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HIGH STRENGTH ALUMINUM CASTING TECHNOLOGY: SQUEEZE CASTING OF 7--ETC(U)
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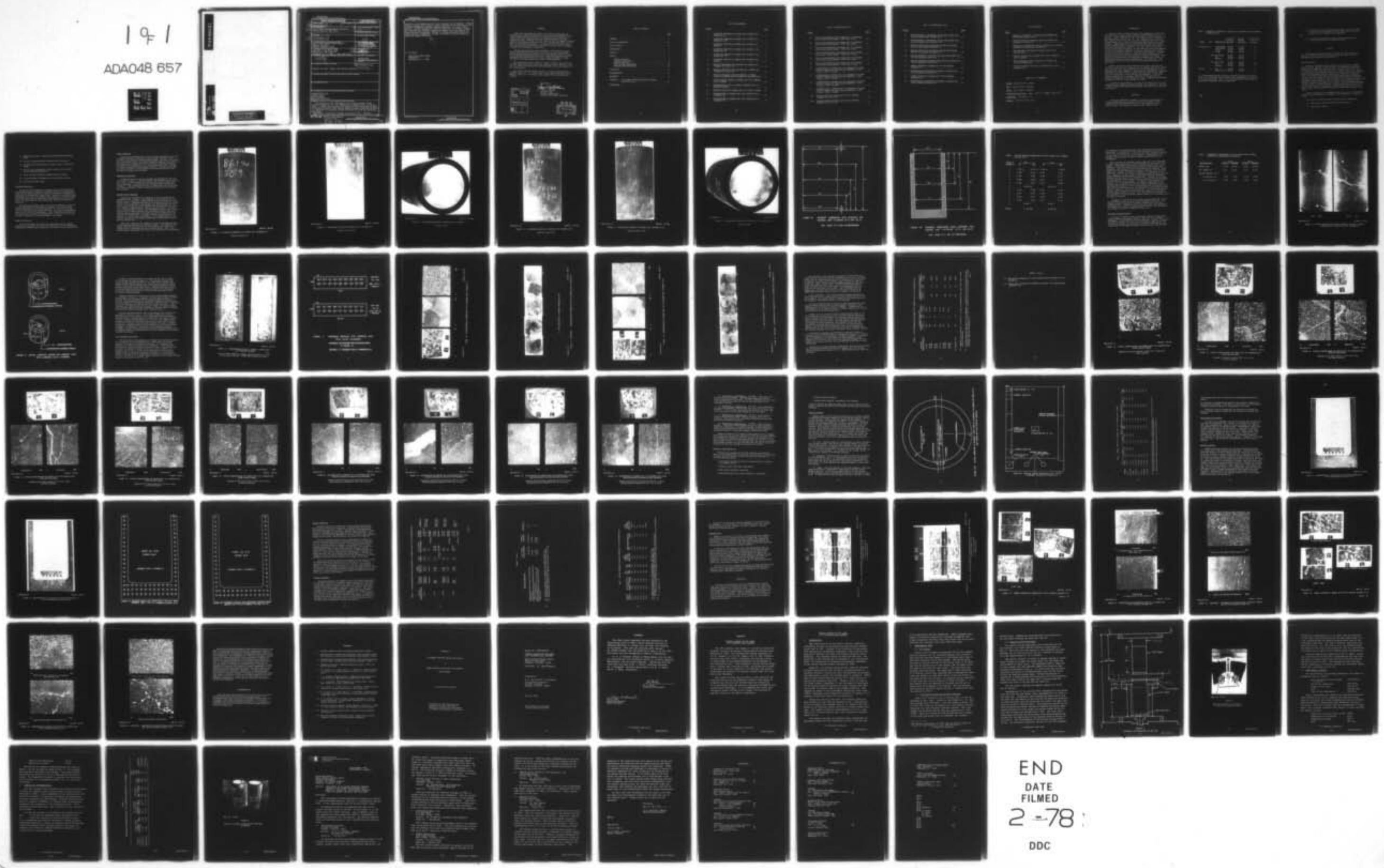

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The objective of this investigation was to develop wrought 7075-T6 mechanical properties in a cast aluminum alloy component of net or near-net shape. A squeeze casting process was selected as the manufacturing process. IIT Research Institute, under Contract N60921-76-M-E701, fabricated cylindrical components for evaluation; wrought 7075 alloy bar stock was used as the melt stock.

Following a limited heat treatment optimization effort, mechanical

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properties of the squeeze cast 7075 alloy components were determined. Sidewall fracture toughness and transverse tensile properties in the closed base of the cylindrical components approached reported properties for wrought 7075-T6 material. Chemical segregation, excessive grain size, low casting soundness, and incomplete heat treatment response are thought to be the causes for the reduced mechanical properties. Methods to overcome these shortcomings are identified and a recommendation is made to continue the efforts required to attain the original objective.

11. Continued.

Naval Sea Systems Command
NAVSEA-653C
Washington, D. C. 20362

FOREWORD

This report describes the results of a study to investigate the application of advanced high-strength aluminum casting technology to the 8-Inch Guided Projectile Program. The objectives of the study were to achieve increased mechanical properties and performance at reduced acquisition costs. Appendix A of this report is the IIT Research Institute report on the squeeze casting of large 7075 aluminum alloy samples to be used for metallurgical evaluation. Inclusion of this contractor report does not constitute endorsement or approval by the Navy, but is provided to expedite the exchange of information.

The work described herein was performed by the Materials Sciences Group, Applied Science and Materials Division, for the 8-Inch Guided Projectile Program Office located in the Guided Weapons Systems Division of the Armaments Development Department. Financial support for this investigation was provided under U.S. Marine Corps Work Request T-0089 and Naval Sea Systems Command Work Request N0002476WR62331.

The author would like to thank Mr. James E. Bennett (now located at the Naval Ordnance Station, Louisville, Kentucky) and Mr. Reuben S. Pitts, III, for their technical support and encouragement during the conduct of this investigation.

This report has been reviewed by Mr. J. D. Hall, Head, Materials Sciences Group; Mr. H. D. Farley, NSWC 8-Inch Guided Projectile Project Manager; and Mr. D. S. Malyevac, Head, Applied Science and Materials Division.

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ENGLISH TO SI CONVERSION

<u>Length</u>: Inches X 0.0254 = meters

<u>Mass</u>: Pound X 0.4536 - kilogram

<u>Stress</u>: psi X 6894.7 = pascals

<u>Stress Intensity Factor</u>: Kpsi $\cdot$ $(in)^{1/2}$ X 1.098855 = MPa$\cdot$$(m)^{1/2}$

<u>Temperature</u>: $(^{o}F-32)/1.8 = {}^{o}C$

<u>Density</u>: lb/in^3 X 27.676 = g/cc

INTRODUCTION

Several of the 8" Guided Projectile (GP) components are fabricated from castings of a high strength aluminum alloy identified as KO-1 or AA 201.0; these components include the afterbody, the fuze housing, the processor housing, and the tail fin. The aluminum alloy, containing 4-5% copper and 0.4-1.0% silver, is a heat treatable alloy and has the highest combination of tensile and yield strength available for premium castings. These properties are considerably lower than the stronger wrought aluminum alloys. Because of the silver content, this alloy is also quite expensive when compared to the cost of more conventional aluminum alloy premium castings; in July 1976, KO-1 ingot was estimated to cost $1.10 per pound compared to $0.45 per pound for AA-A357 while casting prices showed a 2-1/2 to 3 times price differential. Although the AA-201.0 alloy is reported to have fair casting characteristics, one major casting group has reported major problems with porosity, castability, high scrap rates, poor mechanical properties with respect to guaranteed properties, silicon contamination, and weldability. This group further stated that they would no longer quote on castings of this alloy.

Results from 8-Inch Guided Projectile tests have indicated that the KO-1-T6 aluminum alloy components did not possess sufficient strength under the most severe test conditions or may have contributed to poor performance of other components. Similar tests performed with components machined from wrought 7075-T6 aluminum alloy bar stock did not exhibit any of the deficiencies noted with the cast components. Other than chemical composition, the primary difference in the tests was the mechanical properties of the components. Table 1 compares the mechanical properties of the KO-1 alloy and the 7075 alloy.

In addition to performance, the costs of the larger cast KO-1 alloy components were thought by program personnel to be excessive. Machining of these complex configurations from wrought bar stock further increases their costs.

OBJECTIVE

A study was undertaken in support of the Navy 8-Inch Guided Projectile Program with the objective of developing wrought 7075-T6 aluminum alloy mechanical properties in a cast component of net or near-net shape. The approach to achieving this objective was:

TABLE 1. MECHANICAL PROPERTIES OF SELECTED HIGH STRENGTH CAST AND WROUGHT ALUMINUM ALLOYS

Alloy	Ref.	Class No.(a)	0.2% Yield Strength (psi min.)	Tensile Strength (psi min.)	Elongation 2 in. or 4D (% min.)
KO-1/AA-201.0	1	1-Designated	50,000	60,000	5
		2-Designated	50,000	60,000	3
		10-Any	48,000	56,000	3
		11-Any	48,000	56,000	1.5
	2(T6)	Designated	50,000	60,000	5
		Any	48,000	56,000	3
		Separate	50,000	60,000	5
	3(T7)	Designated	50,000	60,000	3
		Any	48,000	56,000	1.5
		Separate	50,000	60,000	3
7075-T6	4	Bar, <4"	66,000	77,000	7
		Sheet,1/8-1/4"	69,000	78,000	8

(a) Class numbers specify location of tensile specimens for casting: Class 1 or 2 indicates critical stress areas (designated) and class 10 or 11 indicates general (any). The term separate means that tests are performed on separately cast test specimens.

(1) to identify a casting manufacturing process with the potential to increase the performance of and/or reduce the cost of the current cast KO-1 aluminum alloy components.

and

(2) to conduct an experimental program which demonstrates the initial feasibility of the selected process.

RESULTS

The following sections document the study in terms of process selection, component fabrication, receipt inspection, heat treatment development, and materials characterization.

PROCESS SELECTION

A survey of advanced casting technology indicated that a squeeze casting process appeared to have potential to economically manufacture aluminum alloy components ranging in size from the 8-Inch GP tail fin (2-3 lbs) up to the afterbody (50-60 lbs.). Squeeze casting is a metalworking process which combines casting and forging into a single operation. During the metalworking process, molten metal is poured into the die cavity and allowed to partially solidify; the desired part configuration is then formed as closely-fitting die members move together, squeezing the metal into all segments of the die cavity. Full pressure is maintained throughout solidification by direct transmission of the applied force through the movable die member as in forging. Under optimized conditions, the end result is a close tolerance, fine surface finish, non-porous part having a fine grained, homogeneous, non-directional structure. At its best, squeeze casting provides forging level properties at casting level costs.

General advantages of the squeeze casting process over conventional casting or forging methods or production are listed below: (references 5-10).

(1) Choice of nominal wrought and casting alloy composition.

(2) Production of porosity-free heat treatable parts.

(3) Good surface finish.

(4) Complex parts cast to shape with reduced machining requirements.

(5) Low Cost starting materials (melting stock and scrap).

(6) High metal utilization since no gates, risers, or flash are needed.

(7) Smaller press requirements (lower tonnages) than forgings due to increased metal flow.

(8) Lower die costs because of reduced forming pressures.

(9) Process capable of automation for high production rates.

(10) Wide range of part sizes.

