10.5
AVG			192.8	197.7	5.3	201.5	210.7	5.8	173.0	[illegible]	[illegible]
85	↓	1+2C+3	193.3	200.7	6.0	203.5	212.6	5.0	184.2	191.2	10.0
86	↓	↓	194.3	200.5	5.0	205.6	213.2	5.0	185.1	[illegible]	[illegible]
87	↓	↓	[illegible]	[illegible]	6.0	201.2	[illegible]	6.0	178.0	[illegible]	[illegible]
AVG			193.2	200.7	6.0	203.5	211.7	5.3	181.1	[illegible]	[illegible]

H.T.

1. Heat to 1815°F & hold 5 min.
2. Cool to 1750°F & hold
   - A. 30 min.
   - B. 90 min.
   - C. 60 min.
3. Cool to R.T. in 2hrs. — Cool to -100°F for 2hrs.

Age @ 1050°F for 90 min.

All the above, except -100°F treatment, done in an argon atmosphere.

CONVAIR—FORT WORTH

TABULATION SHEET 17-7PH Stainless Steel - 0.005, 0.008 & 0.010 Gage Tensiles

TABLE IB-V

SPEC. NO.	GRAIN DIR	H.T.	0.005 GAGE F_{ty}-ksi	0.005 GAGE F_{tu}-ksi	0.005 GAGE % e	0.008 GAGE F_{ty}-ksi	0.008 GAGE F_{tu}-ksi	0.008 GAGE % e	0.010 GAGE F_{ty}-ksi	0.010 GAGE F_{tu}-ksi	0.010 GAGE % e
100	Long.	1+2A+3	180.5	188.7	8.0	201.0	208.3	6.0	157.2	188.0	10.0
101			181.2	188.7	8.0	201.5	208.6	5.5	157.9	188.2	11.0
102			179.9	187.7	5.0	199.6	203.0	7.5	—	—	—
AVG			180.5	188.4	7.0	199.0	206.6	6.3	157.6	188.1	10.5
103		1+2B+3	182.8	195.8	6.0	203.5	210.1	6.0	165.0	185.7	10.5
104			183.3	190.0	5.0	202.6	210.0	7.0	165.3	185.1	10.5
105			186.2	191.8	7.0	203.1	210.4	6.0	[illegible]	[illegible]	[illegible]
AVG			184.1	[illegible]	6.0	203.1	[illegible]	6.3	165.4	[illegible]	[illegible]
106		1+2C+3	183.1	[illegible]	6.0	[illegible]	[illegible]	5.5	[illegible]	[illegible]	[illegible]
107			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.0	[illegible]	[illegible]	[illegible]
108			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.0	[illegible]	[illegible]	[illegible]
AVG			[illegible]	[illegible]	5.5	[illegible]	[illegible]	5.5	[illegible]	[illegible]	[illegible]

H.T.

1. Heat to 1750°F & hold 20 min. - Air cool
2. Cool to -100°F and hold for:
   - A. One hour
   - B. Two hours
   - C. Three hours
3. Age @ 1250°F for 90 min.

[illegible] 1 & 3 were in argon atmosphere

CONVAIR—FORT WORTH

TABULATION SHEET 17-7PH Stainless Steel-0.005, 0.008 & 0.020 Gage Tensiles

TABLE IB-XI

SPEC NO	GRAIN DIR	H.T	0.005 GAGE F_{ty}-ksi	0.005 GAGE F_{tu}-ksi	0.005 GAGE %e	0.008 GAGE F_{ty}-ksi	0.008 GAGE F_{tu}-ksi	0.008 GAGE %e	0.020 GAGE F_{ty}-ksi	0.020 GAGE F_{tu}-ksi	0.020 GAGE %e
109	Long.	1A+2	51.3	125.2	38.5	53.6	1483	31.0	45.7	123.7	31.5
110	↓	↓	51.4	126.5	41.0	53.4	1476	30.0	46.9	123.3	38.0
111	↓	↓	51.3	119.3	26.0*	52.[illegible]	1466	29.5	46.5	120.[illegible]	45.0
AVG			51.3	123.7	35.2	53.3	1475	30.2	46.4	122.[illegible]	[illegible]
88	↓	1B+2	33.3	131.4	26.0	54.6	1425	27.0	NONE	115.6	42.5
89	↓	↓	41.4	127.5	30.0*	56.0	1[illegible]2.3	27.0	↓	117.2	43.0
90	↓	↓	39.4	135.[illegible]	[illegible]	55.3	[illegible]	30.0	↓	117.[illegible]	[illegible]
AVG			38.0	131.[illegible]	[illegible]	55.[illegible]	[illegible]	[illegible]	NONE	117.[illegible]	[illegible]
91	↓	1C+2	53.2	136.[illegible]	35.0	54.[illegible]	[illegible]	[illegible]	NONE	[illegible]	[illegible]
92	↓	↓	41.3	[illegible]	32.0	[illegible]	[illegible]	[illegible]	↓	[illegible]	[illegible]
93	↓	↓	42.0	[illegible]	26.0*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AVG			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
94	↓	1D+2	50.7	134.3	[illegible]	[illegible]	[illegible]	[illegible]	NONE	[illegible]	[illegible]
95	↓	↓	51.0	135.1	[illegible]*	[illegible]	[illegible]	31.0	↓	[illegible]	[illegible]
96	↓	↓	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32.5
AVG			[illegible]	[illegible]	31.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*Broke outside gage marks

H.T. 1. Cool Cond. A mat'l to -100°F for:
A. 10 min.
B. One Hour
C. Two Hours
D. Four Hours

2. Age @ 1050°F for 90 mins – Argon atmos.

CONVAIR—FORT WORTH

TABULATION SHEET

TABLE IB-VII

17-7 PH Stainless Steel-0.040, 0.063 & 0.080 Gage Tensiles (0.005, 0.008, 0.020)

SPEC. NO.	GRAIN DIR.	H.T.	0.040 GAGE F_{ty}-ksi	F_{tu}-ksi	%e	0.063 GAGE F_{ty}-ksi	F_{tu}-ksi	%e	0.080 GAGE F_{ty}-ksi	F_{tu}-ksi	%e
120	Long	3A+4	179.1	190.3	8.5	186.3	199.4	9.0	145.9	170.3	12.0
121	↓	↓	177.6	189.7	7.0	189.6	200.6	8.0	155.0	182.2	13.0
122			179.1	190.2	8.0	189.8	202.9	8.0	149.3	180.3	13.0
AVERAGE			178.6	190.0	7.8	188.6	[illegible]	8.3	150.1	181.1	12.7
123		3D+4	196.1	196.7	6.0	196.8	205.5	7.0	176.6	194.[illegible]	11.0
124			191.0	197.2	6.5	196.1	205.7	6.0	173.3	191.2	10.5
125	↓	↓	188.6	196.3	[illegible]	197.7	201.1	[illegible]	172.2	193.7	[illegible]
AVERAGE			[illegible]	[illegible]	[illegible]	197.2	204.1	6.3	174.2	[illegible]	[illegible]

SPEC. NO.	GRAIN DIR.	H.T.	0.005 GAGE F_{ty}-ksi	F_{tu}-ksi	%e	0.008 GAGE F_{ty}-ksi	F_{tu}-ksi	%e	0.020 GAGE F_{ty}-ksi	F_{tu}-ksi	%e
120	Long	3A+4	182.9	196.3	[illegible]	205.7	212.2	4.0	[illegible]	[illegible]	[illegible]
121	↓	↓	187.6	195.[illegible]	4.0	207.1	[illegible]	4.5	[illegible]	[illegible]	[illegible]
122			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AVERAGE			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.5	[illegible]	[illegible]	[illegible]
123		3D+4	197.1	203.0	5.0	210.3	215.8	4.0	200.2	205.[illegible]	6.0
124			195.9	201.[illegible]	4.5	211.9	216.1	4.5	199.7	204.[illegible]	5.0
125	↓	↓	197.1	201.0	4.5	[illegible]	215.0	5.0	202.2	[illegible]	5.5
AVERAGE			196.7	201.9	4.7	210.5	215.6	[illegible]	[illegible]	[illegible]	5.5

H.T. 3 - Heat to 1400°F & hold 90 min.
Air cool to:
A. +59°F
B. -20°F

4 - Age at 1050°F for 90 min.

TABLE IB-VIII - Heat Treatments Rated On The Basis Of Tensile Properties Conferred On 17-7PH Steel Sheet

Highest Yield & Ultimate Strength With Elongation Above Specified Minima

	.005" Thick	.008" Thick	.020" Thick
*Rank of Heat Treatment	1 - 3D+4 - VII	1 - 3D+4 - VII	1 - 3D+4 - III
	2 - 1+2C+3 - IV	2 - 1+2C+3 - V	2 - 3D+4 - VII
	3 - 2 - II	3 - 1+2C+3 - IV	3 - 1+2C+3 - IV
	4 - 3D+4 - III	4 - 3A+4 - III	4 - 2 - II
	5 - 1+2C+ - V	5 - 2 - II	5 - 1+A - I
	6 - 1+A - I	6 - 1+A - I	6 - 1+2C+3 - V

Highest Elongation With Acceptable + Yield & Ultimate Strength

	.005" Thick	.008" Thick	.020" Thick
*Rank of Heat Treatment	1 - 3A+4 - VII	1 - 1+2B+3 - V	1 - 1+2B+3 - V
	2 - 1+2A+3 - V	2 - 1+2B+3 - IV	2 - 1+2C+3 - IV
	3 - 3A+4 - III	3 - 1+B - I	3 - 3B+4 - III
	4 - 1+2C+3 - IV	4 - 2 - II	4 - 3A+4 - VII
	5 - 1+A - I	5 - 3E+4 - III	5 - 2 - II
	6 - 2 - II	6 - 3A+4 - VII	6 - 1+A - I

* 1, highest; 6, lowest. Treatments and tables of data given for each thickness.

+ Substantially above specified minima.

HEAT TREATMENT

ITEM C - COMPARISON OF BRAZING CYCLES FOR HEAT TREATMENT OF 17-7PH STEEL SHEET BRAZED WITH STERLING SILVER PLUS 0.2% LITHIUM ALLOY

Early in 1957, work was carried out on the evaluation of the sterling silver plus 0.2% lithium alloy for brazing 17-7PH steel. As one result, the lowest satisfactory brazing temperature for this alloy was found to be 1650 F (cf. Section II, Item G). The production brazing temperature for the 85:15 silver-manganese alloy, then in use, was 1820 F. An investigation was conducted to determine what effects the lower brazing temperature might have on the response to heat treatment and on the tensile properties of 17-7PH steel. Also, two different heat-treatment cycles were examined. This investigation is summarized here.

In the heat treatment of 17-7PH steel, the three essential steps are: (1) austenite conditioning; (2) cooling to effect transformation of austenite to martensite; and (3) precipitation hardening treatment. The Convair heat-treatment cycle for sandwich panels brazed with the 85:15 silver-manganese alloy included conditioning for 90 minutes at 1400 F after brazing. As mentioned, the brazing was performed above 1800 F. Brazing with the sterling silver plus 0.2% lithium alloy was to be done at 1650 F. In using this alloy, the need for the conditioning at 1400 F was questioned. With the object of settling this, sets of tensile specimens were heat treated with the conditioning step at 1400 F incorporated in the procedure; other sets were heat treated without it. The former are identified as A and the latter as B.

The heat treatments were based on the following simulated brazing cycle:

1. Heat to 1650 F and hold 15 minutes.
2. Cool to 1400 F in 60 minutes and hold 90 minutes.
3. Cool to -20 F within 8 hours and hold 30 minutes.
4. Age at 1050 F for 90 minutes.

The transformation temperature (step 3, above) was varied with some sets of specimens and the aging temperature with others. Most of the tensile tests were performed on sheet specimens .005" and .010" thick. Small numbers of specimens .021", .044", and .061" were also tested. In addition, various tests were made on samples cut from a few brazed sandwich panels. These were brazed in the range 1620 to 1700 F and otherwise processed according to the B cycle.

Table IC-I gives the results of tensile tests on 17-7PH steel specimens .005" thick, and Table IC-II gives the results on specimens .010" thick. The transformation temperature was varied from 0 to -100 F. Otherwise, the heat treatment was in accordance with the A or B cycles as designated in the tables. Table IC-III lists additional results on specimens .005" and .010" thick and also some test values for specimens .021", .044", and .061" thick. Table IC-IV gives the results of tensile, edge compression, flat compression, and axial tension-tension fatigue tests on samples cut from the brazed panels.

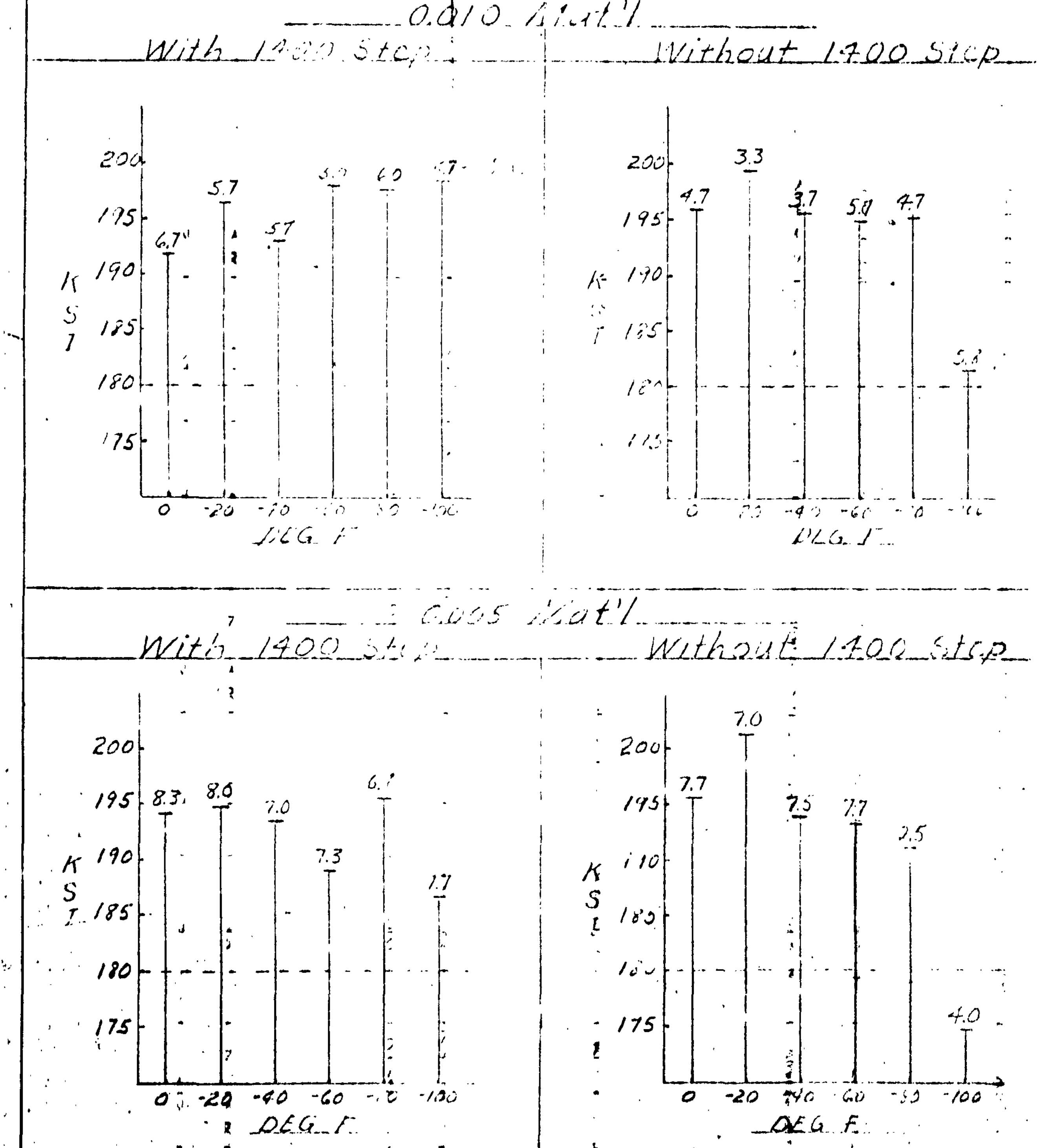
In Figure IC-1 bar charts show the effect of the transformation temperature on the tensile strength and elongation of 17-7PH steel sheet. The charts cover test data on specimens .005" and .010" thick, heat treated with and without the 1400 F step. For the .010" material the strength tended to increase with decreasing temperature of transformation when the 1400 F step was used; the elongations were relatively high. For the same material without the 1400 F step, there was a pronounced loss of strength with transformation temperature of -100 F; the elongations tended to be relatively low.

Referring further to Figure IC-1, for the .005" sheet with the 1400 step, the strength followed no pronounced trend with decreasing temperature of transformation but was appreciably lowered for -60 and -100 F. The elongations were relatively high. For this thickness without the 1400 F step the strength tended to decrease noticeably with decreasing transformation temperature with a marked loss for -100 F. The elongations were relatively high for temperatures down to -60 F.

Table IC-III shows that .005", .044", and .061" sheet, heat treated according to the simulated brazing cycle both with and without the 1400 F step, had acceptable tensile properties. The .020" sheet, with and without the step, and the .010" sheet, without the step, had elongation values below the specified minima.

The test results on specimens cut from the brazed sandwich panels were above the specified minima with two exceptions. Tensile specimens from the skins of panel 45 had elongation of 2% in 2". The specified minimum is 3%. The tension-tension fatigue specimens failed at 669 x 10^3 and 316 x 10^3 cycles. The specified minimum is 1 x 10^6 cycles without failure.

ULTIMATE STRENGTH vs TRANSFORMATION TEMP


0.010 Mat'l

With 1400 Step

Without 1400 Step

0.005 Mat'l

With 1400 Step

Without 1400 Step

FIGURE TC-1

CONVAIR — FORT WORTH

TABLE IC-I

TABULATION SHEET TENSILE PROPERTIES OF 17-7PH STEEL -.0005 Gage

SPEC. NO.	H.T. GROUP	TRANS TEMP	GRAIN DIR	GAGE			YIELD KSI	ULT. KSI	%e	AVERAGE F_{ty}	F_{tu}	%e
1	A	-100F	LONG	.0050			179.3	189.1	7.0			
2				.0049			176.6	183.2	8.0	178.4	186.5	7.7
3				.0048			179.4	187.2	8.0			
4		-80F		.0046			184.4	194.1	6.0			
5				.0045			185.0	194.1	6.0	186.7	195.5	6.3
6				.0046			190.6	198.4	7.0			
7		-60F		.0048			185.7	193.3	8.0			
8				.0050			177.9	185.6	7.0	180.6	188.4	73
9				.0047			177.1	186.3	7.0			
10		-40F		.0046			181.4	188.4	7.0			
11				.0045			174.0	193.7	6.0	184.7	193.1	7.0
12				.0046			182.6	192.2	8.0			
13		-20F		.0045			192.2	201.3	8.0			
14				.0048			183.6	190.9	7.0	186.5	194.5	[illegible]
15				.0045			192.2	191.3	9.0			
16		0°F		.0047			190.0	197.2	9.0			
17				.0047			182.9	190.9	7.0	186.2	194.6	8.5
18				.0047			—	—	9.0			
1	B	-100F	LONG	.0048			157.8	170.7	4.0			
2				.0046			173.0	179.8	4.0	165.5	174.4	4.0
3				.0048			165.8	172.7	4.0			
4		-80F		.0046			190.0	194.6	3.5			
5				.0046			184.5	193.8	2.0	183.8	191.2	2.5
6				.0047			176.8	185.2	2.0			
7		-60F		.0048			182.0	190.1	7.0			
8				.0047			—	194.2	8.0	183.0	192.8	7.7
9				.0047			183.9	194.2	8.0			
10		-40F		.0046			192.0	192.4	8.5			
11				.0042			184.8	190.1	8.0	187.4	193.5	7.5
12				.0048			—	192.1	6.0			
13		-20F		.0046			192.0	198.9	7.0			
14				.0046			185.7	200.5	6.5	189.2	201.5	7.0
15				.0045			189.9	205.0	7.5			
16		0°F		.0047			185.9	196.2	7.0			
17				.0048			182.0	194.1	8.0	184.6	195.5	7.7
18				.0047			185.9	196.3	8.0			

CONVAIR — FORT WORTH

TABLE LC-II

TABULATION SHEET TENSILE - PROPERTIES OF 17-7PH STEEL - 0.010 Gage

SPEC. NO.	H.T. GROUP	TRANS. TEMP.	GRAIN DIR.	GAGE	YIELD KSI.	ULT. KSI.	%e	AVERAGE F_{ty}	AVERAGE F_{tu}	AVERAGE %e
1	A	-100F	LONG	.0095	197.5	204.1	6.0			
2				.0098	189.2	196.0	5.0	191.5	198.0	5.7
3				.0100	187.7	193.9	6.0			
4		-80F		.0096	~~195.5~~	200.6	~~6.0~~	—	—	—
5				.0097	189.2	195.0	7.0	191.0	196.9	6.0
6				.0098	188.2	195.0	5.0			
7		-60F		.0097	193.9	199.9	5.0			
8				.0099	187.2	194.1	5.0	190.5	197.5	5.0
9				.0097	190.5	198.5	5.0			
10		-40F		.0098	185.3	193.1	5.0			
11				.0097	188.8	194.1	6.0	186.9	192.9	5.3
12				.0100	186.7	191.6	5.0			
13		-20F		.0099	175.2	192.2	6.0			
14				.0099	~~189.2~~	~~192.2~~	~~5.0~~	~~183.0~~	~~196.1~~	~~6.7~~
15				.0096	192.1	193.2	6.0			
16		0°F		.0096	181.1	192.2	6.0			
17				.0099	183.3	191.2	7.0	183.5	191.9	6.7
18				.0098	186.2	192.2	7.0			
1	B	-100F	LONG.	.0096	174.6	181.8	6.0			
2				.0098	174.4	182.4	5.0	171.5	181.5	5.7
3				.0096	165.4	180.4	6.0			
4		-80F		.0097	189.7	197.8	4.0			
5				.0099	184.3	192.1	6.0	186.8	195.0	4.7
6				.0098	186.3	195.1	4.0			
7		-60F		.0098	186.3	199.1	6.0			
8				.0098	187.3	199.1	5.0	186.6	194.4	5.3
9				.0098	186.3	195.1	5.0			
10		-40F		.0099	182.2	196.1	3.0			
11				.0099	183.3	195.1	4.0	186.9	195.4	3.7
12				.0099	185.3	195.1	4.0			
13		-20F		.0098	190.2	196.1	3.0			
14				.0096	191.5	202.6	3.0	190.6	199.0	3.3
15				.0097	190.2	198.2	4.0			
16		0°F		.0099	186.7	195.5	6.0			
17				.0098	185.3	196.3	4.0	185.2	195.8	4.7
18				.0099	183.7	195.7	4.0			

CONVAIR — FORT WORTH

TABULATION SHEET TENSILE PROPERTIES OF 17-7PH STEEL 0.005, 0.010, 0.020, 0.040 & 0.063 Gage

TABLE IC-III

SPEC. NO.	H.T. GROUP	TRANS TEMP	AGE TEMP	GRAIN DIR.	GAGE	YIELD KSI	ULT. KSI	%e	AVERAGE F_{ty}	F_{ty}	%e
AC-1	A	-20°F	1050°F	LONG.	.0049	—	186.4	5.5			
2						171.3	181.1	6.0	175.6	184.1	5.5
3						179.9	184.8	5.0			
BC-1	B					176.1	182.9	4.5			
2						184.6	189.0	8.0	181.7	187.2	6.5
3						184.5	189.8	7.0			
AC-1	A	-20°F	1050°F	LONG	.0100	192.5	195.5	6.0			
2						194.1	197.1	6.0	193.3	196.3	6.0
3						—	—	—			
BC-1	B					183.2	194.2	4.0			
2						185.7	201.7	2.0	184.5	196.7	3.3
3						184.5	194.9	4.0			
AC-1	A	-20°F	1050°F	LONG	.0210	201.1	203.0	4.0			
2						196.5	202.1	4.0	198.4	202.1	4.0
3						197.5	203.7	4.0			
BC-1	B					197.9	203.6	4.0			
2						199.2	206.0	4.0	200.3	206.1	4.3
3						203.1	208.7	5.0			
AC-1	A	-20°F	1050°F	LONG	.0437	—	194.5	—			
2						187.2	195.2	6.0	186.7	194.4	5.5
3						182.1	193.4	5.0			
BC-1	B					185.6	197.6	6.0			
2						183.3	197.2	7.0	186.5	198.1	6.3
3						190.7	198.4	6.0			
AC-1	A	-20°F	1050°F	LONG	.0610	179.5	197.6	7.0			
2						190.3	198.6	7.0	186.0	198.2	6.3
3						188.1	198.5	5.0			
BC-1	B					190.2	206.6	7.0			
2						188.8	201.2	7.5	190.3	203.8	7.2
3						191.8	203.5	7.0			

CONVAIR—FORT WORTH

TABULATION SHEET PROPERTIES OF PANELS BRAZED WITH Ag-Cu-Li

TABLE IC-IV

PANEL-SAMP NO	SKIN	CORE	BRAZE TEMP.	HEAT TREAT	TYPE TEST		YIELD KSI	ULT. KSI	%e
41-1	.010	1/2"(3-15)	1700°F	TH no 1400	tensile		199.0	200.4	4.0
2	↓	↓	↓	↓			199.0	206.5	3.0
3	↓	↓	↓	↓			205.0	228.0	3.0
[illegible]	.010	1/2"(3-16)	1650°F	TH no 1400	tensile		—	191.8	3.0
2	↓	↓	↓	↓			189.8	195.3	4.0
3	↓	↓	↓	↓			184.7	189.4	—
45-1	.010	7/8"(3-15)	1620°F	TH no 1400	tensile		194.2	204.2	2.0
2	↓	↓	↓	↓			195.2	202.1	2.0
41-1	.010	1/2"(3-15)	1700°F	TH no 1400	Edge Comp.			201.9	
2								181.2	
3								160.3	
4								166.5	
5	↓	↓	↓	↓				182.6	
42-1	.010	1/2"(3-15)	1650°F	TH no 1400	Edge Comp.			116.6	Uneven Loading
2								142.3	
3								183.6	
4								174.0	
5	↓	↓	↓	↓				175.8	
41-1	.010	1/2"(3-15)	1700°F	TH no 1400	Flat Comp.			1.600	
2	↓	↓	↓	↓				1.535	
42-1	.010	1/2"(3-15)	1650°F	TH no 1400	Flat Comp.			1.492	
2	↓	↓	↓	↓				1.571	
43-1	.010	7/8"(4-15)	1650°F	TH no 1400	Flat Comp.			.838	
2	↓	↓	↓	↓				.877	
41-1	.010	none	1700°F	TH no 1400	Ten-Ten Fat.	95-55 KSI		669×10^3 Cycles	
42-2	↓	↓	1650°F	↓				316×10^3 Cycles	

HEAT TREATMENT

ITEM D - ELIMINATION OF CONDITIONING TREATMENT AT 1400 F FOR 17-7PH STEEL.

In the Spring of 1957, an investigation was undertaken to determine the necessity of the conditioning treatment at 1400 F for brazed sandwich panels in 17-7 PH steel. This investigation was occasioned by the adoption of the sterling silver .2% lithium brazing alloy. As a result of this together with subsequent and related investigations, the 1400 F step was discontinued in March 1959.

The data given here are the results of tensile and fatigue tests carried out before and after the elimination of the conditioning step. These tests were performed on 17-7PH steel sheet both with and without conditioning at 1400 F.

Table ID-I through ID-IV give the tensile-test values obtained in 1957 for different thicknesses of sheet. The values in the first three tables are summarized in Table ID-V. The values in Table ID-IV were not included in the summary of Table ID-V because of the long cooling times from the conditioning temperatures. These long cooling times, 6 and 12 hours, apparently had relatively small effects on the tensile properties. All the specimens for which data are given in Table ID-I to ID-IV were cut with the rolling direction parallel to their long axes (longitudinal). The specimens were prepared from sheet stock and heat treated in the ETL. In Tables ID-II and ID-III the identification "Heats 5, 6, 7, and 8" refers to different lots.

The specimens of the first three tables were heat treated according to the following simulated brazing cycles:

1. Heated to 1650 F in 30 minutes and held 10 minutes.
2. A. Cooled from 1650 F to room temperature in 3 hours.
   B. Cooled to 1400 F in 60 minutes, held 90 minutes, and then cooled to room temperature in 3 hours.
3. Cooled to -20F and held for 30 minutes.
4. Aged at 1050 F for 90 minutes.

Reference may again be made to Table ID-V. As shown there, the averages of the tensile properties are above the minimum required by Convair specification FZS-4-046(C) except for the elongations of the .010" and .020" thick sheet.

The values summarized in Table ID-V were not regarded as an adequate basis for discontinuing the conditioning step at 1400 F. This was mainly because no transverse specimens were tested. Tensile specimens pulled transversely to the rolling direction of 17-7PH steel sheet usually exhibit noticeably lower percentages of elongation than do specimens tested longitudinally.

Several test programs to determine the necessity for the 1400 F step were conducted during 1958. The results were unsatisfactory for one reason or another. For example, where low tensile properties were obtained on specimens heat treated without the conditioning step, specimens treated with it likewise had low properties. The data obtained in these programs are not included here.

Table ID-VI and ID-VII give the results of tensile tests on specimens cut from sheets which were heat treated in production brazing facilities at Convair, Ft. Worth. The sheets were .010" and .025" thick. They were heat treated without the 1400 F step in the production equipment, and aged at the ETL. The test data given in the above tables were obtained early in 1959.

In Tables ID-VI and ID-VII the heat treatments are referred to as furnace and salt-bath cycles. The former was carried out in a Holcroft furnace and the latter in a salt bath. These heat treatments were as follows:

Holcroft Furnace

1. Heated from 1000 F to 1400 F in 15 minutes.
2. Heated from 1400 F to 1650 F in 75 minutes.
3. Held at 1650 F for 10 minutes.
4. Furnace cooled from 1650 F to 1400 F in 65 minutes.
5. Air cooled from 1400 F to 1000 F in 45 minutes.
6. Cooled to -20F and held for 30 minutes.
7. Aged at 1050 F for 90 minutes.

Salt Bath

1. Heated to 1650 F in 60 minutes and held for 10 minutes.
2. Cooled from 1650 F to 1400 F in 30 minutes.
3. Cooled from 1400 F to 1000 F in 45 minutes.
4. Cooled to -20 F and held for 30 minutes.
5. Aged at 1050 F for 90 minutes.

As shown in Tables ID-VI and ID-VII, the tensile yield and ultimate strength were considerably above the minimum required by Convair specification FZS-4-046 (C), but the elongations were below.

The reason for the low elongations was not understood at the time the tests were made. Subsequently, information was received that the aging temperature in production was usually between 1060 and 1070 F (in order to obtain adequate elongation) as contrasted with 1050 F as used at the ETL. The lower aging temperature would be expected to result in lower elongation.

In March 1959, decision was reached to eliminate the conditioning treatment at 1400 F of production nacelle panels. However, additional tests on .025" material were requested.

Tables ID-VIII through ID-XII give test results on specimens cut from filler sheets, .025" thick, processed with standard nacelle panels in production brazing facilities. All the material was heat treated without the 1400 F step except that for which test values are given in Table ID-XI. The values in this table are for filler sheets processed with the last panels for which the 1400 F step was included in the brazing cycle.

As in evident from the data in Tables ID-VIII to ID-XI, all the strength values were above the minima required by Convair Specification FZS-4-046(C). The average elongation values were above and below the minimum specified, both with and without the 1400 F step. Following is a summary of the elongation values:

Average Elongation Values Below Minimum

With 1400 F Step		Without 1400 F Step	
As Heat Treated	After Salt Spray	As Heat Treated	After Salt Spray
6 of 7	2 of 3	10 of 16	4 of 16

Referring to the fatigue data in Tables ID-VIII to ID-XI, the average numbers of cycles to failure were as follows: For specimens with the 1400 F step as heat treated and after salt spray, 261 x 10^3 and 97 x 10^3 cycles, respectively; and for corresponding specimens without the step, 191 x 10^3 and 97 x 10^3 cycles.

Table ID-XII gives the results of tests on notched tensile specimens of .025" thick sheet. The specimens were taken from filler stock processed with sandwich panels brazed in production. Based on the data, the sheet heat treated without the 1400 F step was somewhat notch sensitive. However, the tests were insufficient to fix the probable notch sensitivity. The results of the tests on the material processed with panel No. 687918 are to be ignored as all the specimens except one were out of alighment in the grips.

Table ID-XIII gives the results of tests designed to determine the effect of specimen geometry on the elongation of thin 17-7PH steel sheet. Representative measurements are plotted in Figure ID-1. The data show considerable scatter, but certain trends are broadly apparent. First, with increasing width of specimen the elongation increased. Second, with decreasing gage lengths there was less scatter. Third, with increasing gage length the measured elongation increased although the percent elongation is decreasing.

CONVAIR — FORT WORTH 0.020, 0.090

TABLE ID-I

TABULATION SHEET 0.005 & 0.010 Gage 17-7PH Steel Tensile Data

1400°F STEP	GRAIN DIR	SAMP NO.	GAGE	YIELD KSI.	ULT KSI.	%e	SAMP NO	GAGE	YIELD KSI.	ULT KSI.	%e
No	Long	A-1-1	0.005	178.0	182.8	5.0	A-1-1	0.010	178.3	186.7	4.0
		2		177.2	182.4	7.0	2		179.1	183.9	4.5
		3		178.0	182.4	4.5	3		179.8	188.0	4.5
		4		176.4	182.0	5.5	4		175.1	182.3	5.0
		5		178.4	183.2	6.5	5		175.3	183.9	4.5
		A-2-1		176.0	181.6	7.0	A-2-1		177.3	183.8	4.0
		2		182.1	187.1	5.5	2		177.7	184.2	4.0
		3		175.2	180.0	5.5	3		177.7	183.8	4.0
		4		183.3	187.9	6.0	4		179.0	185.9	4.0
		5		182.9	187.4	6.0	5		170.6	186.3	4.0
		AVG		178.8	182.7	5.8	AVG		178.0	184.9	4.2
Yes	Long	B1-1	0.005	182.8	187.5	8.0	B-1-1	0.010	172.7	180.8	5.0
		2		180.0	186.3	8.0	2		178.0	185.6	5.0
		3		174.3	180.0	7.5	3		174.6	182.3	4.0
		B-2-1		180.0	184.6	7.0	B-2-1		172.6	182.4	4.5
		2		180.1	185.3	8.0	2		176.9	183.7	4.5
		3		180.1	185.3	8.0	3		177.1	183.9	4.5
		AVG		179.3	185.0	7.7	AVG		177.0	184.1	4.6
No	Long	A-1-1	0.020	183.8	190.3	6.0	A-1-1	0.090	179.8	194.3	6.0
		2		180.0	186.9	6.0	2		188.1	194.7	8.5
		3		178.5	184.1	5.0	3		187.9	194.5	8.5
		4		181.9	187.9	6.0	4		188.7	195.1	7.5
		5		181.2	188.3	6.0	5		188.4	194.7	6.5
		AVG		181.1	187.5	5.8	AVG		188.6	194.7	7.4
Yes	Long	B-1-1	0.020	180.5	186.4	5.5	B-1-1	0.090	186.1	192.0	6.5
		2		179.1	185.9	6.0	2		187.1	193.5	7.0
		3		181.7	187.1	7.0	3		181.8	191.6	8.0
		AVG		180.4	186.3	6.2	AVG		185.0	193.0	7.2

NOTE: The first digit in each sample number distinguishes between heats of material. The actual heat numbers were unknown.

CONVAIR—FORT WORTH 0.010 &
TABULATION SHEET 0.005 - Gage 17-7PH Steel - Tensiles -- Heats - 5,6,7&8

TABLE ID-II

1400F STEP	GRAIN DIR	SAMP NO.	GAGE	YIELD KSI	ULT KSI	%e	SAMP NO.	GAGE	YIELD KSI	ULT KSI	%e
No	Long	A-5-1	0.005	192.8	194.4	—	A-5-1	0.010	182.2	196.0	3.5
↓	↓	2	↓	190.4	195.2	6.0	2	↓	185.7	195.6	6.0
		3		193.5	199.2	4.5	3		177.2	193.0	6.0
		AVG		191.6	196.3	5.3	AVG		181.7	194.9	5.2
↓	↓	A-6-1	↓	192.0	194.4	2.0	A-6-1	↓			
		2		192.4	195.2	3.0	2		NOT	RUN	
		3		191.6	194.0	3.0	3				
		AVG		192.0	194.5	2.7	AVG				
↓	↓	A-7-1	↓	185.0	189.9	5.0	A-7-1	↓	198.2	203.7	2.0
		2		180.9	186.1	7.5	2		191.2	194.7	4.0
		3		—	186.5	7.0	3		—	—	—
		AVG		183.0	187.5	6.5	AVG		194.7	199.2	3.0
↓	↓	A-8-1	↓	186.0	192.5	5.0	A-8-1	↓	172.5	204.9	—
		2		187.3	192.5	6.0	2		200.7	204.6	3.5
		3		186.6	190.5	6.0	3		—	—	—
		AVG		186.6	191.6	5.7	AVG		186.6	204.6	3.5

NOTE: The first digit in each sample number distinguishes between heats of material. The actual heat numbers were unknown.

CONVAIR—FORT WORTH 0.010 &
~~TABULATION SHEET~~ 0.005 Gage 17-7PH Steel - Tensiles -- Heats 5,6,7&8

TABLE ED-III

1400F Step	GRAIN DIR	SAMP. NO.	GAGE	YIELD KSI.	ULT. KSI.	%e	SAMP NO.	GAGE	YIELD KSI	ULT KSI	%e
YES	Long	B-5-1	0.005	190.0	193.7	4.0	B-5-1	0.010	180.4	186.2	6.0
↓	↓	2	↓	177.9	184.3	4.0	2	↓	182.4	185.3	7.0
		3		184.6	190.1	4.0	3		180.3	184.2	6.0
		AVG		184.2	189.4	4.0	AVG		181.0	185.2	6.3
↓	↓	B-6-1	↓	—	191.3	4.0	B-6-1	↓	187.7	193.7	—
		2		184.3	187.4	4.0	2		187.8	192.2	4.0
		3		185.7	187.5	4.0	3		188.7	197.6	—
		AVG		185.0	188.1	4.0	AVG		188.1	193.7	4.0
↓	↓	B-7-1	↓	172.6	179.5	4.5	B-7-1	↓	192.3	196.0	3.0
		2		174.4	[illegible]	4.0	2		194.1	195.0	—
		3		179.2	183.4	4.0	3		191.4	191.4	—
		AVG		175.7	182.6	4.2	AVG		192.6	194.1	3.0
↓	↓	B-8-1	↓	175.9	184.6	5.0	B-8-1	↓	195.9	200.7	3.0
		2		182.7	183.6	3.5	2		192.1	195.3	3.0
		3		182.7	[illegible]	5.0	3		192.3	201.7	—
		AVG		180.4	187.1	4.5	AVG		194.9	199.4	3.0

NOTE: The first digit in each sample number distinguishes between heats of material. The actual heat numbers were unknown.

TABLE ID-VI

CONVAIR — FORT WORTH 0.005 & 0.010 Gage 17-7PH Steel Tensiles

TABULATION SHEET Effect of Cooling Time on

1400F STEP	GRAIN DIR	SAMP NO	GAGE	YIELD KSI	ULT KSI	%e	SAMP NO	GAGE	YIELD KSI	ULT KSI	%e
No	Long.	A-6-1	0.005	172.0	186.7	7.0	A-6-4	0.010	182.0	190.8	5.0
↓	↓	2	↓	174.3	185.1	6.0	5	↓	182.6	191.6	5.0
↓	↓	3	↓	174.5	182.2	7.0	6	↓	181.6	190.9	5.0
		AVG		173.6	182.9	6.7	AVG		182.1	191.1	5.0
Yes	↓	B-6-1	↓	180.7	185.4	2.5	B-6-4	↓	173.3	190.1	3.5
↓	↓	2	↓	180.5	184.8	3.0	5	↓	173.3	190.1	3.5
↓	↓	3	↓	179.7	184.4	4.0	6	↓	172.3	189.1	3.0
		AVG		180.3	184.9	3.2	AVG		173.0	189.8	3.3
No	↓	A-12-1	↓	176.2	181.7	4.0	A-12-4	↓	179.9	185.2	3.5
↓	↓	2	↓	176.7	181.7	3.0	5	↓	176.7	185.5	3.5
↓	↓	3	↓	176.7	182.1	4.0	6	↓	174.9	182.0	3.0
		AVG		176.5	181.8	3.7	AVG		177.2	184.2	3.3
Yes	↓	B-12-1	↓	180.5	187.1	3.0	B-12-4	↓	184.4	194.1	3.0
↓	↓	2	↓	178.9	185.5	3.5	5	↓	185.6	194.5	3.0
↓	↓	3	↓	178.9	185.5	4.0	6	↓	185.7	193.3	3.5
		AVG		179.4	186.0	3.5	AVG		185.3	194.1	3.2

Heat Treatments

Samples numbered A-6:
1. Heated to 1650F in 30 min, held for 10 min.
2. Cooled from 1650F to RT. in 6 hrs.
3. Cooled to -20F and held 30 min.
4. Aged at 1050F for 90 min.

Samples numbered B-6:
1. Heated to 1650F in 30 min, held for 10 min.
2. Cooled to 1400F in 1 hour, held for 90 min.
3. Cooled from 1400F to RT. in 6 hrs.
4. Cooled to -20F and held 30 min.
5. Aged at 1050F for 90 min.

Note: On specimens numbered A-12 & B-12 the cooling time was 12 hrs.

CONVAIR—FORT WORTH
TABULATION SHEET Minimums, Maximums & Averages from 17-7PH Steel Tensiles in Tables TD-I, TD-II & TD-III

1400F STEP	GAGE	NO HEATS	NO SPECS	MIN F_{ty}	MAX F_{ty}	AVG F_{ty}	MIN F_{tu}	MAX F_{tu}	AVG F_{tu}	MIN %e	MAX %e	AVG %e
Yes	0005	6	18	173.6	190.0	1804	179.5	193.7	1864	3.5	8.0	5.4
No		6	22	175.2	193.5	184.0	180.0	199.2	188.5	2.0	7.0	5.4
Yes	0010	6	18	172.7	196.8	185.1	170.8	201.7	190.1	3.0	7.0	4.6
No		5	17	175.2	200.7	181.6	182.3	204.9	190.7	2.0	6.0	4.2
Yes	0020	1	3	177.1	181.7	180.4	185.9	188.1	186.3	5.5	7.0	6.2
No		1	5	178.5	183.8	181.1	184.1	192.3	187.5	5.0	6.0	5.8
Yes	0090	1	3	181.8	187.1	185.0	191.6	194.0	193.0	6.5	8.0	7.2
No		1	5	187.9	189.8	188.6	194.3	195.1	194.7	6.0	8.5	7.4

CONVAIR—FORT WORTH

TABLE ID-VI

TABULATION SHEET 0.025 Gage 17-7PH Steel Tensiles -- No 1400F Step

GRAIN DIR	GAGE	SAMP NO	CYCLE	YIELD KSI	ULT KSI	% e	SAMP NO	CYCLE	YIELD KSI	ULT KSI	% e
Trans.	0.025	2JT-1	Furnace	213.3	219.2	3.5	3KT-1	Salt B.	215.8	222.3	4.0
		8		214.9	222.3	3.5	2		202.6	215.1	5.0
		10		215.0	221.7	3.5	7		202.8	215.3	5.0
		9		210.7	219.0	3.5	9		214.0	221.1	5.0
		6		212.0	218.6	3.5	10		213.8	220.7	4.5
		2		214.9	220.3	3.5	4		216.3	222.7	3.5
		3		214.1	221.2	3.5	12		214.6	223.6	4.0
		4		212.1	218.3	3.5	3		214.5	224.4	3.5
		5		212.1	216.7	4.0	8		214.6	222.9	3.5
		7		214.8	219.1	3.5	5		210.7	220.1	3.5
		AVG		213.4	219.7	3.5	AVG		213.2	220.9	4.2
Long.	0.025	2JL-4	Furnace	208.2	214.8	4.0	3KL-1	Salt B.	211.1	217.6	3.5
		7		209.3	216.3	4.0	2		211.1	218.4	4.0
		6		209.0	216.1	4.0	3		209.7	216.9	3.5
		5		207.8	213.1	3.5	6		209.7	217.7	4.0
		1		205.6	211.2	4.0	9		206.9	216.5	3.5
		2		203.2	208.4	3.5	10		209.3	216.1	3.5
		3		204.8	210.8	5.0	5		209.4	217.2	4.0
		8		206.9	213.4	4.0	4		209.3	218.7	4.0
		9		206.9	213.4	4.0	11		211.3	220.0	5.0
		10		205.6	212.8	4.0	13		208.6	218.4	4.0
		AVG		206.7	213.0	4.0	AVG		2096	217.8	3.9

CONVAIR—FORT WORTH

TABLE ID-VIII

TABULATION SHEET 0.010-Gage 17-7PH Steel Tensiles -- No 1400F Step

GRAIN DIR	GAGE	SAMP NO	CYCLE	YIELD KSI.	ULT KSI.	%e	SAMP NO	CYCLE	YIELD KSI.	ULT KSI.	%e
Trans.	0.010	2KT-3	Furnace	—	187.8	6.0	3KT-5	Salt B.	197.7	204.3	4.0
		10		196.0	201.5	4.0	10		202.0	207.0	3.5
		6		190.3	194.7	3.0	7		210.9	215.9	4.0
		8		188.0	190.8	3.0	2		205.2	211.1	4.0
		2		202.7	207.0	4.0	6		203.8	210.2	4.0
		1		195.7	200.0	3.5	1		202.7	207.0	3.0
		9		191.7	195.8	3.0	3		202.8	208.1	3.0
		4		195.7	197.9	3.5	4		200.0	202.1	3.5
		7		187.5	191.7	3.5	9		196.8	202.1	4.0
		5		189.4	193.6	3.0	8		190.6	203.1	5.0
		AVG		193.0	196.2	3.6	AVG		201.2	207.1	3.8
Long.	0.010	2KL-7	Furnace	194.6	197.6	5.0	3KL-6	Salt B.	184.5	190.1	4.0
		8		203.9	210.3	4.0	8		192.9	205.4	3.5
		3		200.0	204.4	4.0	7		196.8	202.1	3.5
		9		192.2	195.5	3.5	11		193.2	199.0	3.5
		10		185.2	189.5	3.0	2		193.3	202.1	3.5
		4		189.4	192.1	3.0	17		188.8	196.9	4.0
		1		193.9	198.2	3.0	10		204.8	209.4	3.0
		2		195.6	200.5	3.5	12		198.7	204.2	4.0
		6		195.1	200.2	4.5	3		203.3	207.4	3.5
		5		199.5	202.6	2.0	9		204.2	209.6	4.0
		AVG		194.5	198.9	3.6	AVG		196.8	202.6	3.6

CONVAIR—FORT WORTH
TABULATION SHEET

Mechanical Properties of 0.025 Gage 17-7PH Steel – No 1400F Conditioning Step

PANEL NO	GRAIN DIR	As Heat Treated			After 50hr Salt Spray			GRAIN DIR	Ten.-Ten. Fat.		
		F_{ty}-ksi	F_{tu}-ksi	%e	F_{ty}-ksi	F_{tu}-ksi	%e		As H.T. 10³ Cycles	50hr S.S. 10³ Cycles	Stress Max-Min (KSI)
687917	Long	181.8	177.9	4.5	181.5	190.1	4.0	Trans.			120-12
	↓	180.4	188.8	4.5	179.1	185.2	4.0	↓	NOT	RUN	↓
					180.2	188.7	4.0				
AVG		181.1	188.4	4.5	180.3	188.0	4.0				
719058	Trans.	175.8	183.2	5.0	177.2	184.7	6.0	↓	239	44	↓
	↓	176.4	182.7	5.0	177.0	183.0	6.0		60	79	
					177.0	121.4	4.0		104	32	
AVG		176.1	183.0	5.0	175.1	183.0	5.3		134	52	
719078	↓	171.6	180.0	6.0	172.4	178.3	5.0	↓	248	80	↓
		172.0	180.0	6.0	170.0	178.8	5.0		202	140	
					172.0	179.2	6.0		140	142	
AVG		171.8	180.0	6.0	170.8	178.8	5.3		197	123	
687329	↓	172.7	180.3	8.5	166.0	174.0	8.0	↓			↓
		172.0	179.9	8.0	164.2	175.7	5.0		NOT	RUN	
					166.3	176.1	7.0				
AVG		172.4	180.1	8.2	165.7	175.3	6.7				
687356	↓	191.7	196.7	6.0	189.8	197.0	5.5	↓	176	38	↓
		192.2	196.3	4.5	187.5	196.3	5.5		177	20	
					191.3	199.6	6.0		223	—	
AVG		192.0	196.5	5.2	189.5	197.6	5.7		192	29	
687304	↓	173.6	184.0	8.0	169.9	181.3	6.0	↓	1272^{B}	101	↓
		174.0	184.8	8.0	169.5	181.9	6.5		189	57	
					171.0	181.0	6.5		401	101	
AVG		173.8	184.4	8.0	170.1	181.1	6.3		295	86	
691936	↓	187.8	194.8	5.0	171.2	179.6	4.0	↓	92	89	↓
		186.6	194.8	4.0	176.5	184.9	5.0		157	70	
					183.3	193.0	5.0		—	94	
AVG		187.2	194.8	4.5	177.0	185.8	4.7		124	84	

Note: ^{B} indicates specimen failed in bearing.