COMPONENT FABRICATION

Because of their background in squeeze casting, their R&D status, and the availability of tooling, IIT Research Institute was requested under Contract N60921-76-M-E701 to fabricate cylindrical components for evaluation by the Materials Science Group. Following a limited process development study, two 7075 aluminum alloy samples of cylindrical shape having one end closed were produced by IITRI and delivered for evaluation. The IITRI report on their fabrication efforts is provided as Appendix A.

The delivered components were in the as-cast condition, except for a light sand blasting of the exterior surfaces. These castings had nominal dimensions of 6-3/4 inch diameter by 3/4 inch wall thickness by 12-1/2 inch length and weighed 21-22 lbs. This size closely approximates that of the 8" GP fuze housing. IITRI identification markings on the castings were B6140/SC-9 and B6140/SC-10; only SC-9 and SC-10 will be used to identify the castings throughout this report.

RECEIPT INSPECTION

The cast cylinders, SC-9 and SC-10, were subjected to a receipt inspection process which included visual inspection, limited dimensional measurements, nondestructive inspection, and structural characterizations.

Visual Inspection

Photographic documentation of the as-received cylinders is presented in Figures 1 through 6. The lower quarter exterior surface of both cylinders (near the closed ends) was quite rough; the face of the closed ends was equally rough. This surface roughness appears to be related to non-optimum tooling design and could be corrected without difficulty. The scribe marks in Figures 1, 2, 4, and 5 were made by NSWC personnel to indicate locations for dimensional inspection. Figures 3 and 6 show the interior surfaces of the cylinders to be relatively smooth except for some tool marks at the open end.

Dimensional Inspection

Dimensional data for the two cylinders was determined at the locations noted in Figure 7. Outside diameters were determined with calipers and a rule; inside micrometers and calipers were used to measure the cavity dimensions. These data and the cylinder weights are presented in Table 2. From the dimensional data, it appears that the cavity walls were slightly tapered in order to facilitate stripping of the castings from the punch.

Nondestructive Inspection

Radiographic nondestructive inspection of the two cylinders was performed by NSWC (Poppen). The sidewalls of the cylinders were inspected using a single-wall exposure method with the film on the inside of the cylinder; exposures were made at 45° intervals around the circumference. The closed end of the cylinders was inspected with the X-ray source above the open end of the cylinder and the film under the closed end. Surface roughness effects tended to mask the results. No areas of gross porosity were detected. The radiographs did show some "texture" which could be caused by surface pits and material density variations. Isolated porosity was noted in cylinder SC-9 near the open end at the 180° and 225° orientations. The lower sidewall area of cylinder SC-10 appeared to contain cracks or shrinkage. It was recommended that the exterior surfaces of the cylinder be machined to remove surface defects and then reinspected.

Additional nondestructive inspection of the two cylinders was performed using dye penetrant and ultrasonic methods. The extremely rough surface area near the closed end of the cylinders (the bottom 2-1/2 inches) was not inspectable with the ultrasonic method. Most of the observed defect indications were found in the closed end of the cylinders;

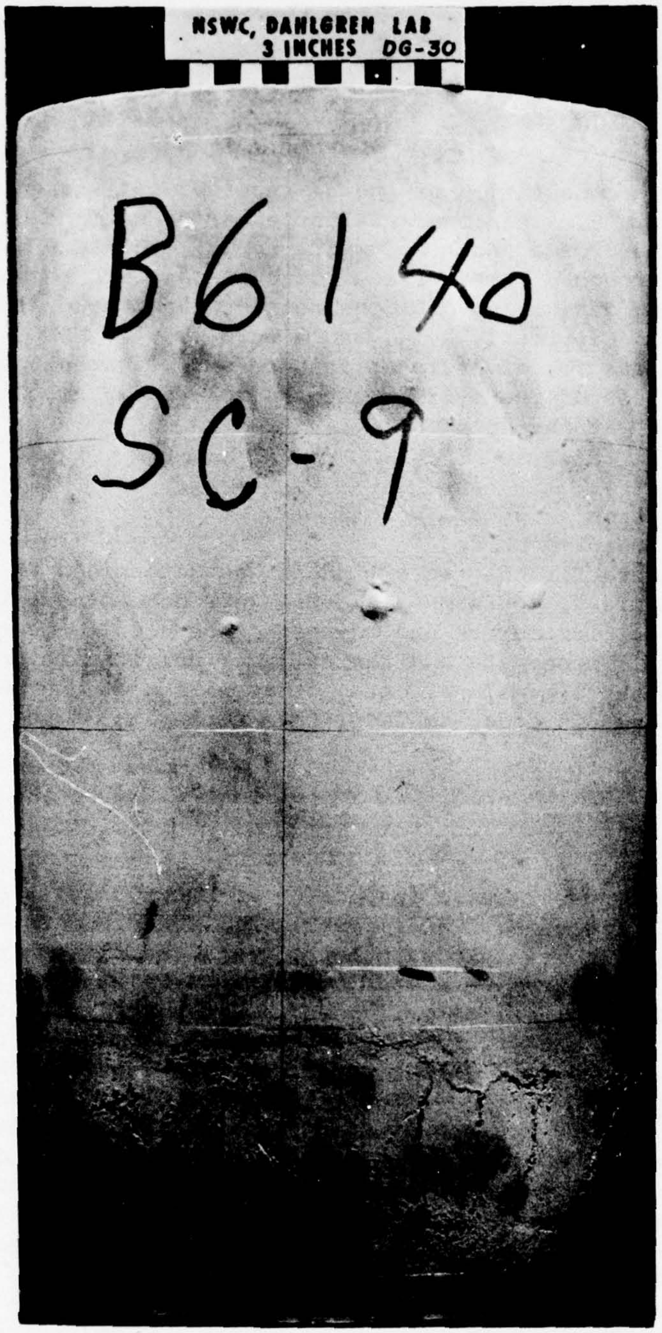

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FIGURE 1. AS-RECEIVED APPEARANCE OF SQUEEZE CAST CYLINDER SC-9.

Exterior View at 0°

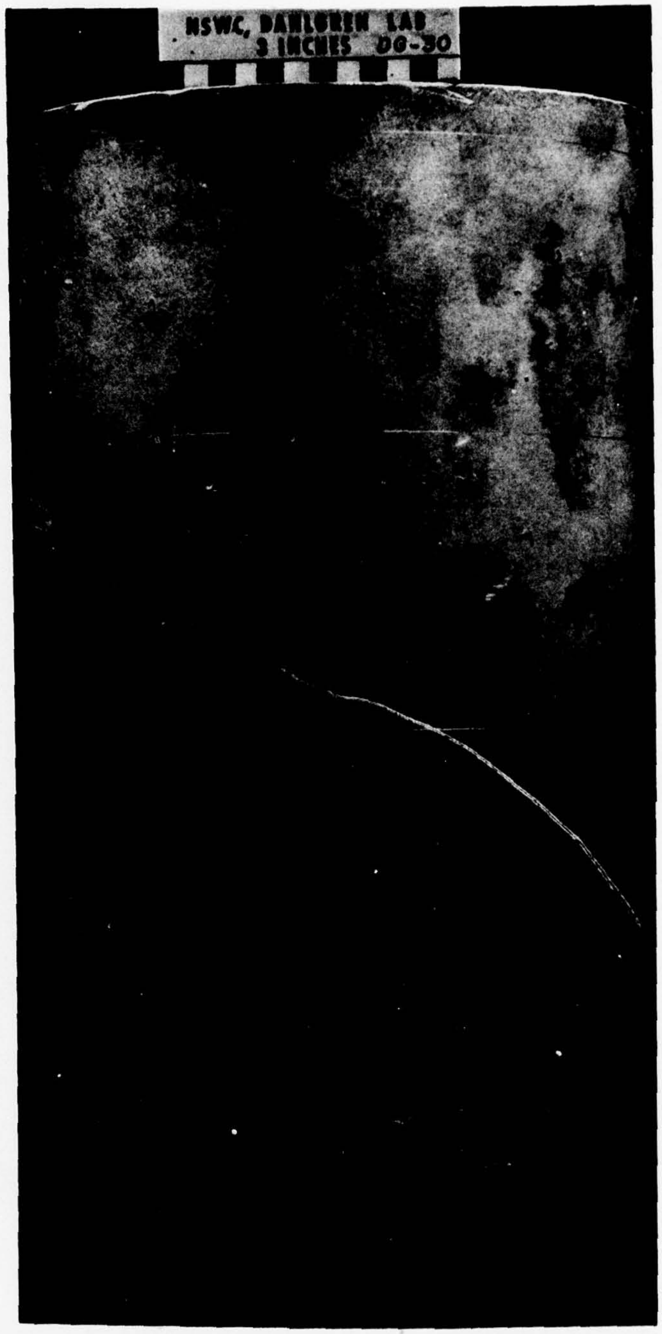

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FIGURE 2. AS-RECEIVED CONDITION OF SQUEEZE CAST CYLINDER SC-9.

Exterior View at 180°

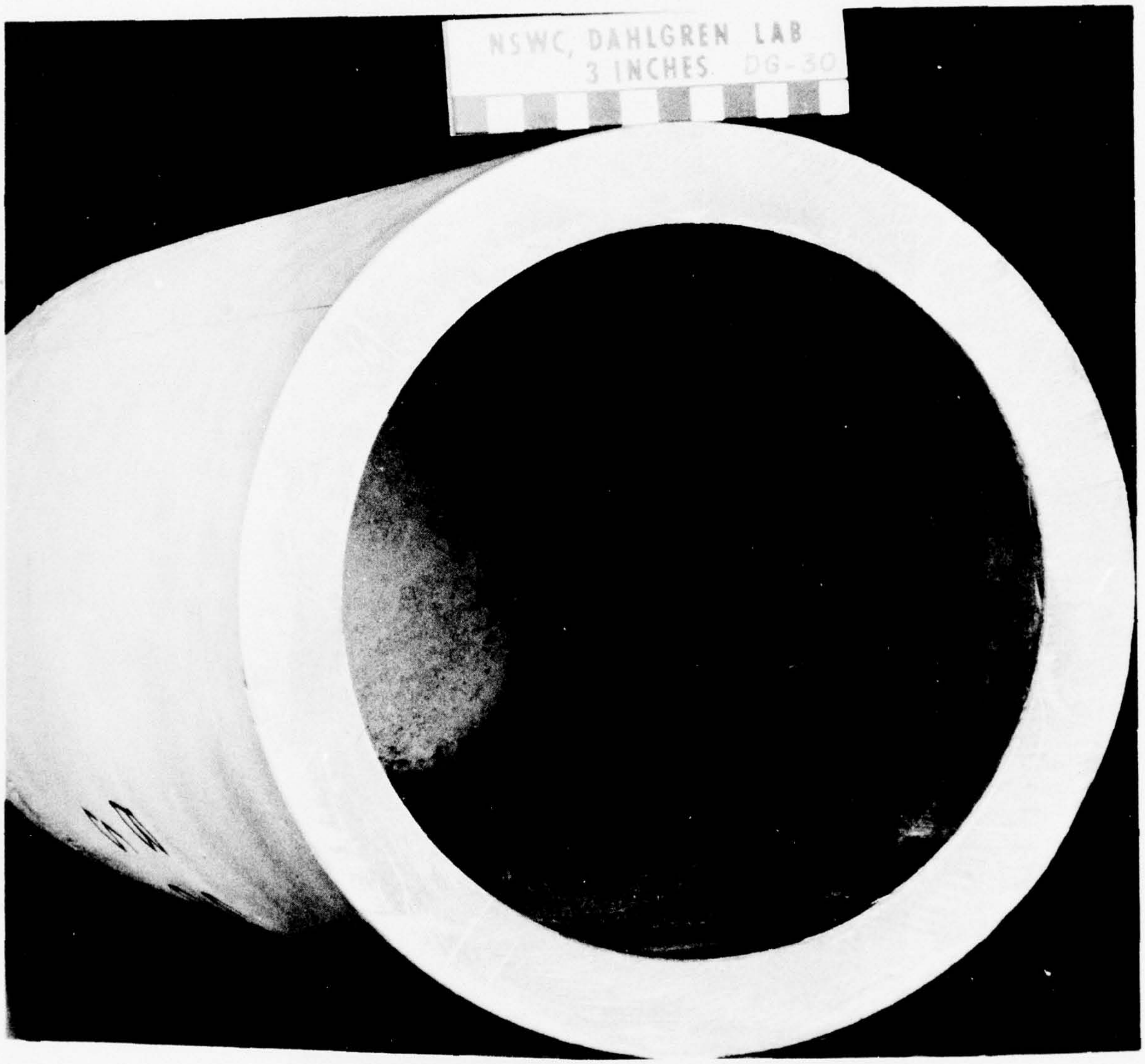

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FIGURE 3. AS-RECEIVED CONDITION OF SQUEEZE CAST CYLINDER SC-9.