CONVAIR – FORT WORTH
TABULATION SHEET

TABLE IV-1

Mechanical Properties of 0.025 Gage 17-7PH-Steel – No 1400F Conditioning Step

PANEL NO.	GRAIN DIR	As Heat Treated F_{ty}-ksi.	As Heat Treated F_{tu}-ksi.	As Heat Treated %e	After 50hr. Salt Spray F_{ty}-ksi.	After 50hr. Salt Spray F_{tu}-ksi.	After 50hr. Salt Spray %e	GRAIN DIR	Ten-Ten Fat. As H.T. 10^3 Cycles	Ten-Ten Fat. 50hr. Salt 10^3 Cycles
687238	Long.	193.4	200.0	5.5	192.3	200.9	6.0	Trans	134	80
		192.3	199.3	5.0	192.8	199.2	5.5		333	—
					191.7	192.2	6.0		83	177
AVG		192.8	199.6	5.2	192.3	199.6	5.8		183	128
687237		182.1	188.3	5.5	183.0	189.4	6.0			
		182.1	188.7	5.5	184.3	189.8	5.5		NOT	RUN
					182.3	188.1	—			
AVG		182.1	188.5	5.5	183.2	189.1	5.7			
687250		182.9	188.8	5.5	185.2	191.1	7.0			
		183.8	191.2	6.5	183.0	190.0	5.5		NOT	RUN
					183.1	190.2	5.5			
AVG		183.4	190.0	6.0	183.8	190.4	6.0			
719391		177.5	189.4	7.0	175.8	188.6	6.0		286	110
		180.2	191.3	7.0	178.0	189.3	8.0		319	227
					177.4	188.5	7.5		297	322
AVG		178.8	190.4	7.0	177.1	188.8	7.2		301	220
719395		188.1	193.7	6.0	187.1	192.7	5.5			
		190.8	196.0	6.0	185.0	193.3	6.0		NOT	RUN
					173.6	183.7	7.0			
AVG		189.4	194.8	6.0	181.9	189.9	6.2			
687249		182.4	186.8	6.5	169.2	180.7	6.5			
		179.8	186.8	6.5	177.8	188.8	6.0		NOT	RUN
					173.7	183.5	6.0			
AVG		180.1	186.8	6.5	173.6	184.3	6.2			
687916		166.4	178.1	7.0	175.7	181.1	6.0			77
		166.7	179.3	8.0	171.9	180.8	8.0			38
					169.7	179.4	4.0			63
AVG		166.6	178.7	7.5	172.4	180.4	6.0			59

All tension-tension fatigue spec. run at 120-12 ksi stress level.

CONVAIR—FORT WORTH
TABULATION SHEET

TABLE ID-X
Mechanical Properties of 0.025 Gage 17-7PH
Steel -- No 1400F Conditioning Step

PANEL NO	GRAIN DIR		As Heat Treated F_{ty}-ksi	F_{tu}-ksi	%e		After 50 hr Salt Spray F_{ty}-ksi	F_{tu}-ksi	%e		GRAIN DIR	Ten-Ten Fat As H.T. 10^3 Cycles	50 hr Salt 10^3 Cycles
687305	Trans.		188.4	194.6	4.0		186.6	193.3	3.0		Trans.	71	62
			187.8	193.5	4.0		186.0	193.4	3.5			122	—
							184.8	192.0	3.5			134	27
AVG			188.1	194.5	4.0		185.8	192.9	3.3			116	74
691937	Trans.		173.1	181.9	6.0		169.2	180.3	5.5				
			169.2	180.0	6.0		169.4	179.8	5.0			NOT	RUN
							163.6	179.3	6.0				
AVG			171.2	181.0	6.0		167.1	180.0	5.5				
			Averages of										
			%e Values			NOTE:	All	tension-tension			fatigue specimens		
			from	Tables									
			ID-VIII	IX & X			were	run	at	120-12 ksi	stress level		
Trans. -	As H.T.		5.86										
Long. -	As H.T.		6.03										
All -	As H.T.		5.94										
Trans. -	50 hr Salt		5.48										
Long. -	50 hr Salt		5.89										
All -	50 hr Salt		5.68										

CONVAIR—FORT WORTH
TABULATION SHEET

Mechanical Properties of 0.025 Gage
17-7PH Steel -- With 1400F Conditioning

PANEL No		Tested by RL - As Brazed					Tested in ENV - 52hr Salt S.					Tension Fatigue		
		Gr Dir	F_{ty}-ksi	F_{tu}-ksi	% e		Gr Dir	F_{ty}-ksi	F_{tu}-ksi	% e		Gr Dir	A- [illegible]	[illegible]
687925		Trans.	Eight Spec									Trans.	173	76
				Run				NOT	RUN				124	57
													105	87
AVERAGE			1895	1954	4.0								134	73
677414			Eight Spec										105	53
				Run				NOT	RUN				117	43
													125	—
AVERAGE			1942	2000	3.9								116	47
680867			Eight Spec				Long.	177.6	203.3	6.5			442	61
				Run				177.9	195.3	6.5			412	—
								1791	1957	6.0			751	36
AVERAGE			[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	6.3			[illegible]	[illegible]
691932			Eight Spec				Trans.	199.5	225.5	3.5			170	63
				Run				199.6	206.0	3.0			7569→	226
								197.4	205.0	5.5			514	146
AVERAGE			1947	2010	5.0			1992	2055	4.0			342	[illegible]
680859			Eight Spec				Long.	179.4	195.5	4.5			—	107
				Run				197.1	203.7	5.0			124	141
								196.6	203.8	6.0			188	143
AVERAGE			1941	1992	3.7			1944	2010	5.2			156	130
687939			Eight Spec										108^{3}	—
				Run				NOT	RUN				175^{3}	122
													560	214
AVERAGE			1823	1880	3.7								281	168
687323			Eight Spec										7400→	43
				Run				NOT	RUN				228	121
													135	43
AVERAGE			920	1794	3.7								207	69

All tension tension fatigue specimens were run at 120-12 KSI stress level.
* [illegible] 10^3 C[illegible]

CONVAIR —FORT WORTH

TABULATION SHEET Notch Tensiles from 0.025 Gage 17-7PH Steel

Bnd No. - Spec.	1400F Step	Notch Radius	Ult Ksi	Attachment	Notch Ratio
681033 - 1	Yes	0.004	204.2	Pins	
2			209.7		
3			201.8		
4			202.3		
5			211.6		
6			192.1		
7		0.003	223.7		
8		0.004	196.8		
9			200.5		
Average			202.5		1.02
719397-1	No	0.005	194.1	Pins	
2			172.1		
3		0.004	194.5		
4		0.005	135.6		
5			137.8		
6		0.004	135.1		
7			189.2		
8			170.5		
9			185.7		
Average			135.1		0.88
687918-1	No	0.005	*154.4	Grips	
2		0.004	*166.5		
3			*156.3		
4			*155.3		
5			*152.9		
6			*148.0		
7			*150.0		
8			188.0	Pins	
9			—— B		
Average			188.0		1.02

B - Bearing failure

*Not included in average - Visual inspection indicated uneven loading

CONVAIR — FORT WORTH
TABULATION SHEET Effect of Specimen Width on % Elongation — in 0.025" & 0.010" Thick 17-7PH Steel

Gage		Width		Ult. KSI		Elongation — Inches x 10^{-3} Ga. Leng →	0.2"	0.4"	1.0"	2.0"
0.010"		.500		196.0				50	87	120
		.450		191.0				60	97	154
		.400		196.0				47	83	116
		.350		197.0			^{1}40	47	83	114
		.300		197.0			^{1}30	50	80	90
		.250		200.0			^{2}32	33	63	80
		.200		202.0			^{1}40	50	73	112
		.150		184.0			26	47	93	116
		.100		183.0			25	43	70	72
.025		.500		199.0				52	89	[illegible]
		.450		195.0				60	92	123
		.400		192.0				50	72	100
		.350		196.0			^{2}30	40	83	114
		.300		193.0			^{1}30	47	73	100
		.250		192.0			^{2}30	35	65	80
		.200		204.0			^{2}32	42	65	80
		.150		187.0			^{2}25	40	80	82
		.100		181.0			25	37	55	64

Note: Each elongation value is average of 3 specimens except as noted

Superscripts in 0.2" gage length column indicate fewer than 3 specimens were tested

Effect of Gage Length and Specimen Width on Elongation

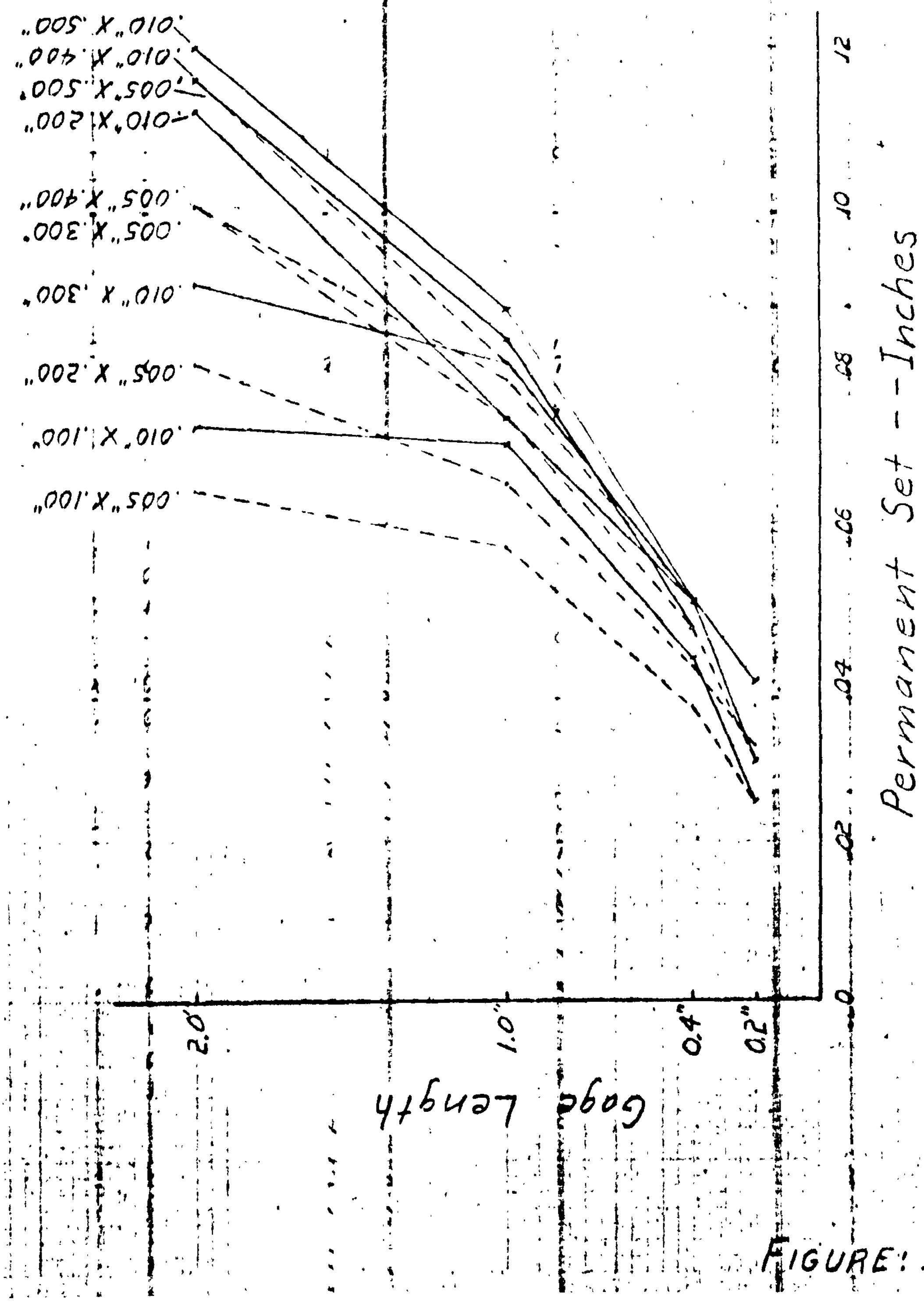


FIGURE: ID-1

HEAT TREATMENT

ITEM E - DETERMINATION OF RETAINED AUSTENITE IN 17-7 PH STAINLESS STEEL SHEET

In certain high carbon and alloy steels, rapid cooling causes a metastable, body-centered-tetragonal phase, martensite, to form. These steels usually contain residual untransformed austenite in addition to the martensite phase. The retained austenite is thought to have extensive effects on the mechanical properties of these steels. If the amount of retained austenite could be determined, this knowledge should be useful in predicting the properties which a particular steel will possess.

Dilatometric and magnetic methods of analysis can be used to determine the presence of retained austenite when it is present in amounts of 15% and above. X-ray diffraction techniques (1, 2, 4, 7) have been used to determine the amount of retained austenite when this phase is present in lesser amounts. The work reported in this section is the result of an attempt to adapt the X-ray diffraction method to 17-7PH stainless steel sheet.

The X-ray method for the determination of retained austenite in steel, first described by Averbach and Cohen (1), was used in this investigation. The method may be described as follows:

If a polycrystalline material containing austenite and martensite is irradiated with X-rays, each crystal will diffract independently according to Bragg's Law.

$$n\lambda = 2d \sin \theta$$

where n = any integer

λ = wavelength of X-rays

d = interplaner spacing in crystal

θ = angle of incidence of X-rays with the sample

The diffracted energy at any Bragg angle can be shown to be:

$$P_{\alpha}^{(hkl)} = \frac{K}{\nu_{\alpha}^{2}} F^{2} m (L.P.) e^{-2m} V_{\alpha} A(\theta)$$

where $P_{\alpha}^{(hkl)}$ = integrated intensity of martensite (hkl)

K = constant for a given experiment

F^2 = structure factor squared

m = multiplicity of (hkl)

L.P. = Lorentz Polarization factor

e^{2m} = Debye-Waller temperature factor

$A(\theta)$ = sample absorption factor (constant for diffractometer)

V_α = volume fraction of martensite

ν_α = volume of unit cell of martensite

A similar equation may be written for each diffraction peak of austenite (γ). The factors V, F, m, (L.P.) and e^{-2m} can be obtained for each interplanar spacing furnishing a diffraction peak. The values listed in Table IE-I were taken from Taylor's book "X-ray Metallography" (8). These constants can be combined into the coefficient R, and the following equations written:

$$P_\alpha = KR_\alpha V_\alpha \quad \text{(Eq. A)}$$

$$P_\gamma = KR_\gamma V_\gamma \quad \text{(Eq. B)}$$

The volume irradiated is then the only unknown. If the sample can be assumed to contain only austenite and martensite:

$$V_\alpha + V_\gamma = 1$$

Since K depends only on the experimental conditions and is independent of the kind and quantity of the diffracting substance:

$$\frac{P_\alpha}{R_\alpha} :: V_\alpha \quad \text{and} \quad \frac{P_\gamma}{R_\gamma} :: V_\gamma$$

Using these ratios for V_α and V_γ, the percent austenite in the sample may be calculated from the following:

$$\% \text{ austenite} = \frac{V_\gamma}{V_\alpha + V_\gamma} \text{ X } 100 \qquad \text{(Eq. C)}$$

This investigation was concerned with the amount of retained austenite present in heat treated 17-7PH stainless steel. After heat treatment, this steel is primarily martensitic; however, there are other phases present. Delta ferrite (a high temperature body-centered-cubic phase), carbides, intermetallic compounds, and retained austenite are all found in varying amounts. The delta ferrite can be observed after proper metallographic preparation and can comprise as much as 20% of the steel. This phase is indistinguishable in ordinary X-ray diffraction patterns from either martensite or alpha iron. This is because the differences in interplaner spacing within the crystalline lattices of these phases are extremely slight. The carbides can be seen metallographically but are not picked up by ordinary X-ray diffraction procedures. This fact and theoretical calculations based on stoichiometry and carbon content indicate that 17-7PH steel contains less than 1% carbide phases by weight. The intermetallic compounds are present in such low concentration as to leave doubt as to their identity. The amount of retained austenite varies with the heat treatment. However, this phase is usually picked up on X-ray diffraction patterns and so can be assumed to be in excess of 5% of the total alloy content.

The presence of carbides and intermetallic phases was ignored during this investigation. Their concentration is so low as to have no appreciable effect on the analytical results of the determination. The assumption was made that delta ferrite and austenite were present before heat treatment. After heat treating, martensite, delta ferrite and austenite were considered to be present. No attempt was made to distinguish between the martensite and delta ferrite phases in the X-ray diffraction patterns.

A major portion of the time spent on this investigation was concerned with surveying the pertinent literature and determining a possible test procedure. It was decided to use an X-ray diffractometer (2, 4) and record the diffraction pattern with a Brown Recorder. The other alternative was to use a camera-film procedure. No densitometer was available for reading film intensities, and the diffractometer seemed to provide a more straightforward method.

It soon became apparent that 17-7PH sheet is a troublesome material for this type of analysis. Previous workers had avoided orientated textures in the material being analysed. This was obviously impossible in the case of steel sheet. Also, the metallography of 17-7PH steel posed several problems. Metallographic procedures could provide a convenient means of cross-checking results obtained by the X-ray diffraction method. In 17-7PH steel several phases are present, and also the grain size in heat treated material is quite small.

Throughout the project, attempts were made to use the delta ferrite phase as a reference standard. The amount of this phase was determined by the lineal analysis or point counting method (6) in several instances. The results obtained by point counting did not agree with those obtained by the X-ray diffraction procedure. The reason for this lack of correlation is discussed later.

After the first few diffraction patterns were obtained, it was evident that severe grain orientation was present in the 17-7PH material. This can be seen in the P/R values listed in the tables. Assuming that the calculations for R are correct, the P/R values should be equal for all reflections in a particular phase and sample.

A rotating sample holder was introduced to attempt to compensate for the preferred orientation in the specimen. This attachment rotated the specimen around an axis perpendicular to the surface being irradiated. The results of the rotated specimens were as follows:

(hkl	Phase	17-7PH Cond.	P/R	17-7PH Cond.	P/R	17-7PH Cond.	P/R
(110)	α	A	0.2	T	20.9	TH	26.3
(200)	α	A	11.7	T	58.0	TH	64.0
(211)	α	A	9.0	T	Off S.	TH	100.0
(111)	γ	A	7.0	T	1.3	TH	2.1
(200)	γ	A	8.4	T	2.3	TH	2.1
(220)	γ	A	51.4	T	7.7	TH	8.8

It is apparent that the P/R values still showed large variations.

Next an attempt was made to cancel out the orientation effects by irradiating specimens taken from three directions with respect to the 17-7PH steel sheet. Figure IE-1 illustrates the manner in which the 17-7PH sheet was sectioned and the notation used to identify the sample direction with respect to the sheet in the tables. Results from three heats of material are given in Tables IE-II and IE-III. Again the P/R ratios varied.

Information concerning rolling textures was obtained from Barrett (3). Austenite has a face-centered cubic lattice. The primary rolling texture for this phase is (110) [$\bar{1}$12]. This indicates that the 110 plane will tend to be parallel to the rolling plane. The (110) planes will tend to be alined in a [$\bar{1}$12] direction with respect to the rolling direction. In the case of delta ferrite the primary texture should be (100) [011]. The expected orientation of the martensite phase was not determined. Its orientation would depend on the orientation present in the austenite phase prior to transformation.

From the preceding paragraph it can be seen that, when the flat surface of the steel sheet was irradiated, the (200) reflection from ferrite and the (220) reflection from austenite should have been strongest. This was found to be in agreement with the experimental results. However, the degree to which this orientation was present varied from sample to sample.

Further conclusions from the above information can be applied to specimens taken from other directions in the sheet. The interplaner angles between reflecting planes can also be calculated. From these angles and the experimental P/R ratios it was determined that the (211) line of martensite and the (200) line of austenite were least affected by the rolling texture. The average values obtained from these reflections were determined by adding the integrated intensities for the flat, edge, and end specimens and dividing by three. The average P value obtained was then divided by R and substituted in equation C. These results together with the % delta ferrite obtained by point counting are listed in Table IE-III. The tensile results from each heat of 17-7PH steel are also listed. Figures IE-2, 3, and 4 are photomicrographs of A condition 17-7PH steel etched to show the delta ferrite phase. The difference in orientation in the flat, edge, and end specimens in evident.

The calculated values for the percent delta ferrite in the three heats of A condition 17-7PH steel do not agree with the measured percentages. In heat 47660 the amount of delta ferrite determined by the X-ray method is almost twice the measured amount. This is in contrast to heats 67200 and 67177 in which the X-ray value is lower than the measured value. This can be explained only if the A condition 17-7PH steel from heat 47660 contained some martensite. Carwile and Rosenbery (5) show photomicrographs of A condition material which seemingly contained martensite. Attempts to show that A condition material from heat 47660 contained martensite were inconclusive. The appearance of a substructure in the austenite grains was observed after severe etching. However, the same type of structure was observed in the other two heats of material after similar metallographic treatment.

It is apparent that, based on the present experimental results, the validity of the retained austenite values cannot be stated. The possibilities of this method of determining retained austenite have not been fully explored. It seems entirely possible, given sufficient time, that a workable method could be determined.

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3. C. S. Barrett, "Structure of Metals", 1952, McGraw-Hill Book Company, New York, N. Y., 631 pages.
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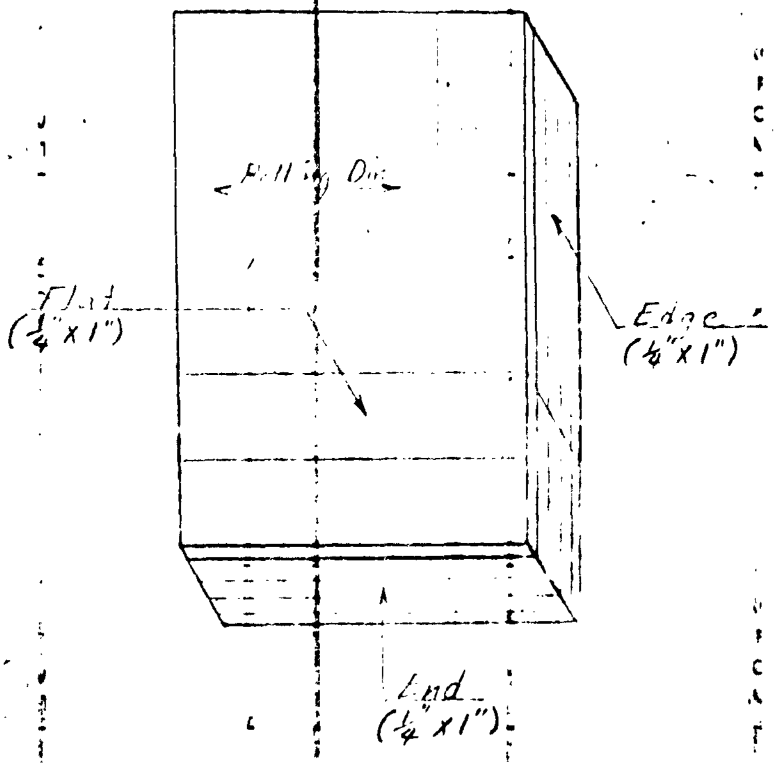
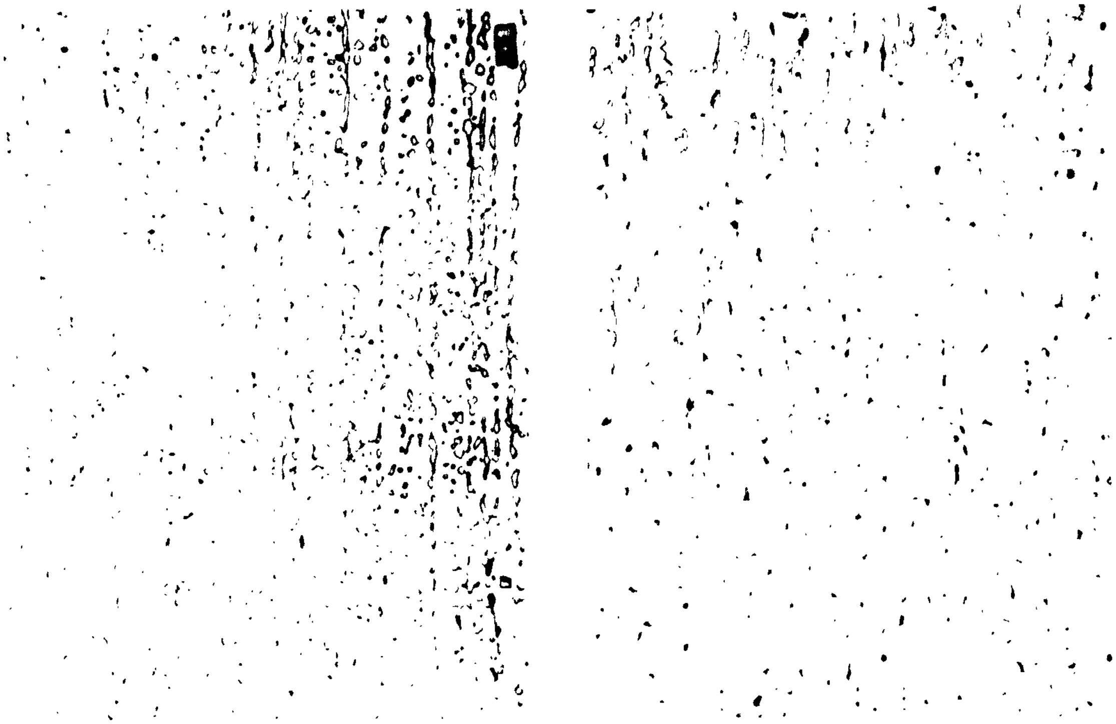
5. N. L. Carwile and S. J. Rosenberg, "A Study of 17-7PH Stainless Steel", WADC Tech. Report 58-653, June 1959, 36 pages.
6. R. T. Howard and M. Cohen, "Quantitative Metallography by Point Counting and Lineal Analysis", Met. Tech., August 1947.
7. R. E. Ogilvie, "Retained Austenite by X-rays", Norelco Reporter, May-June 1959, Vol. VI, No. 3, p. 60.
8. A. Taylor, "An Introduction to X-ray Metallography", 1952, John Wiley and Sons Inc., New York, N. Y., 325 pages.

Surface with Respect to Rolling Direction in Determination of Retained Austenite



Note Arrows point to surface irradiated in each case.

FIGURE: IE-1



CONVAIR—FORT WORTH

~~TABULATION SHEET~~ CONSTANTS FOR AUSTENITE & MARTENSITE

TABLE IE-I

Crystal Structure	Phase	(hkl)	$\theta_{calc.}^{(2)}$	$\sin\theta$	$\sin\theta / \lambda_{Cr}$	f_o	f	F	m	L.P.	e^{-2M}	v	$R^{(3)}$
FCC	γ	(111)	67.24	.5536	.2416	17.5	15.6	62.4	8	4.6	.93	$(3.58)^3$	63.3
"	"	(200)	39.75	.6394	.2792	16.1	14.2	56.8	6	3.3	.90	"	27.3
"	"	(220)	64.72	.9043	.3949	13.4	11.5	46.0	12	4.0	.81	"	39.1
BCC[1]	α	(110)	34.47	.5661	.2471	17.3	15.4	30.8	12	4.1	.91	$(2.86)^3$	77.6
"	"	(200)	53.14	.8000	.3498	14.5	12.6	25.2	6	2.8	.84	"	16.4
"	"	(211)	78.64	.9804	.4290	12.8	10.6	21.2	24	8.7	.78	"	133.8

(1) Since the equipment used did not resolve the body-centered tetragonal doublets of the martensite (α); both F and m for this phase were calculated on the basis of a body centered cubic structure.

(2) The angle θ was calculated from: $\sin^2\theta = \frac{\lambda^2}{4}\left[\frac{h^2+k^2+\ell^2}{a^2}\right]$ using $\lambda = 2.2896$ Å for chromium K_α wavelength radiation.

(3) R was calculated from the equation:

$$R = F^2(L.P.)\,m\,e^{-2M}\left(\frac{1}{v^2}\right)$$

Misc. Items:

(a) Absorption Edge of Fe = 1.7394 kX units

(b) Debye Temp. Factor of Fe = 420° Kelvin

(c) $f = f_o - \Delta f$

$\Delta f = 1.9$ above.

CONVAIR—FORT WORTH
~~TABULATION SHEET~~

TABLE II-II

X-ray Diffraction Results from Heats 67200 & 67177 of 17-7PH Steel Sheet Material

HEAT NO	GAGE	SPEC. DIR.		17-7PH Cond.	(hkl)	P_α/R	(hkl)	P_γ/R		17-7PH Cond.	(hkl)	P_α/R	(hkl)	P_γ/R
67200	0.035	Flat		A	(110)	14.3	(111)	49.7		TH	(110)	39.0	(111)	3.3
					(200)	400.0	(200)	77.0			(200)	203.8	(200)	6.0
					(211)	17.3	(220)	off S.			(211)	89.6	(220)	12.1
		Edge			(110)	50.0	(111)	off S.			(110)	28.6	(111)	7.2
					(200)	33.4	(200)	145.0			(200)	45.0	(200)	7.0
					(211)	22.9	(220)	80.0			(211)	64.2	(220)	3.6
		End			(110)	off S.	(111)	off S.			(110)	117.2	(111)	12.2
					(200)	26.6	(200)	124.0			(200)	32.5	(200)	7.0
					(211)	17.1	(220)	72.6			(211)	49.0	(220)	2.1
67177	0.040	Flat		A	(110)	23.6	(111)	38.0		TH	(110)	62.5	(111)	3.7
					(200)	122.0	(200)	24.0			(200)	190.0	(200)	9.0
					(211)	14.9	(220)	111.0			(211)	70.5	(211)	12.9
		Edge			(110)	26.3	(111)	47.0			(110)	67.0	(111)	15.9
					(200)	10.3	(200)	48.0			(200)	78.4	(200)	17.5
					(211)	8.3	(220)	64.0			(211)	76.8	(220)	15.0
		End			(110)	43.0	(111)	off S.			(110)	68.3	(111)	12.2
					(200)	43.3	(200)	143.0			(200)	80.0	(200)	6.0
					(211)	16.1	(220)	74.0			(211)	71.5	(220)	13.6

Notes:

1. 17-7PH Cond. A was in as rec'd annealed condition.
2. 17-7PH Cond. TH was heat treat with Armco TH 1050 treatment.
3. hkl are indices of reflecting plane
4. P_α is integrated intensity from Δferrite or martensite phase.
5. P_γ is integrated intensity from austenite phase.
6. R is a constant

TABLE IE-III

CONVAIR—FORT WORTH
TABULATION SHEET

X-ray Diffraction Results from Heat ~~47660 of~~ 17-7PH Steel Sheet Mat'l

HEAT NO.	GAGE	SPEC. DIR		17-7PH Cond	(hkl)	P_α/R	(hkl)	P_γ/R		17-7PH Cond	(hkl)	P_α/R	(hkl)	P_γ/R
47660	0.025	Flat		A	(110)	10.7	(111)	54.0		TH	(110)	41.0	(111)	2.4
↓	↓	↓		↓	(200)	100.0	(200)	48.0		↓	(200)	195.0	(200)	4.0
					(211)	920	(220)	2500			(211)	99.0	(220)	9.3
↓	↓	Edge		↓	(110)	off S.	(111)	off S.		↓	(110)	off S.	(111)	8.7
		↓			(200)	0.0	(200)	96.0			(200)	37.5	(200)	3.0
					(211)	17.2	(211)	57.0			(211)	46.0	(220)	3.0
↓	↓	End		↓	(110)	off S	(111)	off S.		↓	(110)	off S.	(111)	7.2
		↓			(200)	53.5	(200)	98.0			(200)	53.0	(220)	4.0
					(211)	19.5	(211)	800			(211)	75.0	(220)	4.3

Calculated % △ Ferrite (α) or % Retained Austenite (γ)

HEAT NO.	17-7PH Cond.		(hkl)	Avg. V_α		(hkl)	Avg. V_γ		Exp % α	Exp % γ	Measured % α	F_{tu}	% e
67200	A		(211)	19.1		(200)	115.3		14.2		18.7		
67177	A		(211)	13.1		(200)	71.7		15.5		18.7		
47660	A		(211)	26.3		(200)	80.7		24.6		13.6		
67200	TH		(211)	67.6		(200)	6.7			9.0		196.2	5.0
67177	TH		(211)	72.9		(200)	10.8			12.9		197.1	8.7
47660	TH		(211)	73.0		(200)	3.7			4.8		217.9	6.2

ITEM - CONCLUSIONS FOR ITEMS A THRU E

The conclusions drawn from the several investigations relating to the heat treatment of 17-7 PH steel sheet, summarized in Items A to E, are given in the following paragraphs.

ITEM A - INITIAL HEAT TREAT RESPONSE STUDIES ON 17-7 PH STEEL.

Tensile tests were made on sheet after various heat treatments. The tests were mostly on specimens .005", .008", and .020" thick. With the RH 1050 type of treatment, a conditioning time of 30 to 90 minutes gave acceptable tensile properties. Times of 10 and 60 minutes at the transformation temperature of -100 F gave satisfactory tensile properties except for sheet .085" thick. In the TH 1050 type of treatment with variations of the transformation temperature, transformation at +54 F gave more consistent values than did lower temperatures. Aging at 950 F gave higher strength values and lower elongations than aging at 1050 F.

A particular heat treatment without a conditioning step gave acceptable tensile properties. This suggested a suitable brazing regimen might be worked out for elimination of the 1400 F step. In some tests, appreciable variations in tensile properties were noted, depending on several factors. These included the temperature to which heated, the time at the conditioning temperature, cooling rate, and thickness of the sheet. The tensile yield and ultimate strength were generally increased as the conditioning temperature was decreased from 1700 to 1400 F. Both strengths were decreased and the elongation increased with increasing aging temperature from 1050 to 1100 F. Specimens of 17-7 PH steel sheet processed at opposite ends of a retort during the brazing of a sandwich panel showed an average difference of 16 ksi in yield strength and 11 ksi in ultimate strength. The endurance limit of 17-7PH steel sheet .008" thick, in the TH 1050 condition, was determined as 106 ksi in axial tension-tension fatigue.

The dimensional changes of 17-7PH steel sheet specimens on heat treatment were measured. All the specimens grew somewhat during heat treatment through the transformation step. They contracted a little on aging. The final result was growth. With increasing temperature of aging the amount of contraction increased. For some reason the overall growth of the .005" thick sheet was predominantly greater than that of the .008" or .020" material. In all instances, the total growth was relatively small.

ITEM B - COMPARISON OF BRAZING CYCLES OF HEAT TREATMENT OF 17-7PH STEEL SHEET BRAZED WITH 85:15 SILVER MANGANESE ALLOY.

Several basic procedures of heat treatment with variations were investigated in connection with developing a satisfactory brazing cycle for use with the 85:15 silver-manganese alloy. Tensile tests were made on 17-7PH steel specimens mostly in three thicknesses, viz., .005", .008", and .020", after the various heat treatments.

Practically all the treatments tried, as simulated brazing cycles, gave acceptable tensile properties when the specimens were aged at 1050 or 1060 F. Specific treatments gave high yield and ultimate strengths with satisfactory elongation. Other treatments gave high elongation with acceptable strengths. Thus, a choice of procedures was made available.

The elongation generally increased under the following conditions: With increase in the thickness of specimen; with increase in transformation temperature; and with increasing temperature of aging. For a given heat treatment, the elongation tended to increase with decrease in time at the transformation temperature of -100 F.

Usually, when the elongation increased, the yield and ultimate strengths decreased.

With only one exception, the .008" thick sheet had higher yield and ultimate strengths than the .005" and .020" materials for all heat treatments. The elongation of the .020" thick sheet was highest for these treatments.

ITEM C -

Changing brazing alloys necessitated further work to determine the effect of different heat treatments on the tensile properties of 17-7PH steel sheet. This was for the purpose of comparing simulated brazing cycles for use with the sterling silver plus .2% lithium alloy in brazing sandwich panels. In particular, the effects of transformation and aging temperatures were investigated.

For the .010" thick sheet, when the 1400 F step was incorporated in the cycle, the tensile strength tended to increase with lower transformation temperatures. Without the 1400 F step there was a marked loss of strength with transformation temperature of -100 F. For the .005" sheet, with the 1400 F step, the strength was appreciably decreased by transforming at -60 and -100 F. Without the 1400 F step the strength tended to decrease noticeably with decreasing temperature of transformation, with a marked loss for -100 F; there was a considerable increase for -20 F.

The values for various tests on specimens cut from brazed sandwich panels were mostly acceptable. However, tension-tension fatigue specimens failed considerably below the specified minimum, and skin specimens from one panel showed low elongation.

ITEM D -

The investigation summarized as Item D led to the following conclusions:

The 1400 F conditioning step is not necessary when a brazing temperature of 1650 F is used for 17-7PH steel sandwich panels.

For some heats of 17-7PH steel sheet an aging temperature of 1050 F can give low elongation. An aging temperature of 1060 - 1070 F may be better for production.

The percent elongation of thin 17-7PH steel sheet increases with increasing width of test specimen. With increasing gage length the measured elongation increases. Also, with decreasing gage length the scatter in value decreases.

ITEM E -

As to Item E, the following conclusions were drawn:

The texture developed by rolling 17-7PH steel sheet in light gages exhibits pronounced directionality. The degree of grain orientation varies from heat to heat.

The (211) reflection of ferrite and martensite and the (200) reflection of austenite are least affected by the grain orientation.

The percentages of retained austenite found in 17-7PH steel sheet by the X-ray diffraction method were in the range to be expected on the basis of prior work on martensitic steels. No means was found to validate the results.

CORE PROBLEMS

Three investigations on problems relating to honeycomb core were carried out in 1956-1957. The results were reported in memoranda. Summaries of these investigations are given as Items F, G, and H.

ITEM F - ELEVON RIB CORE, 4T2615:

Early in 1956, a peculiar appearance of honeycomb core was noticed in production after pickling for cleaning and before layup of panels. The core had been supplied by the John J. Foster Mfg. Company, Costa Mesa, California. Cleaning produced a series of bright and dull bands, alternating to suggest zebra stripes. The appearance is shown in the photograph of Figure IF-1. More of the core was bright than dull.

Tests were made to determine the cause of the banding. These disclosed that the elevon rib core (4T2615, S/N 1811, IR 33234) was not fabricated entirely in 17-7PH steel but rather largely in type 321 stainless steel. The smaller amount of the core was 17-7PH steel.

Knoop hardness tests showed some difference between the dull and bright bands. Converted to Rockwell hardness numbers, the values were: Dull, R_B 98.5; bright R_B 90-92. Metallographic examination showed a pronounced difference in structure of the dull and bright core. Figure IF-2 is a photomicrograph of a dull section. This is typical of annealed 17-7PH steel. Figure IF-3 is a photomicrograph of a bright section. This is an austenitic structure similar to that of 18-8 stainless steel. Chemical analysis of the bright core gave results corresponding to the nominal composition of 321 stainless steel.

This investigation indicated that 321 steel foil had lost identification in the plant of the core manufacturer and had become mixed there with 17-7PH steel foil.

When the investigation was completed, recommendation was made that all honeycomb core then at Convair-FW be examined and tested for composition. Recommendation was also made that procedures of quality control be established for all core received at Convair to prevent a recurrence of the situation described.

ITEM G - CERRO-ALLOY ATTACK ON 17-7PH STEEL:

A preliminary investigation was carried out about the middle of 1956 to determine the effect of Cerro alloys on the tensile properties of 17-7PH steel foil. The so-called Cerro alloys are supplied in a variety of analyses and are compositions which melt at relatively low temperatures, e.g., 100 to 200 F.

This preliminary work indicated that the alloy Cerrobend in contact with the steel diffuses into it when the temperature is raised for brazing or heat treatment. The diffusion is quite detrimental to the steel, causing a loss in tensile strength of up to 75%, and mostly or wholly destroying the elongation.

In performing the experimental work, tensile test specimens of 17-7PH steel foil, .002" thick, were subjected to a dondition much more severe than would normally be encountered in the production brazing of honeycomb sandwich panels. Cerrobend was cast around each specimen before heat treatment. The specimens were then exposed to a simulated production brazing cycle and subsequently heat treated in accordance with the schedule of Table IG-I. Cerrobend melts at about 158 F. When the tensile specimens were heated in the simulated brazing cycle, the resulting liquid alloy diffused into the steel.

Table IG-I gives the results of the tensile tests on the specimens as heat treated. The tensile properties of 17-7PH steel foil, .0015-.002" thick, heat treated as indicated may be taken as: Tensile yield strength, upwards of 150 ksi; ultimate strength, upwards of 180 ksi; and minimum elongation in 2", 3%. The values may be compared with the test results in the Table. Figure IG-1 is a photomicrograph which shows the intergranular diffusion of the Cerrobend in the steel.

Additional work was done on selected samples of honeycomb core represented as typical of vendor fabrication in which one of the Cerrolow alloys was used to aid in the milling operation. The particular Cerrolow composition was not identified. The core samples were heat treated at Convair, using a production cycle. Metallographic examination was made to determine whether the vendor's cleaning process had removed all the Cerrolow. Numerous samples were examined, and in two sections areas were found where slight intergranular diffusion had occurred. X-ray fluorescent analysis indicated that small amounts of bismuth, estensively originating in the Cerrolow, were present in core as received and in core after heat treatment at Convair.

ITEM H - INVESTIGATION OF LOW STRENGTH HONEYCOMB CORE:

An investigation was completed early in 1957 on the cause for low strength of honeycomb cores in brazed sandwich panels as detected by the flash test. These panels were produced in 17-7PH steel and were brazed with the 85:15 silver-manganese alloy. Metallographic examination, chemical analyses for carbon and nitrogen, and microhardness tests were made on the core of the panels. Flatwise compression tests were performed on samples from the panels.*

The panels involved in this investigation were production parts from vendors and from Convair as well as experimental items brazed in production facilities. Type 3-10 core was used in some panels. These were tested to determine the structural integrity of the type 3-10 core.

Early in this work, two conditions which affect the strength of core were observed. One was the degree of response to heat treatment and the other was intergranular penetration of the core steel.

The data obtained in testing samples from a number of panels are given in Table IH-I.

A comparative measure of the response to heat treatment of various core samples was obtained from Knoop hardness determinations on cross-sections of the core foil. The values converted to Rockwell C numbers are listed in Table IH-I. These values are considered to be comparable as among core samples but are not convertible to tensile strength. In addition, core hardness is not indicative of panel strength.

The initial work on panels brazed with 3-10 core developed the following observations:

1. The hardness of cores varies among panels.
2. Nearly all carbon determinations were higher than the .09% maximum specified in Mil-S-25043. All nitrogen determinations were above the .03% maximum specified by the Armco Steel Corporation, producer of 17-7PH steel.

*See Supplemental Sheet S-1

3. Core hardness was significantly lower than skin hardness on all panels tested.

4. The lowest core hardness corresponded to exceptionally high contents of both carbon and nitrogen.

5. Core material containing high carbon and nitrogen was heat treated in the laboratory to hardness higher than that of many core samples from panels.

6. Variance in core hardness among panel samples did not correlate consistently with flatwise compression values.

Referring to the chemical analyses noted in item 2 above, the results of a study on the effects of carbon and nitrogen on the response of 17-7PH steel foil to heat treatment has been reported in FGT-2452. Correlation was not established.

Intergranular penetration has been mentioned. This condition was found in the core of panels where the flash test and mechanical tests indicated low strength. The penetration appeared to be an oxidation or corrosion effect associated with the brazing atmosphere. Figure IH-1 is a photomicrograph which shows this type of penetration. Its occurrence is not related to the presence of the brazing alloy. Grain-boundary penetration by oxidation or corrosion diminishes the section of the core and reduces the panel strength. A microstructure regarded as normal for 17-7PH steel core in a brazed panel is shown in Figure IH-2.

During brazing, the conditions which cause the type of penetration just described are not known. However, a penetration of similar appearance can be produced by heat treating in an atmosphere of argon having a high content of water. In examining intergranular penetration, the object was to determine whether it reflected a susceptibility of some core to oxidation or other attack under certain brazing conditions.

Testing was discontinued because the type 3-10 core proved inadequate under marginal processing conditions. Although variations in chemistry, microstructure, and response of core to heat treatment did exist, the performance of the core in a panel was not definitely related to these items. Rather, control of the brazing process and the quality of the resulting brazement appeared to be more important. In general, the response of the core to heat treatment was inferior to that of the skin material. Still, the core did respond well enough to impart adequate strength to the panel.

CONCLUSIONS: ITEMS - F, G, H.

ITEM F - ELEVON RIB CORE

The investigation of a banded appearance of honeycomb core supplied by a vendor showed that the core had been fabricated partly from 17-7PH steel foil and partly from 321 stainless steel foil. The conclusion was drawn that the two steels had become mixed in the fabricator's plant. Also, the conclusion was reached that a recurrence of this situation should be prevented by establishing suitable procedures of quality control.

ITEM G - CERRO ALLOY ATTACK ON 17-7PH STEEL

The investigation of the effect of Cerro alloys on the tensile properties of 17-7PH steel foil showed that diffusion of the alloys caused large loss in strength and mostly or wholly destroyed the elongation of the steel. Examination of honeycomb core from vendors who used Cerro alloys in their milling operations showed that small amounts of bismuth derived from these alloys might be present. This contamination was ascribed to inadequate cleaning of the core.

ITEM H - INVESTIGATION OF LOW STRENGTH HONEYCOMB CORE

The investigation of low strength honeycomb core developed some useful information. At least three factors which affect the strength of core and panels were observed. The first was the degree of response to heat treatment, and the second was intergranular penetration of the core steel. Lastly, the thickness of the core foil was found to be quite significant.

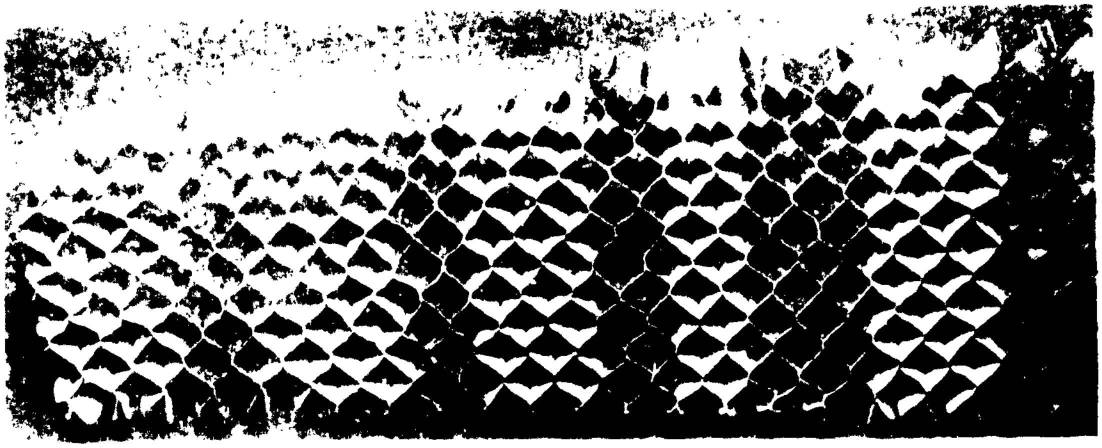
Core hardness varied among panels, and it was consistently lower than skin hardness. Core hardness did not correlate satisfactorily with the flatwise compressive strength of specimens from panels. Both the carbon and nitrogen contents of cores differed markedly among various samples and for the most part substantially exceeded the specification limits. Furthermore, the chemistry as concerns carbon and nitrogen in the cores did not correlate with core hardness or panel strength.

The tests on type 3-10 core did not solve any metallurgical problems. They did indicate that the thickness of .0010" provided scant or no margin for slight imperfections due to manufacture or material.

The results of tests pointed to the possibility that departures from optimum heat-treating procedure may have significant effect on core response without influence on panel skin response. Factors in heat-treating procedure include time and temperature of solution, atmosphere, and details of cooling and of aging.

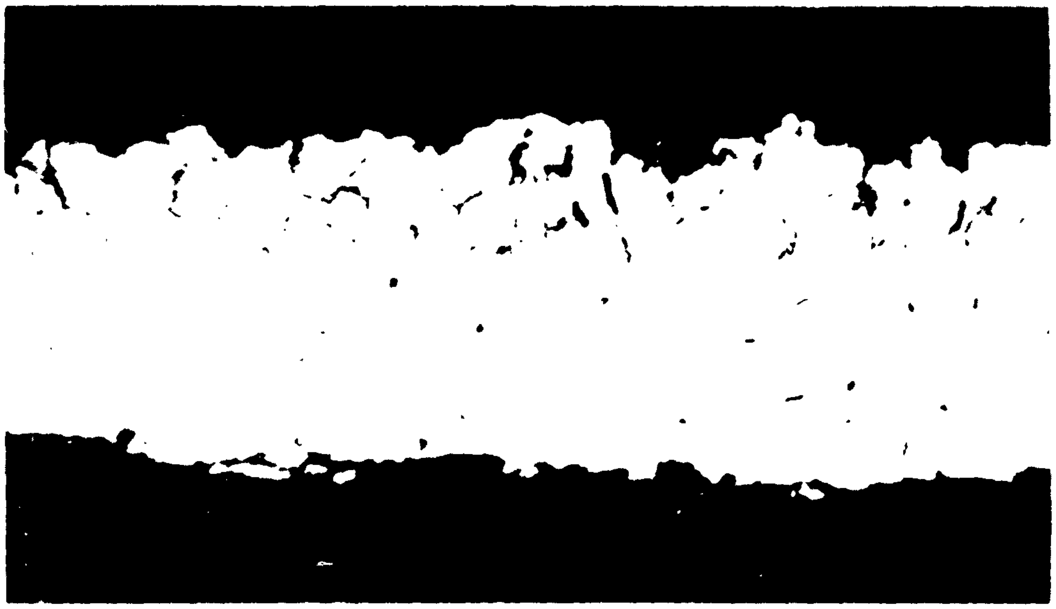
Factors which appeared to affect the flatwise compressive strength of panels include the fillet dimensions, core thickness, intergranular penetration of the core, and the extent of foil buckling developed in fabrication of the core.

Intergranular penetration due to oxidation or corrosion was evidently associated with a contaminant in the brazing atmosphere. At the same time, microstructural differences in core material examined in this investigation indicated the possibility of varying susceptibility to intergranular penetration.



Department 6
FWP 1072-8-54

Figure IG-1: Intergranular diffusion of Cerrobend in 17-7PH steel foil; excess Cerrobend on edges of steel; etchant electrolytic oxalic acid; X250.



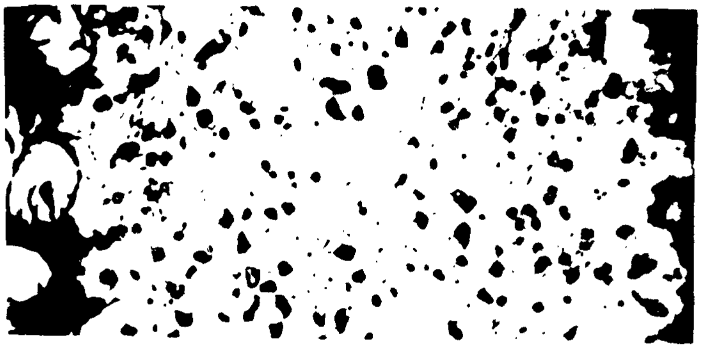


TABLE IG-I

EFFECT OF CERROBEND ON THE TENSILE PROPERTIES OF 17-7PH FOIL, .002" THICK

Specimen	Yield Strength, ksi	Ultimate Strength, ksi	Percent Elongation
1	None	73.5	None
2	None	47.0	None
3	None	79.0	None
4	None	139.6	0.5
5	None	44.1	0.5
6	None	143.4	None
7	158.9	162.8	None
8	None	114.9	0.5
9	None	95.7	None

Heat treatment cycle:

1. Held at 1815 F for 15 minutes
2. Furnace cooled to 1400 F in 90 minutes
3. Held at 1400 F for 90 minutes
4. Furnace cooled to room temperature in 4-1/2 hours
5. Quenched to -20 F
6. Aged at 1050 F for 90 minutes

TABLE IH-1

TEST DATA ON PANELS EXAMINED: 17-7PH STEEL BRAZED WITH 85:15 SILVER-MANGANESE ALLOY

Panel Identification	Core Type	Flatwise Compressive Strength, psi	Core Hardness, Rockwell C	Core Composition Carbon %	Core Composition Nitrogen %
S/N 40,003*	3-10	-	15	.27	.25
1324-45 S/N 4911	3-10	355-644	24-29	.13	.26
1275-8 S/N 21001	3-10	157-244	31	.17	.24
1295-43-2 S/N 51002*	3-10	125-305	31	.23	.08
4P 1326-59 S/N 119	3-10	121-344	36	.09	.09
4P 1326-60 S/N 306-38	3-10		25	.10	.11
4T 14004 S/N 2409	3-10	172-399	27	.12	.07
4P 1271-101 S/N 10,016	3-10	131-307	29	.09	.04
4P 1661-13 S/N RO 3601-23	3-15	716-1116	44	.14	.22
4T 015-2 S/N 5000	3-15		32	.12	
4 FTP 356 S/N 3037	3-15	170-688	36	.20	.12
4T 2234-4 S/N 3274	3-15		27	.10	.13

* Flash Test Failure

EFFECT OF CARBON:

Two investigations concerning the effect of carbon in the brazing operation on 17-7PH steel were carried out. The results of one of these were reported in a memorandum. The results of the other were communicated verbally. Summaries of these investigations are given in the following items I and J.

ITEM I - EFFECT OF GRAPHITE ON 17-7PH STEEL DURING BRAZING AT 1850F.

An investigation was made to determine the amount of carbon absorbed by the steel from the graphite block or from the atmosphere in brazing 17-7PH steel panels. Also, the effect of the absorbed carbon on some mechanical properties was determined.

According to the specification of the Armco Steel Corporation the maximum carbon allowed in 17-7PH steel is .09%.

Specimens from 17-7PH sheet which had been put through the standard brazing cycle, used at the time (1955) with the 85:15 silver-manganese alloy, were analyzed for carbon. The arrangement in the brazing was as shown in Figure I-II. Here, T1 and B1 were top and bottom shim sheets in contact with the skins of the panel, and B2 and B2a were sheets in contact with the graphite form. These lettered sheets were all 17-7PH steel.

Table I-I-I gives the results of the chemical analyses for carbon. The samples identified as 6" x 6" x .008" were associated with a small test panel. It was not brazed but was laid up and put through the standard brazing cycle in the laboratory. The other samples identified as 049- etc. were associated with panels brazed in production. As may be noted, the carbon pick-up by the sheets in contact with the graphite was considerable. The carbon pick-up by the top and bottom shim sheets of the production panels brazed in argon was slight. These shims were shielded from the graphite. The much larger increase in carbon of the B2 and B2a sheets of the small test panel, as compared with the increase of the production panels, is attributed to the hydrogen atmosphere.

Specimens for the mechanical tests were cut from the top and bottom shim sheets and also from the sheets in contact with the graphite, used in the brazing of production panels. Tensile and axial tension-tension fatigue tests were made. The actual test data have been reported as no longer available. In the following two paragraphs are statements concerning these tests as given in the covering memorandum. The term 'shielded' means T1 and B1 shim sheets, and the term 'unshielded' means B2 and B2a sheets. The term 'skin' means shim sheet.

"The minimum ultimate and yield strength design allowables were met by both the shielded and unshielded 17-7PH stainless steel with 4.3 to 4.9% elongation for the 049-837-T4 skins. The 049-843-1 skins had higher ultimate and yield strengths with 2.8 to 3.8% elongation. The shielded skin from 049-841-7 met the minimum design allowables with 4.5% elongation.

"The results from the tension fatigue tests for the shielded and unshielded 17-7PH stainless steel appeared to show only a slight effect due to carbon pick-up for the skins from 049-837-T4. The endurance limit for the unshielded 17-7PH were (sic) approximately 5000 psi lower than those (sic) for the shielded 17-7PH."

ITEM J - INVESTIGATION OF EMBRITTLEMENT IN THE CORNER REGIONS OF 17-7 STEEL SANDWICH PANELS

An investigation was undertaken as a result of the rejection of several brazed 17-7PH steel sandwich panels because of a so-called corner condition. The term "corner condition" was meant to indicate that the panel showed evidence of contamination at the corners. Testing usually showed that such contaminated panel regions failed in a brittle manner.

The contamination was first attributed to air leaks in the incoming argon gas lines. Since several structural members of a sandwich panel join at the corners, these regions contain gaps that serve as openings for circulation of the purging gases into and out of the core during brazing. Air leaking into the argon line was eliminated by maintaining the pressure in the incoming gas line above atmospheric pressure.

Although excluding air from the argon undoubtedly afforded better panels, the corner condition was still found in some. Another possible cause of the contamination was thought to be carbon pick-up from the graphite brazing form. Test data were obtained to determine the validity of this idea.

Nine panels exhibiting contaminated corners were examined during this investigation. The data presented for panels 1, 3, 7, and 9 are representative of the results obtained. Metallographic sections were taken from contaminated areas in each panel, and chemical analyses for carbon and nitrogen were run on adjacent regions.

Figures IJ-1 through IJ-4 are diagrams showing the regions sampled and listing the carbon and nitrogen contents found in various panel sections. Figures IJ-5 through IJ-9 are photomicrographs of specimens removed from various locations in the panels.

The chemical analyses showed that the carbon content in the Z members in almost every instance exceeded the maximum amount, .09%, specified for 17-7PH steel. This excess carbon in the Z members was concentrated at the outer edge and more exposed upper surface, as shown in Figure IJ-2. In one panel, a high content of carbon was found on the outer side of a bottom skin. The nitrogen contents, although high in several analyses, did not suggest any definite pattern of location.

The metallographic examinations confirmed the results of the chemical analyses for carbon. Excessive amounts of carbides were present in the former austenite grain boundaries of the Z-member specimens. This carbide concentration was heaviest toward the surfaces of these parts. Figure IJ-5 shows the difference in carbide content of a Z member and a panel skin. Figure IJ-6 shows the difference in carbide content of a Z member and a panel doubler. Figures IJ-7, IJ-8, and IJ-9 show the presence of intergranular oxidation on the more exposed surfaces of Z members and doublers. This condition is definitely indicated in the photomicrographs in which the grain boundaries are evident when no etchant was used. The oxidation can be inferred, from the photomicrographs of the same sections after etching, by the extent of the attack on the surface layers.

CONCLUSIONS: ITEMS I, J

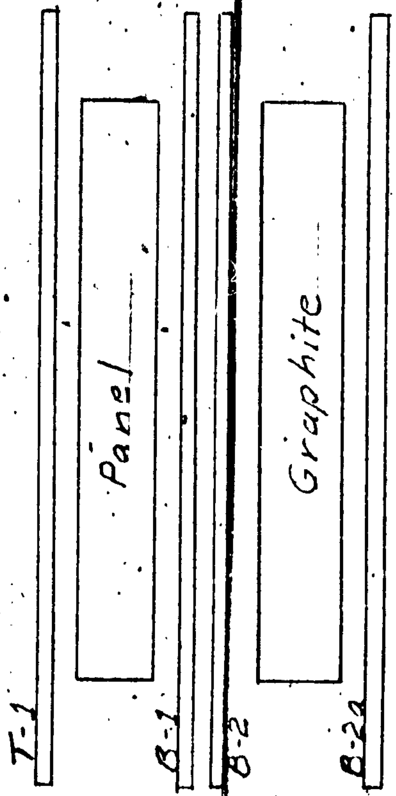
The investigation on the effect of graphite on 17-7PH steel during brazing at 1850 F showed that carbon is absorbed in considerable amount when the steel is in contact with the graphite. The test results indicated that graphite forms can be used successfully in brazing sandwich panels provided that a protection sheet is laid between the graphite and the panel skin.

The study on corner embrittlement disclosed that this condition is due to carbon absorption by the steel. Carbon contamination was found in the Z members of nine panels examined. The contamination was most severe in regions of maximum exposure to the circulating gases during brazing. Superficial intergranular oxidation was observed on the more exposed surfaces.

Table I-I-I - Indicated Carbon Pickup in Brazing 17-7PH Steel

Sample	Location	Brazing Atmosphere	Carbon %	Amount C in excess of Armco Specification
As received			.062	
6 x 6 x .008"	T1	Hydrogen	.128	.038
"	B2	"	.424	.334
"	B2a	"	.570	.480
049-841-7	T1		.074	
049-837-T4	T1	Argon	.072	
"	B1	"	.084	
"	B2	"	.126	.036
049-843-1	T1	"	.07	
"	B1	"	.076	
"	B2	"	.136	.046

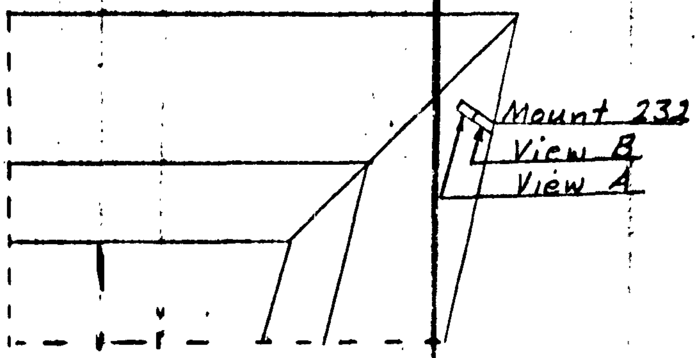
Diagram of Test Panel Layup



T-1 - Top shim sheet
B-1 - Bottom shim sheet
B-2 - Barrier sheet
B-2a - Bottom sheet, same as bottom of retort

FIGURE: IV-1

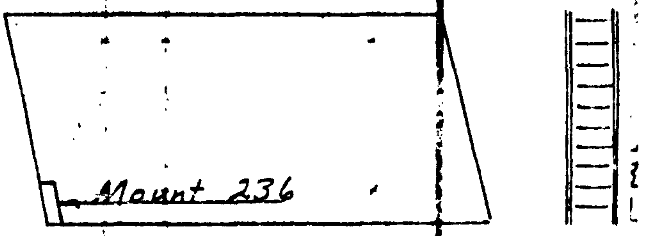
PANEL-1



Section 1-1

Chem:

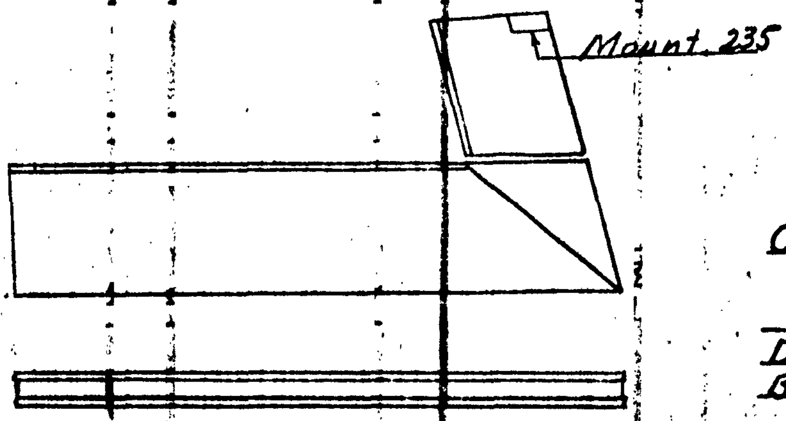
	C	N_2
Z	.128	.028
Doubler	.079	.035
Bot. Skin	.093	.030



Section 1-54

Chem:

	C	N_2
Top Skin	.082	.032



Section 1-10

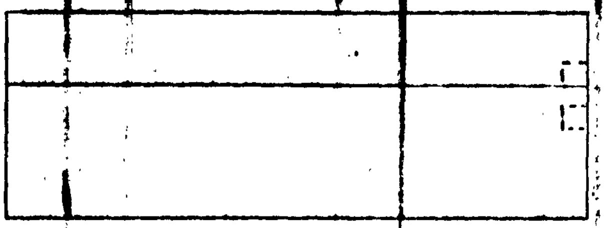
Chem:

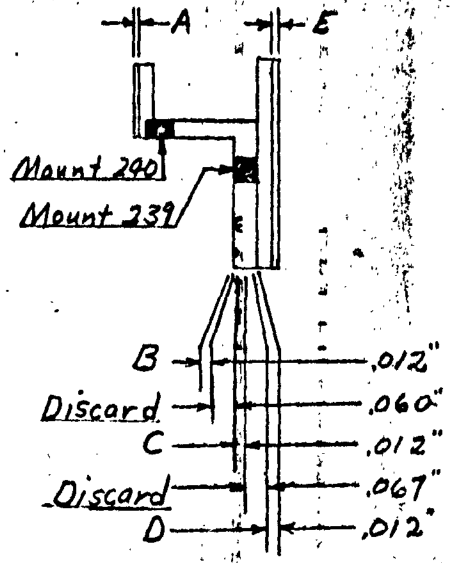
	C	N_2
Z	.177	.055
Doubler	.101	.063
Bot. Skin	.095	.036

FIGURE: IX-1

PANEL -3

Section 3-3





Chem:

	C	N_2
A	.090	.021
B	.172	.020
C	.080	.027
D	.076	.011
E	.098	.034

Section 3-9

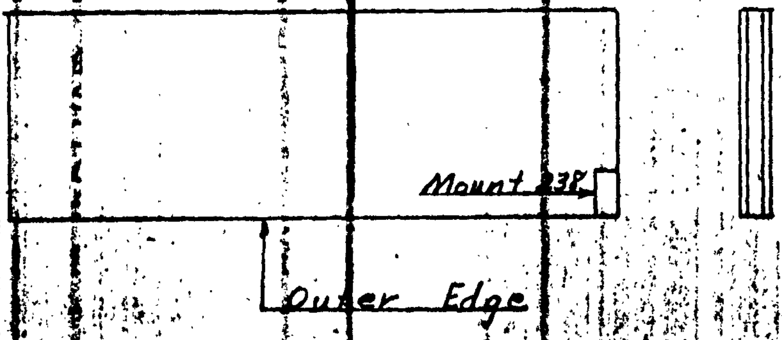
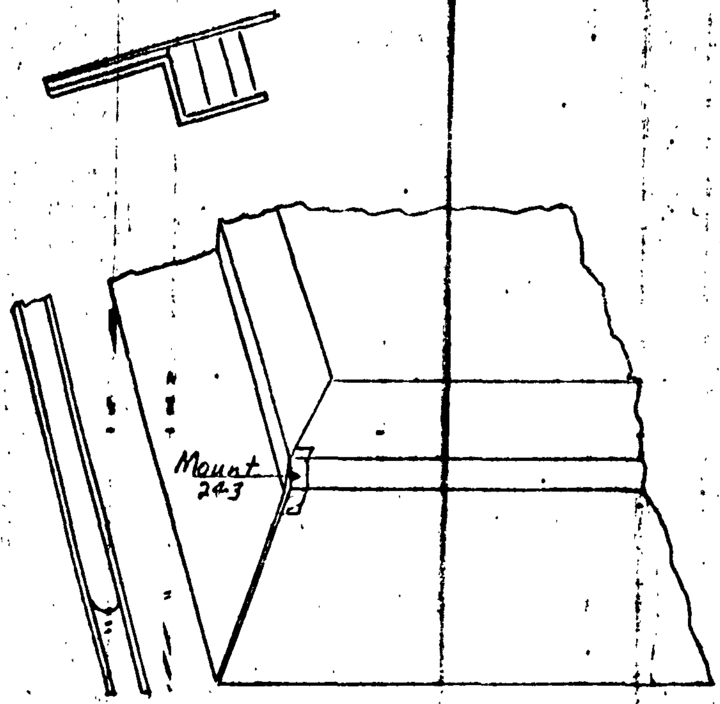


FIGURE: I-52

PANEL -7

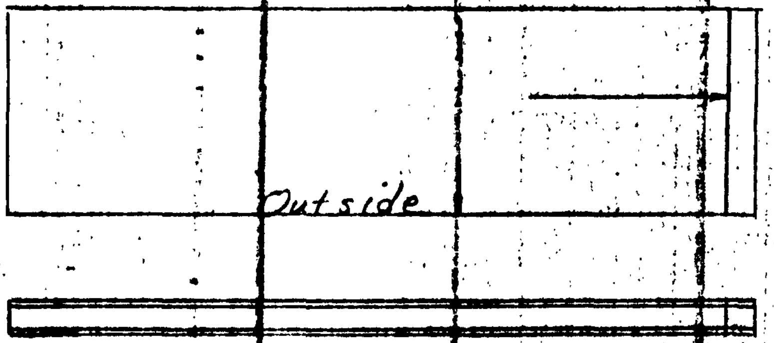
Section 7-55



Chem:

	C	N_2
Z	.188	.014
Doubler	.104	.014
Skin	.147	.025

Section 7-6

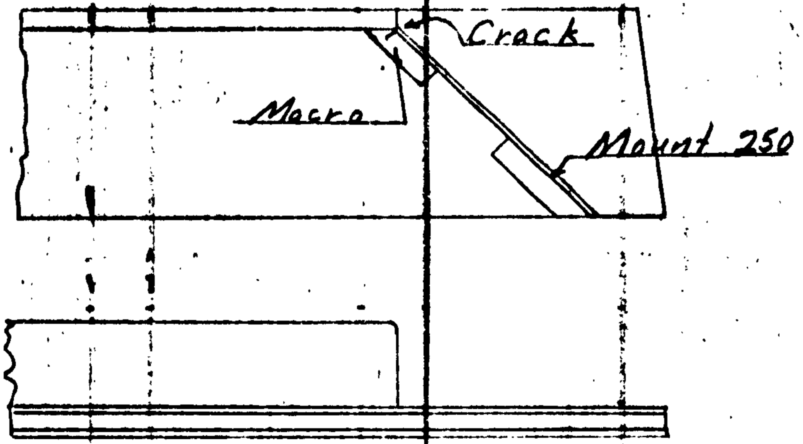


Chem:

	C	N_2
Z	.123	.025
Doubler	.082	.021
Skin	.101	.019

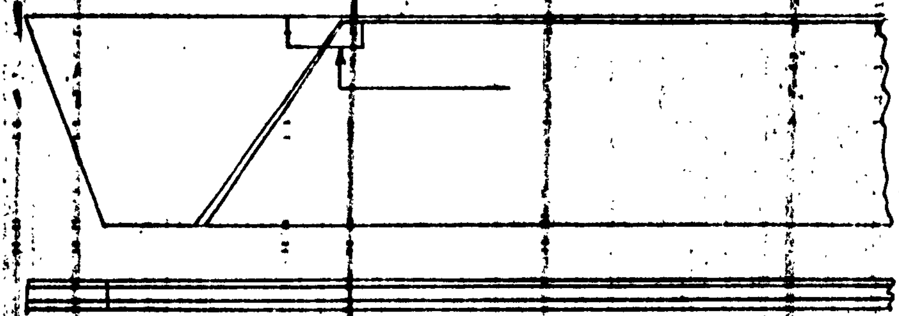
FIGURE: IV-3

PANEL-9



Section 9-3

Section 9-1



Chem:

	C	N_2
Z	.079	.019
Doubler	.082	.025
Skin	.087	.023

FIGURE: II-4

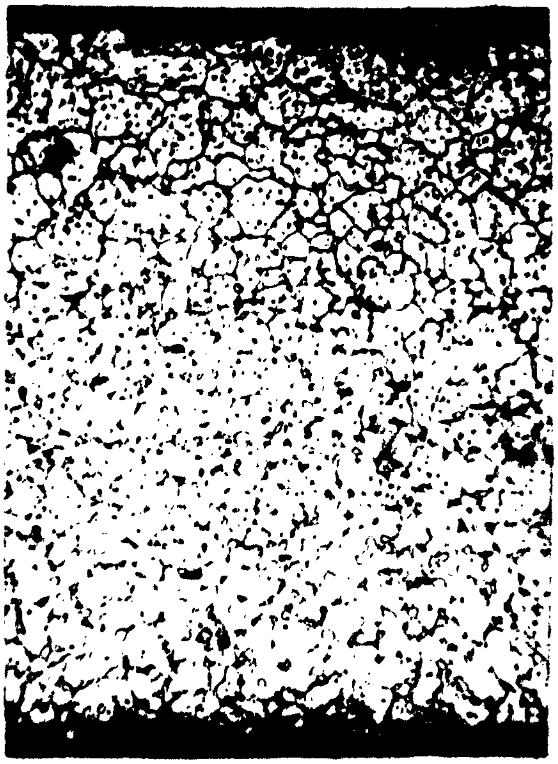
Top of skin

Panel 1, Section 1-54

Vilella's etchant; X500

This section of skin is normal. No contamination is present.

Brazing Alloy



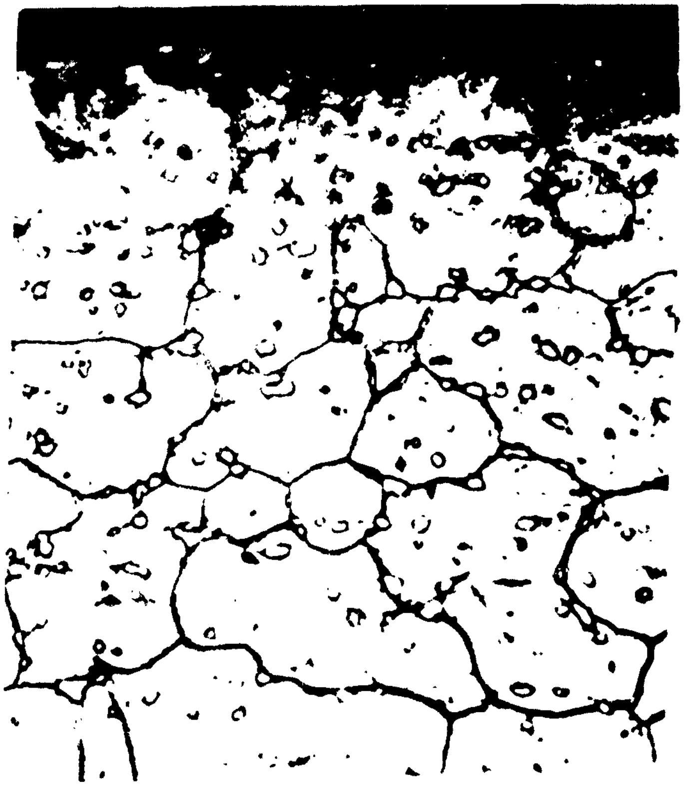
Top of edge member

Panel 1, Section 1-10

Vilella's etchant; X250

The top surface of this edge member shows severe carburization.

Figure IJ-5

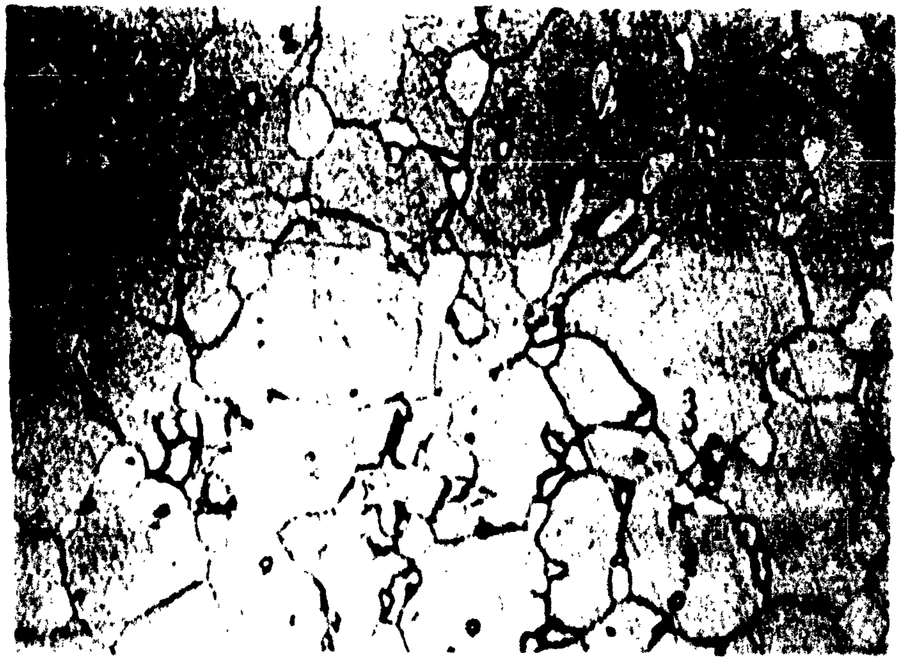


[illegible], Section 1-1

-member surface

Vilella's etchant; X2000

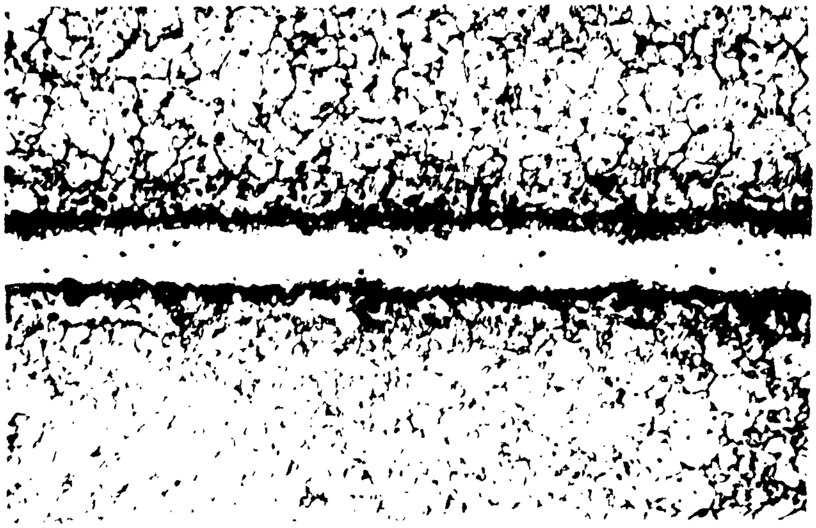
This photomicrograph shows an area of high carbon content. Note large carbides and lack of delta ferrite.

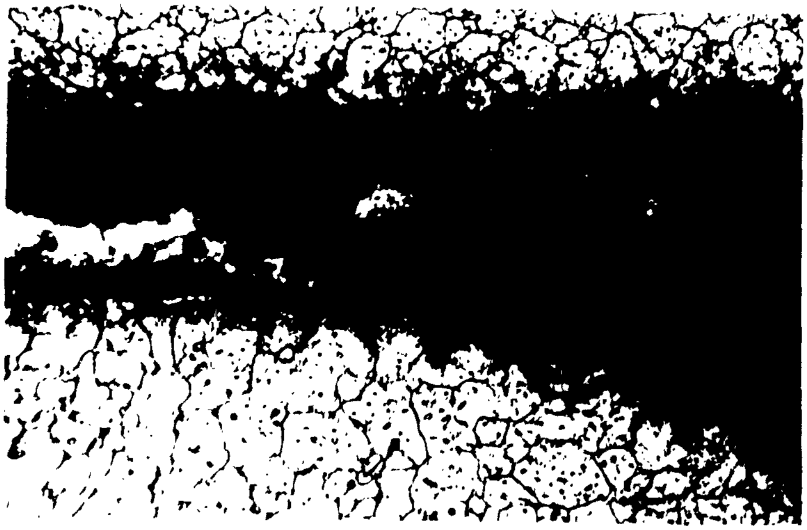


This photomicrograph is typical for 17-7PH stainless steel after a braze cycle. Note areas of delta ferrite (white areas) and the small amount of carbides (white outlined in black).

[illegible]

Figure IJ-6

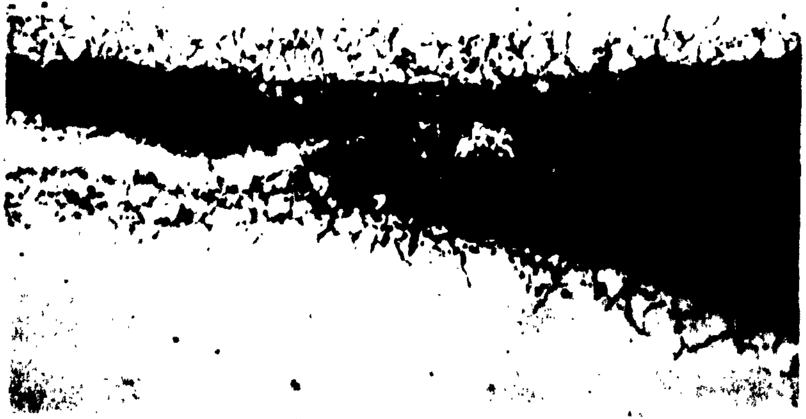




[illegible] view of outer edge of
[illegible] Vilella's etchant; [illegible]

Figure IJ-7

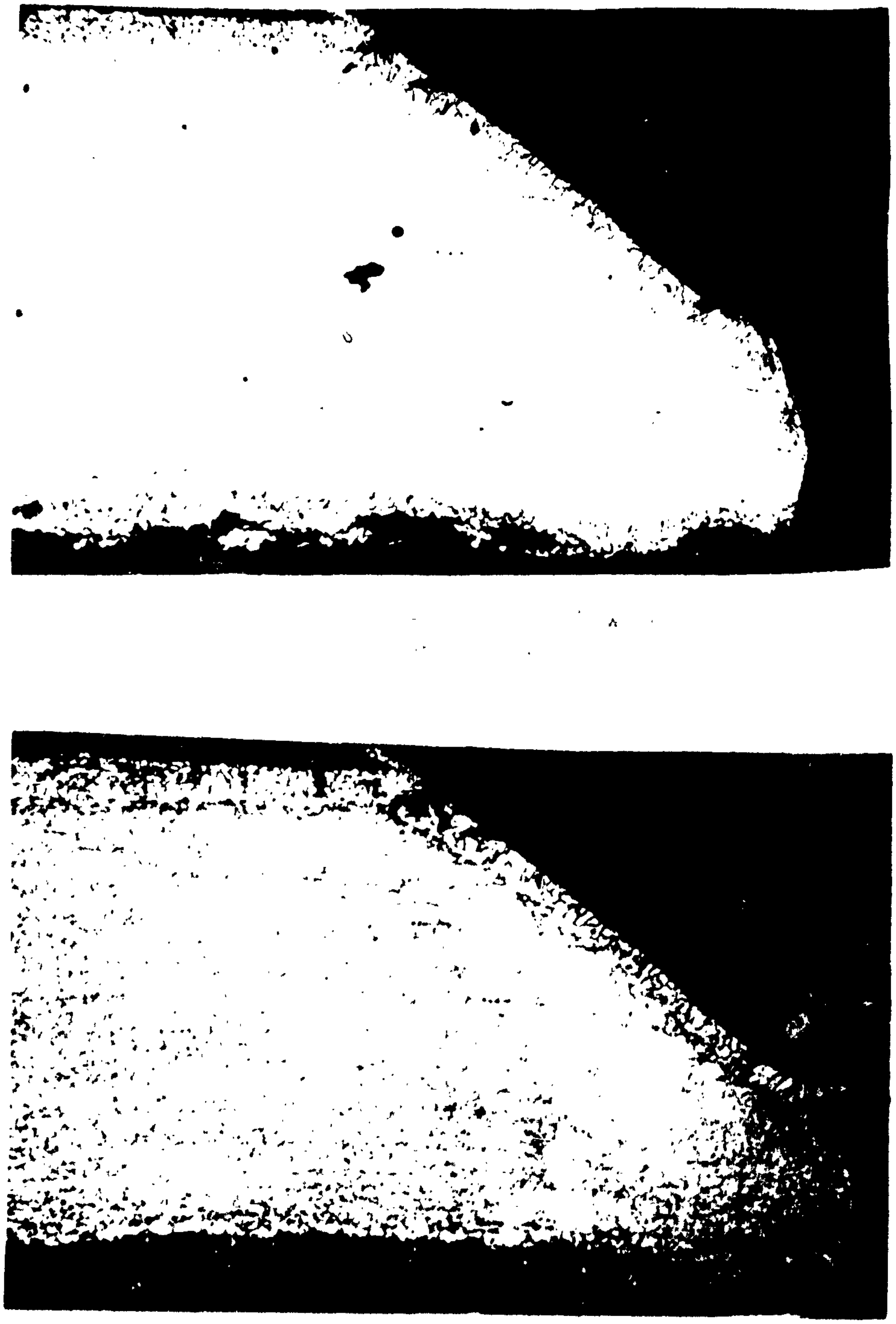
[illegible]



[illegible] B; outer edge of Z to [illegible] joint unetched; X500.

This [illegible] was taken at the edge of the [illegible] surface oxidation w[illegible]

Figure IJ-8



[illegible] /-5%; end view of [illegible]
[illegible] Vilella's etchant; [illegible]

Figure IJ-9

EFFECT OF ELEVATED TEMPERATURES:

Two investigations on the effects of elevated temperatures on 17-7PH stainless steel were recently carried out, the results of which were not published. They were made available by memoranda. In addition, some information on these effects has appeared in two published reports (reference FTDM-1415 and FGT-1362-1). The first gives some values as to the effect of repeated exposures to 1000 F and subsequent cooling to room temperature on the tensile strength and dimensions of 17-7PH steel and two other stainless steels. The second contains some data on the shear strengths of brazements of 17-7PH steel. The results of the two unpublished investigations are given below.

ITEM K - ELEVATED TEMPERATURE PROPERTIES OF 17-7PH STEEL

When the sterling silver lithium alloy was adopted, the brazing temperature was lowered from 1825 to 1650 F. With these changes, the number of edge-member voids increased in 17-7PH steel sandwich panels. One possible cause for this condition was suggested, viz., the higher mechanical properties of the steel at the reduced brazing temperature.

Late in 1957, as connected with the problem of voids, tests were performed to determine the tensile properties and short-time creep strength of 17-7PH steel at elevated temperatures. The data were obtained for use as a manufacturing aid in deciding the amount of mismatch and canning, of the edge-member components of panels, that could be corrected by the pressure applied during brazing.

The tests were made on sheet with nominal thicknesses of .040" and .063". The following properties were determined: Modulus of elasticity in tension and short-time creep strength at 1600, 1650, 1700, and 1825 F; tensile yield and ultimate strength, and elongation in 2", at 1650, 1700, 1750, 1800, and 1850 F. Most of the data are the results of single tests.

The values obtained are given in Tables IK-I to IK-III. The data of Table IK-I and IK-II are plotted in the graphs of Figures IK-I and IK-2, respectively. In Figures IK-3 to IK-6 the data of Table IK-III are plotted. Figure IK-7 is a composite which shows the stress required to deform 17-7PH steel sheet, either elastically or plastically, at temperatures from 1600 to 1825 F on the basis of modulus of elasticity, yield strength, and creep.

ITEM L - EFFECT OF EXPOSURE AT 700 F ON BUTT-WELDED 17-7PH STEEL

In the early months of 1959, an investigation was carried out to determine whether prolonged exposure in air at 700 F would adversely affect the tensile properties of 17-7PH steel sheet as butt-welded and unwelded.

Two lots of sheet stock were tested. One was .005" thick, and the other was .010" thick. Part of the specimens for test were butt-welded by the Heliarc method. The weld seam ran transversely across the middle of the gage section. The rest were not welded. Conjecture had been made that the weld zones might be affected differently than the parent metal as a result of prolonged exposure at 700 F.

The material for test was heat treated in simulation of a production brazing cycle (1650, 1400, -20, 1050 F). Tensile specimens were heated in air at 700 F for 100 and 300 hours. The tests were performed at room temperature after the exposures at the elevated temperature.

The results of the tensile tests are given in Tables IL-I to IL-VI. The specimens referred to as Control had not been welded. Figure IL-1 shows the effect of the exposures on the tensile strength and elongation of the welded specimens. As is evident, the strength of both the .005" and .010" sheet, plain and welded, was increased substantially by the exposures. The precise effect of the heating on the elongation was indeterminate.

As shown in the tables, more weld-zone breaks occurred in specimens which had been heated to 700 F than in those not so heated. However, the tensile strength of nearly all the welded-and-heated specimens was substantially in excess of 200 ksi. Also, as a rule, specimens which failed in the weld zone exhibited appreciably lower elongation than those which broke elsewhere in the parent metal. Weld-area breaks here are not to be construed as having occurred in the weld but rather occurred in the heat-affected zone close to it.

In general, the values for the tensile yield and ultimate strength of the unwelded specimens were in rather good agreement with the values of the corresponding welded specimens. Figures for the elongation of some unwelded specimens, .010" thick, are doubtful due to damage caused by clamping them in contact with welded specimens for machining. The elongation values for the unwelded specimens, .005" thick, are in reasonable agreement with those of the welded specimens.

CONCLUSIONS: ITEMS K, L

Tests on 17-7PH steel at elevated temperatures have shown that the modulus of elasticity in tension decreases from about 14 million psi at 1600 F to 7.6 million psi at 1825 F. The tensile yield strength fell from about 10.9 ksi at 1650 F to 6.1 ksi at 1850 F; the ultimate strengths at these temperatures were 17.1 and 10.5 ksi, respectively; and the elongations were 76 and 44 percent. The extensions under loading in short-time creep are well shown by the graphs of Figures IK-3 to IK-6.

Tests have demonstrated that the tensile yield and ultimate strength of 17-7PH steel in the TH 1050 condition are increased substantially by heating for 100 and 300 hours in air at 700 F. This applies to both unwelded and butt-welded specimens, .005" and .010" thick. The results for the unwelded specimens agreed fairly well with those for the corresponding welded specimens. The values for the elongation were not sufficiently consistent to warrant drawing any definite conclusions.