Interior View

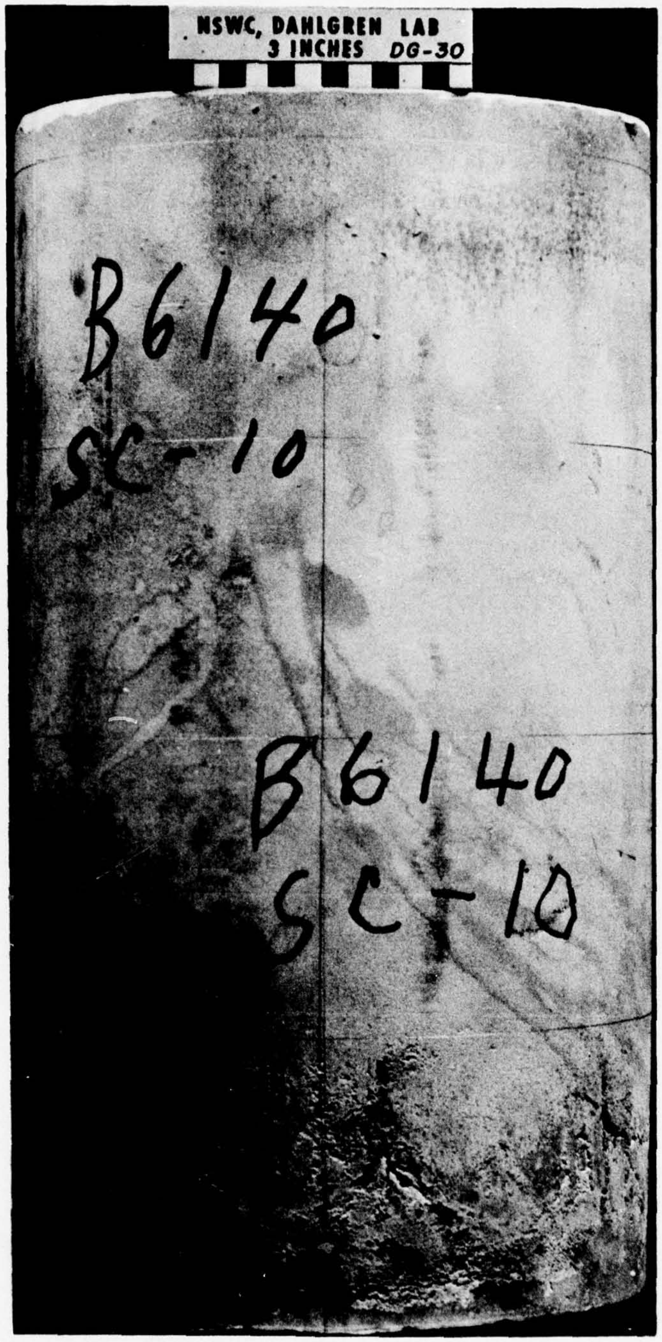

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FIGURE 4. AS-RECEIVED CONDITION OF SQUEEZE CAST CYLINDER SC-10.

Exterior View at 90°

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FIGURE 5. AS-RECEIVED CONDITION OF SQUEEZE CAST CYLINDER SC-10.

Exterior View at 270°

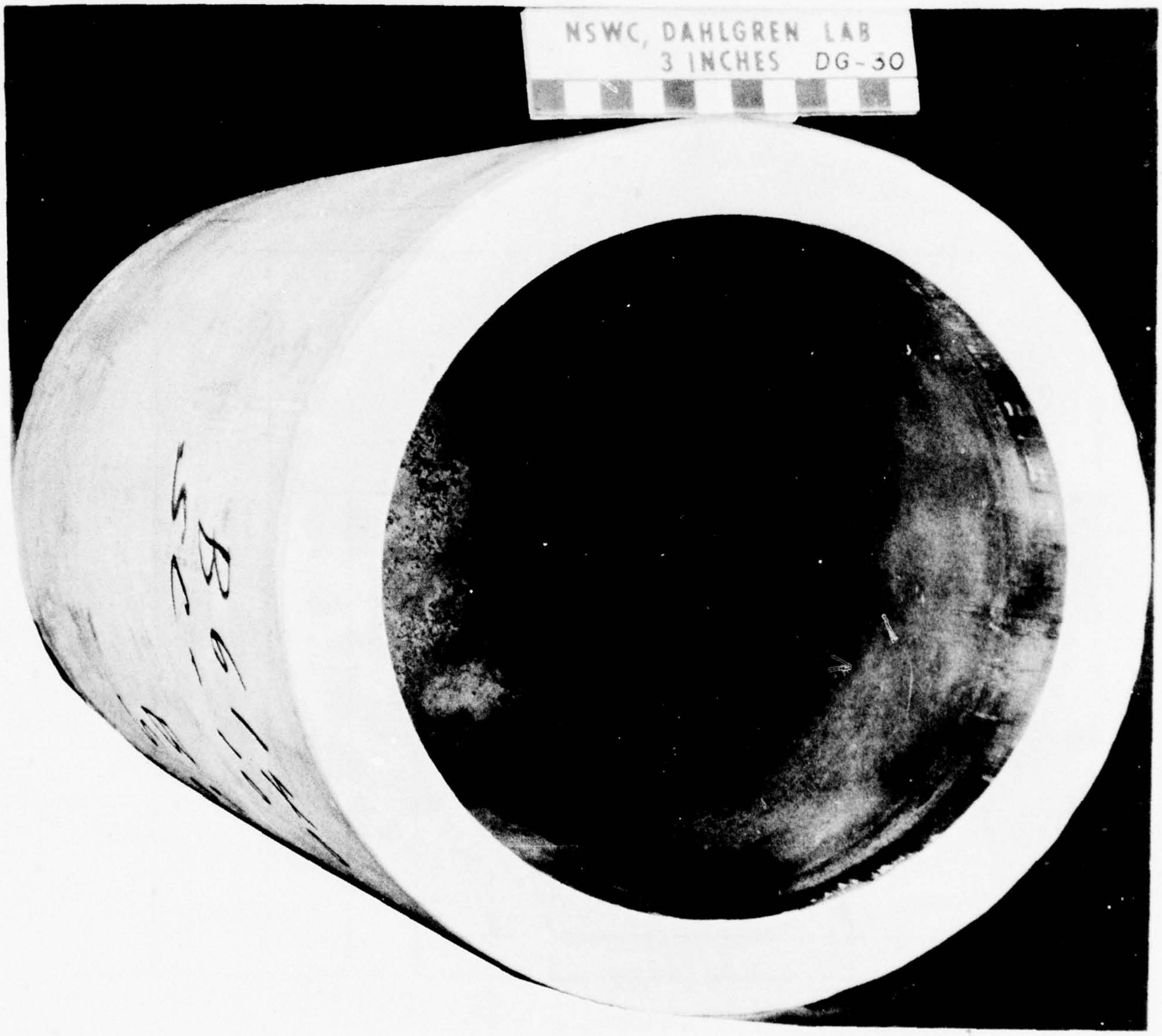

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FIGURE 6. AS-RECEIVED CONDITION OF SQUEEZE CAST CYLINDER SC-10.

Interior View

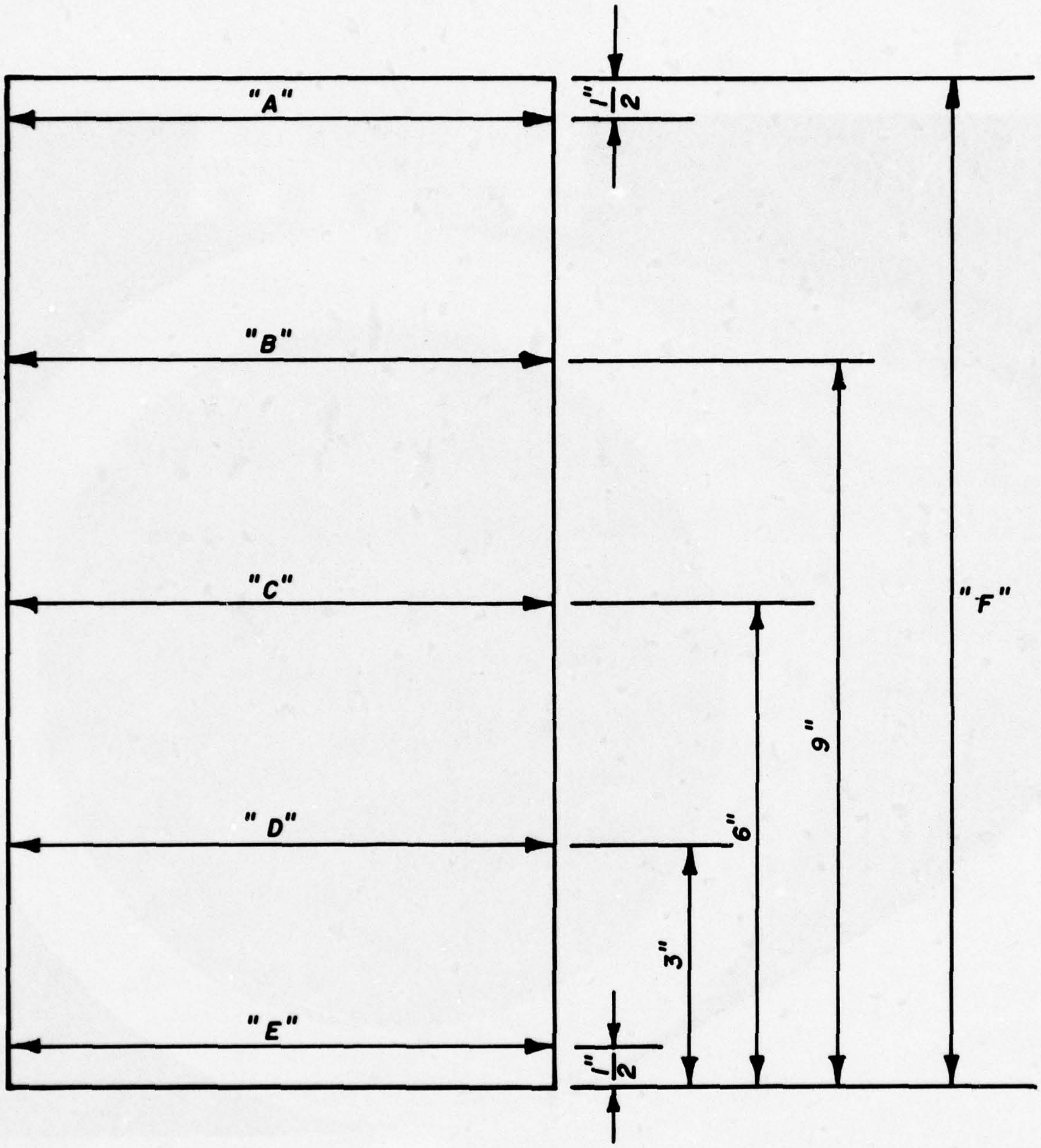


FIGURE 7A. EXTERIOR DIMENSIONAL DATA LOCATIONS FOR SQUEEZE CAST CYLINDERS SC-9 AND SC-10.