Modulus of Elasticity of 17-7 PH Stainless Steel at Elevated Temperatures

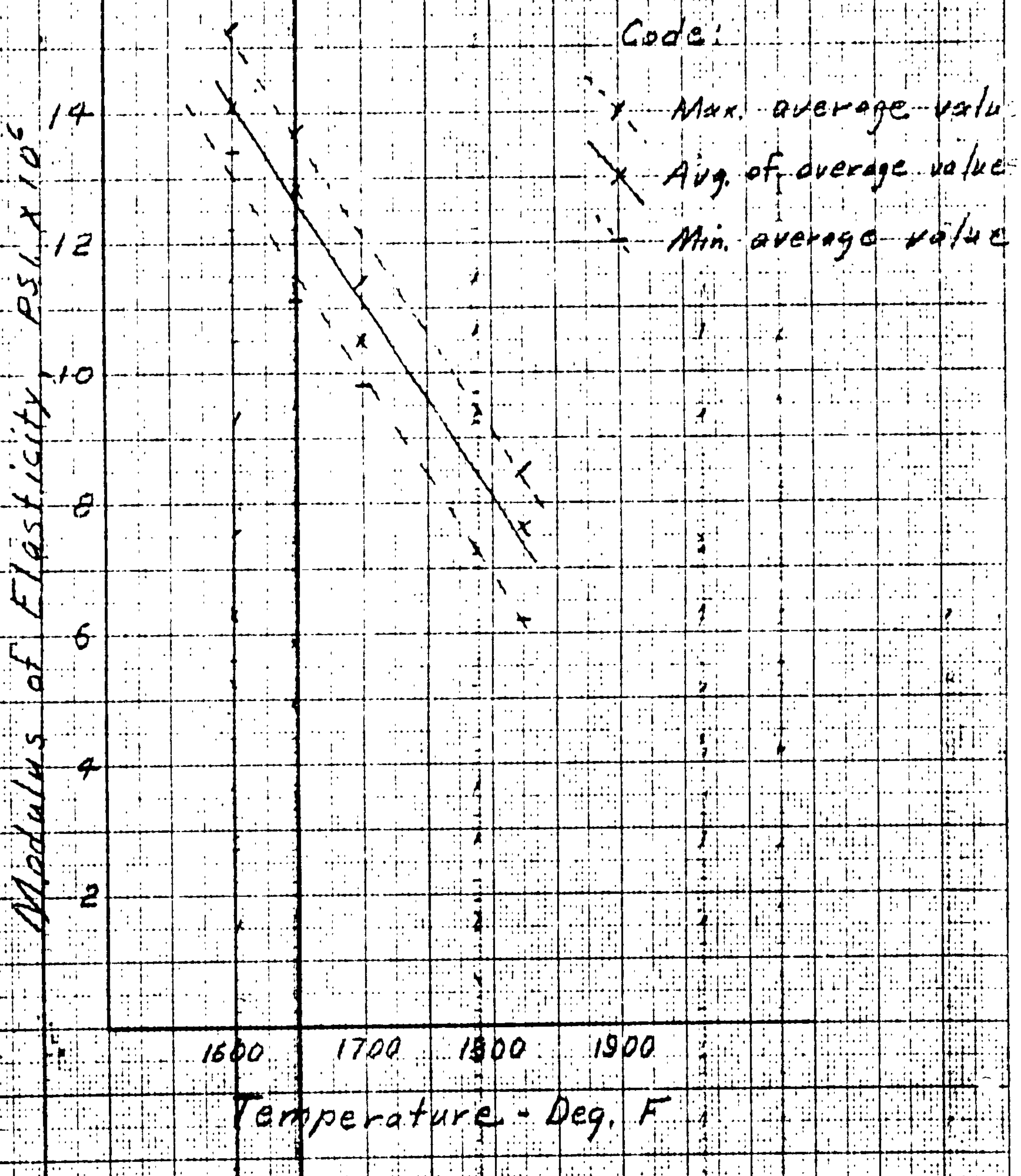


FIGURE: IK-1

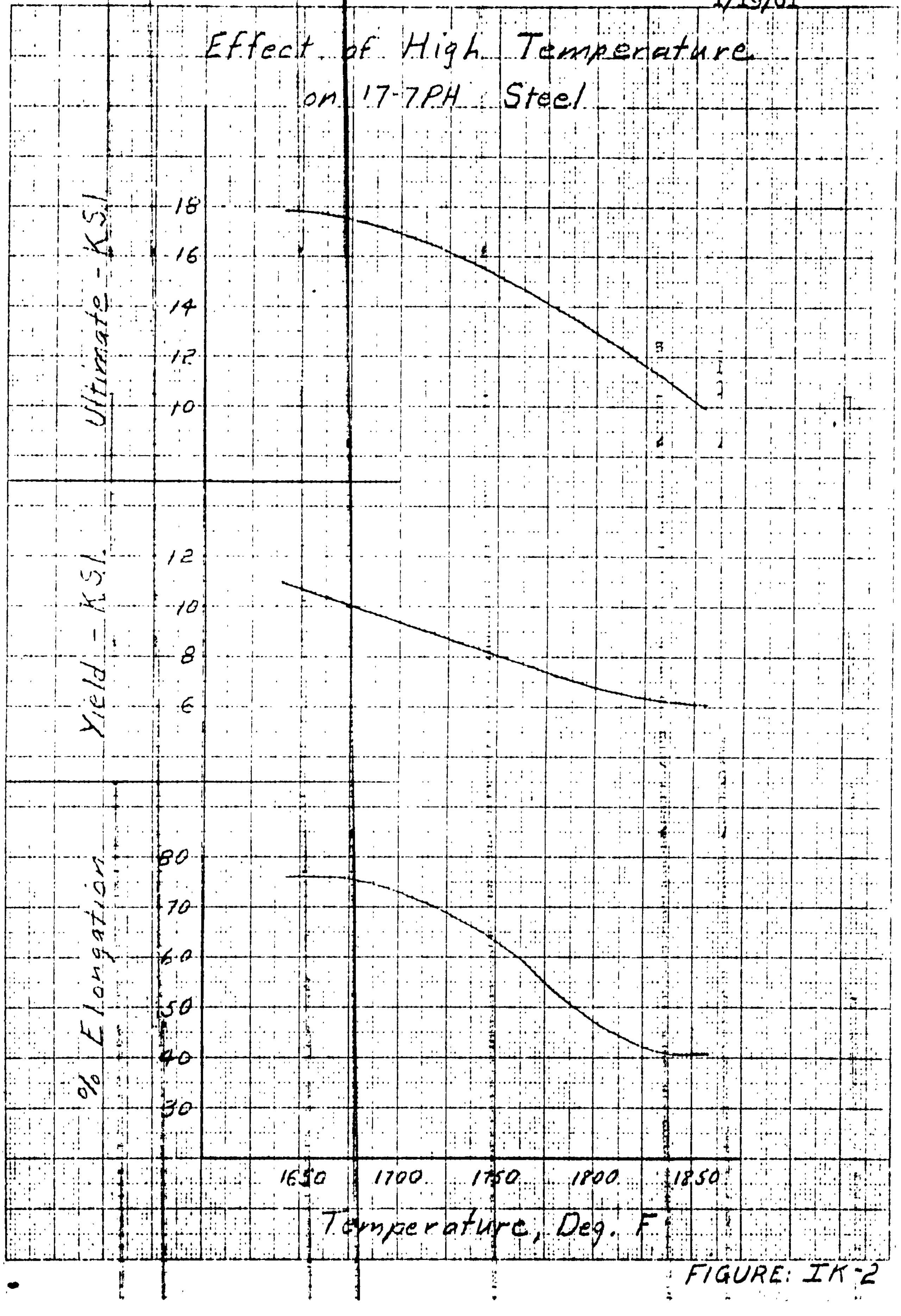
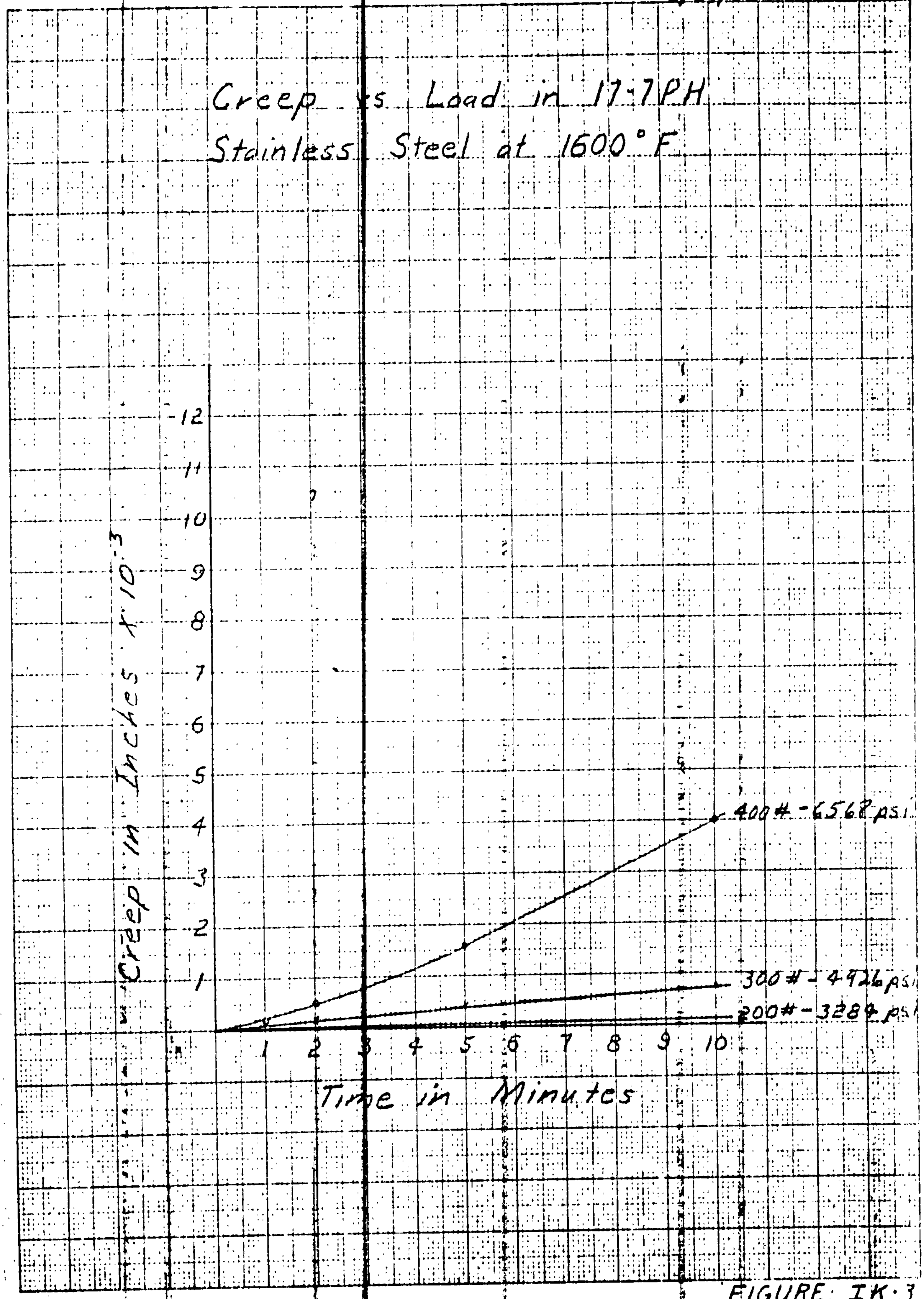

Effect of High Temperature
on 17-7PH Steel
Ultimate - KSI
18
16
14
12
10
Yield - KSI
12
10
8
6
% Elongation
80
70
60
50
40
30
1650
1700
1750
1800
1850
Temperature, Deg. F

FIGURE: IK-2



Creep vs Load in 17-7PH Stainless Steel at 1600°F

FIGURE: IK·3

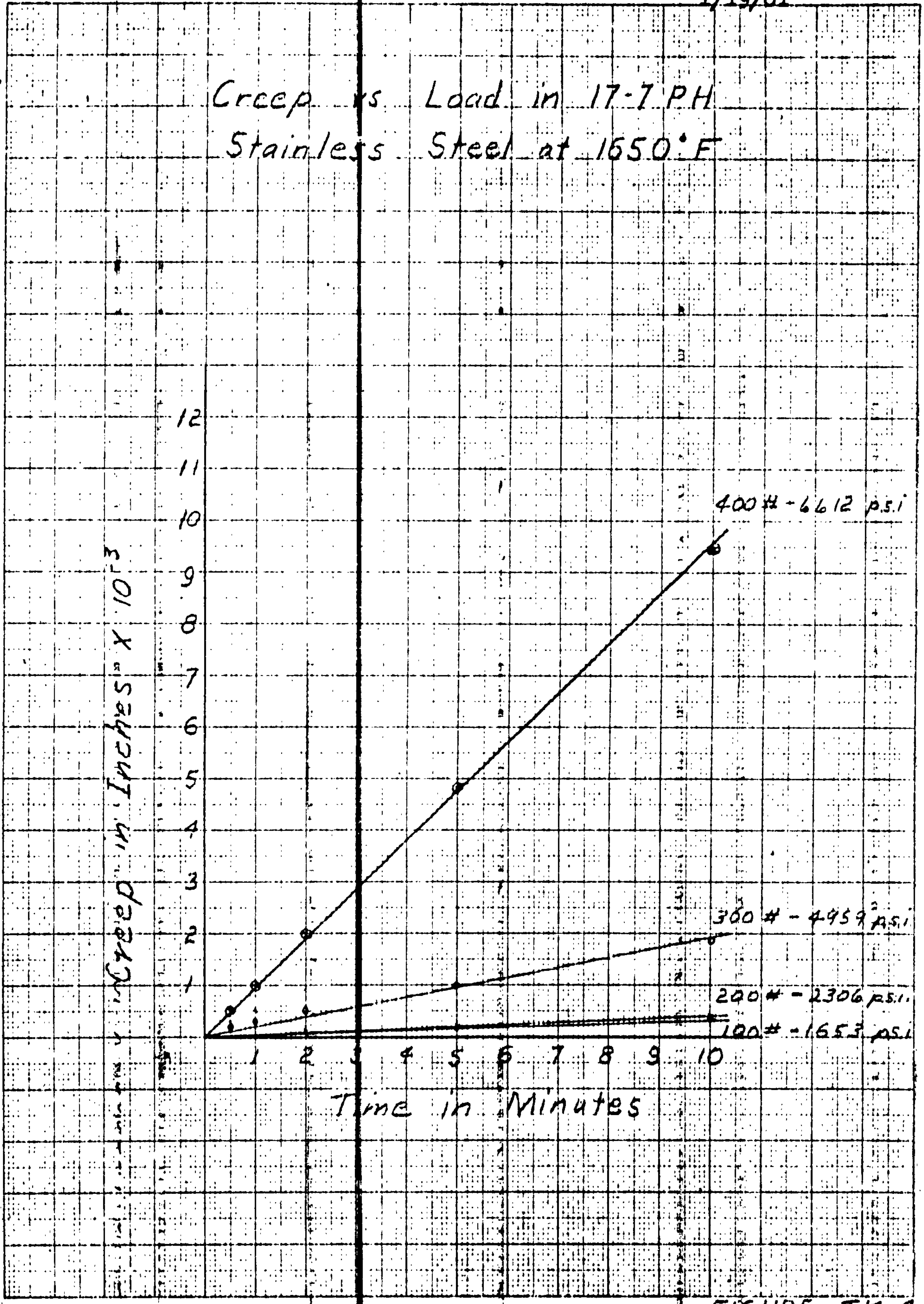

Creep vs Load in 17-7 PH
Stainless Steel at 1650°F
Creep in Inches X 10⁻³
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
Time in Minutes
400# - 6612 psi
300# - 4959 psi
200# - 2306 psi
100# - 1653 psi

FIGURE: IK-4

Creep vs Load in 17-7 PH Stainless Steel at 1700°F

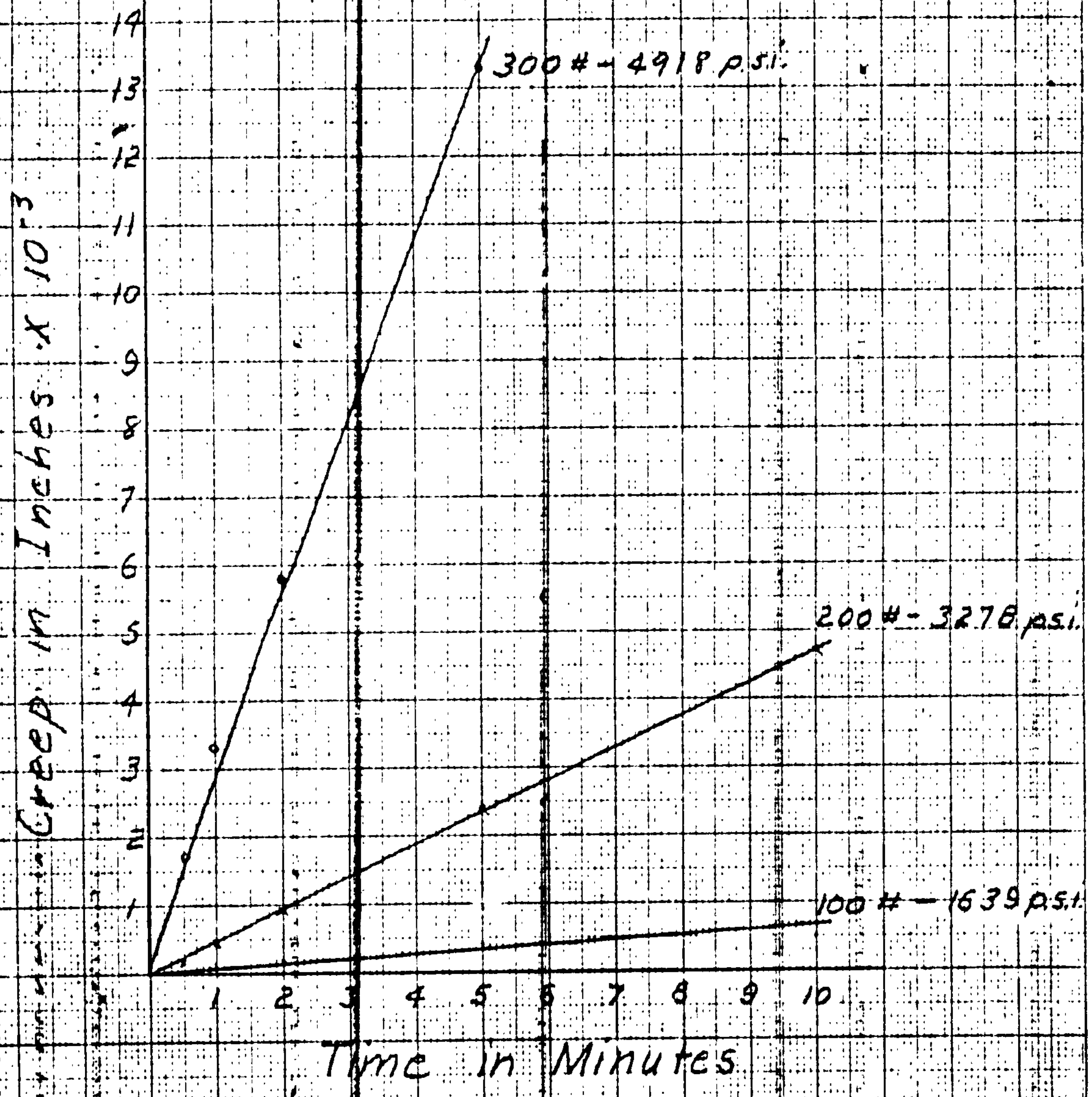


FIGURE: IK-5

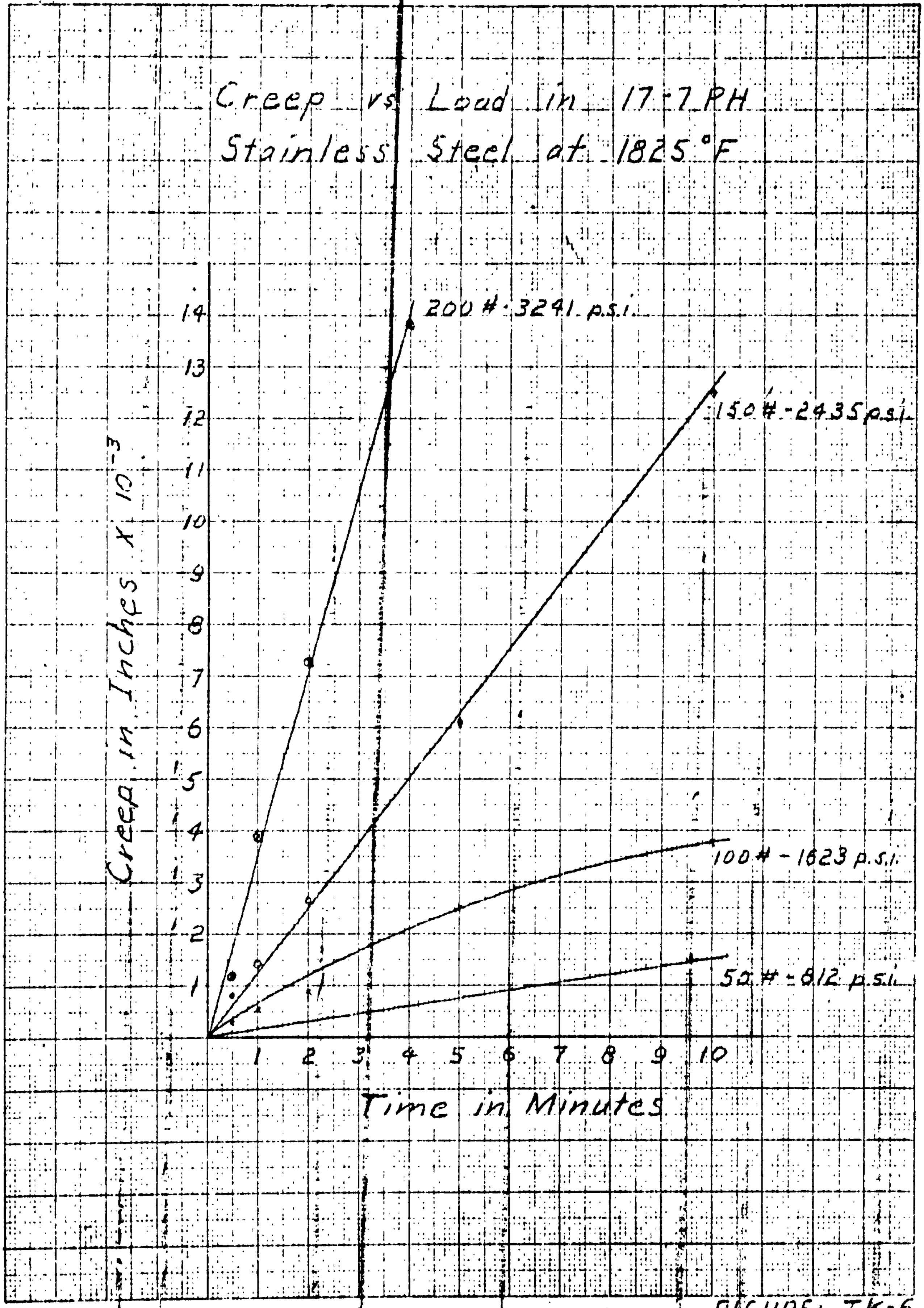
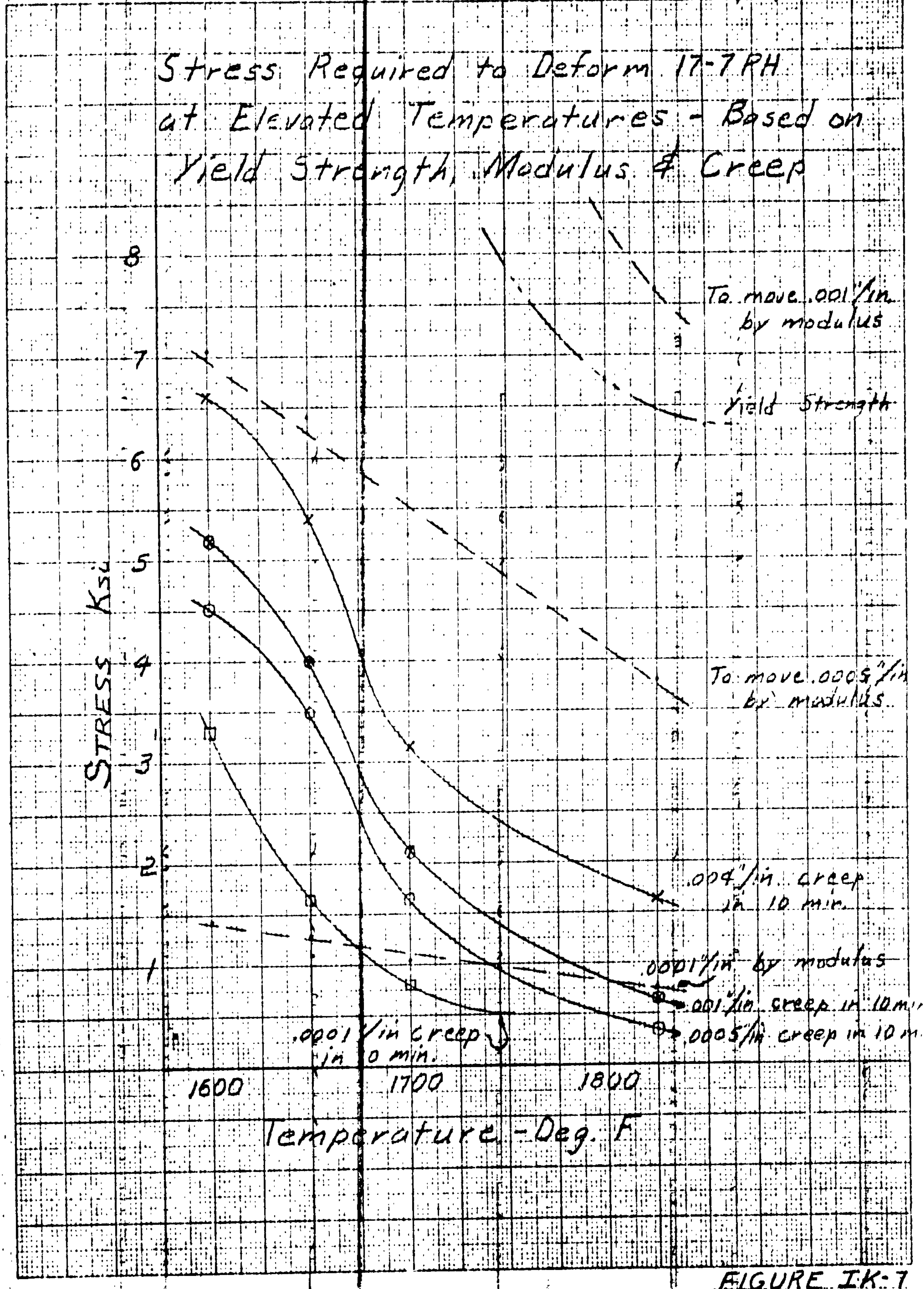

Creep vs Load in 17-7 RH
Stainless Steel at 1825°F
200 # · 3241 p.s.i.
150 # - 2435 p.s.i.
100 # - 1623 p.s.i.
50 # - 812 p.s.i.
Creep in Inches X 10^-3
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
Time in Minutes

FIGURE: IK-6



Stress Required to Deform 17-7PH at Elevated Temperatures - Based on Yield Strength, Modulus & Creep

FIGURE IK-7

CONVAIR—FORT WORTH Modulus of Elasticity of 17-7 PH
TABULATION SHEET Steel at Elevated Temperatures - 0.040 Gage

Temp. Deg. F	Spec 1 Mod x 10⁶	Spec 2 Mod x 10⁶	Spec 3 Mod x 10⁶	Spec 4 Mod x 10⁶	
1600	11.7	14.2	12.6	—	
	13.6	16.4	13.2	—	
	12.1	14.2	14.9	—	
	16.4	16.4	13.6	—	
	13.1	—	—	—	
Avg	13.4	15.3	13.6		Overall Avg 14.1 @ 1600F
1650	10.9	13.2	14.2	—	
	10.9	13.6	13.2	—	
	10.3	11.7	12.6	—	
	11.7	15.6	13.6	—	
	10.5	—	—	—	
	11.7				
Avg	11.1	13.5	13.9		Overall Avg [illegible] @ 1650F
1700	10.3	9.7	12.6	—	
	11.7	10.0	10.2	—	
	11.7	10.0	10.2	—	
	9.7	10.0	12.6	—	
	8.2	9.7	—	—	
	10.3				
Avg	10.3	9.8	11.4		Overall Avg 10.5 @ 1700F
1825	5.5	5.9	9.6	7.4	
	7.3	8.2	7.4	7.9	
	5.9	7.2	8.2	7.7	
	7.3	9.1	8.2	8.2	
	5.5	8.2	7.4	7.2	
	5.9	—	7.2	—	
Avg	6.2	7.7	[illegible]	7.5	Overall Avg 7.7 @ 1825F

CONVAIR — FORT WORTH
TABULATION SHEET

High Temperature Mechanical Properties of 17-7PH Stainless Steel-0.040 Gage

SPEC. NO.	TEMP DEG. F	GAGE	WIDTH	AREA	YIELD		ULTIMATE		%e		AVERAGES		
					LBS.	KSI	LBS.	KSI			F_{ty}-ksi	F_{tu}-ksi	%e
1	1650	.039	.501	.0195	210	12.75	333	17.08	76				
											10.75	17.08	76
2	1650												
3	1700				179	9.22	375	19.33	72				
											9.38	18.20	73
4	1700				182	9.53	326	17.07	73				
5	1750				157	8.05	289	14.82	64				
											8.05	14.37	63
6	1750						269	13.74	61				
7	1800				135	6.89	253	12.91					
											6.73	12.92	44
8	1800				128	6.56	252	12.92	44				
9	1850				124	6.35	191	9.80	49				
											6.13	10.51	44
10	1850				116	5.90	221	11.22	39				

CONVAIR—FORT WORTH
TABULATION SHEET

High Temperature Creep Tests on
17-7PH Stainless Steel

SPEC NO		LOAD LBS	GAGE	AREA	TEMP DEG F		CREEP DEFORMATION - In/In 5 Min	1 Min	2 Min	5 Min	10 Min
1		100	.0063	.0609	1600		0	0	0	0	0
		200	↓	↓	↓		0	0	0	.00005	.00010
		300	↓	↓	↓		0	.00005	.00015	.00040	.00075
		400	↓	↓	↓		.00005	.00015	.00050	.00160	.00400
2		100		.0605	1650		0	0	.00022	.00025	.00030
		200	↓	↓	↓		0	.00005	.00010	.00020	.00035
		300	↓	↓	↓		.00020	.00032	.00050	.00100	.00177
		400	↓	↓	↓		.00050	.00100	.00200	.00420	.00745
3		100		.0610	1700		0	.00015	.00017	.00040	.00050
		200	↓	↓	↓		.00020	[illegible]	.00072	[illegible]	[illegible]
		300	↓	↓	↓		.00170	.00330	.00570	.01330	—
		400	↓	↓	↓		—	—	—	—	—
4		50		.0616	1825		.00010	.00017	.00073	.00093	.00130
		100	↓	↓	↓		.00030	.00052	.00070	.00250	.00330
		150	↓	↓	↓		.00080	.00140	.00265	.00610	.01250
		200	↓	↓	↓		.00120	.00390	.00730	.01380 ← 4 min.	—

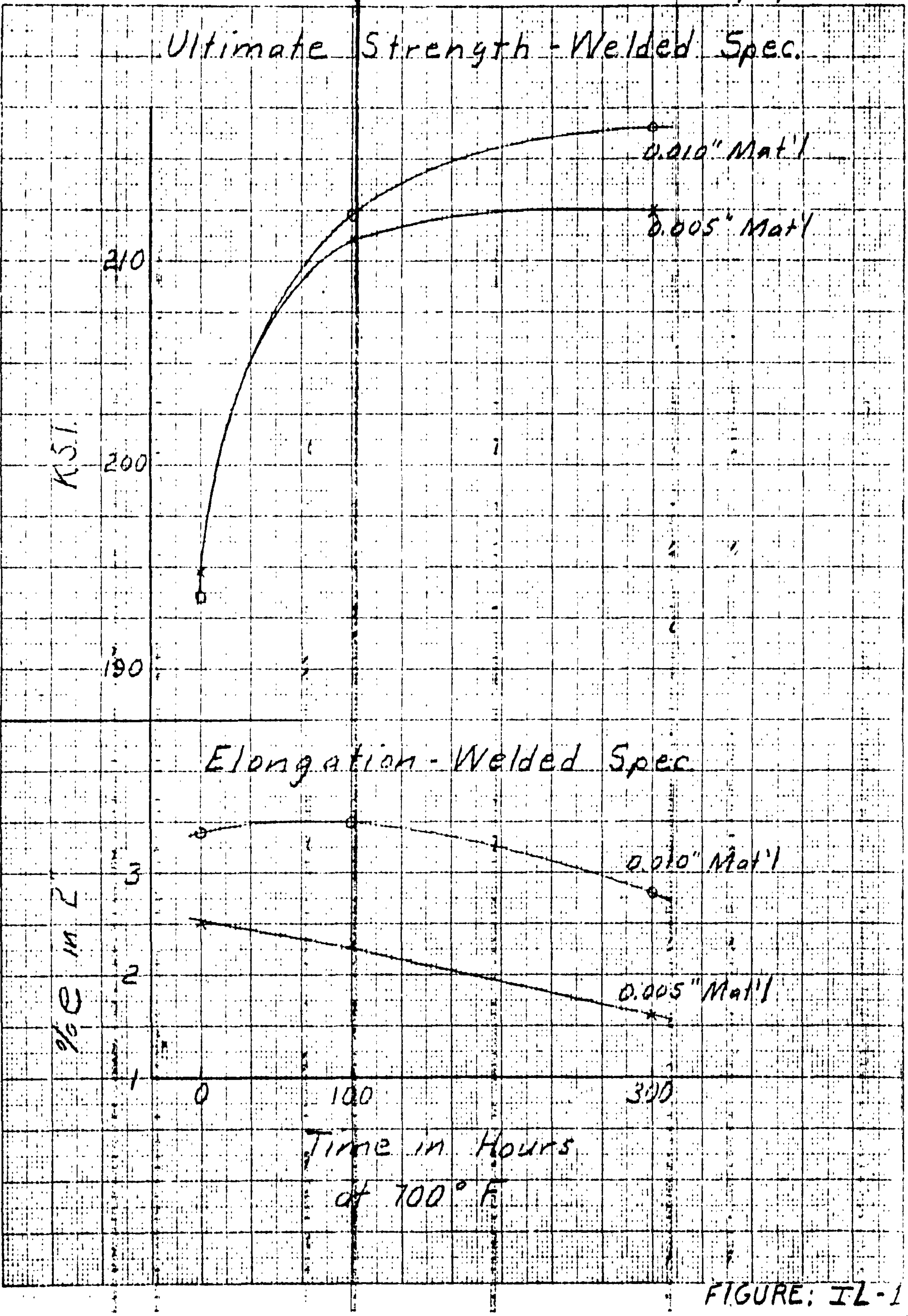

Ultimate Strength - Welded Spec.
K.S.I.
210
200
190
0.010" Mat'l
0.005" Mat'l
Elongation - Welded Spec.
% e in 2"
3
2
1
0
100
300
Time in Hours
at 700° F
K•E 10 X 10 TO THE CM 359-14
KEUFFEL & ESSER CO.

FIGURE: IL-1

CONVAIR — FORT WORTH
TABULATION SHEET

0.010 Gage, 17-7PH Steel--Welded Tensiles,
As Heat Treated

SAMPLE NO.		GAGE		SPEC. TYPE			YIELD KSI		ULT KSI		%e		TYPE BREAK
1-A		.010		Cont'l			186.9		194.3		3.0		A
2-A							184.1		189.7		2.0		C
2-B							186.8		192.6		2.0		C
2-C							184.2		191.7		3.0		C
3-A							186.9		193.7		2.0		C
3-B							187.3		191.8		3.0		C
Average							186.2		192.3		2.5		
1-1-44		.010		Welded			184.4		189.7		3.0		A
1-2-46							192.6		197.5		2.0		A
2-2-38							182.1		193.5		3.5		A
2-1-30							186.4		192.6		2.0		A
2-1-39							179.3*		179.4*		1.0		B
2-2-36							189.8		194.5		4.0		A
3-1-23							186.2		193.8		2.5		A
3-2-12							186.8		194.3		4.5		A
3-20-25							187.8		193.6		3.0		A
Average							187.8		193.7		3.4		
									193.7 ①				

* Not included in average
A - Good break
B - Weld area break
C - Break occurred in dented area
① Average including * values

CONVAIR—FORT WORTH
TABULATION SHEET

.010 Gage, 17-7PH Steel [illegible] Tensiles,
Heat Treated Plus 100 Hours @ 700° F

SAMPLE NO.	GAGE	SPEC. TYPE	YIELD KSI.	ULT. KSI.	% e	TYPE BREAK
1	.010	Cont'l	209.9	217.0	4.0	A
2-A			203.4	210.4	3.0*	C
2-B			200.0	212.0	2.0*	C
2-C			204.7	211.8	4.0	A
3-A			206.9	212.0	3.0	A
3-B			203.7	212.1	3.0	A
Average			204.3	212.6	3.5	
V2-3-29	.010	Welded	194.6	210.7	—	A
V43			204.4	211.7	2.0	A
V43-9			201.6	209.7	4.0	A
V3-3-27			202.6	210.7	4.0	B
V2-3-35			207.2*	213.5*	2.0*	A
~~V1-3-45~~			~~207.2~~	~~213.4~~	~~2.0~~	~~A~~
V3-3-15			211.5	213.0	3.0	B
4-2-2			205.5*	209.6*	1.0*	A
2-2-26			—	209.6	5.0	A
3-2-15			194.1	204.0	3.5	A
3-1-24			203.7	212.6	3.0	A
2-1-38			203.2	210.3	3.5	B
2-1-37			200.0*	211.0*	2.0*	A
1-2-41			205.9	212.0	4.0	A
3-2-23			205.3	211.4	4.0	B
2-2-29			201.7*	211.6*	3.5*	B
1-2-43			203.0	210.1*	2.0*	A
3-1-19			202.1	212.1	3.0	B
4-2-4			199.0*	209.1*	1.0*	B
4-2-11			206.4*	212.7*	2.0*	A
4-1-12			207.9	217.0	4.0	A
1-1-41			206.5	214.6	4.0	
Average			204.1	211.2	3.5	
				211.8 ①		

*Not included in average
A Good break
B Weld area break
C Break occurred in dented area
① Average including * values.

CONVAIR—FORT WORTH 0.010--Gage, 17-7PH Steel -- Welded Tensiles

TABULATION SHEET Heated Treated Plus 300 Hours @ 700°F

SAMPLE NO.	GAGE	SPEC. TYPE	YIELD KSI.	ULT. KSI.	%e	TYPE BREAK
3-1	.010	Cont'l	213.3	219.4	4.0	A
12			207.5	213.3	2.0	C
21			209.2	211.2	2.0	C
22			224.0	213.0	4.0	A
24			208.0	214.0	2.0	C
27			211.2	217.3	2.5	C
28			209.2	214.3	2.5	C
Average			208.9	214.6	2.7	
3-2	.010	Welded	214.3	219.4	2.5	A
3			212.2	219.4	3.0	A
4			211.5	219.8	3.5	A
5			214.3	216.3	2.0	B
6			210.2	215.3	2.0	A
7			211.0	217.0	3.0	A
8			209.2	215.5	4.0	A
9			203.1 *	207.1 *	1.5 *	B
10			210.2	216.3	3.5	A
11			215.3 *	215.3 *	1.0 *	B
13			213.3	217.3	2.5	A
14			206.2 *	213.0 *	1.0 *	B
15			211.4	217.5	3.5	A
16			210.0	217.0	3.0	A
17			207.1	212.2	3.5	A
18			209.2	217.3	3.0	A
19			209.2	215.3	2.0	A
20			209.8	216.0	2.5	A
23			207.1	213.3	2.5	A
25			211.2	216.3	1.5 *	B
26			212.3	216.7	2.0	A
Average			210.5	216.6	2.8	
				215.9 ①		

* Not included in average

A - Good break

B - Weld area break

C - Break occurred in dented area

① Average including * values.

CONVAIR—FORT WORTH
TABULATION SHEET

0.005 Gage, [illegible] Steel -- Welded Tensiles,
As Heat Treated

SPEC NO.	GAGE	SPEC TYPE	YIELD KSI	ULT. KSI	% e	TYPE BREAK
1-58	.0052	Cont'l	184.6	179.6	2.5	A
1-52			176.0	194.8	2.0	
1-61			184.6	195.4	3.0	
1-46			172.7	188.5	2.0	
1-19			176.9	185.4	2.0	
1-103			172.7	182.5	2.0	
1-38			176.9	182.1	2.0	
2-45			180.0	187.2	2.0	
2-51			180.0	177.2	3.5	
2-101			181.2	177.5	2.0	
2-48			176.0	173.6	3.0	
3-48			182.0	182.8	2.0	
3-102			186.5	191.9	4.0	
3-55			174.0	191.2	2.0	
Average			171.7	179.1	2.3	
1-7	.0052	Welded	182.5	196.5	3.0	A
1-12			182.1	195.4	3.0	
1-13			182.5	197.3	2.5	
1-25			189.6	195.8	2.5	
1-28			187.3	195.4	2.5	
1-35			187.3 *	127.7 *	0.5 *	B
2-17			185.7	194.6	3.0	A
2-19			185.0	194.6	1.5	
3-17			187.3	191.9	2.5	
3-18			187.7	193.5	2.5	
3-20			184.6	196.5	2.0	
3-24			183.3	193.8	2.5	
3-26			182.8	194.0	2.0	
Average			187.1	194.7	2.5	
				194.3 ①		

* Not included in average
A-Good break
B-Weld area break
① Average including * values

CONVAIR—FORT WORTH 0.005 Gage [illegible] PH Steel Welded Tensiles,
TABULATION SHEET Heat Treated Plus 100 Hours @ 700°F

SPEC NO	GAGE	SPEC TYPE	YIELD KSI	ULT. KSI	%e	TYPE BREAK
1-59	0.005	Cont'l	206.3	210.6	2.5	A
1-47			202.7	207.7	2.5	
1-92			207.1	211.8	3.0	
1-95			202.7	206.9	2.0	
1-101			203.8	206.9	3.0	
1-51			201.1	207.3	3.0	
1-54			202.3	208.1	3.0	
2-66			192.7	197.3	3.0	
2-96			199.6	206.5	2.0	
2-52			202.0	206.5	3.0	
2-49			201.2	206.5	3.0	
2-58			200.8	208.1	3.0	
2-56			197.6	204.0	3.0	
3-77			203.9	207.3	3.0	
3-46			205.1	207.7	2.0	
Average			201.7	207.0	2.7	
1-2	.0052	Welded	204.2	211.5	2.5	A
1-8			205.4	211.5	3.0	
1-23			205.4	210.8	2.0	
1-24			203.8	210.8	2.5	
1-28			203.1	210.0	2.5	
1-30			201.9	209.2	2.5	
2-4			200.8 *	206.2 *	0.5 *	B
3-14			203.3	210.4	1.5	C
3-19			201.7	208.5	2.5	A
3-21			202.3	210.4	2.5	A
3-23			— *	196.1 *	0.0 *	B
3-25			201.5	207.7	2.0	A
Average			203.1	212.1	2.3	
				208.6 ①		

* Not included in average
B-Weld area break
C-Break near gage mark
① Average including * values
A-Good break

CONVAIR—FORT WORTH 0.005 Gage, 17-7PH Steel -- Welded Tensiles
TABULATION SHEET Heat Treated Plus 300 Hours @ 700°F

SAMP NO	GAGE	SPEC. TYPE	YIELD KSI	ULT. KSI	%e	TYPE BREAK
1-102	.0050	Cont'l	212.9	217.2	2.0	A
1-50			214.0	217.9	2.0	
1-55			212.0	217.4	2.0	
1-105			—	217.4	2.0	
1-88			205.8	213.1	1.0	
2-56			207.2	214.0	3.0	
2-67			207.8	213.5	2.5	
2-103			200.4	205.5	3.0	
2-95			206.5	212.2	2.0	
3-51			202.0	218.3	2.0	
3-54			214.3	219.1	2.0	
3-65			209.6	215.2	2.5	
3-101			210.1	215.1	2.0	
3-66			209.7	215.4	2.0	
3-97			209.7	[illegible]	2.0	
Average			210.2	215.1	2.1	
1-1	.0052	Welded	205.0*	205.8*	2.5*	B
1-3			210.0	216.2	1.5	A
1-19			205.2	209.6	1.5	
1-19			207.7	213.5	1.5	
1-20			206.9	213.8	1.5	
1-21			207.7	214.6	2.0	
1-34			—	163.8*	0.5*	B
2-1			207.3	211.9	2.0	A
2-3			204.2	211.5	2.0	
2-11			206.9	212.3	1.5	
3-13			—	203.1*	0.5*	B
3-15			206.9	212.7	1.0	A
3-16			—	192.8*	0.5*	B
3-27			202.7	211.5	2.0	A
Average			206.5	212.8	1.6	
				206.5 ①		

* Not included in average
A - Good break
B - Weld area break
① Average of all values

WELDING

ITEM M - WELDED EDGE MEMBERS OF PANELS IN 17-7PH STEEL

Two investigations were carried out to determine the effect of welding on the strength of 17-7PH steel in the TH 1050 condition. This work was done in the latter part of 1958 and in the spring of 1959. The investigation of 1958 comprised the evaluation of butt-welded joints on the basis of tensile and fatigue tests. In the work of 1959, the purpose was to appraise the feasibility of welding as a method of sealing the corner joints of sandwich panels.

Referring first to the investigation of 1958, flat portions of edge-member assemblies were butt welded as shown in the inset sketch of Figure IM-1. The results of tensile and axial tension-tension fatigue tests on specimens of such welds are given in Table IM-I. These results show that the welds have tensile strength equivalent to 17-7PH steel in the annealed condition. The elongation of the welded specimens was slightly higher than that of the steel in the TH 1050 condition. Figure IM-1 shows a typical stress-strain curve for the butt-welded specimens. The number of fatigue specimens tested were too few in number to establish an S-N curve, but did indicate a relatively high strength when compared to the yield strength of the joint.

For the investigation of 1959, four welded Z members were supplied by the Solar Aircraft Company. The vertical sections of these members had been welded by the tungsten inert gas method. As filler materials the commercial alloys 6832, 17-7PH, L-605, and 132E were used. The nominal composition of the first is not known. Following are the compositions of the other three alloys:

Alloy	Composition %
17-7PH	16-18 Cr, 6.5-7.5 Ni, .75-1.5 Al, .09 C max.
L-605	50 Co, 20 Cr, 15 W, 10 Ni, 1.51 Fe, .10 C
132E	68 Mn, 16 Co, 16 Ni

For the purpose of evaluating the welded joints, the Knoop hardness was measured in the welds and outward for a distance into the parent metal. Tables IM-II and IM-III list the values obtained. The data are plotted in Figure IM-2. Photomicrographs of the four samples are shown in Figure IM-3. Figure IM-2 indicates that the sample welded with the L-605 filler alloy was the hardest, i.e., had the highest strength. This was true as to the weld, and the parent material was affected for the shortest distance away from the weld. Joints made with the 132E and 17-7PH alloys had equivalent strength in the welds. In the sample where 17-7PH steel was used as the filler metal, the heat affected zone extended a greater distance from the weld. The 6832 alloy as filler material gave still lower strengths both in and adjacent to the welded joint.

TYPICAL STRESS-STRAIN CURVE FOR BUTT WELDED PANEL EDGE MEMBERS.

—AS WELDED—

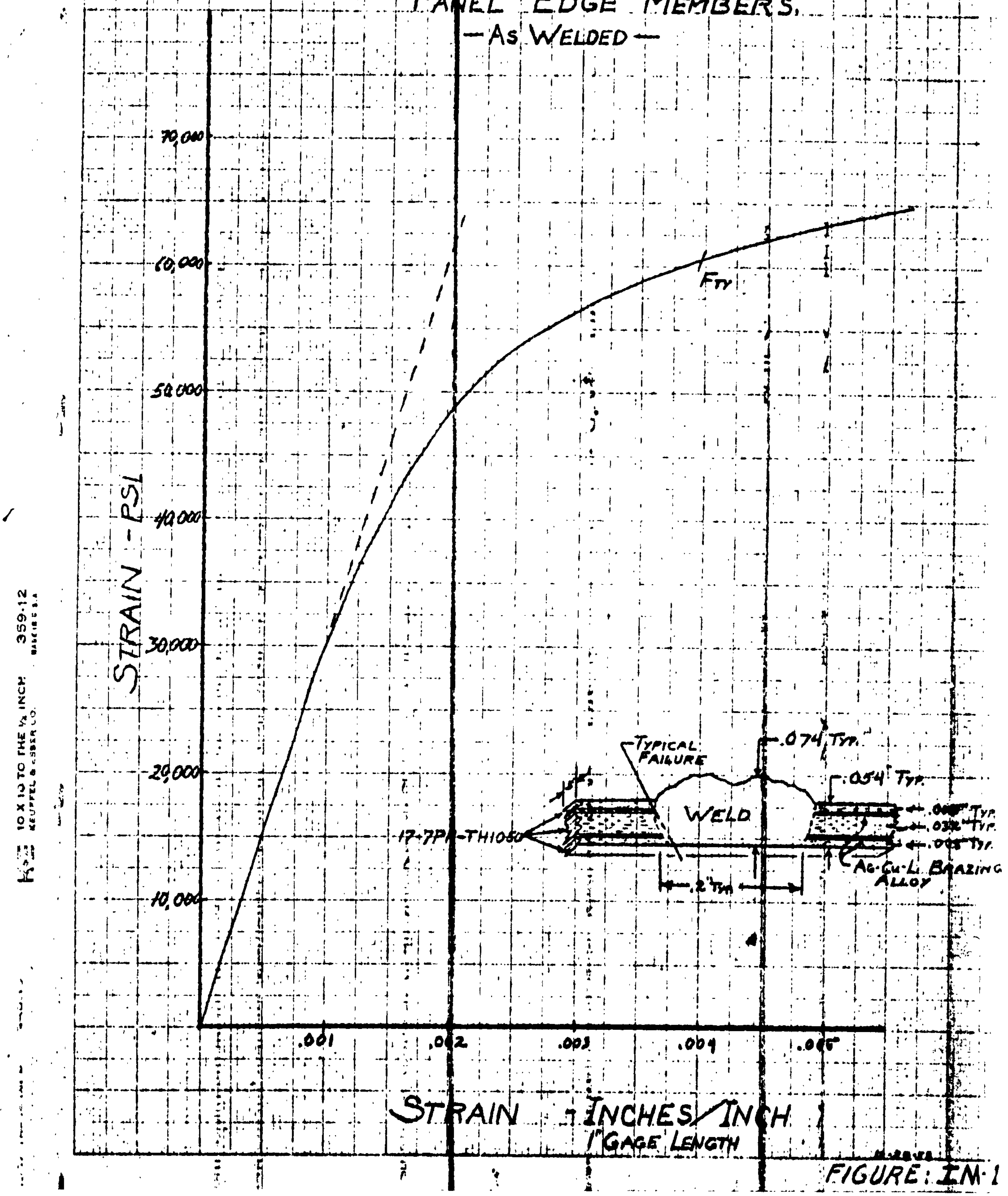


FIGURE: IN-1

Microhardness vs Dist from Weld

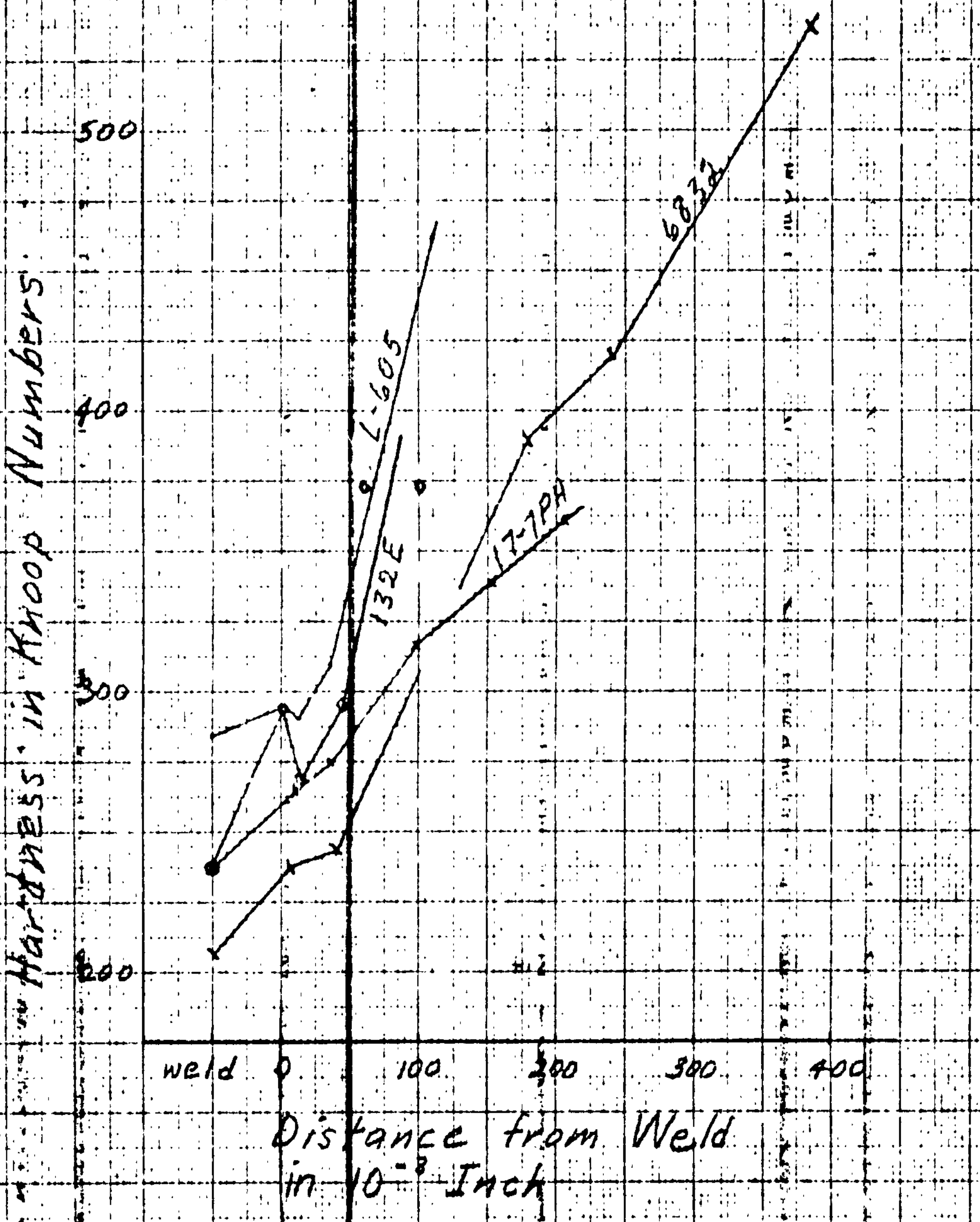
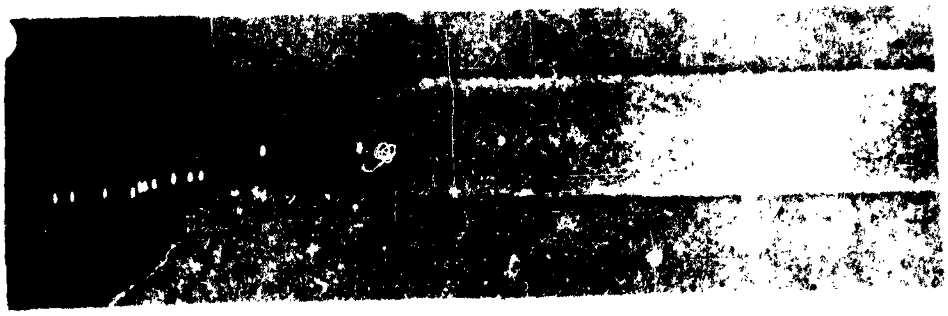


FIGURE: IM



Sample 1
[illegible] Filler

Sample 2
[illegible] Filler

[illegible]

[illegible]

CONVAIR—FORT WORTH
TABULATION SHEET

Tensile & Fatigue Results of Butt Welded
17-7PH Steel Panel Edge Members-"As Welded"

SPEC. NO.	SPEC. THICK	WELD THICK	YIELD KSI	ULT KSI	% e	BREAK REGION
1	.054"	.074	73.2	135.5	9.0	①
2		.076	55.9	126.8	10.0	
3		.075	55.4	123.4	8.0	
4		.073	61.6	134.7	8.5	
5		.075	56.0	131.2	10.0	
6		.075	60.8	132.7	10.0	
7		.063	60.9	134.3	10.0	
8		.072	72.9	139.1	9.0	
9		.064	67.5	127.9	9.0	
10		.067	52.0	135.5	10.0	Weld
Average			62.2	132.2	9.3	

SPECIMEN NUMBER	STRESS Max	STRESS Min	Cycles to Fail	Region of Fail
1	50	20	605000	①
2	50	20	5,113000 →	—
3	60	30	3,892000	①
4	70	40	357000*	—

① Broke in weld-parent metal junction

→ No failure, test stopped

* Crack appeared, test stopped

TABLE IM-II

CONVAIR — FORT WORTH

TABULATION SHEET Microhardness Values on Welded, 17-7PH Steel, Z Members

SAMP NO	Filler Metal	Dist from Weld		Knoop No.	Zone	SAMP NO	Filler Metal	Dist from Weld		Knoop No.	Zone
THREE	L-605	NONE		270	Weld	FOUR	132-E	None		215	Weld
				301						241	
				281						246	
				281						226	
				286						250	
			Avg	284*					Avg.	236*	
		.001		311	HE.			.001		286	HE
		.003		274				.002		307	
		.005		299				.003		288	
			Avg.	295*					Avg.	294*	
		.007		288	Parent Metal			.006		272	Parent Metal
		.012		288				.013		272	
		.021		294				.024		261	
			Avg	290*					Avg.	268*	
		.036		310*				.047		295*	
		.129		462*				.061		373*	
								.101		373*	

* These values were used in plotting Fig. IN-2. Where these are average values a median distance from the weld was used.

HE. – Heat effected zone in which structural change was apparent in base metal

CONVAIR—FORT WORTH

TABLE IN-III

~~TABULATION SHEET~~ Microhardness Values on Welded, 17-7PH Steel, Z Members

SAMP. NO	Filler Metal	Dist. from Weld		Knoop No.	Zone
ONE	6832	None		212	Weld
				202	
				210	
				210	
				206	
				196	
			Avg.	207*	
		.001		238	H.E.
		.003		246	
		.009		232	
		.014		235	
			Avg.	238*	
		.016		246	Parent Metal
		.034		251	
		.061		248	
		.100		229	
			Avg.	244*	
		.177		389*	
		.241		420*	
		.384		537*	

SAMP. NO	Filler Metal	Dist. from Weld		Knoop No.	Zone
TWO	17-7PH	NONE		244	Weld
				246	
				216	
				250	
				229	
			Avg	237*	
		.003		240	HE
		.008		295	
		.015		257	
		.019		270	
			Avg	266*	
		.020		280	Parent Metal
		.028		278	
		.053		266	
			Avg	275*	
		.076		316	
		.103		299	
		.119		335	
			Avg	317*	
		.153		339*	
		.205		361*	

* These values were used in plotting Figure IN-2. Where these are average values, the median distance from the weld was used.

HE - Heat effected zone in which structural change was apparent in the base metal.

MISCELLANEOUS:

Investigations were carried out to determine the tensile properties of two steels of the stainless, precipitation hardening type. These were: AM 350, produced by the Allegheny Ludlum Steel Corporation, and Stainless W, produced by the United States Steel Corporation. The results of these investigations are given below, under Items N and O.

ITEM N - EVALUATION STUDY OF AM 350 STEEL

Tensile tests and measurements of changes in dimensions were made on specimens of AM 350 steel, heat treated according to different procedures. The specimens were in the form of sheet .005" thick.

This work was performed in 1956. The object was to provide data for the preliminary evaluation of the steel with regard to its possible use as an alternate structural material for brazed sandwich panels.

The test results are given in Tables IN-I and IN-II together with the heat treatments employed. In Table IN-I, three basic heat-treating procedures are shown with certain variations for each. The temperature of 1850 F in all three corresponds to a brazing temperature for some filler alloys. Table IN-II shows the effects of three treatments on the tensile properties. Referring to the material in the as-received condition, designated as O, the tensile properties suggest that the steel had been annealed at about 1600 F. Table IN-III includes figures for the dimensional changes caused by the various treatments, as measured after holding at -100 F and after subsequent aging.

Table IN-I shows that the variation of tensile properties was slight with heat treatments I and III. Likewise, the effect of the holding time at 1750 F was small (H.T. - III). These two similar treatments gave desirable tensile properties. Heat treatment II gave values for the tensile yield and ultimate strength which were marginal with respect to Convair Specification FZS-4-046.

Figure IN-1 shows a graphical comparison of the tensile yield and ultimate strengths together with the elongations resulting from the various treatments. The values for the type II heat treatment of Table IN-I were omitted in plotting the figure because the strengths were low. In this treatment the aging temperature was 850 F as contrasted with 750 F for types I and III. In Figure IN-1, items 4 and 5 are indicated as averages. Because of the small differences in values as affected by variations in heat treatments I and III, averages of the average results were plotted.

The dimensional measurements showed that the AM 350 steel specimens exhibited growth after treatment through the -100 F step followed by a slight contraction on subsequent aging. The over-all change was growth. This may be noted by comparing the figures in the last and second-to-last columns of Table IN-II. For the twelve specimens listed, there were two exceptions. Specimen 10 did not change size on aging, and specimen 11 grew a little. The overall average growth for the AM 350 steel was 49% that of 17-7PH steel. This refers to a comparison of results for .005" thick sheet with a variety of heat treatments for both steels.

ITEM D - EVALUATION STUDY OF STAINLESS W STEEL

In the spring of 1958 a preliminary investigation was carried out on Stainless W steel. Part of the resulting test data was reported by memorandum. The object of the work was to determine whether this steel might be used in place of 17-7 PH steel for the fabrication of brazed sandwich panels.

Tensile tests were performed on specimens of Stainless W steel sheet after various heat treatments. Three thicknesses were tested, viz., .005", .008", and .014". All the material was from Heat No. 7X2117. The composition of this heat as shown by certified analysis supplied by the producer was as follows: C .08%, Mn .79, P .025, S .014, Si .64, Ni 6.72, Cr 16.82, Ti .72, and Al .20%.

The variations in heat treatment for the material tested are given below:

Simulated Brazing Step: Heated to 1650 F in 30 minutes and held 10 minutes.

Conditioning Step:

a. Cooled to 1400 F in 60 minutes, held 90 minutes, and cooled to room temperature in 3 hours.

b. Furnace cooled from 1650 F to room temperature in 3 hours.

c. Air cooled from 1650 F to room temperature in approximately 30 minutes.

Transformation or Chill Step:

a. 0 F for 30 minutes

b. -20 F for 30 minutes

c. -50 F for 30 minutes

d. -60 F for 30 minutes

e. -100 F for 30 minutes

Aging Step:

a. 900 F for 90 minutes

b. 950 F for 90 minutes

c. 1000 F for 90 minutes

d. 1050 F for 90 minutes

e. 1100 F for 90 minutes

The particular heat treatments used are shown in the tables of test data.

Table IO-I gives the results of tensile tests on .005" and .008" thick sheet with and without the 1400 F step, stabilized at three different temperatures, and aged at 1050 F. Table IO-II gives the same information for .014" sheet. This table also gives the results of tensile tests on sheet in the three thicknesses, without the 1400 F step, stabilized at -20 F, and aged at 950 F.

On the whole, the transformation temperature gave no invariable pattern of effects on the tensile properties. However, for the .005" sheet with the 1400 F step, the tensile yield and ultimate strengths increased noticeably as this temperature was lowered from 0 to -50 F. Also, for the .014" sheet, with the same treatment, the elongation decreased appreciably. On the other hand, the use of the 1400 F step increased both strengths to some extent in nearly all instances and reduced the elongation.

The specimens aged at 950 F were previously furnace cooled from 1650 F to room temperature and then transformed at -20F. As compared with specimens aged at 1050 F which otherwise had the same treatment, those aged at 950 F had somewhat higher tensile yield and ultimate strengths but lower elongation.

Table IO-III gives the results of tensile tests on .014" sheet, transformed at three subzero temperatures and aged at 900, 1000, and 1100 F. All the specimens were air cooled from 1650 F to room temperature before transforming. Figure IO-1 is a bar chart showing the test values for the tensile strength and elongation plotted in graphical form.

As may be noted from the data, both the strengths decreased with increasing aging temperature. The elongation decreased as the aging temperature was increased from 900 to 1000 F and then increased with further increase to 1100 F. With one exception, the average elongation values were above the specified minimum of 4.5%. The effect of the transformation temperature on the properties was indeterminate. Maximum tensile properties were obtained by aging at 900 F. For the three aging temperatures, transverse specimens, with one exception, had higher strengths and lower elongation than longitudinal specimens.

CONCLUSIONS: ITEMS N, O

The conclusions drawn from the evaluation studies of the AM 350 and Stainless W steels are given below:

Two similar heat treatments imparted desirable properties to AM 350 steel sheet. For example, this steel conditioned at 1750 F, transformed at -100 F, and aged at 750 F had tensile yield and ultimate strengths comparable to those of 17-7PH steel in the TH 1050 condition.

With corresponding strength, the elongation of AM 350 steel was appreciably higher than that usually found for 17-7PH material in thickness of .005".

The growth of AM 350 steel on heat treatment was about half that of 17-7PH steel.

With suitable heat treatment, Stainless W steel gave satisfactory tensile properties. For equivalent acceptable strength its elongation tended to be considerably higher than that of 17-7PH steel.

For certain heat treatments, Stainless W steel gave acceptable tensile properties with transformation temperatures in the range of 0 to -100 F.

For a given prior treatment, maximum tensile properties were obtained by aging at 900 F. Aging at 1100 F gave low strength.

Heat Treat Response of AM 350

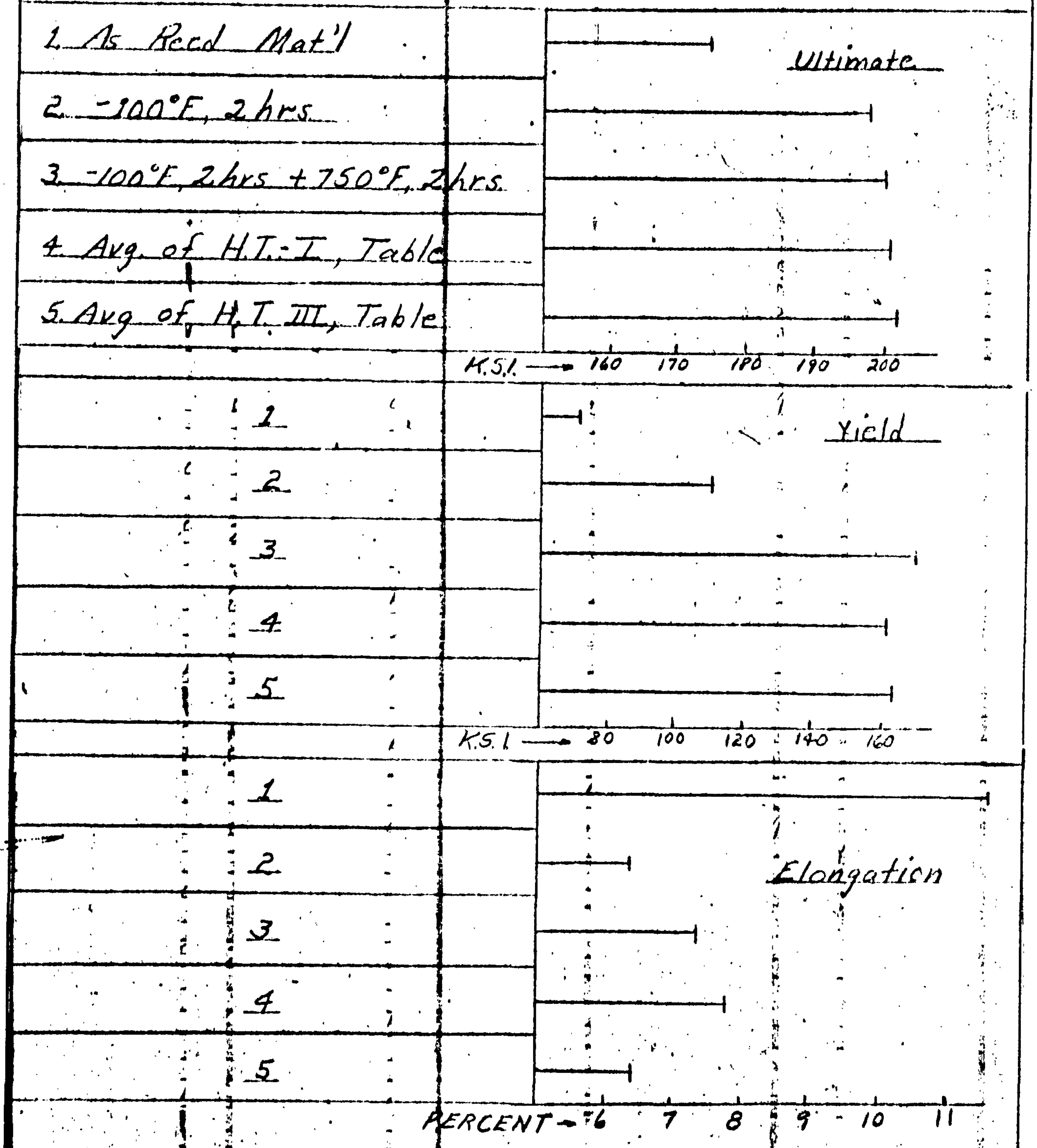


FIGURE: TN-1

CONVAIR —FORT WORTH 0.005 Gage TABLE IN-I

TABULATION SHEET Allegheny AM-350 Steel -- Tensile Data

SPEC. NO.	GRAIN DIR	H.T.	YIELD KSI.	ULT. KSI.	% e
10x	Long	1A+2	162.9	192.6	8.0
11x	↓	↓	152.5	190.2	—
12x			162.7	199.5	7.0
AVERAGE			1570	196.1	7.5
14x	↓	1B+2	162.6	204.0	7.0
15x		↓	164.7	203.0	7.0
AVERAGE			164.2	203.5	7.0

H.T.-I

1\. Heat to 1850°F, hold 15 min.
A. Cool to RT. in 10 min.
B. " " " " 60 min.
2\. -100°F for 2hrs &
temper 750°F for 2hrs

SPEC NO	GRAIN DIR	H.T.	YIELD KSI.	ULT. KSI.	% e
19x	Long.	1a	149.0	177.7	12.0
20x	↓	↓	150.7	186.7	14.0
21x			147.3	177.6	12.5
AVERAGE			149.0	180.7	12.8
22x	↓	1b	154.2	183.3	8.5 *
23x		↓	158.0	172.2	10.5
24x			157.2	175.5	10.0
AVERAGE			156.5	180.3	12.2

H.T.-II

1\. Heat to 1850°F, hold 15 min
Cool to 1350°F in 90 min
Hold 1350°F in 90 min - Cool R.T.
a. Temper @ 850°F for 1 hour
b. -100°F, 2hrs. + Temper 850°F, 2hrs.

*Broke out of test sect'n

SPEC NO.	GRAIN DIR	HT.	YIELD KSI.	ULT KSI.	% e
25x	Long.	1A+2	161.4	200.7	6.0
26x	↓	↓	164.3	202.7	6.0
27x			162.6	200.7	7.0
AVERAGE			162.8	201.4	6.3
28x	↓	1B+2	166.6	205.0	7.0
29x		↓	164.9	204.5	7.0
30x			163.5	221.6	7.0
AVERAGE			1650	2037	7.0
31x	↓	1C+2	1642	2053	7.0
32x		↓	167.7	206.8	6.0
33x			163.1	201.7	5.0
AVERAGE			165.0	204.6	6.0
34x	↓	1D+2	162.9	202.0	6.0
35x		↓	162.2	202.7	6.0
36x			161.4	200.9	6.0
AVERAGE			162.2	201.8	6.0

H.T.-III

1\. Heat to 1850°F, hold 15 min.
A. Cool to 1750°F, hold 30 min
B. " " " " 60 min.
C. " " " " 90 min.
D. " " " " 120 min.
2\. -100°F for 2hrs. &
temper at 750°F for 2hrs.

CONVAIR—FORT WORTH

TABLE IN-II

TABULATION SHEET 0.005 Gage, Allegheny, AM 350 Steel-- Misc. Data

SAMP. NO	GRAIN DIR	H.T.		YIELD KSI	ULT. KSI	%e
7	Long.	O		72.9	177.9	11.0
8	↓	↓		73.5	171.0	12.0
9	↓	↓		70.6	176.4	12.0
AVG				72.3	175.1	11.7
3	↓	C		117.4	198.6	7.0
4	↓	↓		111.6	196.4	5.0
5	↓	↓		116.6	200.6	7.0
AVG				115.2	198.5	6.3
1	↓	D		170.5	202.0	7.5
2	↓	↓		166.8	200.0	7.5
6	↓	↓		172.8	200.3	7.0
AVG				170.0	200.8	7.3

SAMP NO	GRAIN DIR		PRIOR H.T.	Growth In/In	PRIOR HT	Growth In/In
2	Long.		O + C	.0024	O + D	.0022
3	↓		O + C	.0024	O + D	.0022
4	↓		1A' + C	.0024	1A' + D	.0021
5	↓		1B' + C	.0023	1B' + D	.0020
6	↓		1C' + C	.0032	1C' + D	.0031
7	↓		1a + C	—	1a + D'	.0028
8	↓		1a + C	.0032	1b + D'	.0030
9	↓		1A + C	.0030	1A + D	.0027
10	↓		1B + C	.0030	1B + D	.0030
11	↓		1C + C	.0030	1C + D	.0035
12	↓		1D + C	.0030	1D + D	.0026

H.T. - Code:

O - As rec'd mat'l

C - As rec'd material cooled to -100F for 2 hrs.

D - As rec'd mat'l cooled to -100F for 2 hrs plus aged @ 750F for 2 hrs.

H.T. Code:

O - As rec'd mat'l

1 - Heated to 1850F for 15 min.
A' Cooled to RT in 12 min.
B' " " " " 60 min
C' " " " " 9 hrs.
a Fce. cooled to 1350F in 90 min., held 90 min, AC to RT.

A Fce cooled to 1750F, held 30 min
B " " " " " 60 "
C " " " " " 90 "
D " " " " " 120 "

C - Cooled to -100F for 2 hrs.

D - Cooled to -100F for 2 hrs and aged at 750F 2 hrs.

D' - Cooled to -100F for 2 hrs. and aged at 850F 2 hrs.

Effect of Chill & Age Temp on .0014 Gage Stainless W

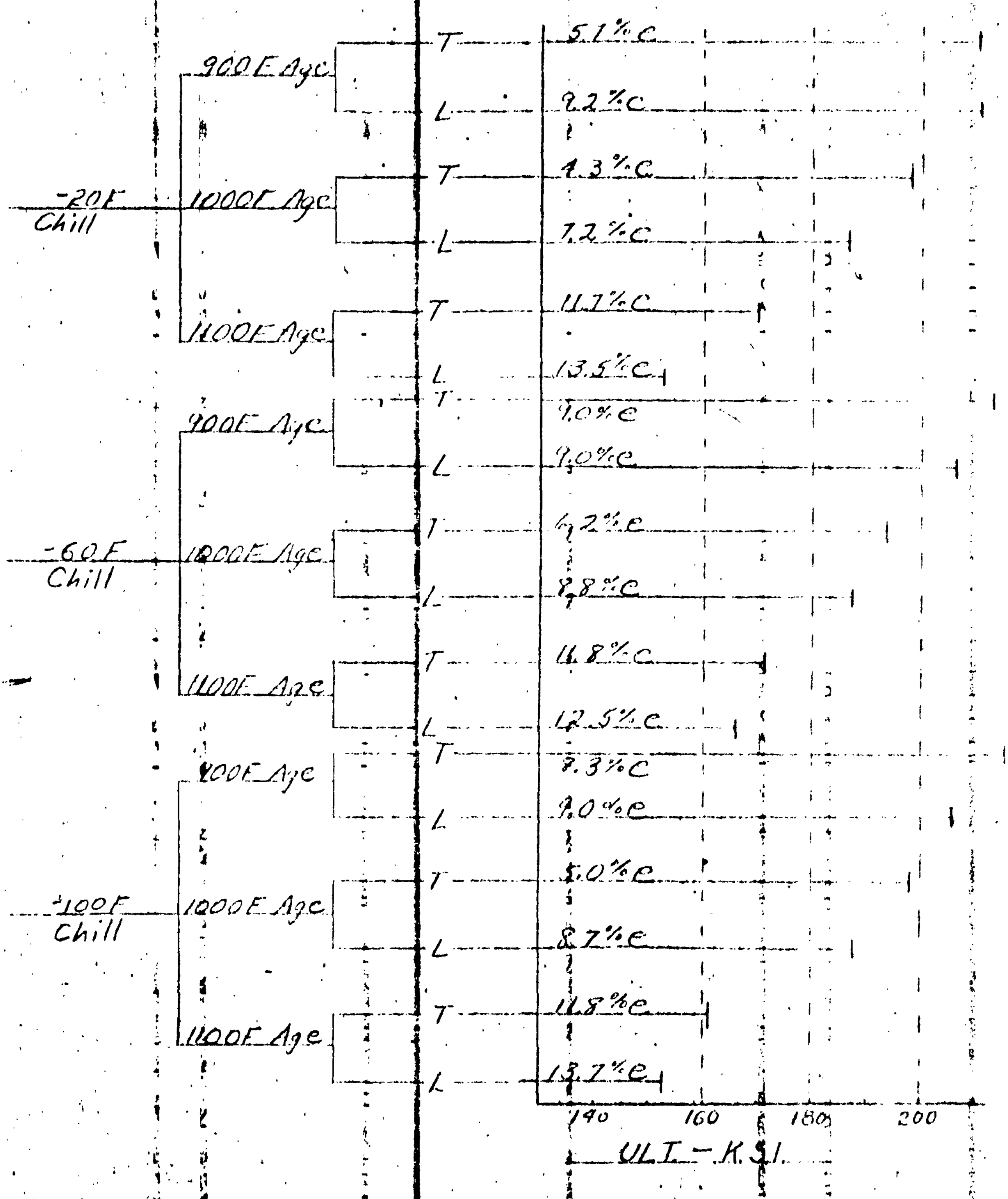


FIGURE 101

CONVAIR—FORT WORTH

TABULATION SHEET 0.005 & 0.008 Gage, Stainless 'W', Tensiles -- Heat: 7X2117

1400F STEP	CHILL TEMP	AGE TEMP		SAMP NO	GAGE	YIELD KSI	ULT KSI	%e		SAMP NO	GAGE	YIELD KSI	ULT KSI	%e
Yes	0°F	1050°F		1	0.005	187.3	196.4	9.5		1	0.008	182.2	192.6	9.0
				2		188.0	196.8	6.0		2		182.2	191.6	9.0
↓	↓	↓		3	↓	184.0	193.4	6.0		3	↓	179.8	189.5	9.0
				AVG		186.4	195.5	7.2		AVG		181.4	191.2	9.2
No				1		181.5	191.5	7.5		1		177.7	[illegible]	9.5
				2		185.0	195.3	5.5		2		179.5	188.9	9.5
↓	↓	↓		3	↓	179.9	192.5	7.5		3	↓	180.5	191.3	9.0
				AVG		182.1	193.1	7.2		AVG		179.2	189.7	9.3
Yes	-20°F			1		190.0	198.8	6.5		1		184.4	192.6	6.0
				2		186.7	195.7	5.5		2		183.3	192.3	7.5
↓	↓	↓		3	↓	190.0	199.2	5.5		3	↓	184.3	192.4	7.5
				AVG		188.9	197.9	5.8		AVG		184.0	[illegible]	[illegible]
No				1		191.6	200.8	6.0		1		186.1	196.6	7.5
				2		186.7	199.2	6.5		2		184.3	194.9	11.0
↓	↓	↓		3	↓	186.3	198.0	5.5		3	↓	186.5	197.9	11.0
				AVG		188.2	199.3	6.0		AVG		185.6	196.5	10.5
Yes	-50°F			1		192.4	200.8	7.5		1		182.3	191.3	7.0
				2		195.6	202.0	6.5		2		189.2	197.7	7.0
↓	↓	↓		3	↓	191.8	202.9	7.5		3	↓	182.6	190.8	9.0
				AVG		193.3	201.9	7.2		AVG		184.7	193.3	7.7
No				1		189.1	200.8	4.0		1		183.3	196.4	11.0
				2		188.3	198.2	9.0		2		178.7	191.9	10.5
↓	↓	↓		3	↓	182.1	194.8	6.5		3	↓	178.2	189.8	7.0
				AVG		186.5	197.3	6.5		AVG		180.1	192.7	9.7

NOTE: All specimens were heated to 1650F in 30 min. & held at 1650F for 10 min

The specimens were furnace cooled from 1650F or 1400F to R.T. in 3 hours.

Grain Direction on these specimens is presumed to be longitudinal

CONVAIR—FORT WORTH

TABLE — 0 —

TABULATION SHEET ~~0.005~~ 0.008 & 0.014 Gage, Stainless 'W', Tensiles -- Heat: 7X2117

1400F STEP	CHILL TEMP	AGE TEMP	GAGE	YIELD KSI.	ULT. KSI.	%e	1400F STEP	CHILL TEMP	AGE TEMP	GAGE	YIELD KSI.	ULT. KSI.	%e
Yes	0°F	1050F	0.014	179.4	191.2	7.5	No	-20°F	950F	0.005	190.8	199.2	5.0
↓	↓	↓	↓	184.8	197.0	8.0	↓	↓	↓	↓	190.8	199.3	5.0
				183.1	194.1	8.0					200.4	210.4	4.0
			AVG.	182.4	194.1	7.8				AVG.	194.0	203.3	4.7
No	↓	↓	↓	178.3	192.8	6.0	↓	↓	↓	0.008	191.0	197.6	4.0
↓				180.4	194.5	8.0				↓	192.7	200.0	3.0
				179.7	192.0	6.0					195.5	202.8	4.0
			AVG.	179.5	193.1	6.7				AVG.	193.1	200.1	3.7
Yes	-20°F	↓	↓	179.0	189.9	6.0	↓	↓	↓	0.014	191.2	202.7	4.0
↓	↓			179.0	191.3	5.0				↓	193.4	205.9	4.5
				180.9	193.4	7.5					188.8	196.3	4.5
			AVG.	179.6	191.5	6.2				AVG.	191.1	201.6	4.3
No	↓	↓	↓	176.1	190.6	10.5							
↓				179.0	192.8	10.0							
				178.3	193.5	8.0							
			AVG.	177.8	192.3	9.5							
Yes	-50°F	↓	↓	179.0	191.3	4.5							
↓	↓			184.3	194.6	4.5							
				184.3	196.3	5.0							
			AVG.	182.5	194.1	4.7							
No	↓	↓	↓	177.9	192.6	6.0							
↓				179.4	194.1	6.0							
				181.6	194.9	6.0							
			AVG.	179.6	193.9	6.0							

NOTE: All specimens were heated to 1650F in 30 min. & held at 1650F for 15 min.

The specimens were furnace cooled from 1650F or 1400F to R.T. in 3 hours.

Grain Direction on all specimens is presumed to be longitudinal

CONVAIR—FORT WORTH

TABLE 0

TABULATION SHEET 0.014 Gage, Stainless 'W', Tensiles -- Heat: 7X2117

GRAIN DIR	AGE TEMP	-20F CHILL F_{ty}-ksi	-20F CHILL F_{tu}-ksi	-20F CHILL % e	-60F CHILL F_{ty}-ksi	-60F CHILL F_{tu}-ksi	-60F CHILL % e	-100F CHILL F_{ty}-ksi	-100F CHILL F_{tu}-ksi	-100F CHILL % e
Trans.	900F	183.1	209.2	5.5	196.4	215.0	9.0	196.4	215.0	7.0
		184.4	211.4	5.5	200.0	214.5	9.0	197.9	216.4	9.0
↓	↓	183.4	210.3	6.0	178.3	210.3	9.0	198.6	215.0	9.0
AVG.		183.6	210.3	5.7	191.6	213.3	9.0	197.6	215.5	8.3
Long.		190.6	216.9	9.0	182.1	200.7	8.0	—	209.3	9.0
		193.5	211.6	9.5	182.6	209.3	9.0	184.1	203.6	9.0
↓	↓	190.0	209.3	9.0	187.1	202.6	10.0	185.5	204.2	9.0
AVG.		191.4	210.6	9.2	185.9	206.2	9.0	184.8	205.7	9.0
Trans	1000F	181.9	199.4	4.5	188.3	195.6	6.0	183.1	196.3	6.0
		180.2	196.1	4.0	184.8	192.8	6.5	183.0	199.0	4.0
↓	↓	172.4	196.8	4.5	181.0	192.5	6.0	182.1	197.5	5.0
~~AVG.~~		~~[illegible]~~	~~[illegible]~~	~~4.3~~	~~[illegible]~~	~~[illegible]~~	~~6.2~~	~~182.7~~	~~[illegible]~~	~~5.0~~
Long.		179.9	188.1	7.0	182.6	187.0	9.0	177.9	188.1	8.0
		175.7	183.7	8.0	177.7	187.1	9.0	177.7	187.1	9.0
↓	↓	180.0	188.1	6.5	179.2	187.7	8.5	177.6	188.1	9.0
AVG.		178.5	186.6	7.2	179.2	187.3	8.8	177.1	187.7	8.7
Trans.	1100F	155.7	168.1	12.0	143.3	168.9	11.5	136.9	161.2	11.5
		146.3	171.6	11.5	146.1	171.4	12.0	134.0	160.2	12.0
↓	↓	143.6	169.4	11.5	143.6	171.1	12.0	134.7	162.0	12.0
AVG.		148.5	169.7	11.7	144.3	171.1	11.8	135.2	161.1	11.[illegible]
Long.		126.6	153.7	13.5	132.5	165.7	12.5	123.4	152.7	13.0
		127.6	154.0	13.5	132.7	165.9	13.0	121.6	152.7	14.0
↓	↓	125.2	152.9	13.5	136.1	165.7	12.0	119.7	152.7	14.0
AVG.		126.5	153.5	13.5	133.6	165.8	12.5	121.6	152.7	13.7

NOTE:

All specimens were heated to 1650F in 30 min.
& held at 1650F for 10 min.

The specimens were air cooled from 1650F to R.T.

SECTION II

CORROSION AND OXIDATION:

Several investigations relating to the corrosion or oxidation of brazed sandwich panels in 17-7PH stainless steel have been carried out. Two reports (FTDM-2270 and FTDM-2355) on oxidation have been published. Abstracts of these are given in the Bibliography. The unpublished results of investigations in this general field have been reported either by memoranda or verbally. Summaries of these are presented here.

ITEM A --IDENTIFICATION OF CORROSION PRODUCT ON PANELS BRAZED WITH SILVER-MANGANESE ALLOY

Some time after 17-7PH steel panels brazed with the 85:15 silver-manganese alloy had been placed in service on the B-58 airplane, routine inspection revealed isolated localities in the panels where corrosion had occurred. These localities were subject to failure during flash testing at 600 - 650 F.*

An investigation was made early in 1957 with the object of identifying the corrosion products in the panels. This comprized metallographic examination and the use of X-ray methods. As a result, regions of high manganese were found on the steel surfaces.

Figure IIA-1 shows a dark etching constituent at the core-alloy and steel-alloy interfaces. The constituent was identified as manganese or a manganese compound by X-ray fluorescence. This technique also showed that the manganese indication on the exterior side of the panel skin was much lower than that on the brazed side. The significance of this is emphasized by the fact that all the brazing alloy was dissolved off the skin specimen before the X-ray fluorescence run. Conjointly, the metallographic and X-ray fluorescence examination showed that manganese from the brazing alloy had diffused into the steel during brazing.

X-ray diffraction patterns obtained from the corrosion product found in the panels indicated the presence of Ag, Mn_3O_4, and Cr_2O_3.

***See Supplemental Sheet - S-1**

ITEM B - FAILURE ANALYSIS OF INBOARD ELEVON WEDGE, RO-93

Metallographic analysis was made in June 1957 of specimens from an elevon wedge that failed in flash test. This wedge was one of the original panels on B-58 airplane No. 1. It was one of the first acceptable wedge panels brazed by the Rohr Aircraft Corporation. The panel material was 17-7PH steel, and the brazing alloy was 85:15 silver-manganese.

Specimens were removed from various areas of the failed panel for metallographic analysis. The examination disclosed that crevice corrosion had occurred at interfaces of the brazing alloy and the steel. This was severe in some locations and slight in others.

Photomicrographs were taken to show typical conditions in different areas. Figure IIB-I is a photomicrograph at a region that failed in flash testing. Figure IIB-2 was taken at an area that was not flash tested. As may be noted in both figures, the core is entirely separated from the fillet of brazing alloy. Crevice corrosion had penetrated along the interface between the steel core and the brazing alloy causing complete separation. Figure IIB-3 shows an area where the fillet is intact although free from both the skin and core.

ITEM C - CREVICE CORROSION IN STAINLESS STEEL SANDWICH PANELS BRAZED WITH SILVER-MANGANESE ALLOY

Early in 1959, metallographic examination was made of plug specimens taken from eighteen flat sandwich panels which had been brazed with 85:15 silver-manganese alloy. The panel material was 17-7PH stainless steel. These panels had been removed from B-58 airplane No. 4. Altogether, nineteen specimens were examined. The object was to determine the presence of crevice corrosion, if any.

All the specimens showed a manganese-rich layer at the brazing alloy-steel interfaces. This indicated that the panels were susceptible to crevice corrosion of the type previously observed when the 85:15 silver-manganese alloy was used for brazing.

Of the nineteen sections examined, three exhibited crevice corrosion. The others were classified as not corroded.

The results of this investigation indicated that preliminary evidence of crevice corrosion can sometimes be found, by metallographic examination, prior to failure of panels brazed with the silver-manganese alloy. The fact that crevice corrosion may not be detected by such examination does not rule out the possibility of its presence.

ITEM D - METALLOGRAPHIC DETERMINATION OF CREVICE CORROSION IN SILVER-MANGANESE BRAZED PANELS FROM A/P #4.

A memorandum issued in April 1959 gave a summary concerning the background of the crevice corrosion problem in 17-7PH steel panels brazed with the 85:15 silver-manganese alloy. The results of metallographic examination of 86 specimens representing 85 panels from B-58 airplane #4 were also reported.

The 85:15 silver-manganese alloy was adopted before information on its resistance to corrosion was available. On test, 17-7PH steel panels brazed with this alloy were found to fail in less than 50 hours in standard salt spray. Failures were also observed on exposure of such panels to air atmospheres of high humidity. All the failures occurred by separation of the brazing alloy from the steel at the interface.

The sterling silver 0.2% lithium alloy was adopted to replace the silver-manganese composition. However, some of the panels brazed with the latter alloy before the change were kept in service. A metallographic test program was started with the object of providing additional information as to the serviceability of these panels together with flash testing.* Metallographic examination was made of plug specimens removed from panels taken from airplane #4. Each specimen was classified in accordance with the degree of corrosion. Of 86 specimens, five showed definite indications of crevice corrosion. Nine were found with less evidence of crevice corrosion, and 67 showed no evidence. Five specimens had no fillet, and these were not classified.

Attention is invited to the fact that the metallographic examination of a small sample does not insure that a panel is good even though corrosion is not found. Also, the location of where corrosion may occur can not be predicted. Crevice corrosion can cause failure on one skin of a panel and not be present on the opposite skin.

***See Supplemental Sheet S-1.**

ITEM E - OXIDATION OF SILVER-COPPER-LITHIUM ALLOY FILLETS IN AIR AT ELEVATED TEMPERATURES

In the summer of 1958, oxidation of fillets of the standard silver-copper-lithium alloy in brazed 17-7PH steel panels was observed after the parts had been exposed in air at temperatures above 550 F. The presence of cupric oxide was determined by X-ray diffraction patterns of fillet material.

In 1959, specimens cut from a brazed sandwich panel were exposed in air for different times up to 300 hours at 700 F. Edge compression and shear beam tests were performed on these specimens. These tests showed that, given adequate fillets, the oxidation does not significantly decrease the strength for exposures up to 300 hours at 700 F. The results of this investigation have been published (Reference FTDM-2355).

Metallographic examination was made of fillets oxidized in air for various times at temperatures up to 800 F after aging in air for 90 minutes at 1050 F. This examination indicated that the extent of oxidation increased with both time and temperature of exposure. Also, porosity in the fillet caused the depth of attack to be uneven in many specimens.

Figure IIE-1 is a photomicrograph of a sample which had been exposed for 100 hours in air at 700 F after aging.

ITEM F - CONCLUSIONS FOR ITEMS A, B, C, D, E

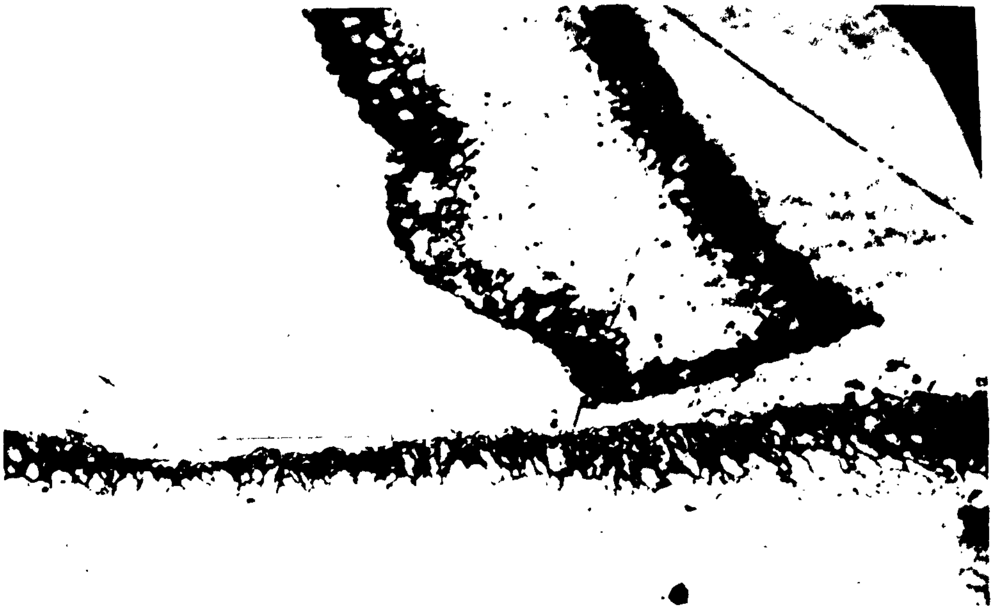
The conclusions drawn from the investigations on corrosion and oxidation of brazed sandwich panels are given below.

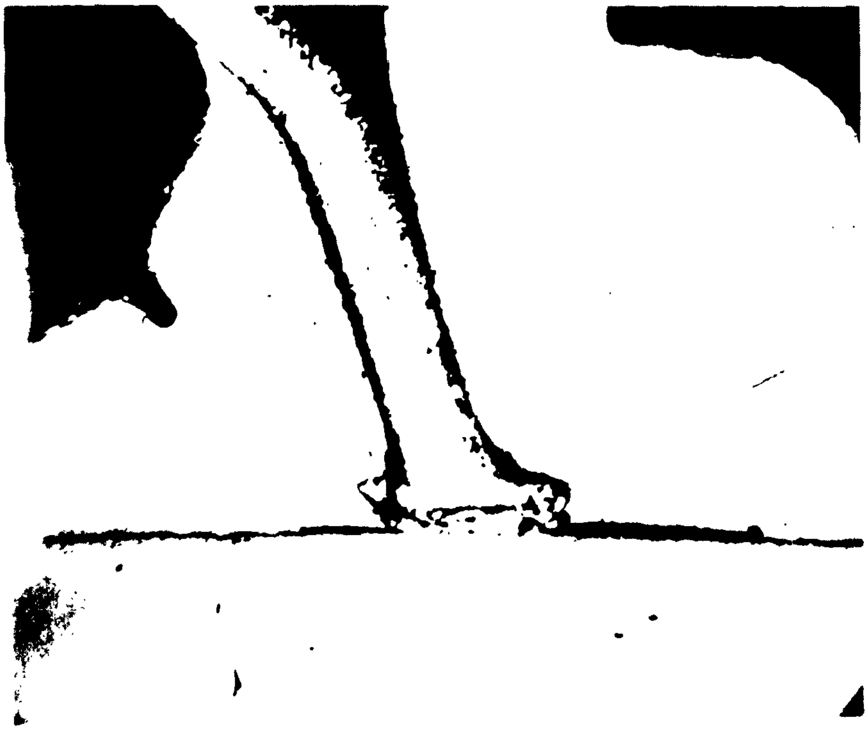
The 85:15 silver-manganese alloy is not suitable for brazing 17-7PH steel panels. Crevice corrosion occurs at the brazing alloy-steel interface and causes separation. The corrosion product is a mixture of manganese oxide, Mn_3O_4, and chromium oxide, Cr_2O_3. On test, 17-7PH steel panels brazed with this alloy were found to fail in less than 50 hours in standard salt spray. Failures also occurred on exposure of such panels to air atmospheres of high humidity.

Metallographic examination of numerous specimens removed from 17-7PH steel panels brazed with the 85:15 silver-manganese alloy has disclosed the presence of crevice corrosion. The extent ranged from slight to severe. Metallographic examination does not insure that a panel is free from corrosion even though no evidence is found. The location of where corrosion may occur can not be predicted.

The sterling silver 0.2% lithium alloy was adopted for brazing in place of the silver-manganese alloy. Brazements with the former alloy have not been observed to develop crevice corrosion. However, they undergo oxidation in air at temperatures above 550 F. Tests have shown that the oxidation does not appreciably impair the strength in edge compression or shear beam loading after exposures in air at 700 F up to 300 hours (Reference FTDM-2355).

On the basis of tests, sandwich panels brazed with the silver-copper-lithium alloy incorporated in iron sponge have unsatisfactory resistance to salt spray and to elevated temperature in air (Reference FTDM-2270).



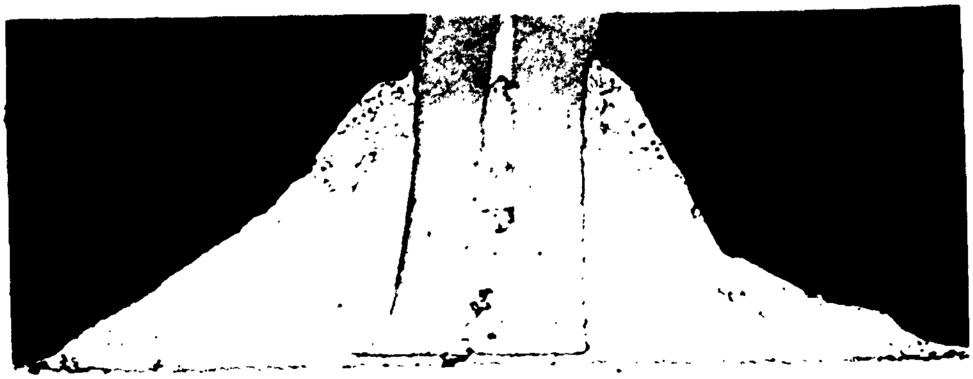


Mag 250X Unetched

Figure IIB-2: Crevice corrosion at core-fillet and fillet-skin interfaces.