DATA TAKEN AT 0° AND 90° ORIENTATIONS.

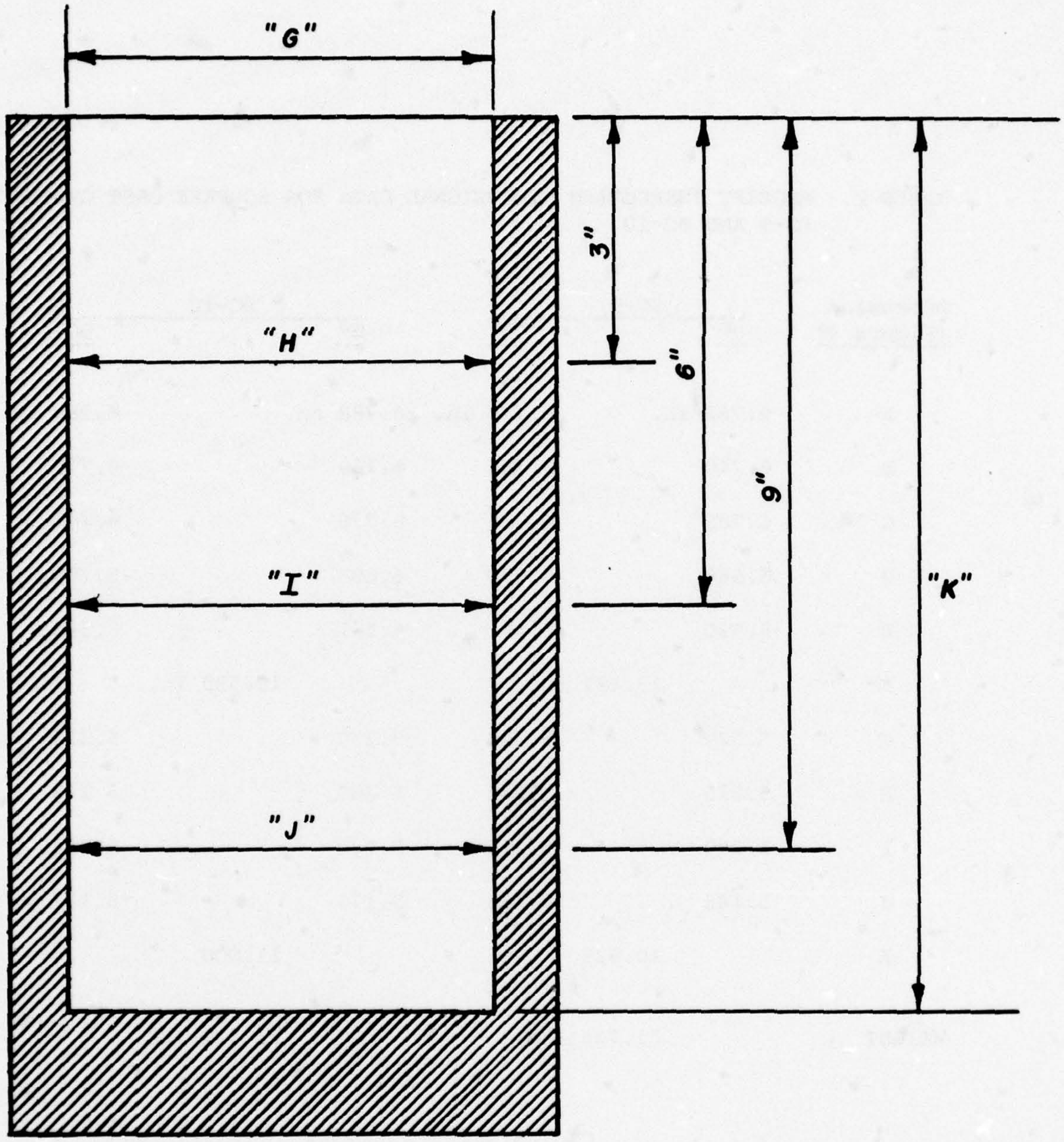


FIGURE 7B. INTERIOR DIMENSIONAL DATA LOCATIONS FOR SQUEEZE CAST CYLINDERS SC-9 AND SC-10.

DATA TAKEN AT 0° AND 90° ORIENTATIONS.

TABLE 2. RECEIPT INSPECTION DIMENSIONAL DATA FOR SQUEEZE CAST CYLINDERS SC-9 AND SC-10

Dimension (Figure 7)	SC-9			SC-10		
	0°		90°	0°		90°
A	6.782 in.		6.779 in.	6.788 in.		6.789 in.
B	6.740		6.744	6.769		6.770
C	6.705		6.706	6.736		6.741
D	6.688		6.680	6.693		6.705
E	6.590		6.591	6.591		6.598
F		12.492 in.			12.595 in.	
G	5.329		5.324	5.330		5.329
H	5.275		5.270	5.280		5.278
I	5.209		5.212	5.220		5.225
J	5.145		5.155	5.170		5.172
K		10.625			11.000	
WEIGHT		21.734 lbs.			21.422 lbs.	

the roughness of the bottom face may have produced artificial defect indications. A two-inch long defect area was detected near the lip of SC-9 at the 270° orientation; a four-inch long area extending from the lip was noted in SC-10 at the 45° orientation. Reinspection of the cylinders after machining to remove surface roughness effects was recommended.

Both cylinders were machined without difficulty to the dimensions in Table 3 and reinspected by X-ray radiography and ultrasonic C-scan methods. Radiographic procedures were the same as used in the initial inspection. The solid bases on both cylinders looked fairly sound although a limited amount of small scale porosity was detected. Radiographic data for the widewalls was similar to that for the as-received conditions. Cylinder SC-9 showed a "pattern" of dense areas in the walls; Figure 8 is a print from a radiograph illustrating this "pattern". Visual examination of the cylinder cavity surface did not provide an indication of the cause of this characteristic. Cylinder SC-10 showed the same behavior as SC-9 except that this "pattern" was more noticeable near the open end of the cylinder. The cause of these "patterns" was thought to be a localized variation in chemical composition of the aluminum alloy or the presence of a high density second phase rather than cracks and porosity. Cracks and porosity would allow greater X-ray penetration and would show up on the radiographs as dark areas and lines (white or light on a print such as Figure 8). A localized high-density material would decrease X-ray penetration and show up a light area on the radiographs (dark on a print). The latter behavior was observed. No reason for the presence of high density regions in the cylinders could be found at this time.

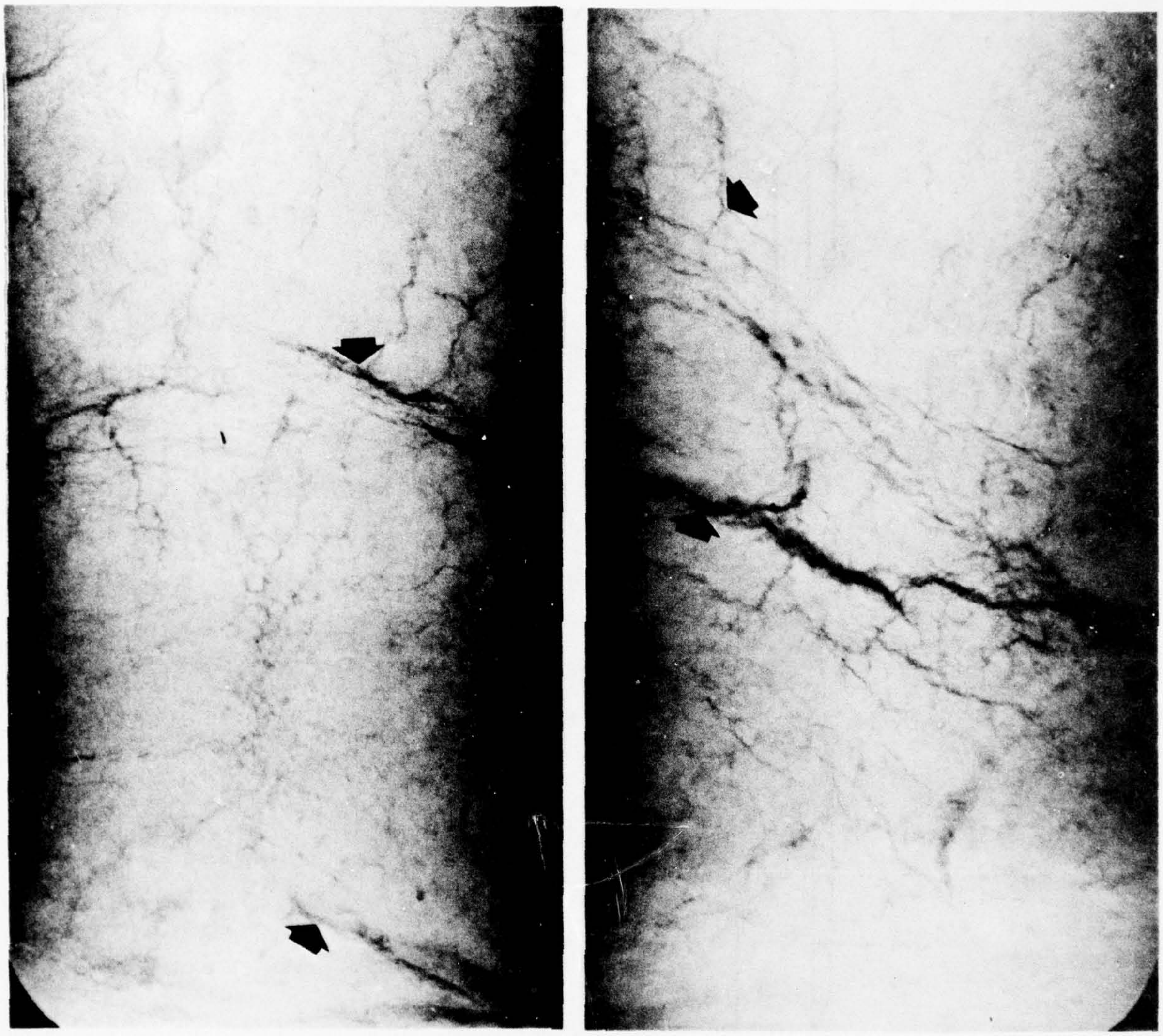
Ultrasonic C-scan NDT of the cylinders was performed using facilities available at both the Naval Research Laboratory and NSWC. The sidewall inspection data were in general agreement with the X-ray radiography data. Inspection data for the solid base areas suggested the presence of inclusions, inhomogenieties or flaws. Detailed destructive evaluation would be required to confirm this.