Mag 5X

Figure IIB-3: Intact brazed fillets separated from both core and skin; arrows indicate the free and original positions of fillets.



M[illegible] [illegible]

[illegible]

BRAZING ALLOYS:

A number of investigations on the evaluation of alloys for brazing 17-7PH steel sandwich panels has been carried out. Most of the results have been published in a series of reports. These are listed in the Bibliography (references FGT-1153, MR 54-5, FGT-1363, FGT-1362-1, FGT-2088, FTDM-2270, and FTDM-2355).

The results of several other studies on brazing alloys have not been published but have been reported in memoranda or otherwise. Summaries of these are given here.

ITEM G - EVALUATION OF SILVER-COPPER-LITHIUM ALLOY:

In the Spring of 1957, the fact was recognized that the 85:15 silver-manganese alloy was unsuitable for use in brazing 17-7PH steel sandwich panels because of its poor resistance to corrosion. Preliminary tests were made with a silver-copper alloy (sterling silver) containing a small amount of lithium. The results were promising. The Engineering Metallurgical Laboratory was then asked to conduct an investigation for the purpose of evaluating silver-copper-lithium brazing alloys. Tests were carried out to determine the following: Resistance to salt spray, effect of lithium content, strength of lap-shear joints, and optimum brazing temperature. Also, general metallographic examination of brazements was made. The results of this work are presented here.

The nominal composition of sterling silver is 92.5:7.5 silver-copper. Brazing and other tests were performed with this alloy to which 0.1, 0.2, and 0.5% lithium had been added. Brazements of 17-7PH steel with these three compositions were satisfactory and had similar characteristics. The alloy containing 0.2% lithium was recommended in place of the 85:15 silver-manganese alloy for use in brazing production panels. The sterling silver composition containing 0.2% lithium seemed a little more likely to give consistent wetting than the 0.1% alloy. A content of 0.5% lithium appeared to be unnecessarily high.

Figures IIG-1 and IIG-2 are photomicrographs at fillets made by brazing 17-7PH steel with the sterling silver 0.2% lithium alloy. The first shows an as-brazed joint, and the second shows a joint after exposure of 69 hours to salt spray. As may be noted, there is no evidence of corrosion by the salt spray. By contrast, similar joints brazed with the 85:15 silver-manganese alloy fell apart after 50 hours exposure.

A few experiments were made on the use of borax as a flux with sterling silver as the brazing alloy. This combination wet 17-7PH steel poorly and formed uneven fillets. Figure IIG-3 is a photograph of a core-to-skin joint in this steel brazed with sterling silver fluxed with borax.

Figure IIG-4 shows double lap-shear strengths of brazements as affected by temperature. For the test specimens, 17-7PH steel sheet stock was brazed with three different alloys. These were sterling silver plus 0.5% lithium, fluxed with borax; 85:15 silver-manganese alloy, fluxed with borax; and 85:15 silver-manganese alloy plus 0.5% lithium. The sterling silver base alloy had higher shear strength at room temperature than the other two. However, it had lower strength than the silver-manganese compositions at temperatures in the range of about 300 to 900 F.

Tests were made to determine whether copper in the sterling silver 0.2% lithium alloy would diffuse into 17-7PH steel at the recommended brazing temperature. Figure IIG-5 may be noted in this connection. It is a photomicrograph which shows an area of a Tee joint in 17-7PH steel brazed with the sterling silver alloy. Knoop hardness determinations were made in the joint area. These values were converted to Rockwell numbers. The hardness in the steel sections of the Tee was 38.3 RC. It was 47.5 R_B in the brazing alloy not close to a steel interface, and near an interface it was 65.5 R_B. In the steel close to an interface with the brazing alloy, the hardness was 43.7 RC. This showed a small increase over the value 38.3 RC. No definite evidence indicated that copper had diffused from the brazing alloy into the steel. The converted hardness values are given at the right of Figure IIG-5.

Figure IIG-6 shows the microstructure of the sterling silver 0.2% lithium alloy as brazed in a small panel. This structure is the result of slow cooling where the silver-rich phases freeze first followed by copper-rich phases, with the latter surrounding the silver areas.

Voids can be formed by the shrinkage of the brazing alloy on freezing. An example of shrinkage cavities is shown in Figure IIG-7. The relatively long solidification range of the alloy contributes to the mottled appearance shown in Figure IIG-8. Work on the 85:15 silver-manganese alloy showed that lithium additions are the major cause of these voids when slow cooling rates are encountered. The amount of contamination present inside the panel package apparently influences the degree of the mottled condition.

Incidentally, sterling silver alloys containing 0.1, 0.2, and 0.5% lithium all gave mottled brazes similar to the appearance in Figure IIG-8.

The optimum brazing temperature for the sterling silver 0.2% lithium alloy was determined by brazing 1" x 1" 17-7PH core-to-skin sections at various temperatures. These temperatures were 1600, 1620, 1630, 1640, 1650, and 1785 F. The optimum temperature was chosen as 1650 F because this was the lowest showing evidence of good node flow.

ITEM H - OPTIMUM BRAZING TEMPERATURE OF NICKEL SPONGE ALLOY:

The material referred to as nickel sponge alloy is a special composition developed by the Handy and Harman Corporation to reduce excessive brazing alloy flow in curved sandwich panels in 17-7PH steel during brazing. A composition supplied for test contained approximately 50% nickel sponge and 50% sterling silver plus 0.2% lithium. Other ratios may be prepared.

An experiment was made to determine the optimum temperature for brazing 17-7PH steel with the nickel sponge material. A sandwich panel 1/2" x 3" x 12" was used for this purpose. It was brazed in a stainless steel retort without fixtures. The retort was used to maintain an even temperature between the top and bottom skins of the panel during brazing. Six thermocouples were spaced at 2" intervals along the long axis of the panel. By leaving the furnace door partly open, a temperature gradient of 1640 F to 1840 F was obtained along the axis of the panel.

Examination of the brazed panel showed that poor brazes were obtained below 1700 F, while temperatures above 1800 F seemed to produce small top fillets. Based on the size of the top fillets obtained, the optimum brazing range appeared to be 1725 to 1775 F. Figure IIH-I shows top fillets formed on brazing at 1725 F. Figure IIH-2 shows the distribution of nickel in a joint brazed at the same temperature. A continuous nickel-steel interface is formed. The effect of nickel diffusion on the strength of the steel is given in Section II, Item M, Figure IIM-1.

ITEM I - OPTIMUM BRAZING TEMPERATURES OF TRI-METAL ALLOYS:

The so-called tri-metal brazing alloys consist of a pure silver center layer sandwiched between layers of the standard sterling silver 0.2% lithium alloy. Perhaps, tri-layer is a more appropriate term. The tri-metal brazing materials were devised with the object of decreasing alloy flow in contoured panels.

About mid-1958, tests were made on three tri-metal alloys to determine their minimum brazing temperatures. The specific designations of the alloys tested were 1-3-1, 1-4-1, and 1-6-1. These designations indicate the relative thicknesses of the three layers in each foil sandwich.

In order to determine the brazing temperatures, three panels 1/2" x [illegible] 12" were brazed, each with one of the tri-metal materials. The temperature was varied over the panel length by leaving the furnace door partly open, as described in Item H.

The temperature range in brazing with the 1-3-1 foil was 1630 to 1830 F. Small fillets were formed at 1650 F. These increased in size with increasing temperature to 1690 F. Temperatures above 1690 F produced no apparent change in size. The minimum suitable brazing temperature was 1680 F.

The temperature range in brazing with the 1-4-1 foil was from 1590 to 1800 F. Figures II-I-I and II-I-2 are photographs of the panel. Figure II-I-I shows the top skin after it was peeled from the core. As can be seen from this photograph, the fillets formed at 1700 F and above retained pieces of core. The minimum suitable brazing temperature was 1700 F.

The temperature range in brazing with the 1-6-1 foil was from 1640 to 1850 F. Good fillets were obtained at 1760 F and higher. The minimum suitable brazing temperature was 1760 F.

ITEM J - METALLOGRAPHIC EVALUATION OF ENVIRONMENTAL CONDITIONS ON SPONGE-TYPE BRAZING ALLOYS:

A metallographic study was made during the first half of 1959 of joints in 17-7PH steel brazed with various so-called sponge alloys. A commercial brazing alloy called T-50 was included. The T-50 alloy is basically 72:28 silver-copper (the eutectic of the system) plus 5% nickel. It was of interest because of alleged resistance to oxidation at elevated temperatures.

The sponge-type alloys were developed to control brazing-alloy flow in contoured sandwich panels. Such alloys consist of a sponge or skeleton of metal having a melting point above the brazing temperature to be used. This sponge is impregnated with the actual brazing alloy. The opinion has been expressed that by capillary action the sponge inhibits gravity flow of the brazing alloy to low regions of the sandwich-panel package during brazing. Nickel, iron, 430 stainless steel, and cobalt have been tested as sponge metals impregnated with the sterling silver 0.2% lithium brazing alloy. Variations in the amount of sponge metal ranged from 25 to 50% by weight.

For the investigation summarized here, small Tee sections in 17-7PH steel were brazed with the various sponge-alloy materials by the Manufacturing Research & Development Dept. Environmental tests and metallographic examinations were conducted by the Engineering Metallurgical Laboratories. The environmental testing comprised exposure for 50 hours to salt spray and also in air at temperatures of 700 or 1000 F for various periods of time.

Figures IIJ-1, IIJ-2, and IIJ-3 show the microstructures of the 50:50 nickel, iron, and 430 stainless steel sponges, respectively, in the as-received condition. They exhibit differing fibrous structures. The fibers are developed by deformation on rolling to the required thickness.

Figure IIJ-4 shows the microstructure of a joint in 17-7PH steel brazed at 1725 F with 25:75 nickel sponge. The nickel diffusion layer along the steel sections may be noted. The dispersed particles in the brazing alloy (light) are nickel from the sponge. Metallographic examination of joints brazed at 1675, 1700, 1725, and 1750 F showed that the depth of the diffusion increased appreciably with higher temperature. The diffusion of nickel in 17-7PH steel impairs the response to heat treatment and measurably reduces the strength. Joints brazed with the nickel sponge compositions had good resistance to salt spray but were susceptible to oxidation at elevated temperatures.

Iron-sponge brazements were found to etch in air, that is, they were quickly attacked by the moisture present in air. Figure IIJ-5 shows a joint in 17-7PH steel, brazed with 40:60 iron sponge, after 50 hours in salt spray. The corrosion along the iron of the alloy-depleted sponge, between the fillet above and the skin below, is marked. Figure IIJ-6 illustrates the appearance of a joint after oxidation in air at 700 F for 100 hours. The advance of the iron oxide formed is indicated by the unsound borders at the right and left of the photomicrograph. These unsound areas are darker in coloration than the unoxidized brazing alloy. Brazements made with iron sponge are unsatisfactory as concerns resistance to both salt spray and oxidation. Data on the edge compression and shear strengths of specimens from a sandwich panel brazed with iron sponge and exposed to the conditions just mentioned are given in FTDM-2270.

Joints brazed with 50:50 430 stainless steel sponge were outstandingly good as compared with those brazed with the other sponge compositions. The former exhibited neither corrosion nor diffusion, but they did not resist oxidation at elevated temperatures. However, brazements made with the other sponge materials or with sterling silver 0.2% lithium alloy are also subject to oxidation at elevated temperatures.

Figure IIJ-7 shows the structure at a Tee joint in 17-7PH steel as brazed with 50:50 430 stainless steel sponge. Figure IIJ-8 shows the structure after 50 hours in salt spray. The small fillets may be noted. These are more or less typical of the fillets observed when sponge compositions are used for brazing. Since the sterling silver 0.2% lithium alloy is oxidized in air at elevated temperatures, fillet size is important in relation to the service life of a brazed panel. In the use of stainless steel sponge, fillet size might be increased by several means. These include varying the sponge metal-brazing alloy ratio, varying the size of the sponge fibers or particles, and utilizing the optimum brazing temperature.

Joints in 17-7PH steel brazed with 50:50 cobalt sponge had good resistance to salt spray. Slight diffusion of cobalt in the steel was apparent. The oxidation of the brazed fillet in air at 700 F was evidently accelerated by the presence of cobalt. As to this, comparison may be made of the photomicrographs of Figures IIJ-9 and IIJ-10. The former shows the extent of oxidation at a honeycomb core-skin joint of a panel after exposure in air for 300 hours at 700 F. This joint was brazed with the sterling silver 0.2% lithium alloy. The latter photomicrograph shows the oxidation at a Tee joint after the same exposure. This joint was brazed with 40:60 cobalt sponge.

Joints brazed with the T-50 alloy appeared to be about equal to those brazed with the sterling silver 0.2% lithium alloy as concerns susceptibility to oxidation at elevated temperatures. Nickel diffused from the alloy into 17-7PH steel to an appreciable extent on brazing.

ITEM K - CONCLUSIONS FOR ITEMS G, H, I, J

The conclusions drawn from the studies on brazing alloys are given below.

Tests carried out to evaluate silver-copper-lithium alloys for brazing 17-7PH steel showed that satisfactory results could be obtained with several compositions. The alloy consisting of sterling silver plus 0.2% lithium was recommended for replacing the 85:15 silver-manganese alloy. The former has since been used as the standard for brazing sandwich panels in production.

Brazements in the sterling silver 0.2% lithium alloy exhibit good resistance to corrosion in salt spray and have moderate strength in lap shear at temperatures up to about 600 F. Tests indicated that copper does not diffuse from this alloy into 17-7PH steel at the recommended brazing temperature. This temperature was determined as 1650 F. This alloy apparently has a tendency to form shrink cavities under the slow cooling conditions of brazing.

For bonding 17-7PH steel with a nickel-sponge alloy, the optimum brazing range was determined by test to be 1725 to 1775 F. This alloy contained about 50% nickel sponge and 50% sterling silver plus 0.2% lithium.

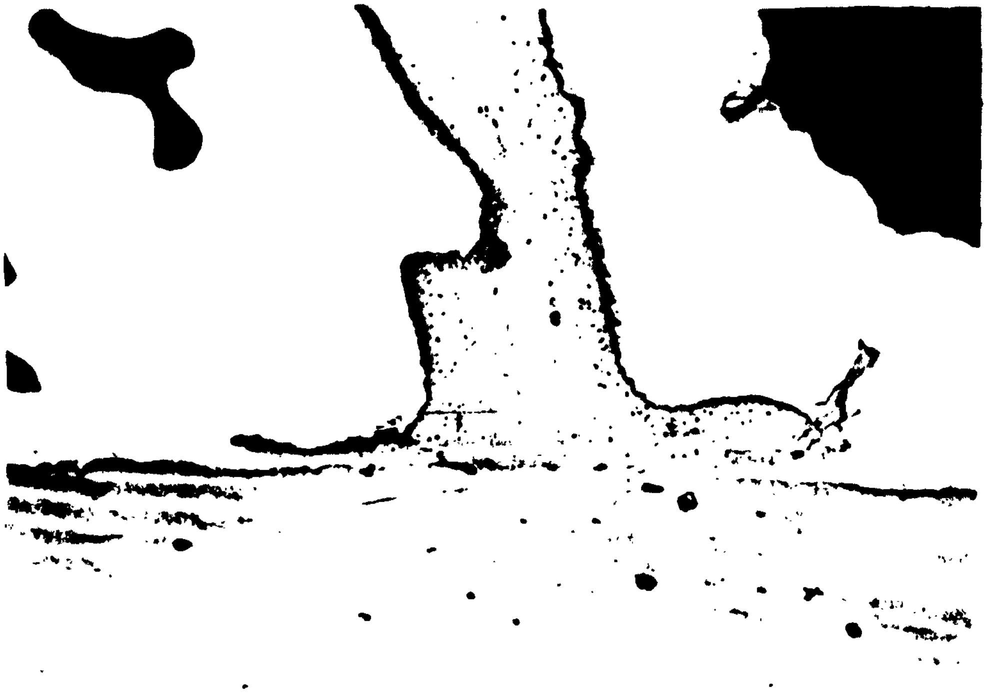
The minimum temperatures suitable for brazing 17-7PH steel with three tri-metal alloys were determined. These alloys were made up as foil with pure silver as the center layer and sterling silver plus 0.2% lithium as two outer layers. In the composite foil, the relative thicknesses of the layers corresponded to 1-3-1, 1-4-1, and 1-6-1. Tests with small 17-7PH steel panels indicated that suitable brazing temperatures were 1680, 1700, and 1760 F, respectively.

Metallographic study of joints in 17-7PH steel brazed with various sponge alloys showed the effects of certain environmental conditions. The sponge metals were nickel, iron, 430 stainless steel, and cobalt. These were impregnated with sterling silver 0.2% lithium. The amount of sponge metal in the composites ranged from 25 to 50%. The environmental conditions were exposure for 50 hours to salt spray and also in air at 700 or 1000 F for various periods of time.

Metallographic examination of the brazements, exposed as indicated just above, disclosed the following: All the sponge alloys were susceptible to oxidation in air at elevated temperatures. All except the iron-sponge alloy had good resistance to salt spray. Cobalt and nickel diffused from the corresponding sponges into the steel, the diffusion of nickel being greater. The sponge alloys gave light fillets. A sponge material based on stainless steel appeared to be promising.

Mag. 500X Unetched

Figure IIG-[illegible]: Fillet as brazed; sterling silver .2% lithium alloy.

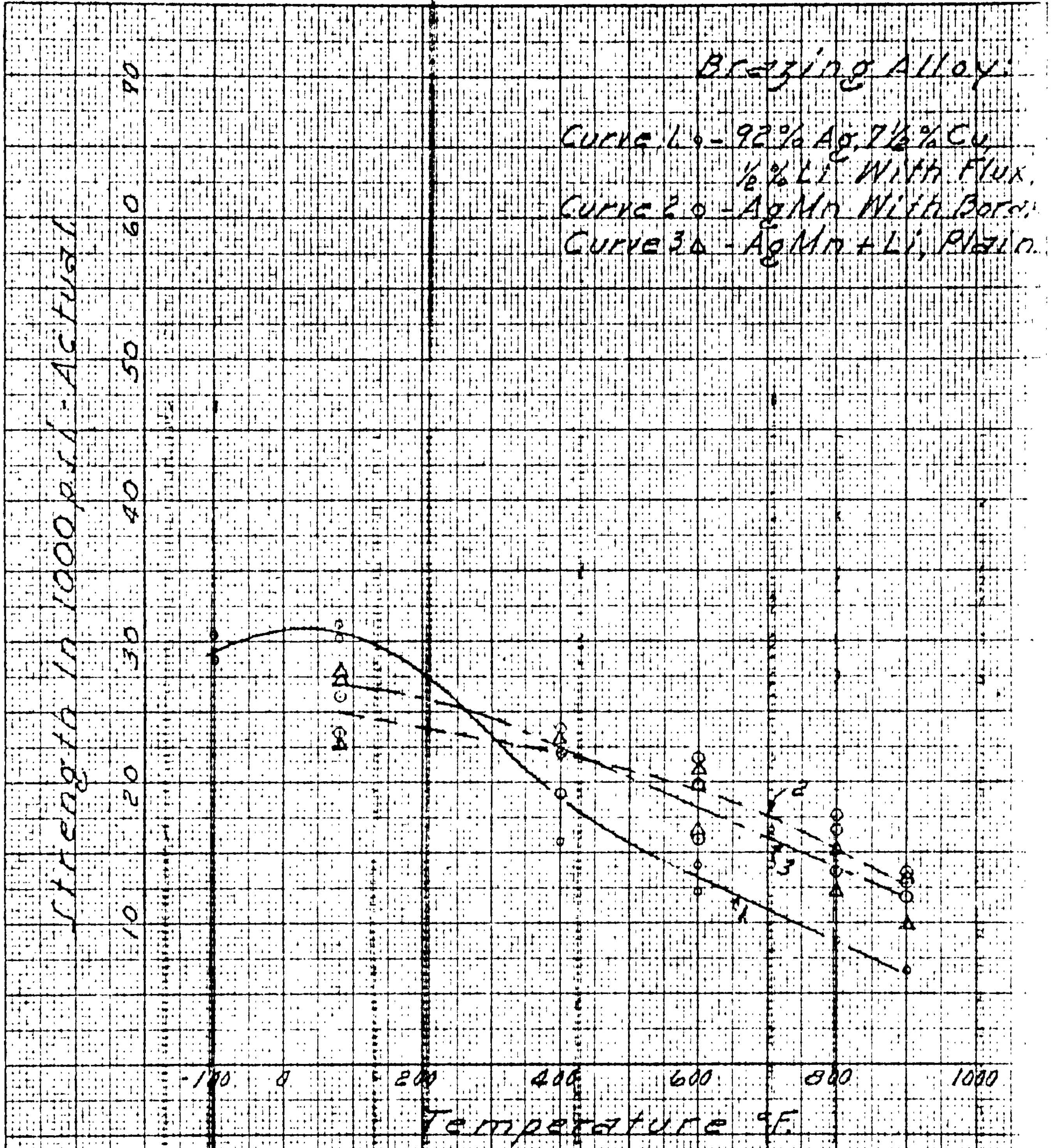


Mag. 500X Unetched

Figure IIG-2: Fillet after 69 hours in salt spray; sterling silver, .2% lithium alloy.

Mag. 25X Unetched

Figure IIG-3: Uneven fillet at core-to-skin joint; 17-7PH steel brazed with sterling silver and borax flux.



Brazed Double Lap Shear Results

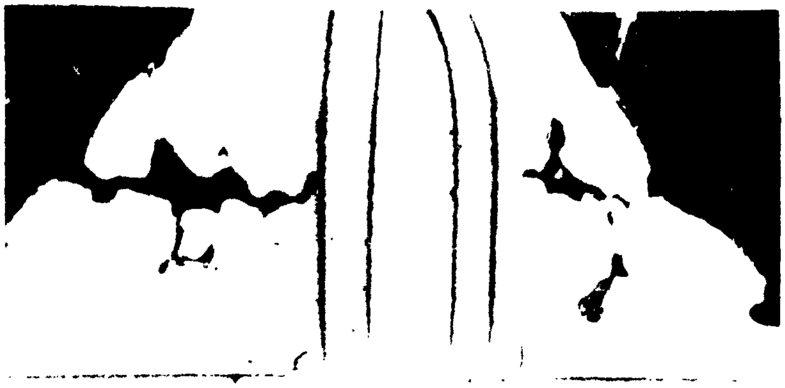
FIGURE: II G-4

Mag. X500 Etchant-Vilella's

Figure IIG-5: Area of Tee section, 17-7PH steel brazed with sterling silver .2% lithium alloy; converted hardness values correspond with indentations.

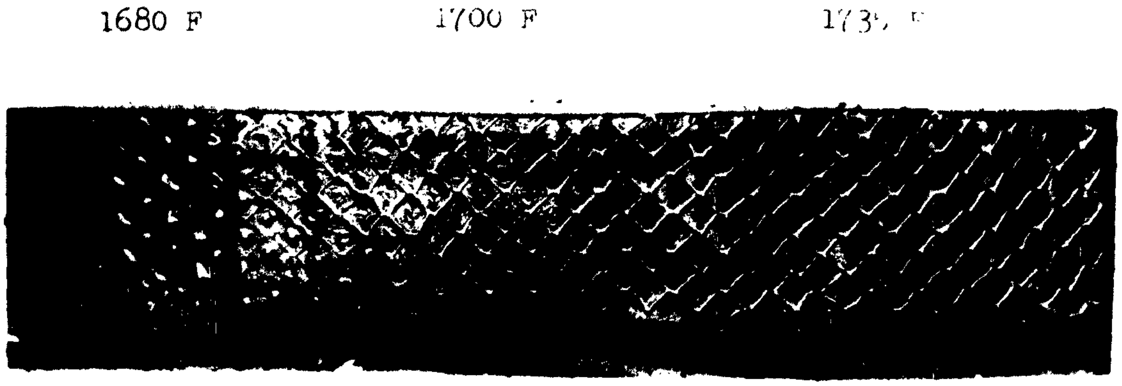
Mag. 500X Etchant - Chromate

Figure IIG-6: Structure of sterling silver .2% lithium alloy, as brazed.



[illegible]

[illegible] m.

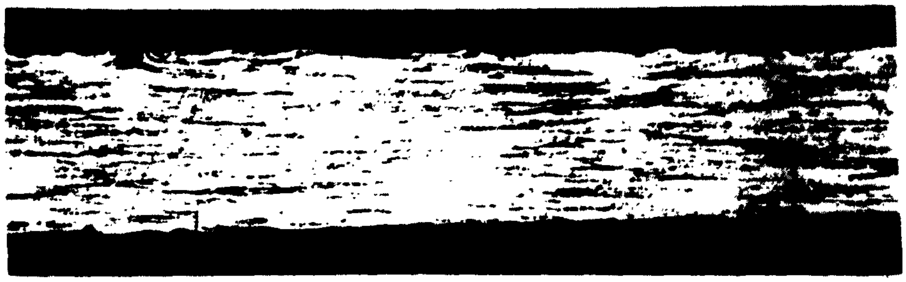


Mag. 1X

Figure II- [illegible] panel brazed with [illegible]

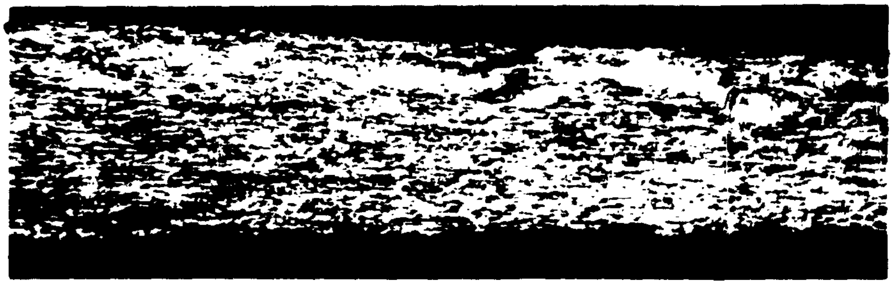
Mag. 4X

Figure II-I-2: Fillets at top skin of panel brazed with 1-4-1 alloy; temperature range 1690 - 1710 F.



Mag. 250X [illegible] Vilella's

[illegible]

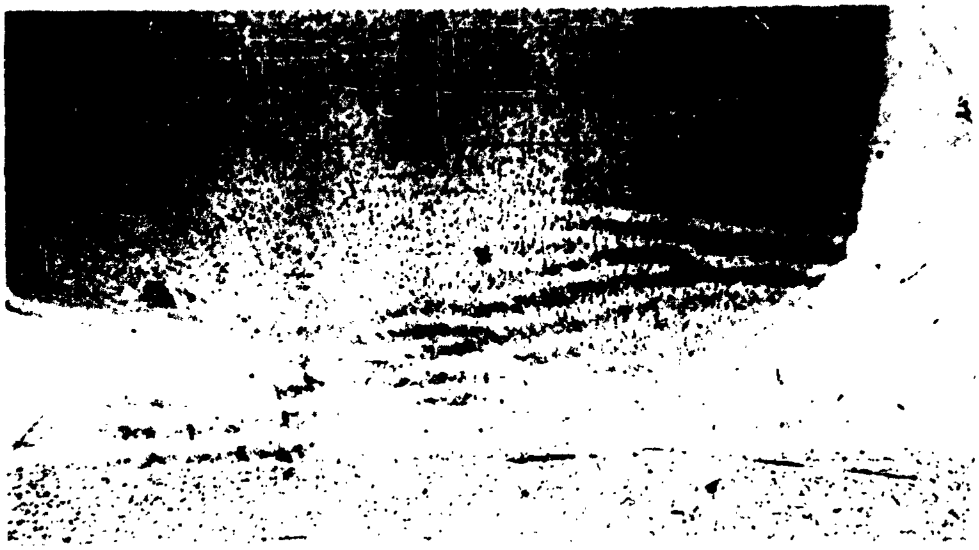


M[illegible]

Figure [illegible] [illegible] from [illegible] brazing [illegible] etched
[illegible] Same [illegible]

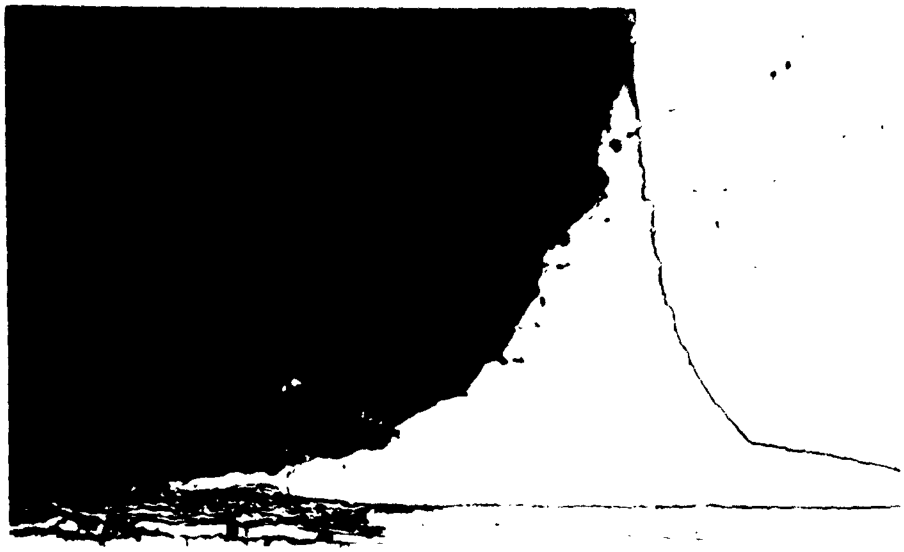
Mag. [illegible] Unetched

Figure [illegible] [illegible] stainless steel sponge brazing
[illegible]



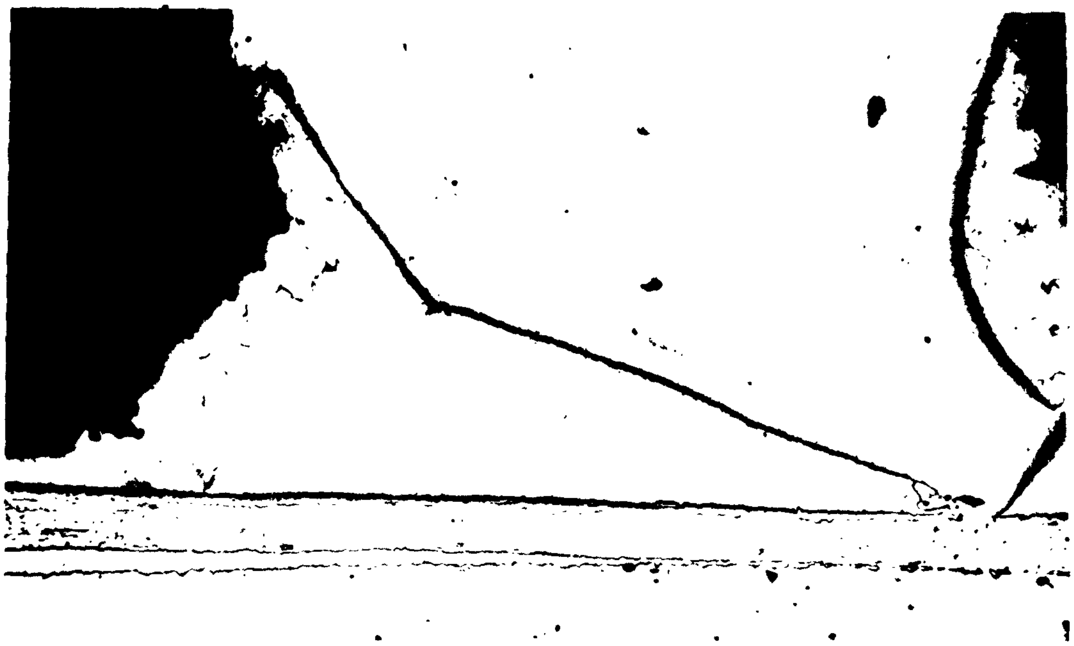
Mag. [illegible] Vilella's

Figure [illegible] Joint in 17-7PH steel, brazed at 1725 F with [illegible] flake sponge.



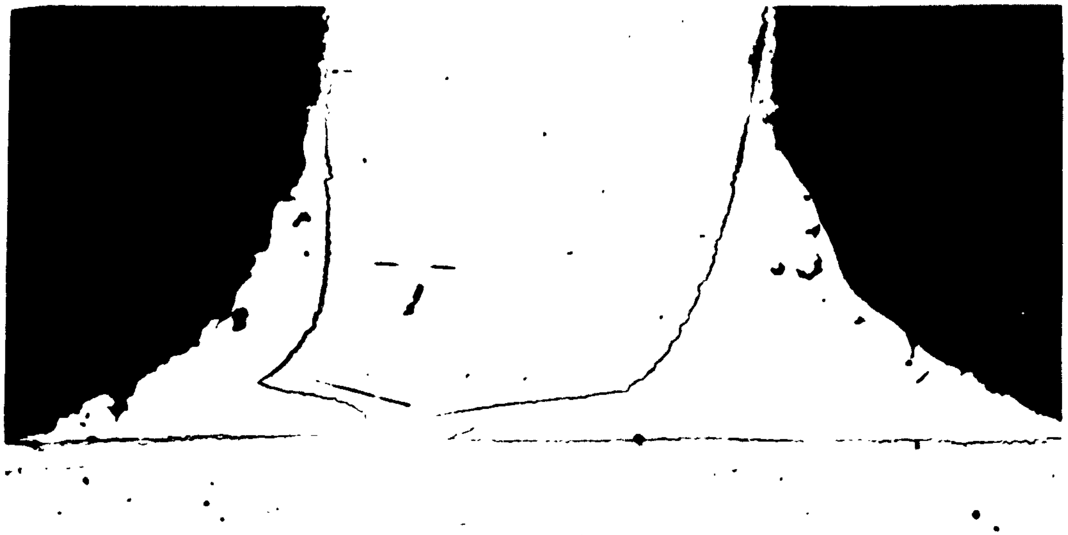
Mag. [illegible] Unetched

Figure [illegible] steel, brazed with
[illegible] Iron sponge brazing alloy,
after [illegible] hours in salt spray.



Mag. [illegible]

Figure [illegible] 17-7PH [illegible] brazed with [illegible] iron sponge, after 10 hours at [illegible] air.



M[illegible] [illegible]

Figure [illegible]J-7: Joint in 17-7PH steel, brazed with 50:50 430 stainless steel sponge brazing alloy.

Ma[illegible]

[illegible] salt spray.

[illegible]

[illegible]

[illegible]

BRAZING ALLOY FLOW:

Several investigations were carried out, mostly in 1958, on the flow of liquid brazing alloys during the operation of brazing, but the results were not published. Memoranda were issued on three of the investigations. Summaries of all are given here.

One method advocated to control brazing alloy flow consists in plating one or both surfaces of the components to be joined. Another is to plate the brazing foil. If 17-7PH steel were plated with silver and brazed with the sterling silver 0.2% lithium alloy, additional silver would be made available to the brazing alloy. Thus, its melting point would be raised and its rate or extent of flow reduced. However, tests have shown that this expedient is largely useless except for decreasing node flow in thick core sections of sandwich panels.

In one published report (reference FGT-2510) a description is given of the sandwich type test for measuring brazing alloy flow under controlled conditions. This gives reproducible values.

ITEM L - EDGE-MEMBER VOIDS:

Increasing numbers of void areas were observed in the edge-member joints of brazed sandwich panels after the adoption of the sterling silver 0.2% lithium alloy.

Prior to the investigation summarized here, the MR&D Department carried out a study on the effect of joint gap or spacing on the occurrence of voids in brazements. Subsequantly, the Metallurgical Section, ETL investigated the effect of nickel plating the brazing surfaces of edge members. The results of this latter work are summarized in Item M of this section. In the present Item L, general observations concerning the causes of edge-member voids are given together with photographs of typical void areas.

Voids have been ascribed to a variety of causes including badly mating parts or wide joint gaps, low brazing temperatures, foreign included matter, gas evolution, oxide films or oxidized areas on the brazing surfaces, alloy shrinkage on freezing, and stop-off. Of these, there seems little doubt but that wide gaps and oxidized brazing surfaces are the most important. In passing, note may be made that inadequate flow of the brazing alloy is closely related to oxidized surfaces which cause poor wettability and to low brazing temperatures.

Figure IIL-1 is a radiograph of panel 5N6255C. This panel was rejected because of edge-member voids and lack of vertical ties. The light areas at the top and left indicate voids which are typical of those observed in the joints of edge members.

The spacing, clearance, or gap between the detail parts in sandwich panels to be brazed depends upon the dimensional quality of the parts and upon the quality maintained in the components of the fixtures. The fixtures transmit contact pressure to the panel details during brazing.

Figure IIL-2 is a radiograph showing the size of void areas in brazed joints of definite spacing. The light areas are void and the dark are brazed. Obviously, the percentage of void area increases with increasing joint spacing. Additional information on this subject is available in MR&D Brazing Memorandum No. 18, dated August 7, 1957.

In brazing, some foreign matter is likely to be present in a joint. The foreign substances may be solids or gases. Successful procedures for brazing sandwich panels are quite complicated, and the presence of foreign matter in the joints can be troublesome. However, foreign solids and gases evidently have little effect on the over-all quality of the joints provided that proper brazing procedures are followed.

Foreign substances in brazed joints may be classified as follows:

(a) Oxide and other non-metallic films on the surface of the parts to be brazed;

(b) Non-metallic inclusions in the brazing alloy;

(c) Gases dissolved in, or mechanically held by, the brazing alloy.

Figures IIL-3 to IIL-6 are photographs at low magnification showing interior locations at brazed joints of edge members after the panel skin had been peeled off. The joints were brazed in 17-7PH steel, using the sterling silver 0.2% lithium alloy. All show discontinuities, that is, voids or inclusions or both.

Referring to Figure IIL-3, the small black spots were identified as silicates by X-ray diffraction. The intermittenly dark regions, associated with lighter ones, inside the larger voids of Figures IIL-3 and IIL-4 are thought to be non-metallic films on the 17-7PH steel Z member. These films, presumably oxide, would produce voids because of the poor wetting characteristics of the contaminated surfaces. The circular depression at the center of the large void of Figure IIL-4 was caused by tack welding during the lay-up of the panel. The dark ribbons or channels of Figure IIL-5 may indicate non-metallic included matter in the brazing alloy. Figure IIL-6 shows irregularly shaped voids. These may present an optical illusion, appearing as depressions or elevations on successive views by an observer.

No voids have been found which could definitely be attributed to gas entrapment in an edge-member joint. Figure IIL-7 illustrates gas entrapment between a panel skin and a nickel-plated brazing alloy. The imprint of a honeycomb core cell can be seen surrounding the bubble. Of course, gas bubbles could be trapped in edge-member joints. Figure IIL-8 shows the void channels formed by the sterling silver 0.2% lithium alloy as the result of shrinkage on freezing. Unless additional conditions are present to promote the occurrence of voids in the brazing alloy, the indications are that alloy shrinkage of itself will not cause objectionable voids.

Finally, the evidence is that the presence of only relatively large and numerous void areas will seriously decrease the overall strength of an edge-member joint. Close joint spacing is the most critical factor in eliminating voids, assuming proper control of the cleaning and brazing operations.

ITEM M - EFFECT OF NICKEL PLATING STAINLESS STEEL BRAZING SURFACES

An investigation was carried out with the object of eliminating oxidized areas on 17-7PH steel by applying a nickel-plated surface. The idea was held that this surface would afford more uniform wetting by the brazing alloy. Tensile specimens, double-lap shear specimens, and Z member surfaces of sandwich panels were nickel plated. After plating, the latter two were brazed. All the samples were tested to determine the effect of nickel plating the 17-7PH steel surfaces.

Samples for the tensile tests were prepared from thin sheet material of 17-7PH steel in nominal thicknesses of .005", .008", and .010". Nickel electroplates designated as flash, .0001", .0002", and .0005" thick were applied to the tensile specimens. After plating, they were subjected to a typical production brazing cycle. Two unplated samples were included for each thickness of nickel plate.

The tensile yield and ultimate strength together with the elongation were determined for the various specimens. For brevity, the actual tensile data are not included here. Figure IIM-1 shows the decrease in strength plotted against the thickness of nickel plate. The unplated nominal thickness was used in calculating the tensile strength. Figure IIM-1 indicates decreases in tensile strength in the three thickness of sheet as the initial diffusion of nickel lowers the strength of the 17-7PH steel. The loss in strength is greatest in the thinnest material. As is apparent, the strength of the three materials increases as the thickness of the nickel plate becomes appreciable.

The double lap-shear specimens were prepared to obtain some measure of the braze strength when nickel plate was present on the brazing surface of the steel. Nickel was applied by both dipping and electroplating. Nickel plate applied by dipping is referred to as electroless. Specimens, with plates in both electro and electroless nickel, were prepared as flash, .0001", .0002", and .0005" thick.

The plated lap-shear specimens were tested at room temperature, 400, 600, 800, and 900 F. For brevity, the actual shear test data are omitted here. Figure IIM-2 shows the shear strength plotted against temperature for the flash and .0001" thicknesses in both electroplated and electroless nickel. The figure shows that considerably higher values were obtained by electroplating than by dipping.

For either method of application, the effect of the plate thickness was seemingly unimportant. The shear-strength values obtained in these tests are within the range usually given by specimens brazed with the sterling silver 0.2% lithium alloy.

Ten test sandwich panels in 17-7PH steel were brazed to evaluate the effect of nickel plating and other treatments on the quality of joints. These panels were 1/2" x 6" x 6" with Z edge members. The brazing operation was conditioned more or less to simulate production practice. Most of the work on test panels was directed toward trying to obtain improved brazes of edge members with a lessened number of voids. Nickel was applied to Z members by electroplating in flash, .0001", .0002", and .0005" thicknesses. On two panels, the skins as well as the edge members were nickel plated. Tests were also made in which the sterling silver 0.2% lithium alloy was nickel or silver plated. A few experiments were carried out to examine the effect of borax flux and of positioning the brazing alloy so as to direct flow. Panels were brazed where the surface of each edge member was given the same treatment and also where different treatments were applied.

The brazed test panels were X-rayed to determine the effect of plating or other treatment on the quality of the joints. Metallographic examination was made of a few selected sections. The results are summarized below.

Nickel plating the Z members had the effect of producing brazes with equal or better quality than those obtained by other treatments. As stated, the other treatments included using borax flux, silver plating the brazing alloy, and positioning the alloy. Insufficient tests were made with the latter two methods to define their effects. The addition of borax flux seemed to aid somewhat.

Comparisons of various methods of treatment can be obtained from the radiographs in Figures IIM-3 to IIM-5. The most noticeable improvement from nickel plating appeared along the edges and in the corner joints of Z member brazements. Here, the brazing alloy completely filled the areas that would have only partially filled if the nickel plate were not present. The thickness of the plate had no effect on the quality of the brazements.

On one panel where the skins as well as the edge members were nickel plated, exceptionally large fillets were formed. Figure IIM-6 is a photomicrograph showing a core-skin joint with the large fillets.

and Figure IIM-7 is a radiograph illustrating the core area. An attempt to reproduce the large fillet size by nickel plating the skins of another test panel was unsuccessful. The conditions necessary for the formation of unusually large fillets were not determined.

ITEM N - NODE FLOW ON THICK CORE SECTIONS BY SILVER-COPPER-LITHIUM BRAZING ALLOY

A few experiments were carried out to determine the reasons for the difficulty in retaining sufficient brazing alloy in the top skin of deep sandwich panels to form large fillets.

Four test panels, 3" x 6" x 6", were prepared of 17-7PH steel. The standard sterling silver 0.2% lithium alloy was used for brazing. Figure IIN-1 shows the arrangement of the brazing foil at the core junctions with the top and bottom skins. The time and temperature of brazing were as follows:

Panel 1 - 10 minutes at 1600 F

Panel 2 - 10 minutes at 1650 F

Panel 3 - 20 minutes at 1650 F

Panel 4 - 20 minutes at 1725 F

Figure IIN-2 shows sections of top and bottom skins peeled from the core. The panel was brazed at 1600 F. The photograph indicates the amount of brazing alloy which flowed up or down the 3" core section and was deposited on the opposite skin.

Observations of the panels showed that the flow of brazing alloy into the core node region proceeds from both top and bottom skins simultaneously. It is the major mechanism causing insufficient alloy to be present to form adequate fillets in deep sandwich-panel sections. The force of gravity augments the capillary flow of brazing alloy to the bottom skin. Thus, larger fillets are formed at the bottom than at the top skin. Flow from the bottom to the top is the result of capillary action at the node.

Node flow takes place 30 to 50 F below the temperature necessary to form satisfactory fillets. The variation in temperature at which node flow occurs is probably due to differences in the oxide film present on the core. Another factor affecting node flow may be the time during which a panel is held at the brazing temperature. However, no effect was noted for the times 10 and 20 minutes at 1650 F, as tried in these experiments. The intervals necessary to measure the time effect are probably much shorter than that used in this work.

ITEM O - LIMITING NODE FLOW IN THICK CORE SANDWICH PANEL SECTIONS BY SILVER PLATING:

A preliminary investigation was carried out with the object of trying to control node flow, in brazing deep core sections of sandwich panels, by silver plating. The plating was intended to make additional silver available to the sterling silver 0.2% lithium alloy during the brazing operation. With additional silver provided for solution by the brazing alloy, the melting range should be raised and flow restricted. Initial brazing experiments incorporating plating were promising.

Five 2-1/2" x 5" x 5" sandwich panels were brazed. These were identified as A-1 to A-5. The material was 17-7PH steel. Figure IIO-1 shows the variations in positioning and amount of brazing alloys together with the location of the silver plating. A flash silver electroplate was applied wherever plating is indicated. The flash plates were about .0005" thick. On panels which had silver plated on the core faces, the length of the plate along the cell walls varied from 1/8" to 3/8".

In addition to the usual cleaning procedure, a hot sulfuric acid pickle was used on the core sections of panels A-1 and A-2, prior to plating, to obtain good adherence of the silver to the steel. For panels A-3, A-4, and A-5, the pickle was omitted on the core sections to be plated. There was no evidence that this omission changed any of the brazing characteristics.

Large fillets were formed at both the top and bottom joints of panels A-1, A-2, and A-3. The illustrations in Figures IIO-2 and IIO-3 are typical of these joints. The use of extra layers of the brazing alloy or a silver plate on one-half of both the top and bottom skins, as with panel A-1, resulted in no apparent difference in the type of braze obtained. Node flow in these three panels extended from 0 to 1/4" up or down the core from the brazed joints.

Tests of three specimens taken from panel A-3 gave average strength of 1057 psi in flatwise core compression. This is considerably above the minimum strength of 875 psi specified for the type 3-15 core material used in the panels brazed in this investigation.

An attempt was made with panel A-4 to freeze the brazing alloy in the top fillets restrictedly and prevent its flow down the core nodes by silver plating only the top edge of the core. The bottom edge of the core was not plated. Thus, the brazing alloy on the bottom was expected to develop some node flow upwards. The desired results were not attained. Node flow extended 1/4" or less downwards from the top braze joints but was completely absent above the bottom joints in the half section having the silver plate on the top edge of the core. This condition was not caused by the brazing atmosphere inasmuch as the panel half which was not silver plated on any surface showed definite node flow from both top and bottom joints. The reason is not known for the lack of node flow from the bottom in the panel section having the silver plate on only the top core edge. The foregoing observations concerning panel A-4 were confirmed by repeating the test brazing with another panel prepared in the same way.

The 1-3-1 tri-metal alloy was used at the top of panel A-5. As explained in Item I under Brazing Alloys, this section above, the designation 1-3-1 indicates the relative thicknesses of the three layers in the foil sandwich. In the present alloy, the outer 1 layers were sterling silver 0.2% lithium and the center 3 layer was pure silver. This tri-metal alloy did not flow at the brazing temperature used, viz., 1660 F.