Structural Characterization

The top 2.5 inches of each cylinder were removed to obtain macrographic samples, micrographic samples, samples for heat treatment development, and samples for historical reference. Figure 9 illustrates the sampling scheme. The face of the macrographic sample at the 90° orientation was used for evaluation of gross structural defects; the reverse side of the sample was used to determine the as-cast hardness.

TABLE 3. COMPARISON OF DIMENSIONAL DATA FOR SQUEEZE CAST CYLINDERS SUBJECTED TO NONDESTRUCTIVE INSPECTION

	SC-9		SC-10	
Metrology Data	As Rec'd.	Machined	As Rec'd.	Machined
Weight, lbs.	21.734	19.734	21.422	19.078
Avg. Length, in.	12.49	12.46	12.59	12.54
Outside Diameter, at 0^{o}				
½" from top, in.	6.782	6.560	6.788	6.565
6" from top, in.	6.705	6.567	6.736	6.564



SC-9 225°

SC-10 45°

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FIGURE 8. TYPICAL LOCALIZED HIGH DENSITY MATERIAL "PATTERNS" DETECTED IN SQUEEZE CAST CYLINDERS BY X-RAY RADIOGRAPHY.

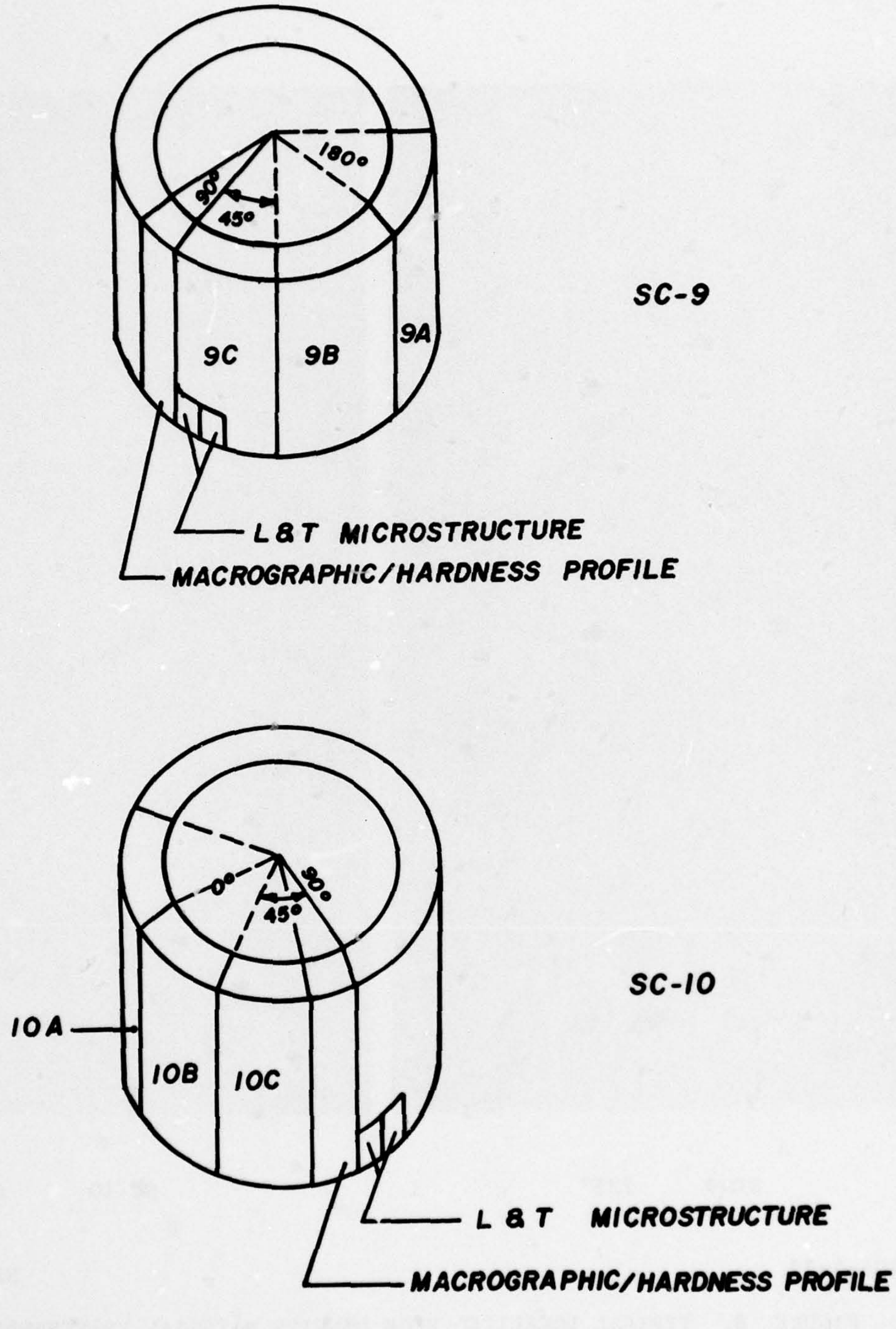


FIGURE 9. INITIAL SAMPLING SCHEME FOR SQUEEZE CAST 7075 ALUMINUM ALLOY CYLINDERS.

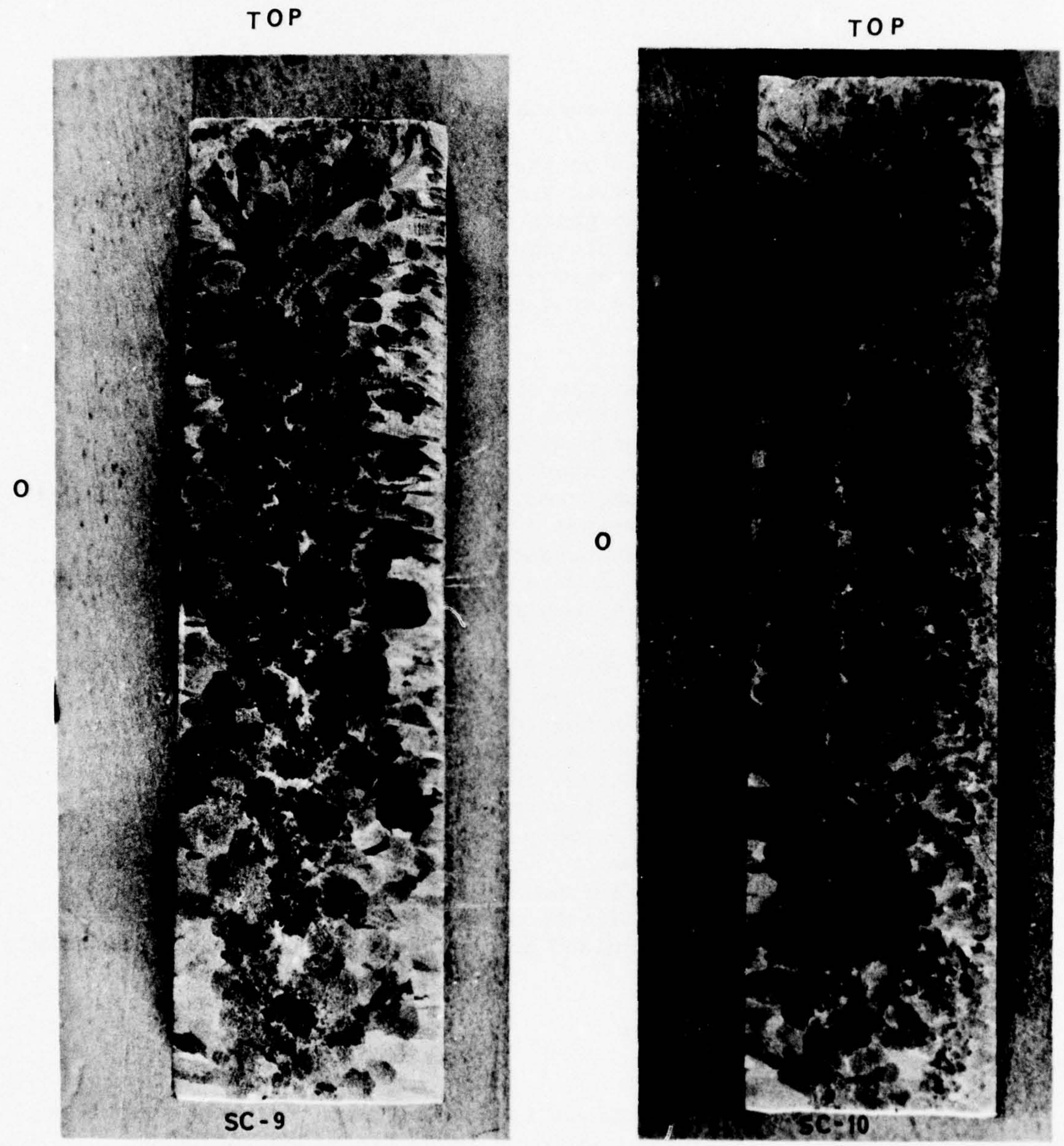
Results of the macrostructure evaluation for the top 2.5 inches of the castings are shown in Figure 10. The structure is relatively coarse grained, with the structure on the inside being somewhat finer because of high-pressure contact with the punch part of the die system. A light colored, nearly continuous phase of unknown composition can be seen near the center of the cross section. This phase may be the source of the high-density material indications observed in the radiographs. The as-cast grain size of SC-10 is slightly finer than that of SC-9; no reason is readily apparent.

Hardness profiles for the reverse side of the macrographic specimen are presented in Figure 11. Comparison of these data to reported literature was difficult as reported hardness data for aluminum alloys is limited. These hardness data are intermediate between the typical hardness data reported by the Aluminum Association (reference (4)) for annealed (0) and for precipitation heat treated (T6) wrought 7075 alloy. Other information for typical acceptable hardness values for wrought aluminum alloys indicate these data to be comparable to hardness data for naturally aged (T4) 2014 and 2024 aluminum alloys (reference (11)).

As-cast microstructures for each of the squeeze cast cylinders are presented in Figures 12 and 13. The extremely coarse grain size of these materials is very evident in the lower magnification photographs. This coarse grain structure should be replaced by a fine grain structure in order to develop optimum properties in the cast 7075 aluminum alloy. Chemical segregation or coring and some porosity can be seen in Figures 12c and 13c. Coring is typical for many casting alloys and is usually eliminated by homogenization annealing treatment or a solution annealing treatment. The porosity is not desired and was probably caused by entrapment of gases during solidification; tooling designed specifically for squeeze casting the desired guided projectile components would probably overcome this problem.

HEAT TREATMENT DEVELOPMENT

The next stage of the program was to develop heat treatment practices for the squeeze cast 7075 aluminum alloy. These practices included solution annealing and precipitation hardening; the homogenization annealing was combined with the solution annealing. No reported data were found for the heat treatment of cast 7075 alloy. The standard heat treatment for wrought 7075 alloy of the size of the cylinders is to solution treat at 870 $\pm$ 10°F in air for 90 minutes and then rapidly quench the part in agitated cold water (condition W). Precipitation hardening (T6 condition) is accomplished by heating the 7075-W material at 250 $\pm$ 10°F for 23 to 28 hours. The T6 condition is the highest strength properties attainable in the 7075 alloy.