ITEM P - CONCLUSIONS FOR ITEMS L, M, N, AND O

A study of the causes for and methods of eliminating voids in edge members of brazed sandwich panels led to the following conclusions:

Edge member voids are of more frequent occurrence when the sterling silver 0.2% lithium alloy is used for brazing as contrasted with the 85:15 silver-manganese alloy.

The observed causes of voids are large joint gaps, foreign matter in the joint, and brazing alloy shrinkage. Foreign matter includes oxide films on the surfaces to be joined, non-metallic inclusions in the brazing alloy, and gas evolved from the metal brazed or from the brazing alloy.

Close joint spacing is the most critical factor in eliminating or minimizing voids in brazed edge members. Foreign matter and shrinkage may be difficult or impossible to control.

Only relatively large void areas are thought to impair seriously the over-all strength of a joint.

An investigation to determine the effect of nickel plating 17-7PH steel surfaces before brazing gave useful information. This investigation was carried out primarily with the object of decreasing the occurrence of edge-member voids by nickel plating.

Nickel plating was found to provide a surface more responsive to brazing or wetting by the brazing alloy. Brazements of equal or better quality were produced by nickel plating than by other methods tried for reducing the number of voids.

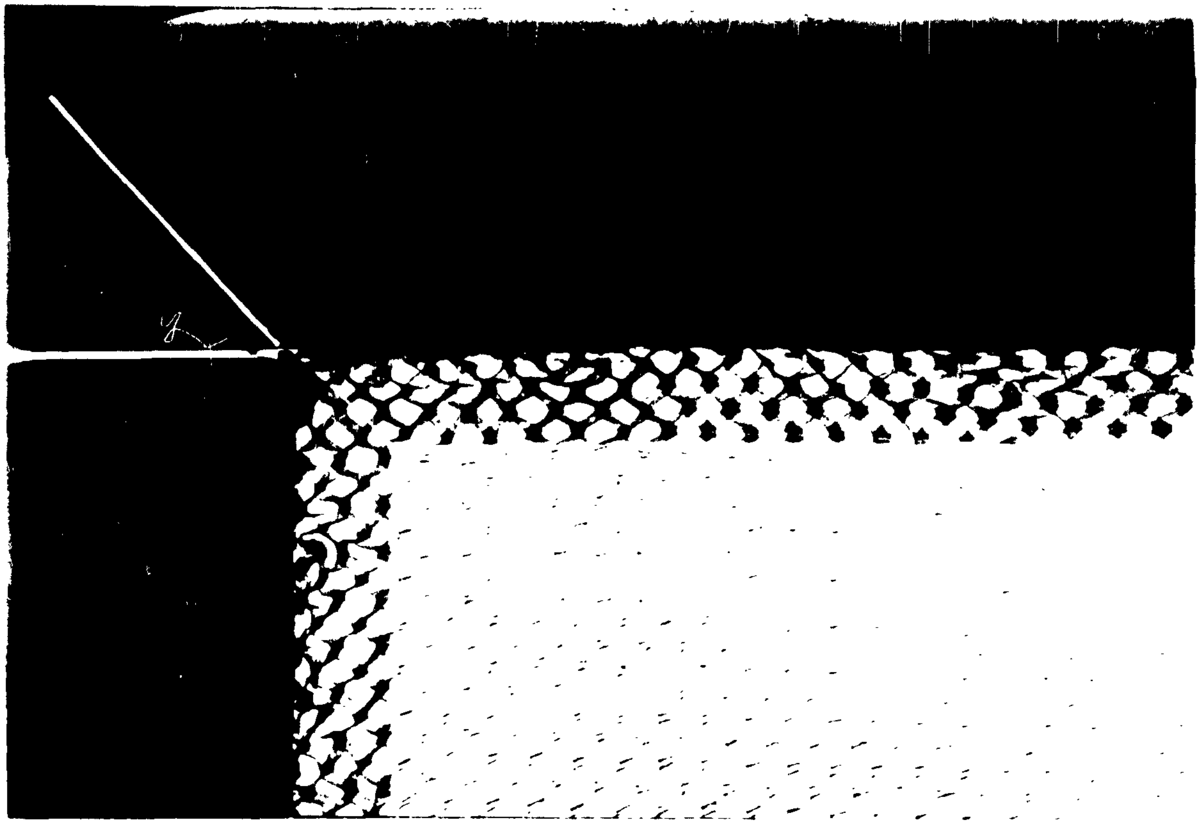
The tensile properties of 17-7PH steel in light sheet were not appreciably changed by nickel plating. Also, the double lap-shear strength of specimens was but little affected by nickel plating. The effect of various thicknesses of nickel on the properties was relatively unimportant.

The least possible thickness of nickel plate is apparently as helpful as larger thicknesses on the results obtained in brazing.

A few experiments made to observe the node flow of brazing alloy on thick core sections in sandwich panels afforded interesting facts. This work showed that brazing alloy flows into the core nodes from both the top and bottom skins. The flow from the top skin is accentuated by gravity. These observations serve to explain why insufficient alloy is retained at the top skin to form large fillets. They also explain why large fillets are formed at the bottom skin.

Another investigation carried out with the object of inhibiting node flow by silver plating showed that this was feasible. In this work, the plating was applied variously to skins and core edges of thick test panels. The results showed that a flash electroplate of silver, on the edge and extending along the core about 1/8" from the edge, eliminated node flow at 1660 F. The effect was brought about by the additional silver from the plate, this dissolving in the sterling silver 0.2% lithium alloy on brazing and thus raising its flow temperature.

In connection with the above investigation on silver plating, face compression tests were made on samples from a typical panel brazed in the laboratory. The results showed that the column strength of the core without node flow was considerably above the specified minimum strength with flow.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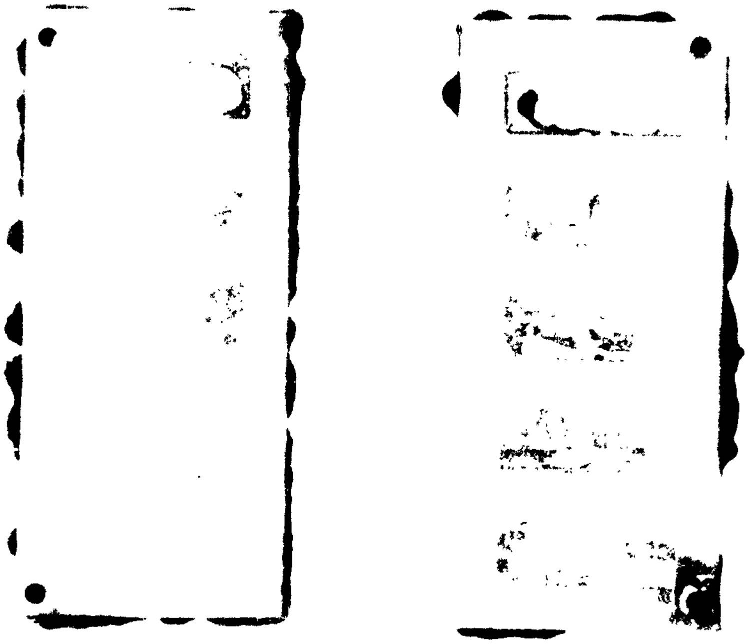


Mag. [illegible]

Figure IIL-4: Voids in skin to member joint; circular depression caused by tack welding.

Mag. 25X

Figure IIL-5: Voids in skin to Z member joint; channels are included matter.

Mag.

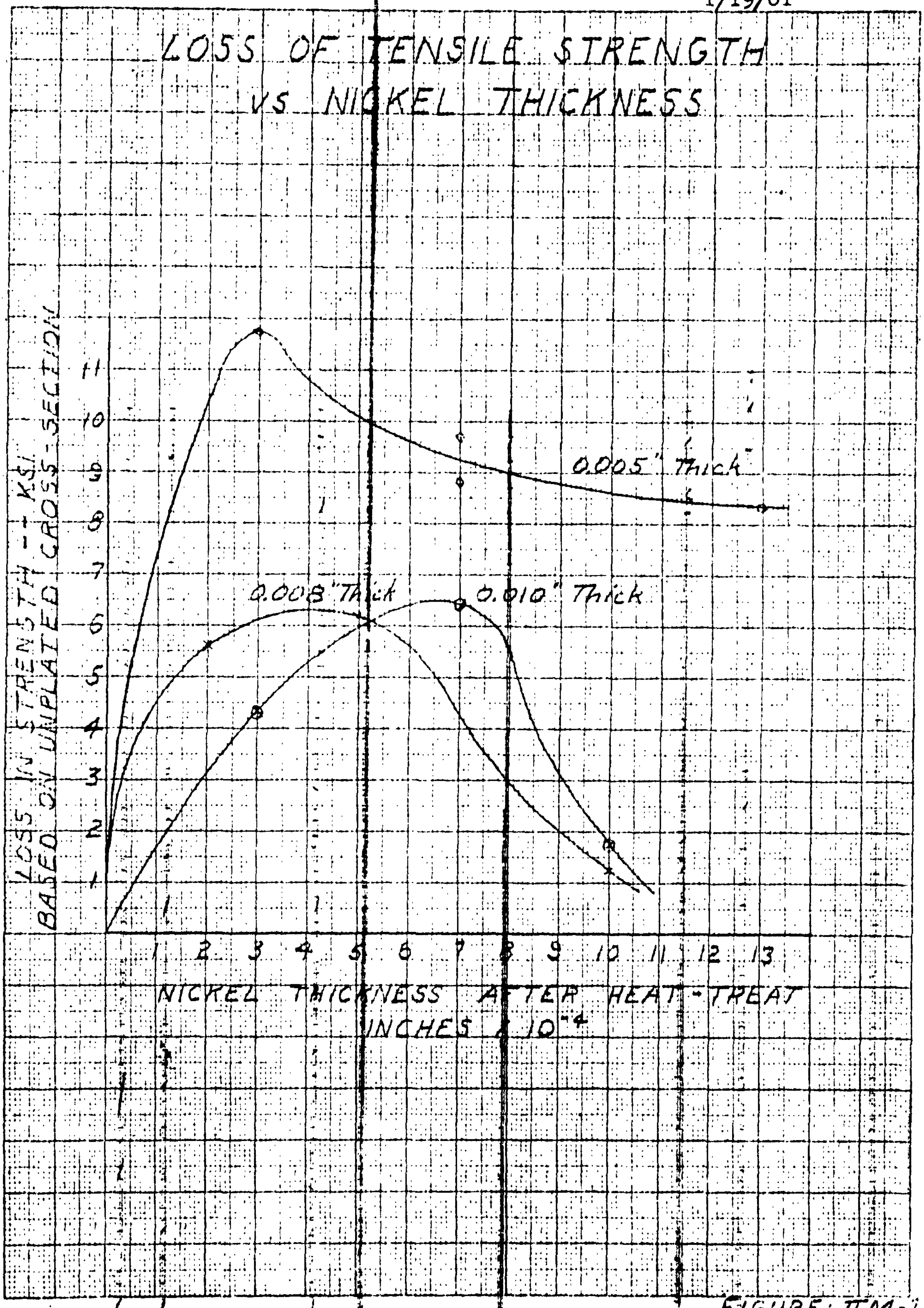
Figure [illegible]: Irregular voids in skin to member joint.

Mag 25X

Figure III-[illegible]: [illegible] brazing alloy on [illegible] center of honeycomb core cell.

Ma[illegible]

Fi[illegible]
[illegible]



LOSS OF TENSILE STRENGTH VS NICKEL THICKNESS

FIGURE: IIM-1

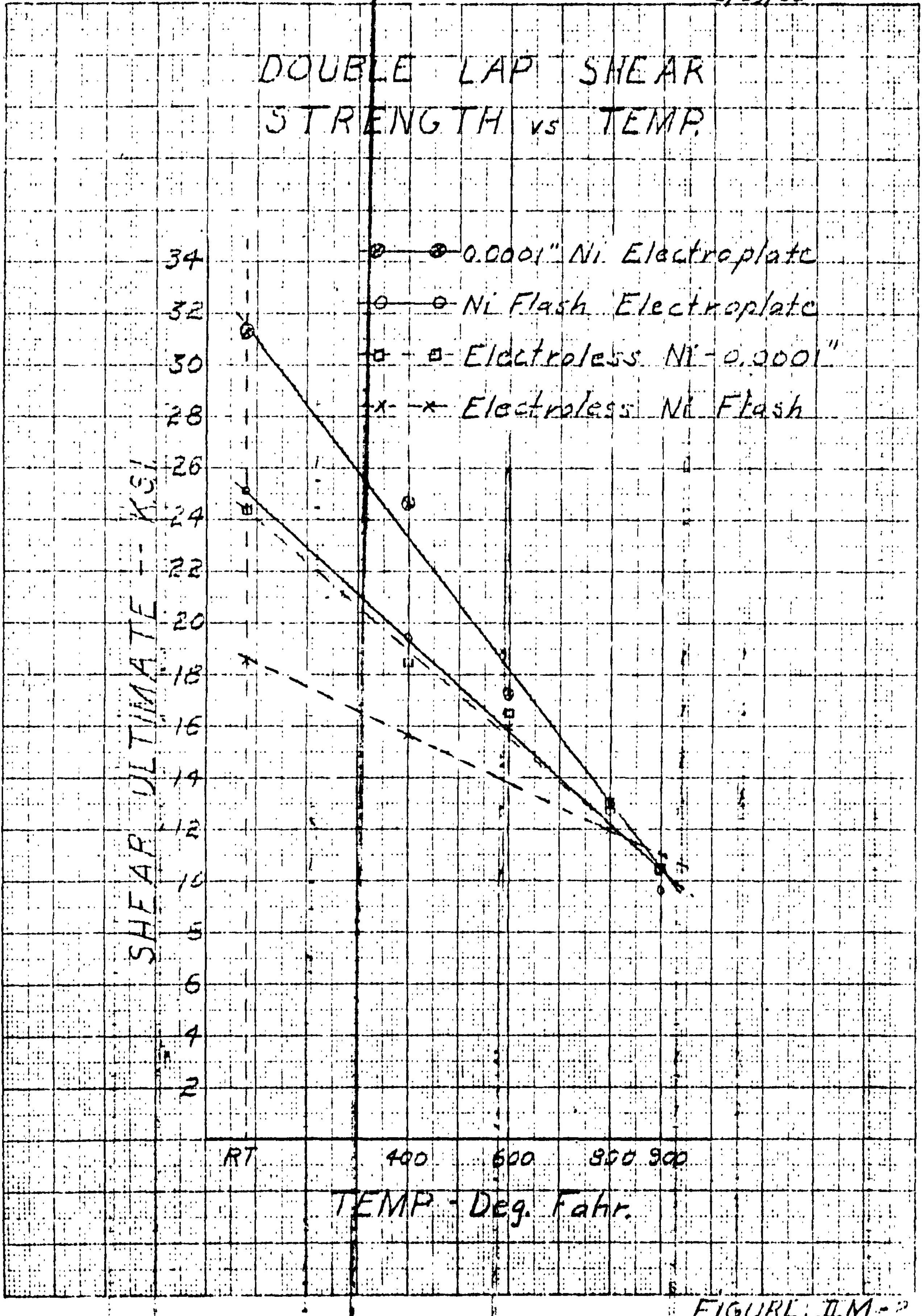
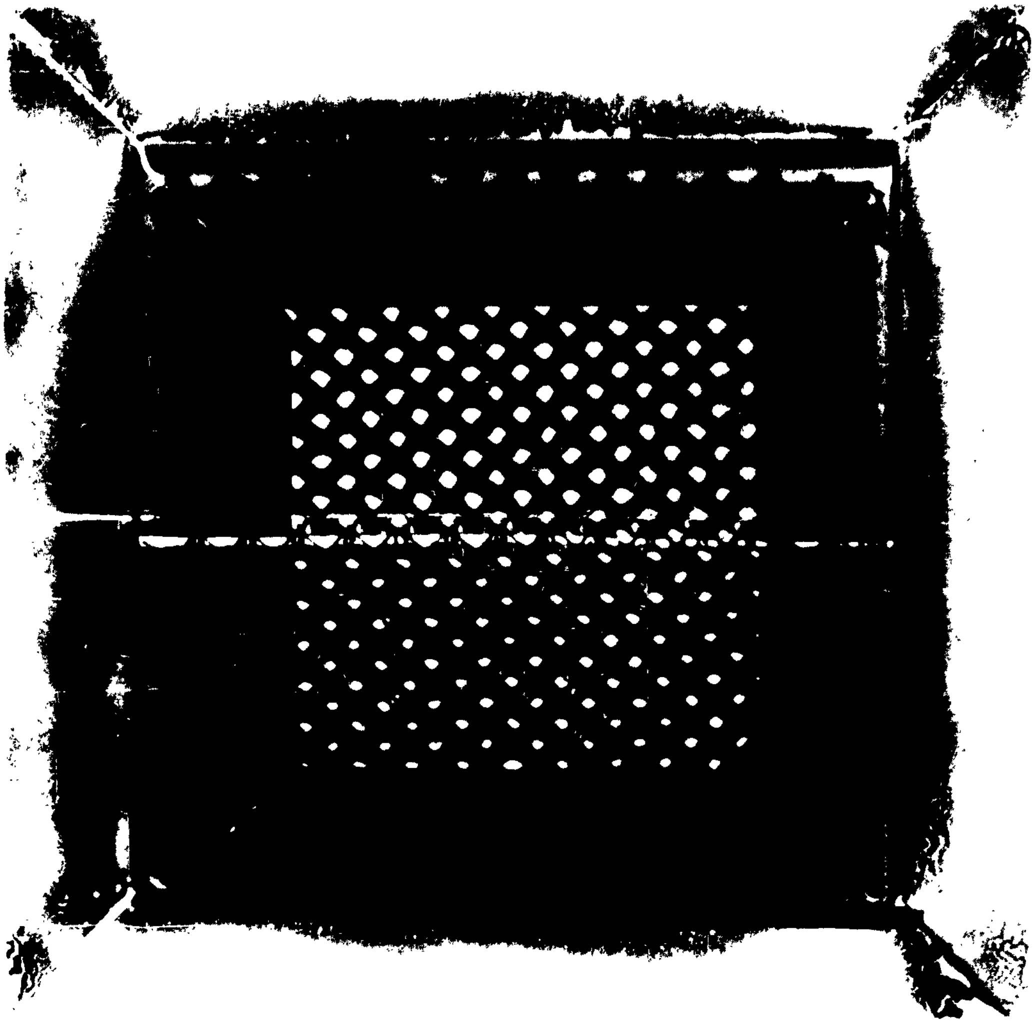
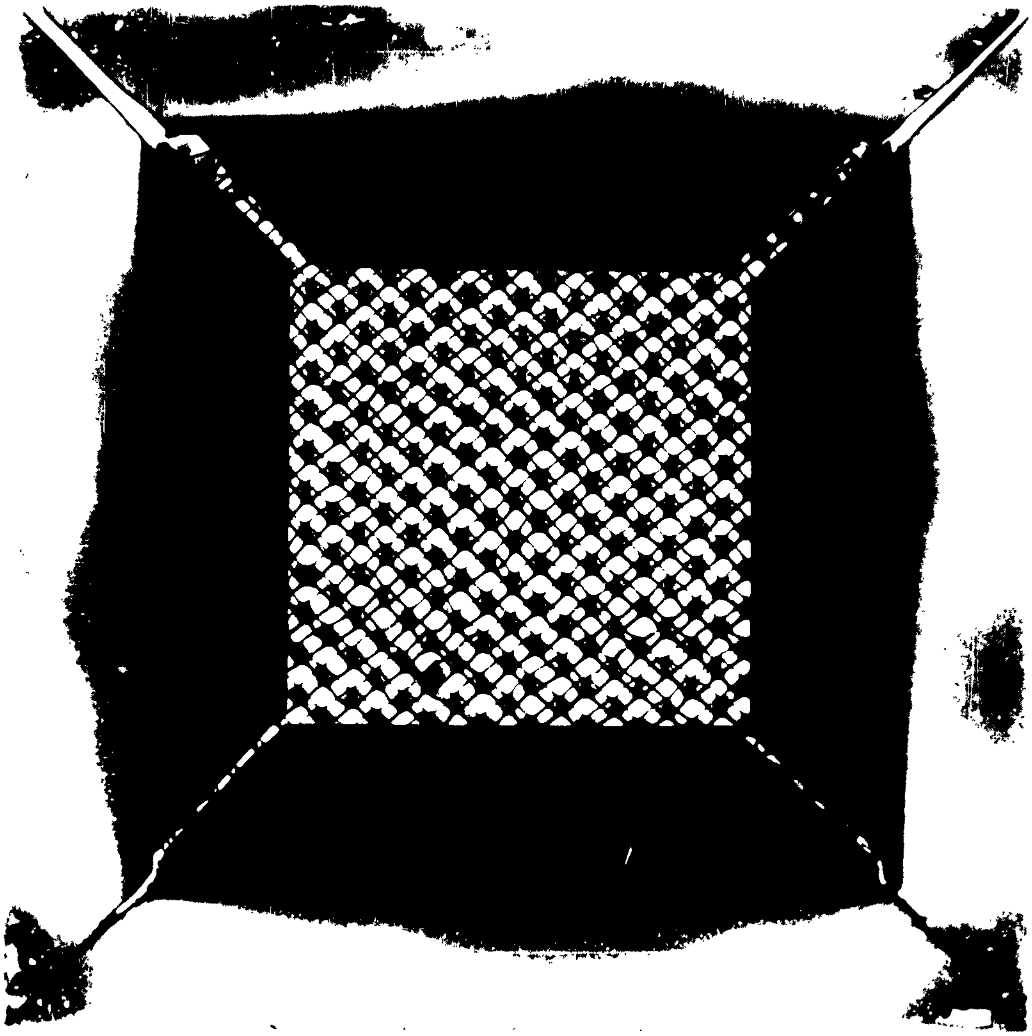

DOUBLE LAP SHEAR
STRENGTH vs TEMP.
0.0001" Ni. Electroplate
Ni Flash Electroplate
Electroless Ni - 0.0001"
Electroless Ni Flash
SHEAR ULTIMATE - KSI
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
RT
400
600
800
900
TEMP - Deg. Fahr.

FIGURE: IIM-2





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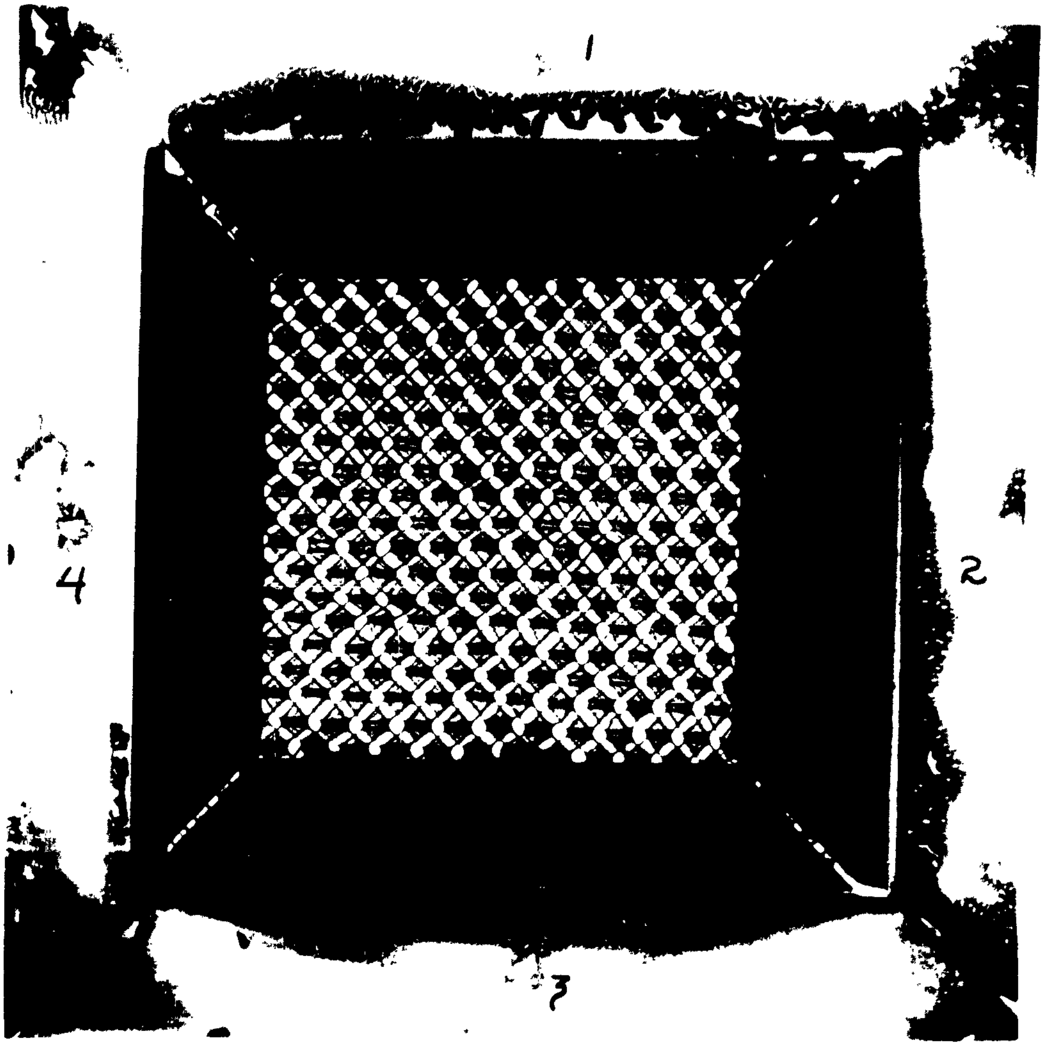
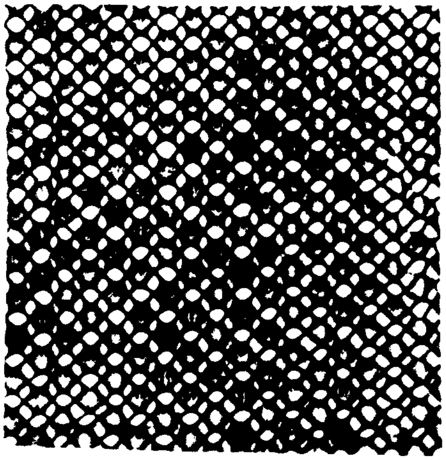
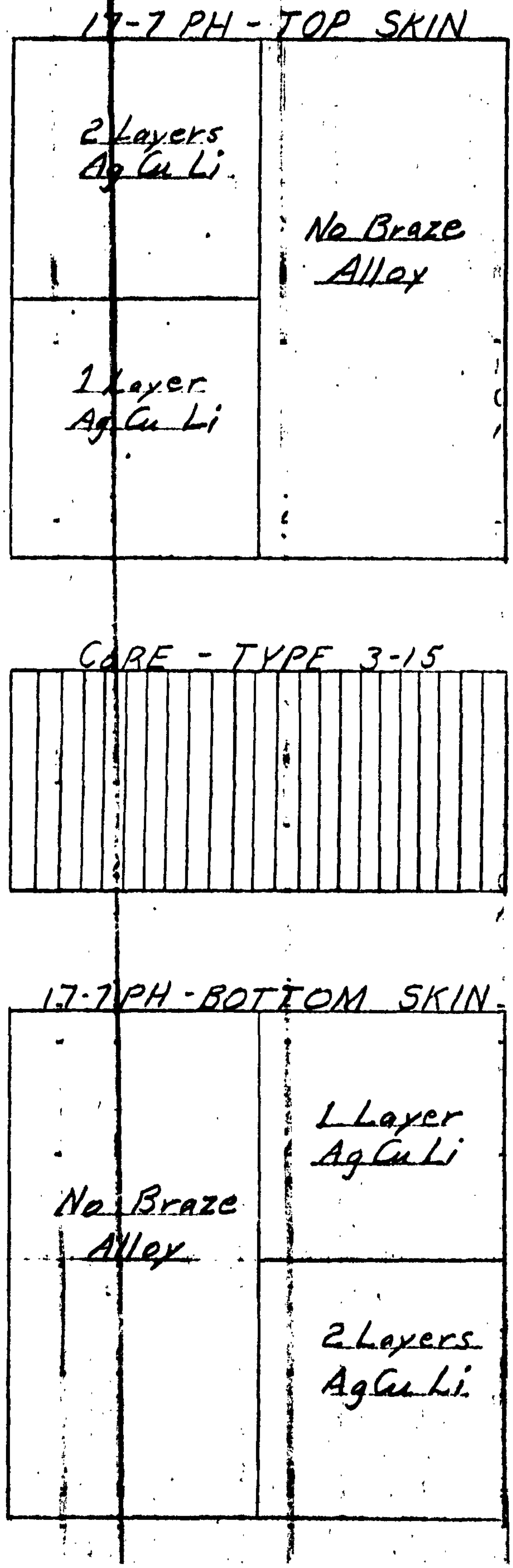

1
2
3
4




17-7 PH - TOP SKIN
2 Layers AgCuLi
1 Layer AgCuLi
No Braze Alloy
CORE - TYPE 3-15
17-7 PH - BOTTOM SKIN
No Braze Alloy
1 Layer AgCuLi
2 Layers AgCuLi

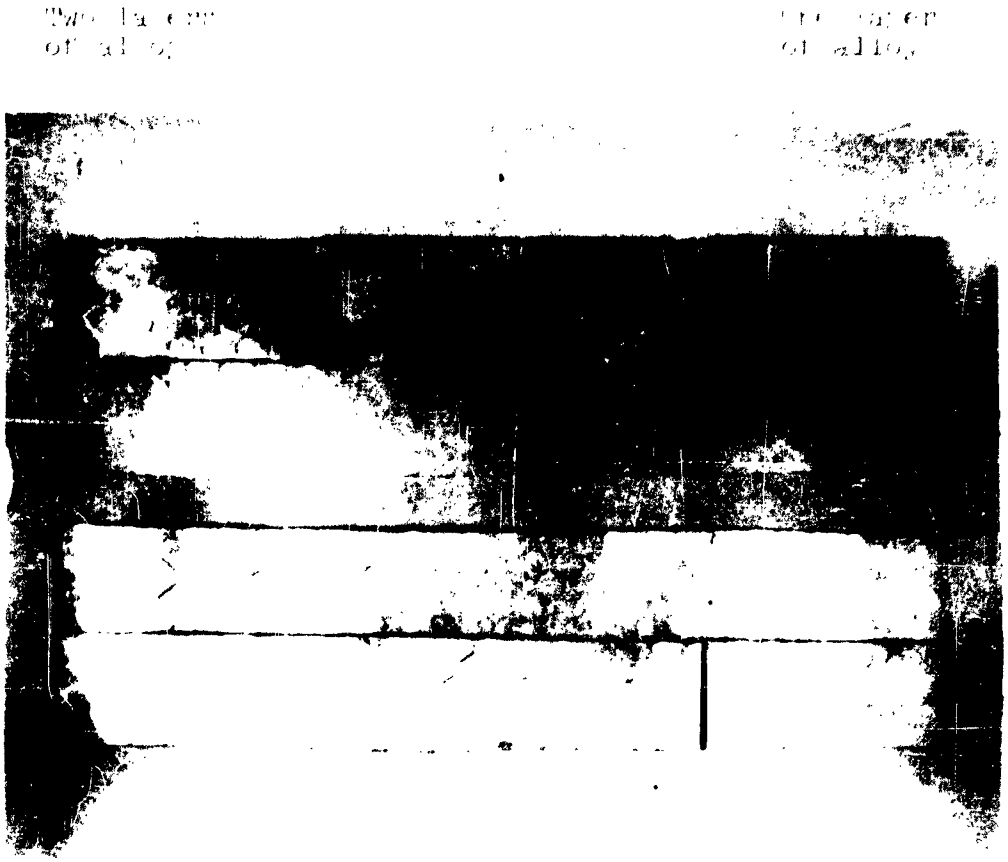
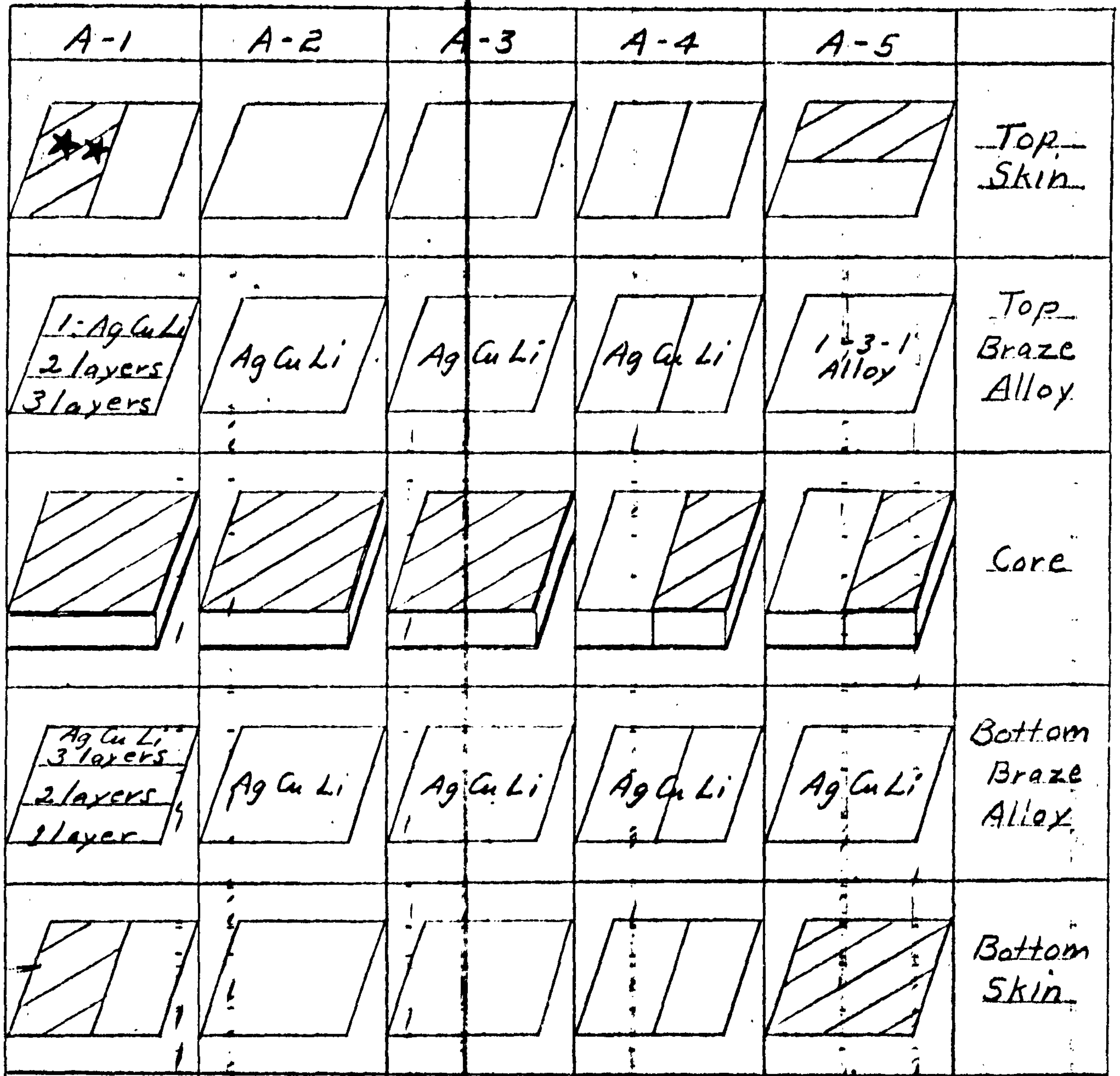


Figure III-[illegible]: Top and bottom skins of test panel brazed at [illegible] F.

The top two sections show flow from brazing alloy placed on bottom skin of a 3' core panel section to top skin where no alloy was originally present.

The bottom two sections show flow from brazing alloy placed on top skin of a 3' core panel section to bottom skin where no alloy was originally present.

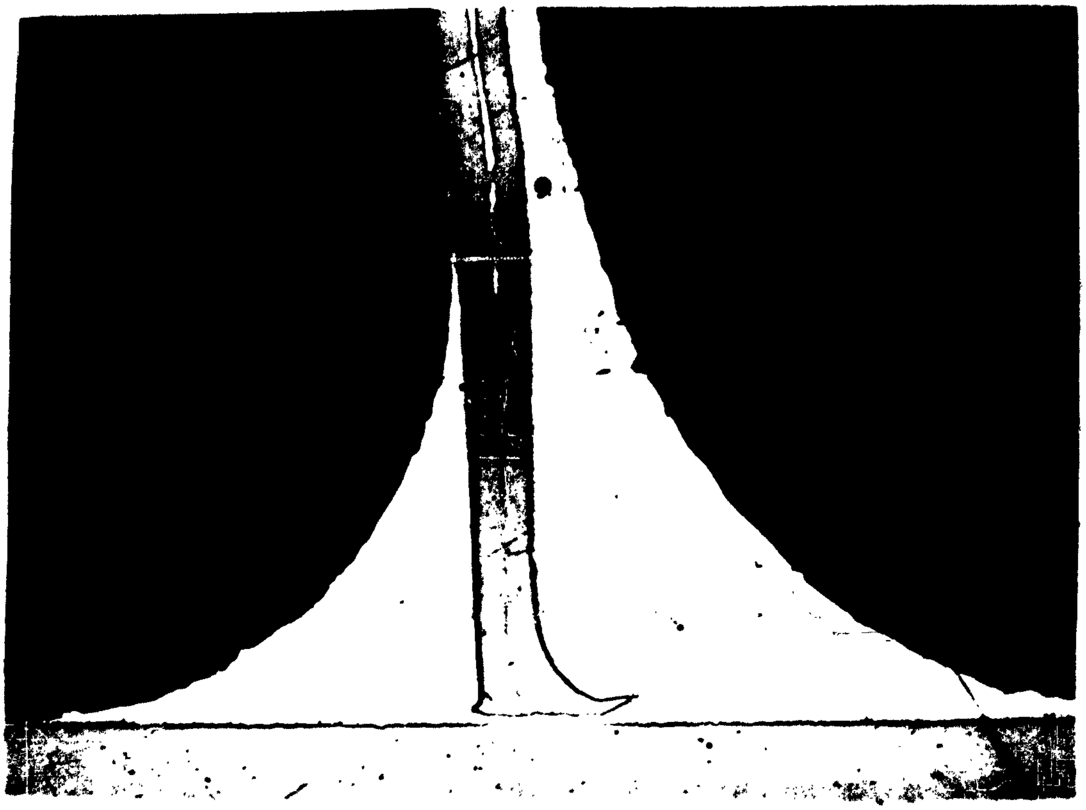
PANEL COMPONENT DIAGRAM



A-1	A-2	A-3	A-4	A-5	
9" Hg	9" Hg	9" Hg	15" Hg	15" Hg	Pressure
1660F	1660F	1660F	1660F	1660F	Temperature
10 min.	10 min.	10 min.	10 min.	10 min.	Time
TH 1050	None	TH 1050	None	None	Heat Treat

**  ← Ag Flash

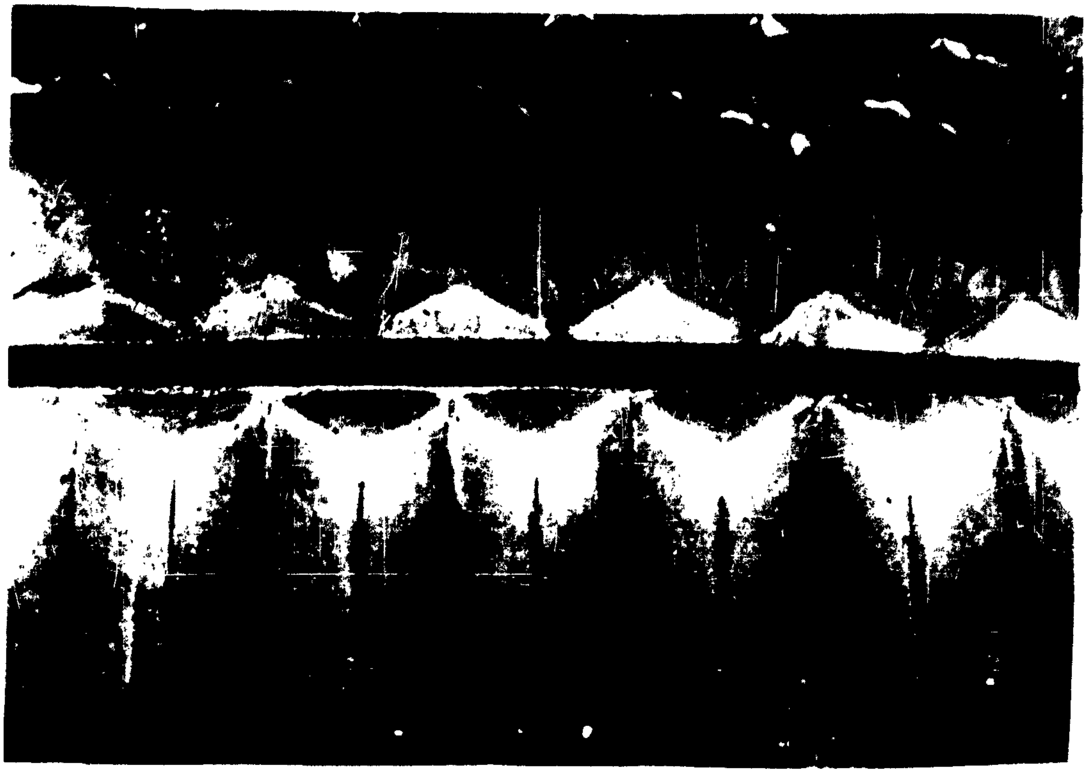
FIGURE : II O-1



Mag. 100X Unetched

Figure IIO-2: Top brazing fillet; panel A-2.

PAGE [illegible]
REPORT NO [illegible]
MODEL [illegible]
DATE [illegible]



[illegible]

INDUCTION BRAZING OF STAINLESS STEEL SANDWICH PANELS

INTRODUCTION

In September 1955 a detailed manufacturing research proposal was approved which included several research programs on problems associated with the fabrication of stainless steel sandwich panels. The purpose of these programs was to investigate various methods of sandwich panel joining, such as resistance brazing and welding, ultrasonic welding, and induction brazing. The problems were studied simultaneously at Convair and by certain other companies under contract agreements. The preliminary results of the investigations indicated that the induction brazing approach showed considerable promise.

Battelle Memorial Institute conducted research on induction brazing from March 1956 through August 1958. Summary reports covering their work were issued in February 1957 and August 1958. Convair Report MR 55-14 summarizes their work from March 1956 to January 1957.

Induction brazing studies conducted at Convair, Ft. Worth were similar to those pursued by Battelle during the early stages of the investigation, but were more limited in scope. From March 1958 to February 1959 an effort was made at Convair to adapt induction heating to contoured sandwich panel brazing.

Induction brazing of sandwich panel structures offers two advantages over the conventional furnace brazing methods. The time during which the brazing alloy is molten can be materially reduced by the induction method. Diffusion of a brazing alloy into the base metal is a function of time at temperature. Thus, induction brazing could afford a means of control over the diffusion problem in sandwich panel brazing. Induction brazing also affords a means of controlling brazing alloy flow in curved sandwich panels through its application to a zone brazing technique.

This memorandum is issued to summarize the basic conclusions regarding brazing by an induction heating process. Additionally, it describes the work on contoured sandwich panel brazing done at Convair in the later stages of the program.

SUMMARY

A method of induction brazing flat or contoured stainless steel honeycomb sandwich panels has been proven to be feasible on an experimental basis. The larger portion of work on brazing flat panels was accomplished at Battelle Memorial Institute. The contoured sandwich panel brazing was done in the Engineering Metallurgical Laboratory at Convair, Fort Worth, flat test panels 1/2" x 10" x 20" and 180° contoured panels 1/2" x 10" x 15" were brazed satisfactorily by induction heating.

The following statements will serve to summarize the basic requirements and limitations determined during this investigation for the use of induction heating in sandwich panel brazing.

1. It is not ecomonically feasible to heat an entire honeycomb sandwich panel by induction because of the excessive power requirements. This limitation necessitated the adoption of controlled movement of a narrow brazing zone.

2. It was found that to maintain a specified panel contour a reference form was necessary. This need was accentuated by the use of the zone brazing technique indicated above. A panel package similar to that used at Convair for furnace brazing proved satisfactory for the induction-heating method.

3. It was necessary to maintain the over-all panel temperature within 200 to 300 F of the braze zone temperature. Otherwise, the thermal expansion forces caused warpage. By inclosing the entire brazing operation inside a resistance-type electric furnace this requirement was fulfilled.

4. Wrinkling problems were solved by the use of a 0.060" wrinkle barrier sheet. The wrinkle barrier was inserted between the top panel skin and the vacuum cover sheet of the panel package. It protected the panel skin from wrinkles that sometimes developed in the vacuum cover sheet.

5. There was a slight tendency for the panel core to bridge away from the bottom panel skin in the lower section of 180° contour panels. This condition extended less than 1" into the panel from the panel edge on each side. It was thought that this was caused by poor mating of the detail parts of the panel package rather than by the brazing method itself.

6. A two to four turn, flattened, loop-type induction coil seemed to provide the best configuration for transforming the electrical power into heat in the panel package. The use of induction heating frequencies in the 4 to 10 Kc range proved satisfactory for this application. These frequencies gave greater depth of heating, had less tendency to arc, and made the coil-to-work spacing less critical as compared with much higher frequencies.

7. Little or nothing was gained by attempting to heat from both sides of the panel package when a brazing form was included. The brazing form shielded the bottom panel skin from any induction heating effect and thus made attempts to heat the panel from this side of the panel package useless. Sandwich panels up to 0.75" thick have been brazed by heating from only one side of the package with a temperature gradient of less than 50 F between the top and bottom skins.

Although all important variations of the above factors have not been examined, these tests are sufficient to provide a sound background for adapting induction heating to the production brazing of honeycomb sandwich panels.

PROCEDURE:

This section describes the method used by Convair to braze contoured sandwich panels by induction heating. The procedure used by Battelle in brazing flat panels is not covered here. It is mentioned briefly in the discussion section. Details of their method are given in Convair Report MR 55-14.

Figure IIQ-1 illustrates the experimental brazing setup. The equipment shown is a two loop, induction-heating coil inside a Temperite, resistance-heated furnace. A device for rotating the packaged, sandwich panel assembly is mounted inside the resistance furnace. This apparatus was rotatable from the rear of the furnace by means of a hand crank, not shown in the picture. The panel assembly is attached to the rotative device by slotted steel tabs welded to each corner of the panel package. These tabs were bent around the 1/2" stainless steel prongs of the rotative device. The panel assembly was centered in the induction coil by means of lock nuts on the prongs of the rotative device.

The cavity of the resistance furnace served for both preheating and postheating. An inert atmosphere was obtained inside the panel package by alternately pumping out air and admitting argon gas through a stainless steel tube welded into the upper left end of the panel package.

After the panel had been properly purged, the resistance furnace was set at 1000 F for heating overnight while the interior of the panel package was held at less than 200 microns pressure. The following morning the furnace temperature was raised to 1550 F, and the differential pressure on the panel reduced to 12" of mercury. As soon as the panel temperature reached 1500 to 1550 F, the induction heating unit was turned on and the panel assembly was rotated through the hot zone under the induction coil. The package was then cooled, and the panel was cut out for examination.

Induction heating frequencies of 450 and 4.2 Kc were used for the testing as listed in Table IIQ-I. The 450 Kc frequency was obtained from a Westinghouse 10 KVA vacuum tube oscillator type unit. The 4.2 Kc frequency was obtained from a 30 KVA motor generator unit.

Panels for experimental brazing were packaged according to the types of assembly illustrated in Figure IIQ-2.