PHD-1410-4-77 NSWC/DL (DG-30)

FIGURE 10. MACROSTRUCTURE OF TOP 2.5 INCHES OF SQUEEZE CAST 7075 ALUMINUM CYLINDERS. 2.5X

Top of cylinders near top of page; outside surface of cylinder on left side of section. Arrows note unidentified phase.

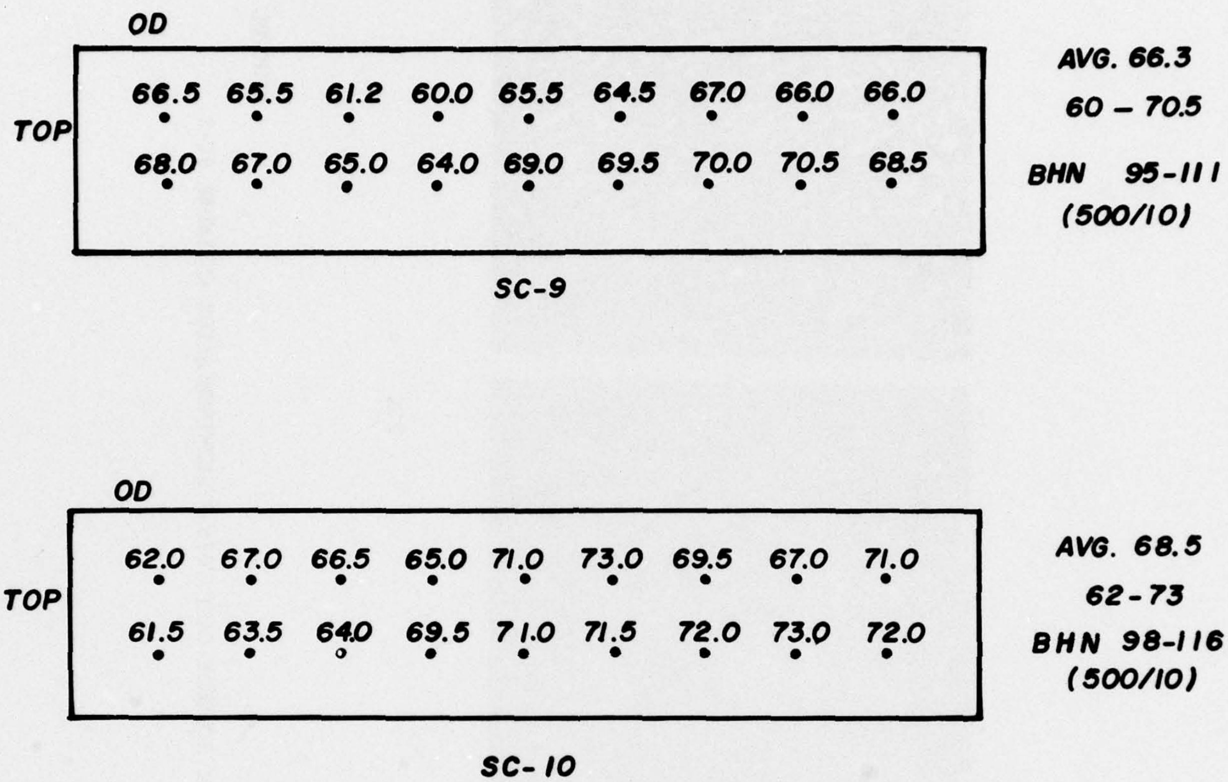
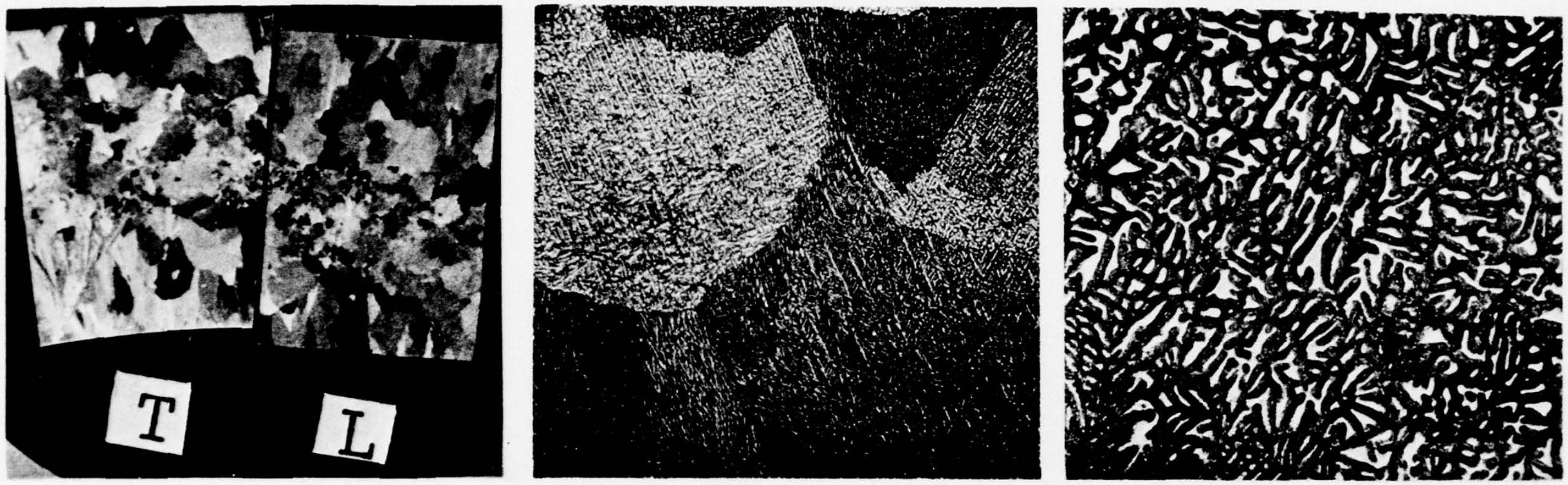


FIGURE 11. HARDNESS PROFILES FOR SQUEEZE CAST 7075 ALLOY CYLINDERS

SPECIMENS ARE REVERSE SIDE OF SECTIONS SHOWN IN FIGURE 10.

ROCKWELL B HARDNESS SCALE; APPROXIMATE 2X.



a. 3X b. 25X c. 100X

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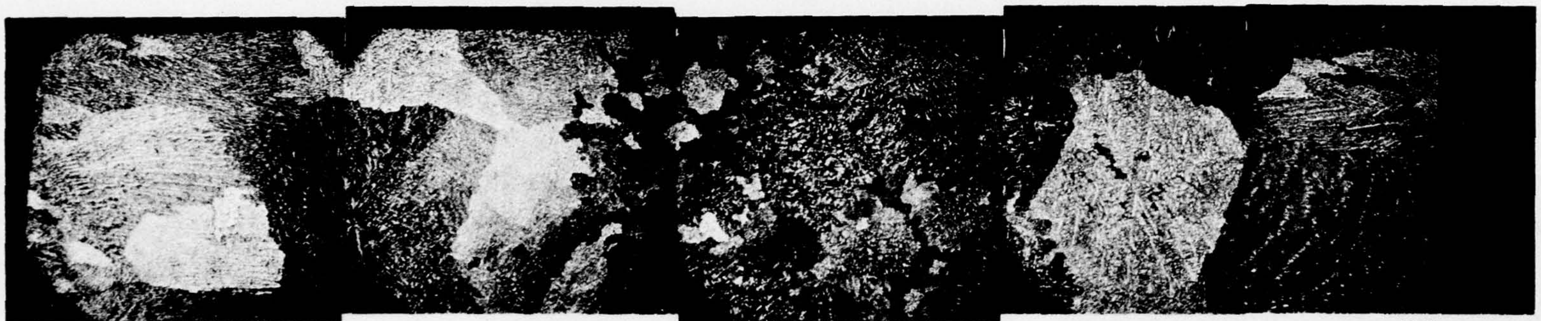
FIGURE 12. MICROSTRUCTURES OF SQUEEZE CAST 7075-F ALUMINUM ALLOY CYLINDER SC-9.

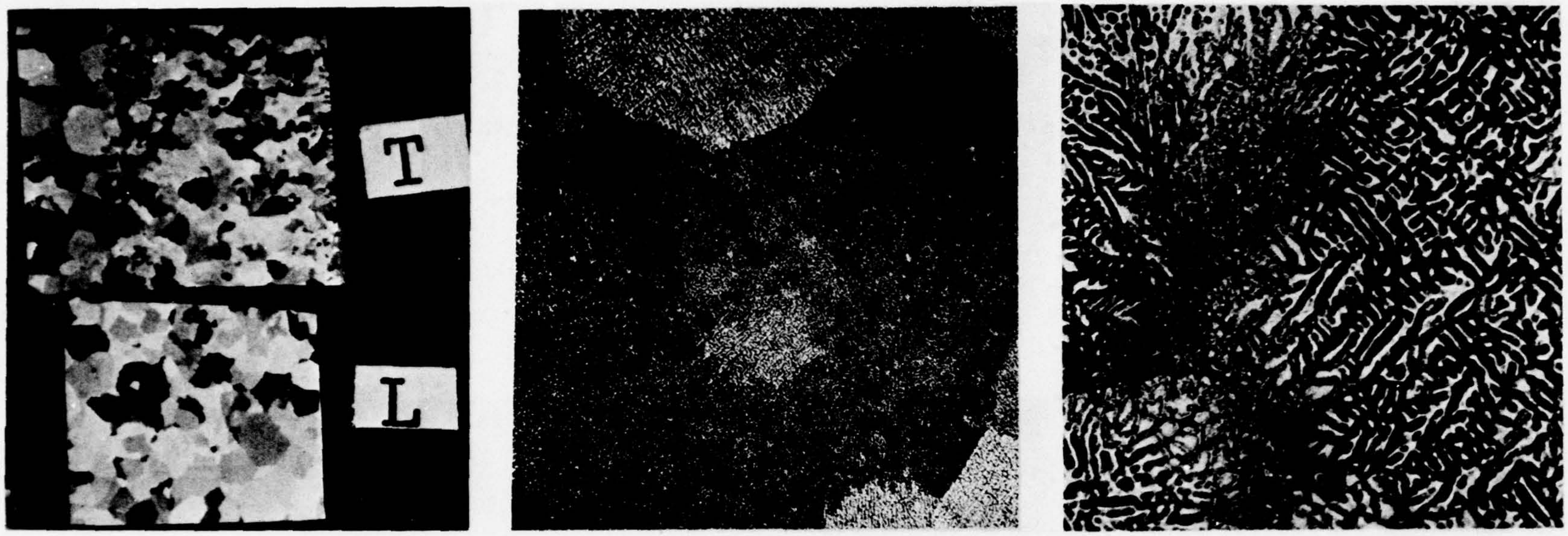


OD

d. Wall Cross-Section - Original Photograph at 25X

PHD-1412-4-77 NSWC/DL (DG-30)