Twelve 17-7PH 180° contoured sandwich panels were prepared for brazing during this investigation. These panels are listed in Table IIQ-I. Panels 1 to 5 were heated by passing an induction heating coil completely around the assembly as shown in

Position 1 of Figure IIQ-3. Panels 6 to 12 were heated by placing the induction coil on top of the package as shown in Position 2 of Figure IIQ-3.

Two methods of temperature measurement were used in the testing. Either thermocouples or an optical pyrometer was used. No dependable method of placing a thermocouple under the induction heating coil was found.

The experimental procedure of brazing is described in more detail under the discussion following.

DISCUSSION

This section is divided into two parts. Part I is a summary of the basic problems encountered during the induction brazing program and of the methods used to solve these problems. Part II describes the method developed to apply induction heating to brazing of contoured sandwich panels.

PART I:

In order to produce satisfactory stainless steel sandwich panels three conditions must be satisfied. First, at brazing temperatures of silver-base brazing alloys a nonoxidizing atmosphere is necessary. Second, some sort of brazing form is needed to produce panels having the shape required and quality desired in aircraft structures. Third, some method of maintaining contact of the various panel parts during the brazing cycle is necessary. In furnace brazing these conditions are satisfied by encasing the sandwich panel in a welded braze box containing a graphite brazing form, purging with argon gas, and brazing under a partial vacuum. Meeting these requirements in induction brazing is complicated by the relative position of the brazing form and panel package to the induction heating coil. Considerable experimentation was necessary to determine a satisfactory brazing procedure.

One of the first decisions was that it would be impracticable to heat more than a narrow zone of the packaged sandwich panel to brazing temperature at one time because of power considerations. Such a conclusion necessitated movement of either the panel past the induction coil or movement of the coil past the panel package. All work throughout this investigation was accomplished by movement of the panel past the induction coil. This involved a minimum of problems, at least for relatively small panels.

The adaption of a narrow brazing zone necessitated preheating and postheating the work to reduce thermal gradients in the panel package. In the Battelle investigation, preheating and postheating zones were two separate furnace regions with the induction coil placed between them. In the contoured panel brazing at Convair, the same furnace space served for both preheating and postheating as well as brazing. Attempts to braze one portion of the panel while the remainder was not heated were completely unsuccessful. It was found that preheating to 150 - 200 F below the brazing temperature produced panels which satisfied the flatness specifications for Convair production panels. It was possible to maintain the postheat temperature as much as 300 F below the brazing temperature without causing permanent warpage of the panel. This subject is discussed at some length in the Battelle Progress Reports.

Attempts to eliminate the graphite reference block or substitute a ceramic material were likewise unsuccessful. An example was the use of Vycor plates by Battelle in brazing 6" x 6" flat test panels. Tests with Vycor were abandoned because plates were unavailable in larger sizes. The panel package adopted was essentially the same as that used by Convair in furnace brazing. Three variations of this package are shown in Figure IIQ-2.

The coil configuration found to be satisfactory was a helically wound two to four turn coil. This coil was passed completely around the package in the flat panel brazing program as in Position 1 of Figure IIQ-3. An induction heating frequency of 450 Kc was used during all of the flat-panel and part of the contoured-panel brazing programs. This frequency was selected in an effort to obtain maximum efficiency for transformation of electrical energy into heat. This selection proved to be unsuitable because of the geometry of the sandwich panel in the package. Efficiency was approximately equal and ease of operation much better when frequencies in the 4 to 10 Kc range were employed. This was due to the increased depth of heating obtained at the lower frequencies. It can be seen in Figures IIQ-2 and IIQ-3 that the bottom sandwich panel skin must be further away from the coil windings than the top panel skin in a package of this type.

Using the above procedures, Battelle was able to braze satisfactory 1/2" x 12" x 24" sandwich panels. Their final arrangement consisted of a Globar preheat and postheat furnace with a two turn induction work coil operated at 10 Kc. The preheat zone of the furnace was heated to 1575 F and the panel was brazed using sterling silver plus 0.2% Li at 1725 F. The panel was drawn through the heating coil at a rate of 3" per minute at a power setting of 4 KVA. The temperature was read with an optical pyrometer. The postheat zone was operated at 1400 F to coincide with the conditioning step temperature in the heat treatment of 17-7PH stainless steel.

PART II:

The use of the zone technique in induction brazing flat sandwich panels led to the attempt to adapt this procedure to controlling brazing alloy flow in severely contoured panels. Brazing alloy flow occurs under the influence of gravity while the alloy is molten and causes a buildup of the brazing alloy in low portions of the sandwich panel at the expense of the higher regions. If the brazing alloy were molten only in the lowest portion of the panel, no flow could occur. This can be accomplished by the use of a narrow brazing zone.

In order to try zone brazing a contoured panel, a stainless steel rotating device or hanger was mounted inside a resistance furnace, as shown in Figure IIQ-1. Hooks were welded onto each corner of a 180° simply contoured panel brazing retort so that it could be fastened onto the hanger. The induction heating coil was mounted so that it encircled the panel package.

A vacuum line was welded into one end of the package to permit control of the atmosphere and pressure. During brazing, the panel was rotated 90° from the position shown in Figure IIQ-1, and the induction power was turned on. The panel was then slowly passed through the heating coil until the entire panel area had been brazed.

The first five panels were test brazed using a 10 KVA Westinghouse vacuum tube oscillator unit. The frequency of this unit was 450 Kc per second. These panels were packaged as shown in Type 1, Figure IIQ-2. The results as given in Table IIQ-1 were quite unsatisfactory. To obtain the required brazing temperature the induction coil-to-panel spacing was held at 0.25" or less. This made the alinement of the panel on the rotative device quite critical. Also, the heat on the inner panel skin was inadequate, although the best measurements obtained showed the temperature gradient from top to bottom skin was less than 50 F. The temperature difference between top and bottom panel skins is a function of the speed at which the panel is passed through the heating coil. A speed of 1 to 2" per minute was used for all the contoured panel brazing.

After the first five panels had been brazed, it was decided to try lowering the induction heating frequency. A 30 KVA motor generator was available; this operated at 4.2 Kc. It was also decided to heat from only the top side of the sandwich panel package. Because of the presence of the 1" graphite braze form, it was obvious that from distance considerations alone very little heat could be transferred to the inner panel skin from the bottom section of the work coil. Tests showed that the same coil configuration was still satisfactory when placed in Position 2 of Figure IIQ-3.

It was thought that the graphite form might be sapping heat from the bottom panel skin. Consequently, a layer of Fiberfrax insulation was introduced as shown in Type 2 of Figure IIQ-2. After the Fiberfrax was added, no further trouble was experienced in heating lower panel skins. On panels 8 to 17 the barrier sheets were placed as shown in the Type 3 package of Figure IIQ-2. The bottom 0.032" barrier protected the bottom of the panel from imperfections in the Fiberfrax. The top 0.060" sheet protected the panel from wrinkles formed in the vacuum diaphragm sheet of the brazing retort during brazing.

A problem which caused some trouble was that of insulating the water cooled induction coil from the brazing package. The methods shown as Types a, b, c and d in Figure IIQ-4 were successively tried. It was found that Type d was best from the standpoint of thermally insulating the coil from the sandwich panel itself.

Accurate temperature measurement of the brazing zone was difficult. Several methods of introducing thermocouples were tried. All the temperatures shown in Table IIQ-I represent surface temperatures on the vacuum diaphragm sheet of the brazing retort. The only usable thermocouple measurements were obtained by wiring the couples underneath the center loop of the induction heating coil so that the thermocouple was between the Fiberfrax and the brazing retort. This method was not dependable because the wires sometimes burned off or the thermocouple arced out on the brazing retort. Readings taken with an optical pyrometer were satisfactory although the temperature read was usually 30 to 50 F higher than that obtained by thermocouples. The thermocouple readings were considered more accurate.

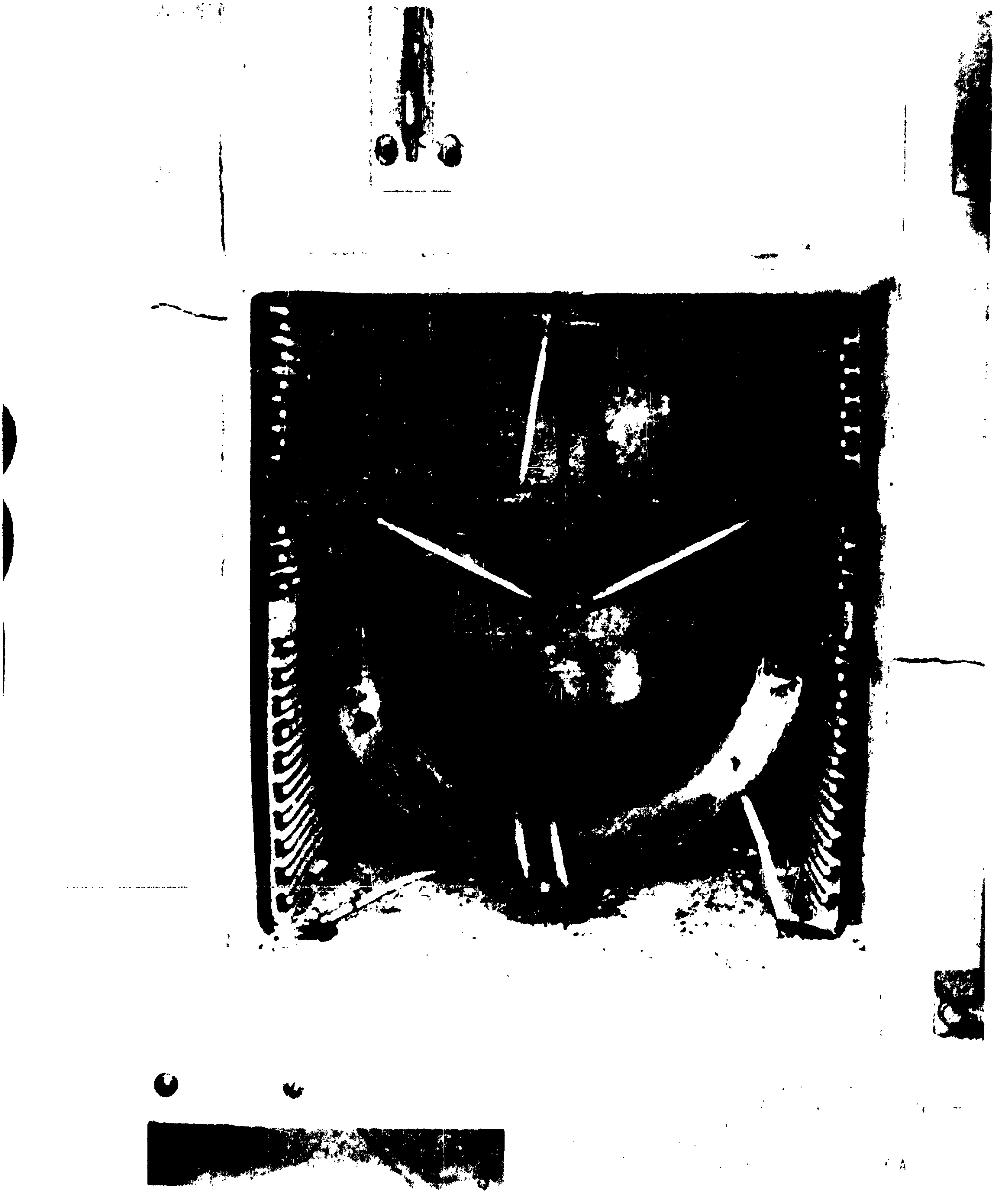
Test panels 9 to 12, listed in Table IIQ-1, were regarded as satisfactory from an experimental standpoint. Items such as cleaning, atmosphere conditions, and fit of detail parts were not as closely controlled in this investigation as they would be in production brazing. Panels 9 and 10 consisted of 180° panels 1/2" x 10" x 15". A photograph of panel 9 is shown in Figure IIQ-5. The uneven fillets were caused by poor wetting of the 92.3% Ag 7.5% Cu plus 0.2% Li brazing alloy on the 17-7PH stainless steel surfaces. This was caused by inadequate cleaning of the panel parts.

The bridging or separation of the core and skins in the center section of the edges of panel 10 was the result of poor fit of the braze block in the brazing retort. Panel 11 was brazed with 0.125" stiffeners around the edges of three sides of the panel. This arrangement was for the purpose of checking the heat transfer through the greater mass. The braze on this panel was excellent although the mismatch of the panel parts caused inferior over-all panel quality.

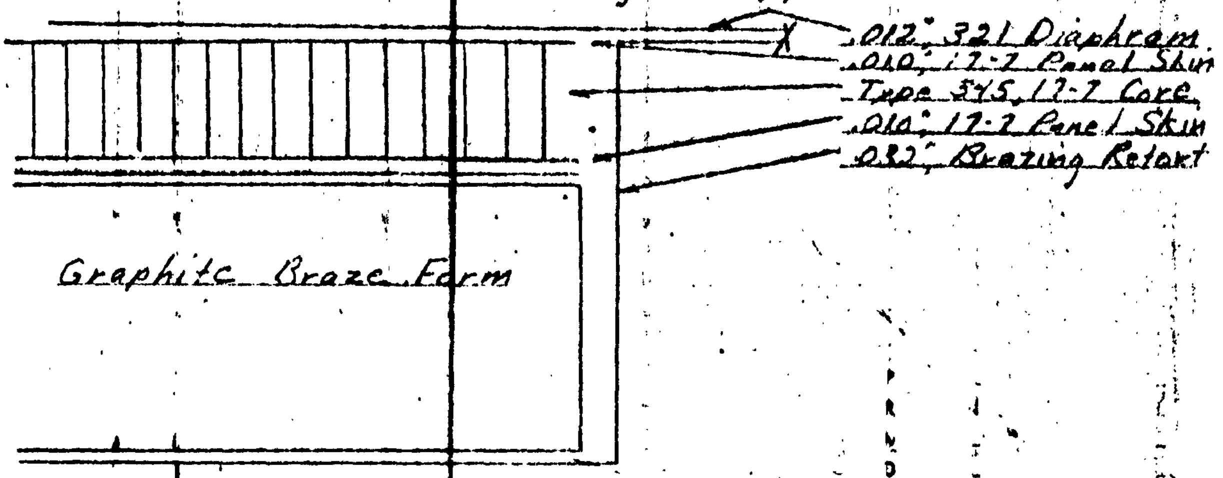
Panel 12 was brazed with 0.75" thick honeycomb core. When heat is applied to only one side of a sandwich panel there must be a maximum thickness over which the inner panel skin can not be brazed. This panel showed that 0.75" is within the limiting thickness which can be brazed by such a method. None of the 180° contoured panels listed in Table IIQ-I exhibited any brazing alloy flow.

CONCLUSIONS:

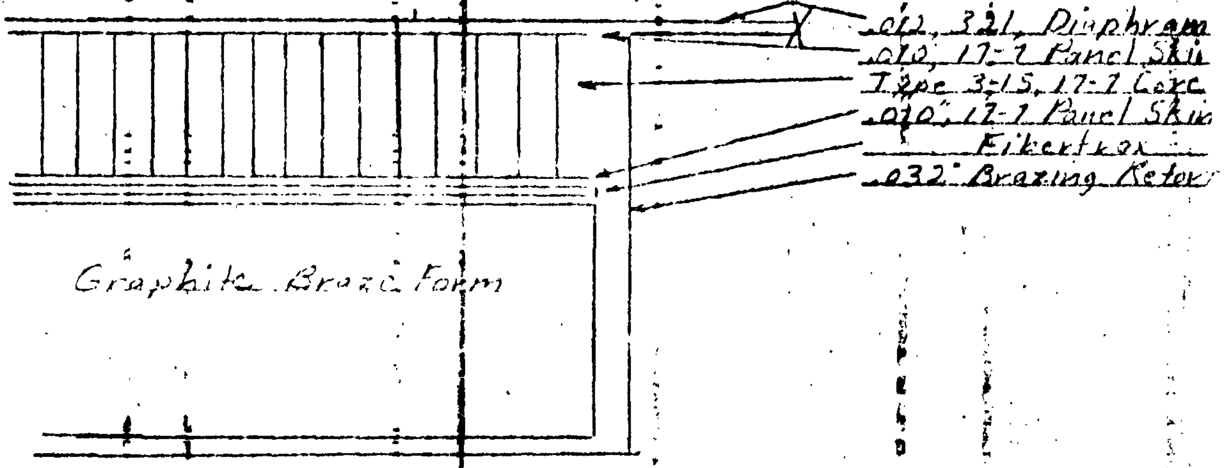
1. Induction heating is a feasible method of brazing honeycomb sandwich panels.
2. A major asset of this method is the speed at which the brazing can be accomplished.
3. Induction heating offers a method of eliminating alloy flow in contoured sandwich panel brazing.
4. Induction heating frequencies in the 4 - 10 Kc range are suitable for sandwich panel application.
5. Sandwich panel structures up to 0.75" thick can be brazed by heating from only one side of the panel.



Panel Package - Type 1



Panel Package - Type 2



Panel Package - Type 3

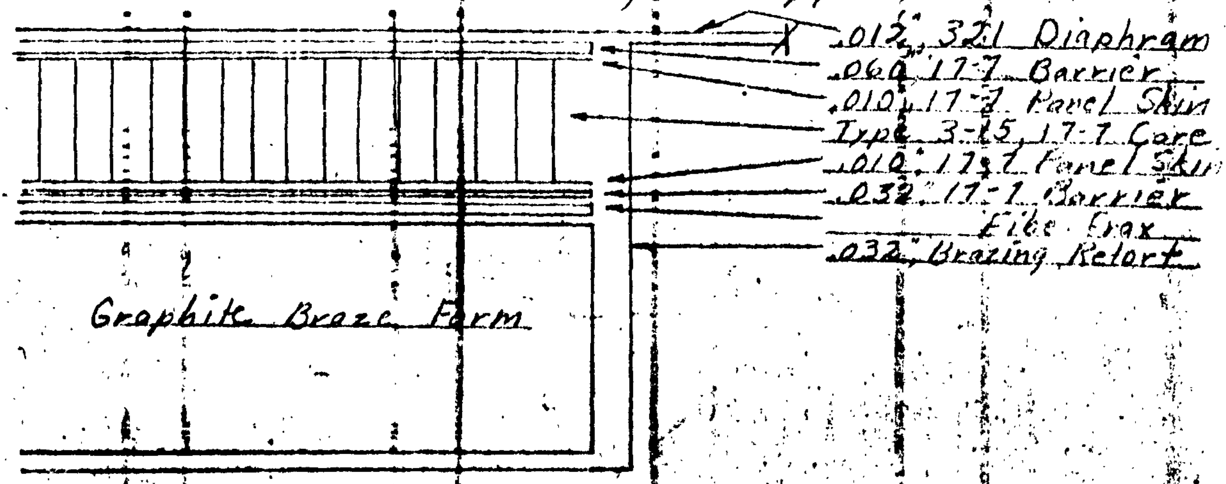


FIGURE: II Q

Coil Position

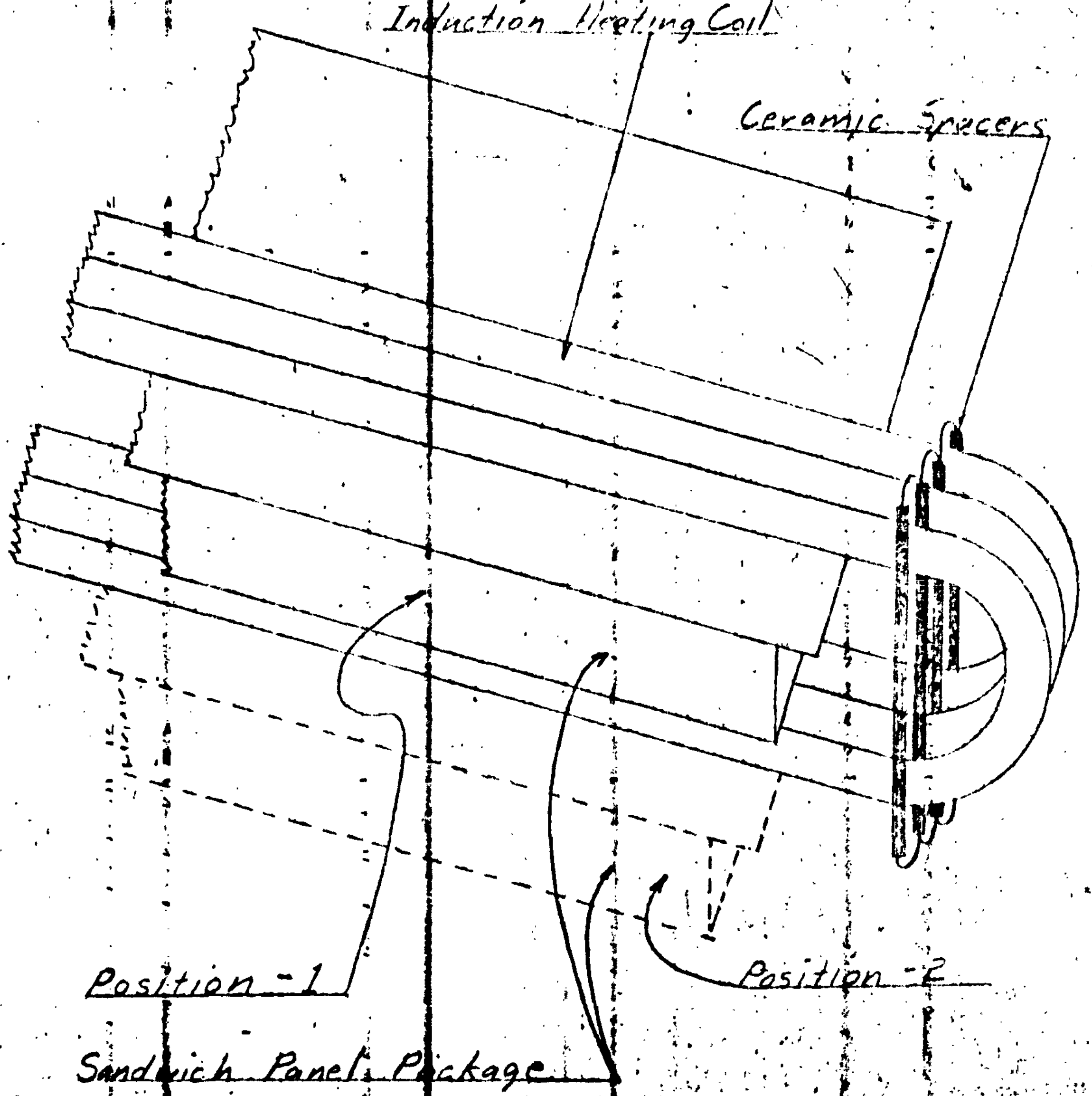


FIGURE: IIQ-3

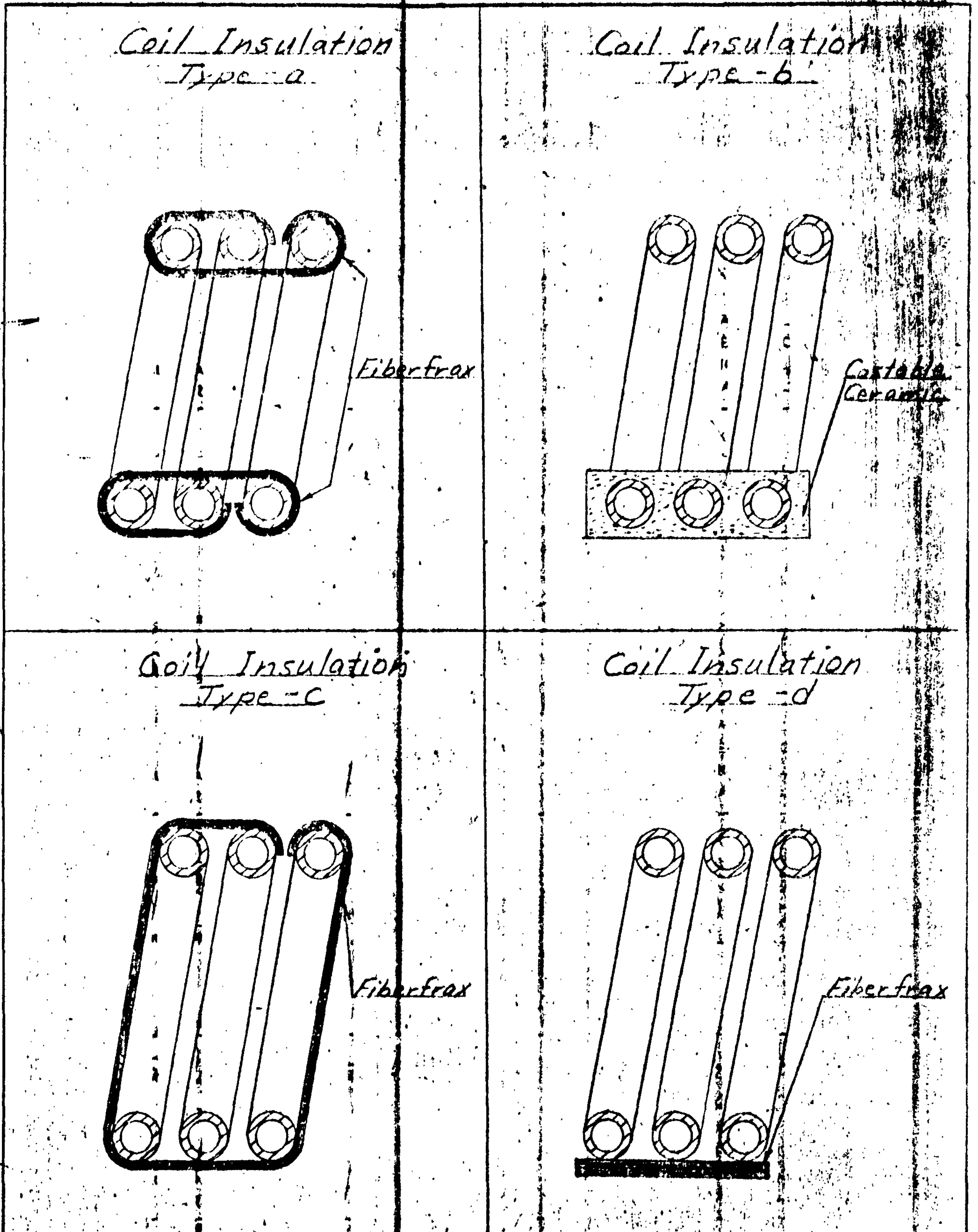

Coil Insulation
Type - a
Fiberfrax
Coil Insulation
Type - b
Castable Ceramic
Coil Insulation
Type - c
Fiberfrax
Coil Insulation
Type - d
Fiberfrax

FIGURE: III-4

2-25079 11-13-59
TEST PANEL NO. 9 -
B-58 F-4696
CONVAIR FT. WORTH TEXAS

Figure IIQ-5

CONVAIR—FORT WORTH

TABLE IIQ-I

TABULATION SHEET LIST OF PANELS & SETUP PROCEDURE

PANEL No.	← POWER →		← HEATING COIL →				PACKAGE COIL		PREHEAT	BRAZE	TEMP	REMARKS
	f	KVA	MAT'L	TURNS	LENGTH	POSITION	TYPE	INSULAT.	TEMP.	TEMP.	MEAS.	
1	450 Kc	10	$\frac{3}{8}$" Cu Tubing	3	13"	1	1	a	1550°F	NONE	O.P.	Panel fell off rotating device
2	"	"	"	1	"	"	"	"	"	1500	"	Insufficient power Front bearing sagged
3	"	"	"	2	"	"	"	"	"	1600	"	Arcing burned hole in braze retort
4	"	"	"	3	"	"	"	"	"	1660	"	Bad atmosphere little brazing
5	"	"	"	4	"	"	"	b	"	1660	"	Top panel skin brazed
6	42Kc	"	"	4	11"	2	2	c	"	≈1680	Visual	Both skins brazed, center section only
7	"	"	$\frac{1}{4}$" Cu Tubing	5	14"	"	"	d	"	1730	T.C.	All top, most of bottom skin brazed
8	"	"	"	3	16"	"	3	"	1340°F	1750	"	Good Braze Badly Warped
9	"	"	"	"	"	"	"	"	1550°F	1750	"	Good Panel Uneven fillets
10	"	13	"	"	"	"	"	"	"	1750	O.P. & T.C.	Good, some bridging
11	"	13	"	"	"	"	"	"	"	1750	"	$\frac{1}{2}$" brazed, both top & bottom
12	"	10	"	"	"	"	"	"	"	1750	"	$\frac{3}{4}$" core, small fillets, atmos. fair

TABLE II Q-I (cont)

References & Symbols Used In Table II Q-I.

Coil Position 1 & 2 refers to positions shown in Figure II Q-3.

Package Type 1, 2 & 3 refers to types shown on Figure II Q-2.

Coil Insulation a, b, c & d refers to types shown in Figure II Q-4.

O.P. - Optical Pyrometer

T.C - Chrome alumel thermocouple

SECTION III - BIBLIOGRAPHY

The results of some investigations on brazing 17-7PH steel and related subjects, carried out by members of the Engineering Metallurgical Laboratory, have been described in published Convair reports. These are listed below together with an abstract of each. The abstracts are mostly verbatim statements, from the individual reports, giving the purpose and a summary of the various investigations.

The results of the experimental work not previously published by Convair are given in the present report. Practically all of the unpublished data have been made available from time-to time as memoranda, tables of test values, graphs, photomicrographs, and other information to a limited number of interested individuals.

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1. Z. R. Wolanski, "Material - High Temperature Honeycomb - Methods of Bonding - Determination of -", FGT-1153, November 5, 1953, 26 pp. (F-4182).

ABSTRACT:

One purpose of this investigation was to develop methods of bonding stainless steel skins to honeycomb core using high temperature brazing alloys. Another purpose was to determine the optimum heat treatment for 17-7PH steel in the annealed and cold worked conditions.

Six commercial brazing alloys were tested. These had flow points in the range of 1145 to 2100 F. Type 321 stainless steel was used for skin material, and 17-7PH steel was used for core.

Microscopic examination of brazed panels showed that good fillets between the core and skins and good bond between the core ribbons at the spot welds were essential for satisfactory results.

Furnace brazing was found to be feasible for both flat and curved panels. After application of the brazing alloy, the panels were assembled in a holding fixture and sealed in an atmosphere envelop or chamber. Resistance blanket brazing presented possibilities of practical application.

For annealed ("A" condition) 17-7PH steel, the maximum tensile yield and ultimate strength, together with relatively high elongation, was obtained by the following heat treatment: Conditioned at 1400 F, quenched in water at 60 F or slightly below, and aged at 900 F for 2 hours. High values were also obtained by aging at 950 F for 1/2 hour to 1-1/2 hours.

For cold rolled ("C" condition) 17-7PH steel, the maximum tensile yield and ultimate strength, together with very low elongation, was obtained by aging at 900 F for 1-1/2 hours. High values were also obtained by aging for 1 hour and 2 hours.

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2. Z. R. Wolanski, "Empirical Data - Stainless Steel Sandwich Panels - Low Temperature Brazed - General Research Tests of -", FGT-1340, April 7, 1955, 22 pp. (F-4696, Suppl. 1).

ABSTRACT:

The purpose of this investigation was to determine the effects of various cooling rates, during brazing and conditioning treatments, on the tensile properties of 17-7PH stainless steel. Sheet .005", .010", and .020" thick, ultimately aged to the TH 1050 condition, was tested. The information obtained was required in establishing procedures for brazing and heat treating stainless steel sandwich panels.

This investigation showed that in the heat treatment of 17-7PH sandwich panels, the cooling rate for the conditioning treatment in the temperature intervals 1400 to 60 F and 1400 to 0 F was not critical. The test results indicated that cooling times as long as 20 hours in both temperature intervals had little or no effect on the tensile properties.

For brazing operations on 17-7PH sandwich panels, the cooling rate in the temperature intervals 1700 to 1400 F and 1700 to 1100 F was not critical as concerns tensile properties. The test results showed little or no effect on tensile properties for cooling times as long as 50 minutes. For the interval 1700 to 0 F the tensile yield and ultimate strength showed little or no change, but the elongation decreased by about 33% for cooling times between 16 and 50 minutes.

The results of this investigation indicate that in brazing 17-7PH sheet at 1700 F the conditioning treatment at 1400 F may be omitted and the required tensile properties still be obtained.

3/ S. D. Tannenbaum et al., "Manufacturing Research - Materials - High Temperature Brazing Alloy - Metal to Metal Sandwich Panel Construction - Preliminary Evaluation of -", MR 54-5, April 20, 1955, 14 pp. (F-4743).

ABSTRACT:

The purpose of this investigation was to evaluate several commercial brazing alloys for possible use in the manufacture of honeycomb sandwich panels in 17-7PH steel.

Each alloy was evaluated by brazing lap shear specimens and test sandwich panels in a hydrogen atmosphere. The lap shear specimens were tested in tension at room temperature and at 1000 F. Acceptable test panels were loaded as simple beams to failure at room temperature.

Of five alloys tested, only one, a silver-base composition, appeared to give satisfactory results. The others showed penetration and disintegration of the steel or quite deficient bond.

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4. P. F. Ghena, "Materials - 17-7PH, 302-3/4 Hard, and 321 Annealed - Strength and Size Effect on Repeated Exposure to 1000 F - Determination of -", FTDM - 1415, May 3, 1955, 21 pp. (F-4696, Suppl. 4)

ABSTRACT:

The purpose of this investigation was to determine the effect of repeated exposure to 1000 F and subsequent cooling to room temperature on the tensile strength and dimensions of three stainless steel alloys, including 17-7PH.

The repeated exposures were made on specimens of heat treated 17-7 steel, aged at 1050 F. This material was in the form of sheet, .018" thick. The tests showed that exposures for 30 seconds at 1000 F had no effect on the tensile strength or dimensions of the 17-7PH specimens.

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5. P. F. Ghena, "Empirical Data - Armco 17-7PH Stainless Steel - Heat Treatment - Transformation and Precipitation Hardening - Effect of Time and Temperature -", FGT-1347, May 9, 1955, 77 pp. (F-4696).

ABSTRACT:

The purpose of this investigation was to examine various methods for the heat treatment of Armco 17-7PH steel and to determine the feasibility of combining the conditioning treatment with a low temperature brazing cycle for the production of sandwich panels. In addition, the effects of a conditioning treatment after a low temperature brazing cycle were studied.

Tensile and bend specimens were prepared from 17-7PH steel sheet in thicknesses of .008", .014", and .040". For the study of conditioning treatments, the effects of various temperatures for times of from 5 to 60 minutes were investigated. After the heating, some specimens were immediately quenched in water at 60 F. Others were cooled in air to room temperature in 15 or 60 minutes and then cooled at once to 0 or 60 F. Precipitation hardening was effected at several temperatures from 850 to 1050 F for periods of 10 minutes to 24 hours.

The .008" and .014" thick sheets were found to be relatively insensitive to conditioning variables of time and temperature. However, the .040" material required longer times at the lower temperatures to produce strengths comparable to those obtained at higher temperatures. The quench at 0 F was quite beneficial to the strength of specimens slowly cooled from the conditioning temperature.

The precipitation hardening temperatures of 950 F and below gave increased strength with increasing time at temperature up to 24 hours. By contrast, the temperatures 1000 and 1050 F gave decreased strength as the time was increased. A conditioning treatment of 90 minutes at 1400 F gave more uniform strength values, when the precipitation hardening was carried out at 1050 F, than the conditioning treatments for 30 or 60 minutes.

A correlation between Rockwell "C" and "D" hardness values and tensile strength was established for the .040" thick sheet. No correlation could be established for the .008" and .014" materials.

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6. Z. R. Wolanski, "Empirical Data - Stainless Steel Sandwich Panels - Low Temperature Brazed - General Research - Tests of -", FGT-1363, June 1, 1955, 41 pp. (F-4696).

ABSTRACT:

The purpose of this investigation was to determine whether the remelting temperature of several commercial brazing alloys, having relatively low melting points, would increase substantially due to loss of constituents on brazing. If the remelting temperature increased sufficiently, a conditioning treatment at 1200 F for 17-7PH steel might be carried out.

Four brazing alloys were tested by several methods to establish their remelting temperatures. The results showed that the remelting temperatures of three alloys increased appreciably from the original melting temperatures. However, the increases were not sufficient so that sandwich panels brazed with the alloys could be heat treated after the brazing operation. Heat treating of sandwich panels brazed with this alloy might be accomplished provided that the heat treating procedures are suitably combined with the brazing to produce the required properties in sandwich panels.

Sandwich panels brazed with the fourth alloy could be heat treated after brazing provided that the conditioning temperature did not exceed 1200 F.

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7. Z. R. Wolanski, "Empirical Data - Stainless Steel Sandwich Panels - Low Temperature Brazed - General Research - Tests of", FGT-1362, July 15, 1955, 39 pp. (F-4696).

ABSTRACT:

The purpose of this investigation was to determine whether the conditioning treatment for sandwich panels in 17-7PH steel, brazed at high temperatures, could be accomplished by controlling the rate of cooling from the brazing temperature. If complete transformation could be obtained in the brazing process by controlling the cooling rate, the usual conditioning treatment could be eliminated.

The results of this investigation showed that when 17-7PH steel sandwich panels are brazed at approximately 1800 F, complete transformation will occur if the time of cooling from 1800 to 1100 F is 1 hour or more. Thus, the conditioning treatment at approximately 1400 F, could be eliminated provided that the cooling time between 1800 and 1100 F is 1 hour or more and the panels are subsequently cooled to -20 F. Increased cooling time beyond 1 hour slightly decreased the ductility of 17-7PH sheet.

Panels brazed at 1900 F to 2200 F did not completely transform unless the cooling time to 1100 F was increased to approximately 10 hours and the panels were subsequently cooled to -20 F. Again, the ductility was reduced with increasing cooling times.

A precipitation hardening treatment at 1050 F for 90 minutes should be used in processing 17-7PH steel sandwich panels when strength is a critical design factor. A treatment at 1075 F for 90 minutes should be used when ductility is critical.

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8. F. C. Nordquist, "Sandwich Panels - Stainless Steel - Production Brazed - Structural Evaluation - Tests of -", FTDM-1826, January 13, 1958, 5 pp. (F-7051).

ABSTRACT:

The purpose of this investigation was to determine the cause of the service failure of two wing trailing edge panels, 4T012-2 and 4T013-2, in 17-7PH steel, brazed with 85:15 silver-manganese alloy.

Examination showed that delamination of the skin from the core had occurred on both panels. The delamination was caused by crevice corrosion at the braze alloy-steel interface.

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9. W. M. Pratt, "Materials - Brazing Alloy - Evaluation of -", FGT-1362-1, March 3, 1958, 70 pp. (F-4696).

ABSTRACT:

The purpose of this investigation was to find a brazing alloy that would have all the characteristics desired for the brazing of sandwich panels in 17-7PH steel.

Twenty-one commercial brazing alloys, thought to posses acceptable characteristics for brazing sandwich panels, were selected and tested. The most promising of these alloys were nickel plated, with the object of eliminating the undesirable features of each, and again tested.

Tests were carried out to determine the flow, wetting, and filleting of the alloy on 17-7PH steel. The corrosion resistance of the brazements was also determined. Lap shear and compressive shear tests on brazed specimens were run for the temperature range -100 to + 900 F.

The results of these tests showed that the nickel-base brazing alloys had the highest shear strengths at room temperature and elevated temperature. However, the elements added to reduce the melting points of the alloys had detrimental effects on the 17-7PH steel.

Most of the silver-base brazing alloys were susceptible to corrosion in salt spray. An exception was sterling silver containing lithium, which held up very well. This composition exhibited the best combination of brazing qualities, on 17-7PH steel, of all the alloys tested.

Nickel plating on the silver-base alloys improved their wetting on the steel and also their resistance to corrosion. However, the plating caused a slight reduction in the shear strength of the brazements at room temperature.

No alloy was found that would fulfill all the requirements of an ideal brazing composition for 17-7PH steel sandwich panels.

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10. W. M. Pratt, "Control Surfaces - Low Temperature Braze Material - Evaluation of -", FGT-2088, December 18, 1958, 36 pp. (F-7545).

ABSTRACT:

The purpose of this investigation was to select a brazing alloy for use in the repair brazing of 17-7PH steel sandwich panels. The extent of damage to the strength of the heat treated panels, caused by the localized temperature of the repair brazing, was also to be determined.

To evaluate a brazing alloy for panel repair, a method for making brazed repairs on panels had to be first developed. Briefly, the adopted method consisted of brazing circular patches of 17-7PH steel, condition TH 1050, so as to cover a hole or tear in the panel skin.

The 97:3 silver-lithium alloy, nickel plated, was found to give the most satisfactory brazed repairs. A suitable brazing temperature was about 1250 F. The use of this brazing alloy, with the repair method developed, enabled reproducible repairs to be made on 17-7PH honeycomb sandwich panels. This brazing procedure should be readily adaptable for field repairs.

The tensile yield strength of heat treated 17-7PH steel in the area of the braze was reduced to approximately 40 to 45% of the original TH 1050 value, and the ultimate strength was decreased to 65 to 75%. The elongation was almost doubled.

The largest repair, attempted during this investigation, comprised a hole 2-1/2" in diameter in one skin of a panel.

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11. H. B. Farner, "Materials - Iron Sponge Brazing Alloy - Environmental Evaluation of -", FTDM-2270, May 22, 1959, 3 pp. (F-8619).

ABSTRACT:-

The purpose of this investigation was to determine the effects of exposure to salt spray and to 700 F in air on an iron-sponge brazement in a 17-7PH steel sandwich panel.

A small test panel was brazed with 92.8:7:0.2 Ag-Cu-Li alloy incorporated in iron sponge. Edge compression and shear beam specimens were cut from the panel. Tests were made on these specimens with and without environmental exposure. The results showed that exposure for 50 hours to salt spray and for 300 hours at 700 F in air had quite adverse effects on the edge compression and shear strength. The iron-sponge alloy is unsatisfactory for brazements to withstand the conditions given.

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12. H. B. Farner, "Materials - Silver-Copper-Lithium Brazing Alloy - 17-7PH Sandwich Panels Brazed With - Effects of Elevated Temperature On - Structural Evaluation of -", FTDM-2355, October 12, 1959, 6 pp. (F-8725).

ABSTRACT:

The purpose of this investigation was to determine the effect of oxidation in air at 700 F on brazements made with 92.8:7:0.2 Ag-Cu-Li alloy in a 17-7PH steel sandwich panel.

Specimens for edge compression and shear beam tests were cut from the panel. Tests were made on the specimens with and without the exposure indicated. The time periods of exposure were from 100 to 300 hours.

The test results showed that after exposure, specimens with adequate fillets had strengths equal to or greater than specimens in the unexposed, as-brazed condition.

A new type of corrosion of brazed 17-7PH steel was observed during this investigation. The mechanism of the attack was not determined.

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13. W. M. Pratt, "Materials - Brazed Stainless Steel Sandwich Panels - Butt-Welded Facings - Evaluation Test of -", FTDM-2433, December 20, 1959, 12 pp. (F-8213).

ABSTRACT:

The purpose of this investigation was to evaluate butt-welded facing material in 17-7PH steel for sandwich panels, as supplied by the Airline Welding Company, Solar Aircraft Company, and Rohr Aircraft Corporation. Convair requirements for this material are set forth in specification FPS-0038, paragraphs 3.4 through 3.5.2.

The welded sheet material was supplied in various thicknesses. Test specimens were heat treated in simulation of a production brazing cycle. Tension and axial tension-tension fatigue tests were run, the welds in the specimens being at the center of the reduced section.

All the welded specimens passed the Convair tensile specification. None met the fatigue requirements.

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14. W. M. Pratt, "Materials - Honeycomb Core Ribbon - Relationship Between Flow Characteristics of Brazing Alloy and Oxide Film Formation of - Determination of -", FGT-2510, February 2, 1960, 21 pp., (F-8225).

ABSTRACT:

"Mottled braze" conditions and variable fillet formation and node flow during the brazing of honeycomb sandwich panels in 17-7PH steel have been the cause of panel scrappage at both Convair and sub-contractors. Tests have established that the difficulties are due to the presence of oxide films on the honeycomb core. These oxide films are attributed to variations in the quality of the hydrogen atmosphere in the annealing furnaces of the foil producers.

The purpose of this investigation was to determine (1) the relationship between the flow characteristics of a brazing alloy and the oxide films found on 17-7PH foil, (2) the characteristics and identity of the films, and (3) methods by which the formation of films can be controlled during the rolling and annealing of 17-7PH foil.

Convair-FW and the Armco Steel Corporation collaborated in carrying out the program of investigation.

17-7PH foil, .0015" thick, representing two heats, was annealed by the Armco Research Laboratories by heating in hydrogen gas of different dew points. The presence of water vapor in the hydrogen of high dew points caused the formation of a uniform oxide coating on the surface of the foil. Specimens of 17-7PH foil, .0015" thick, representative of the inventory of John J. Foster Mfg. Company, honeycomb core manufacturer, Costa Mesa, Calif., were obtained. Three heats were included, and specimens from each were forwarded to Armco.

Sandwich type, brazing flow tests were run on samples from all the above heats, using the 92.8:7:0.2 Ag-Cu-Li brazing alloy. The results of the flow tests were compared with the results of other tests, as listed below, in an attempt to find a correlation. The object of this was to find a reliable test by which acceptable brazing flow response of 17-7PH foil could be determined before manufacture into relatively expensive honeycomb core. The tests for comparison with brazing alloy flow were:

1. Determination of color and reflectance values of surface films as obtained from spectrophotometric measurements. These values were determined by The Derby Company, Inc. Lawrence, Massachusetts.
2. Electron diffraction of surface films, performed by the Armco Steel Corporation, Research Department, Middletown, Ohio.
3. Ferric chloride etching. This was also carried out by the Armco Research Department.

As originally planned, following completion of the brazing flow tests, honeycomb core was to be made from the stock, at the John J. Foster Mfg. Co., having the best and worst flow characteristics. The core was to be processed into honeycomb sandwich panels by Convair and tested. The purpose was to correlate brazing alloy flow characteristics with the properties of production sandwich panels. However, when the flow tests had been finished, foil corresponding to the specimens tested was no longer available at the Foster Company.

With the development of a practical brazing flow test, experiments were undertaken to determine the effect of cleaning methods on 17-7PH foil having poor wetting qualities. The object was to determine whether the flow on foil unsatisfactory for core production could be improved by cleaning.

Some tests of specimens cleaned by the Convair production method were inconclusive as concerns the effect on brazing alloy flow. However, limited testing of specimens having poor flow indicated a pronounced improvement in flow after ultrasonic cleaning of the base metal at Convair. On the other hand, some specimens ultrasonically cleaned at Bendix Aviation Corporation did not yield good flow.

No correlation has been found between laboratory brazing flow tests and the color, reflectance, electron diffraction of surface films, ferric chloride etching, or the chemical composition of 17-7PH foil.

SUPPLEMENTAL INFORMATION

This report is supplemented with the following information:

A. Specification FMS-0036 is referenced for specimens and test procedure for brazed honeycomb sandwich panels. The only sandwich panel test specimens tested and reported in this report are flatwise compression. This type specimen is prepared and tested as follows:

1. Specimen size is 2.00" x 2.00" x panel thickness.
2. All edges of specimens are filed and sanded smooth to remove nicks and saw cuts which might induce premature failure.
3. The specimen is placed in a 60,000 pound Baldwin universal testing machine, and the loading head and platen checked for parallelism.
4. A compressive load is applied to the test specimen at a rate of 8,000 pounds per minute until failure.

B. Flash testing as referred to in this report is a nondestructive test procedure for brazed steel sandwich panels. It consists of flash heating 4.0" dia. circular areas of the panels to a temperature up to 800°F within four seconds. This is accomplished with a radiant heating apparatus utilizing heating elements similar to the General Electric Type T-3 quartz envelope. The apparatus is equipped with an automatic timing and control device. U. S. Patent No. 3,008,029 dated 7 November 1961 has been issued covering such an apparatus.