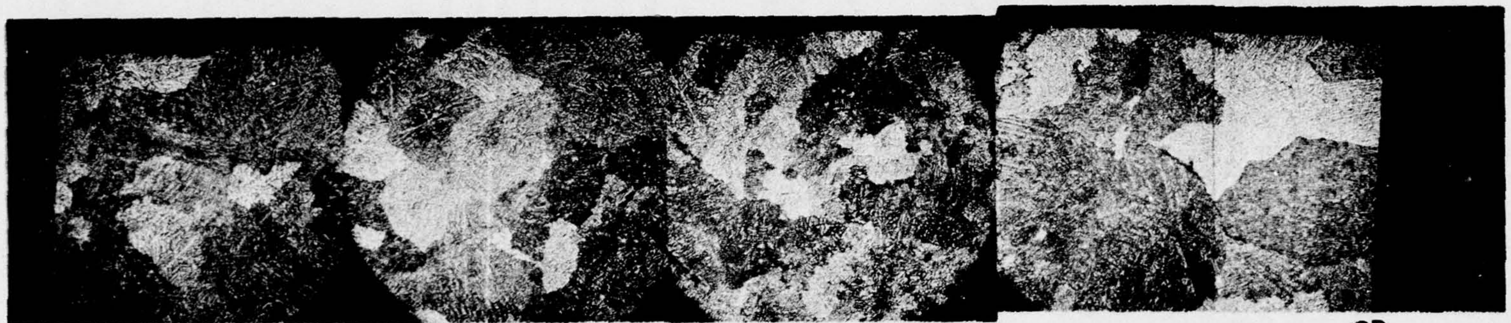
FIGURE 12 (CONTINUED). MICROSTRUCTURES OF SQUEEZE CAST 7075-F ALUMINUM ALLOY CYLINDER SC-9.



a. 3X b. 25X c. 100X

PHD-1413-4-77 NSWC/DL (DG-30)

FIGURE 13. MICROSTRUCTURES OF SQUEEZE CAST 7075-F ALUMINUM ALLOY CYLINDER SC-10.



d. Wall Cross-Section - Original Photograph at 25X

PHD-1414-4-77 NSWC/DL (DG-30)

FIGURE 13 (CONTINUED). MICROSTRUCTURES OF SQUEEZE CAST 7075-F ALUMINUM ALLOY CYLINDER SC-10.

The conventional heat treatment practices for wrought 7075 alloy formed the basis for developing heat treatments for the cast 7075 alloy; longer times at temperature during solution annealing will be required to eliminate the cored microstructures noted in Figures 12c and 13c. In addition, higher solution annealing temperatures may be required to achieve the removal of the coring. Specific consideration must be given to prevent remelting of the alloy as the approximate melting range for the 7075 alloy is 890-1180°F. The 45° segments from the squeeze cast cylinders (see Figure 9) were solution treated at the temperatures and times listed in Table 4 to produce a W condition.

Visual examination of the 7075-W specimens showed some porosity within the walls plus a "grainy pattern" on the outside surface of the SC-10 samples. The "grainy pattern" looked like very large grains and was similar to the patterns noted on the radiographs.

The 7075-W materials were sectioned to obtain specimens for longitudinal hardness profiles and for metallographic evaluation of the completeness of the solution annealing treatment. Hardness data for these materials is presented in Table 4; both the range and the average are similar to the as-cast hardness data.

Figures 14 to 19 illustrate typical microstructures found in the 7075-W materials following the various solution annealing treatments. The low magnification photographs of the overall cross-sections still exhibit a coarse grain structure. The high magnification photographs reveal subgrain structures within the larger grains, some porosity at the subgrain and grain boundaries, some residual coring, and some precipitates or second phases which did not go into solid solution. Based on the hardness and microstructural data, it was decided that specimens 9B, 9C, 10B, and 10C should be precipitation hardened using the standard treatment for wrought 7075 alloy: 250 ± 10°F for 24 hours.

Precipitation hardening was performed as indicated in Table 4. Hardness testing and metallographic investigation, were used to evaluate the effectiveness of the precipitation hardening treatment. Longitudinal profile hardness data for each sample are also presented in Table 4. Comparison of these data with the typical acceptable hardness data for wrought 7075-T6 alloy indicates that only Specimen SC-10CC did not meet expectations.

Results from the metallographic investigation of the solution treated and precipitation hardened (T6 condition) squeeze cast 7075 aluminum alloy are presented in Figures 20 to 23. These results can be summarized as follows:

TABLE 4. HEAT TREATMENT DEVELOPMENT FOR SQUEEZE CAST 7075-F ALUMINUM ALLOY

Specimen Identification[1]	Solution Anneal[2] Temperature °F	Solution Anneal[2] Time hr	Solution Anneal[2] Hardness R_B	Precipitation Hardening[3] Temperature °F	Precipitation Hardening[3] Time hr	Precipitation Hardening[3] Hardness R_B
SC-9A	905	2	59-72			
SC-9B	905	4	57-72			
SC-9BB				250	24	85-89
SC-9C	870	16	37-60			
SC-9CC				250	24	85-90
SC-10A	870	2	60-77			
SC-10B	870	4	62-74			
SC-10BB				250	24	85-95
SC-10C	870	8	56-72			
SC-10CC				250	24	81-90
(4) Wrought 7075	870	1.5		250	24	85-94

(1) Samples are as indicated in Figure 9. BB and CC specimens were taken from B and C after solution annealing.

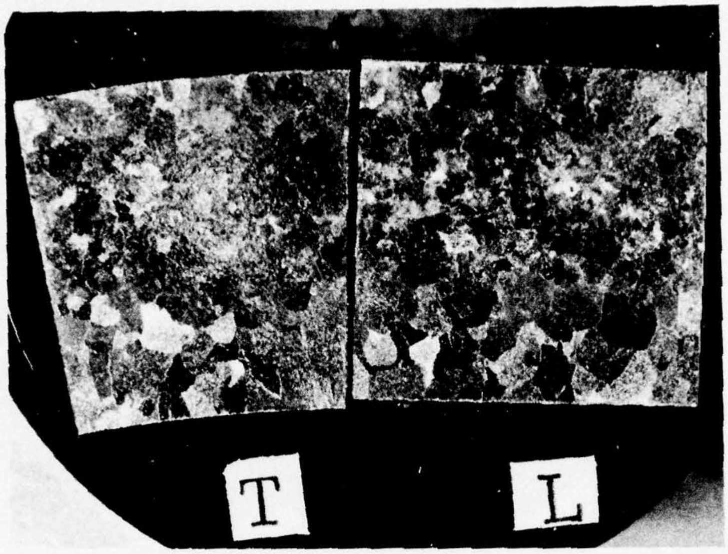
(2) Solution annealing performed in air atmosphere. Specimens were cold water quenched after indicated times at temperature; delay time for quenching was 15 second maximum. Following treatment, material in condition W.

(Cont.)

TABLE 4. (Cont.)

(3) Precipitation hardening to the T6 condition was performed in an air atmosphere.

(4) Typical heat treatment and hardness for wrought 7075 aluminum alloy (reference (8)).



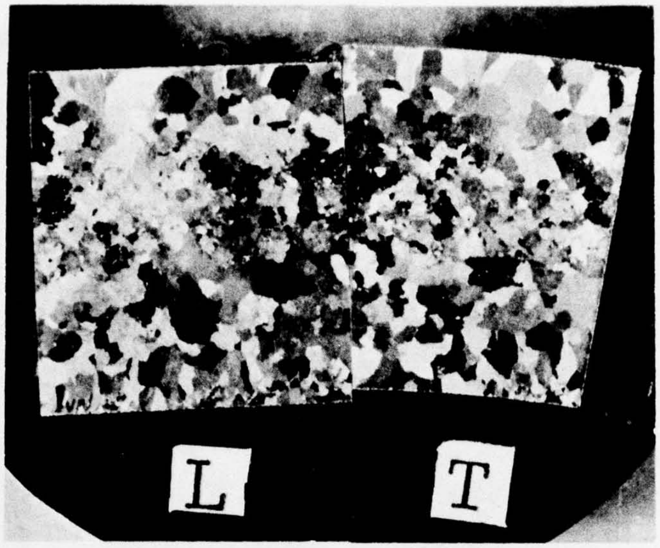
a. 3X

b. 100X

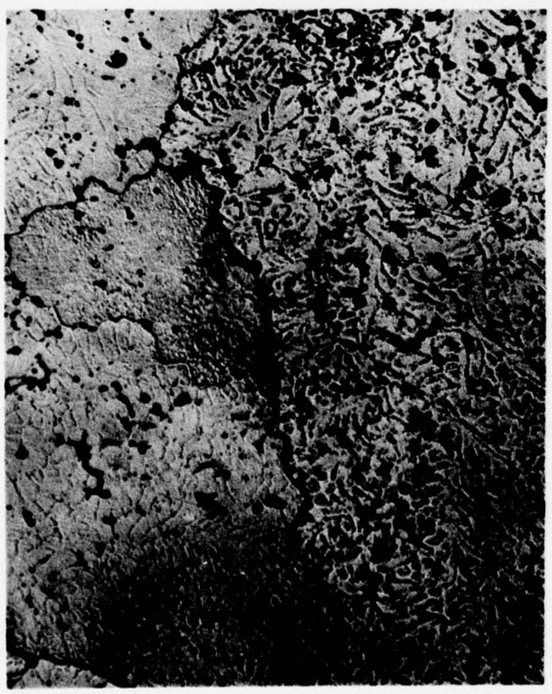
PHD-1415-4-77 NSWC/DL (DG-30)

FIGURE 14. TYPICAL MICROSTRUCTURES FOR SQUEEZE CAST 7075 ALUMINUM ALLOY AFTER SOLUTION ANNEAL.

Specimen SC-9A heat treated at 905°F for 2 hours and water quenched.



a. 3X

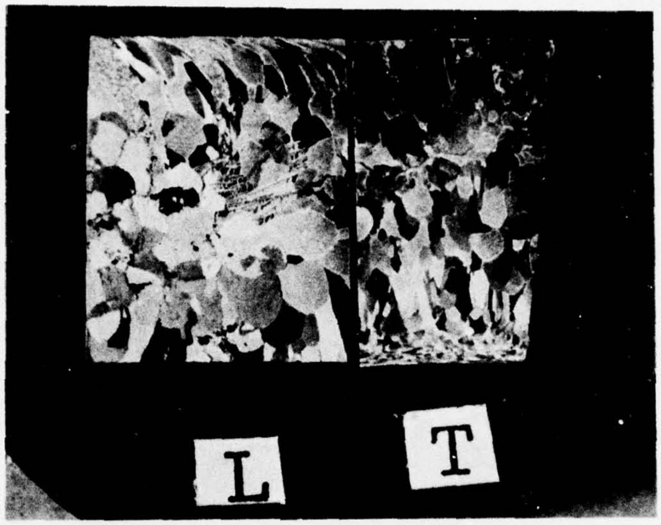


b. Longitudinal 100X c. Transverse 100X

PHD-1416-4-77 NSWC/DL (DG-30)

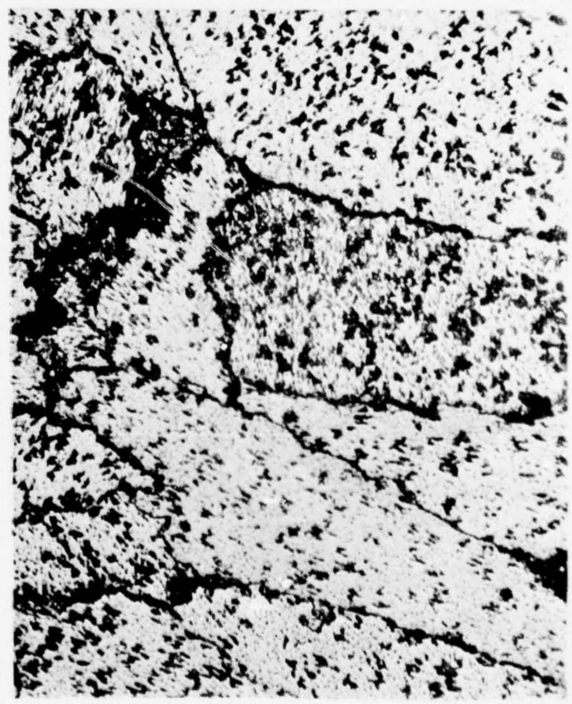
FIGURE 15. TYPICAL MICROSTRUCTURES FOR SQUEEZE CAST 7075 ALUMINUM ALLOY AFTER SOLUTION ANNEAL.

Specimen SC-9B heat treated at 905°F for 4 hours and water quenched.



a. 3X

b. Longitudinal 100X

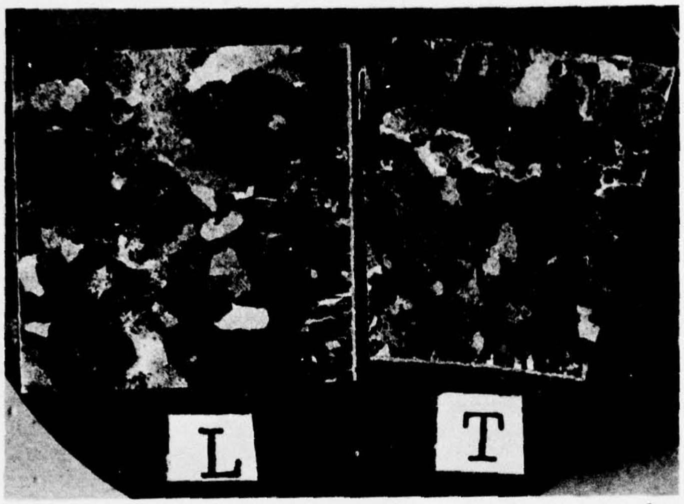


c. Transverse 100X

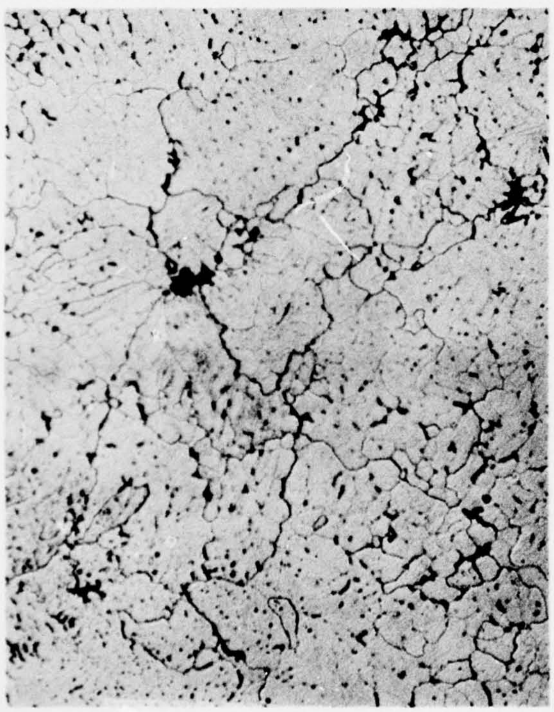
PHD-1417-4-77 NSWC/DL (DG-30)

FIGURE 16. TYPICAL MICROSTRUCTURES FOR SQUEEZE CAST 7075 ALUMINUM ALLOY AFTER SOLUTION ANNEAL.

Specimen SC-10A heat treated at 870°F for 2 hours and water quenched.



a. 3X



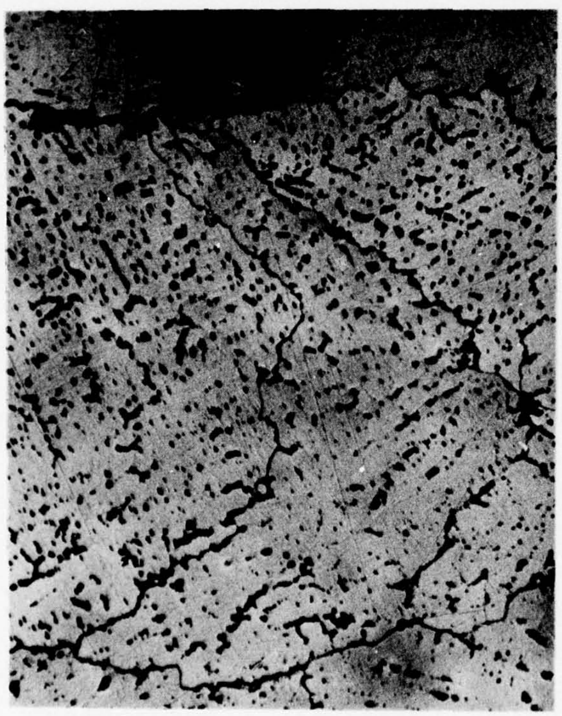
b. Longitudinal 100X c. Transverse 100X

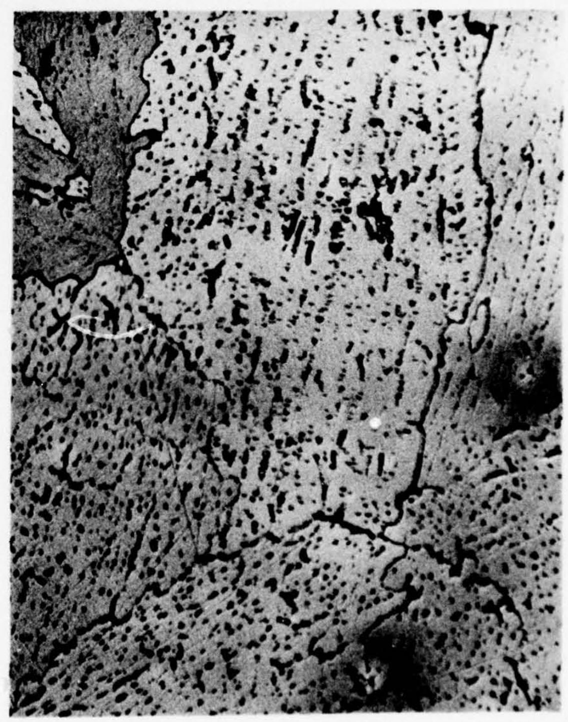
PHD-1418-4-77 NSWC/DL (DG-30)

FIGURE 17. TYPICAL MICROSTRUCTURES FOR SQUEEZE CAST 7075 ALUMINUM ALLOY AFTER SOLUTION ANNEAL.

Specimen SC-10B heat treated at 870°F for 4 hours and water quenched.

a. 3X



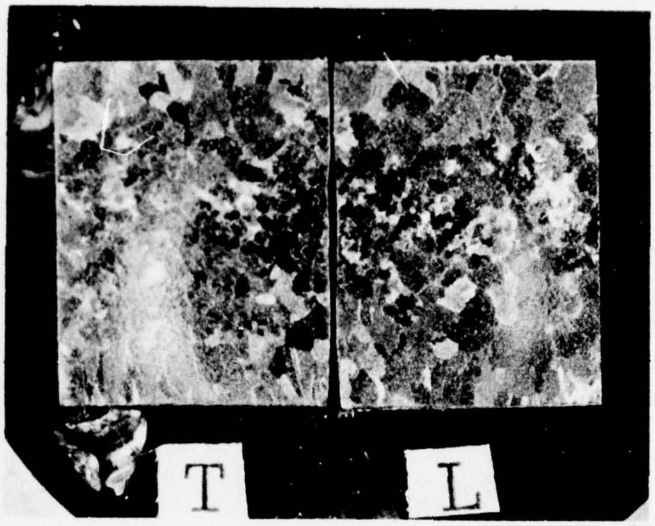


b. Transverse 100X c. Longitudinal 100X

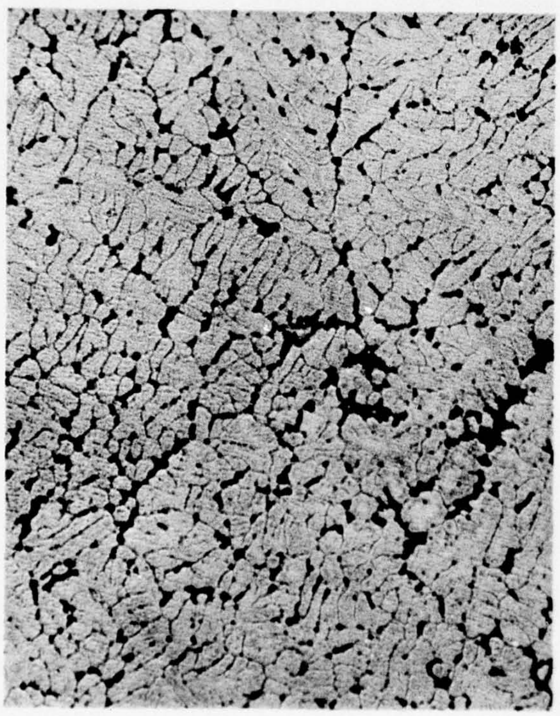
PHD-1419-4-77 NSWC/DL (DG-30)

FIGURE 18. TYPICAL MICROSTRUCTURES FOR SQUEEZE CAST 7075 ALUMINUM ALLOY AFTER SOLUTION ANNEAL.

Specimen SC-10C heat treated at 870°F for 8 hours and water quenched.



a. 3X

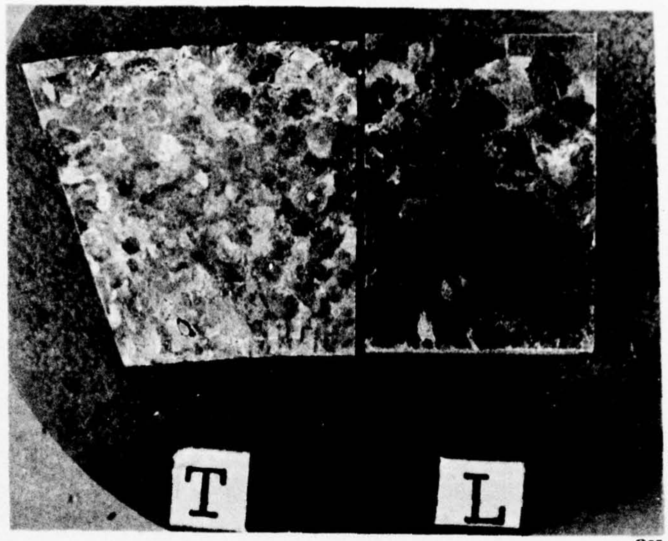


b. **Transverse** 100X c. **Longitudinal** 100X

PHD-1420-4-77 NSWC/DL (DG-30)

FIGURE 19. TYPICAL MICROSTRUCTURES FOR SQUEEZE CAST 7075 ALUMINUM ALLOY AFTER SOLUTION ANNEAL.

Specimen SC- 9C heat treated at 870°F for 16 hours and water quenched.



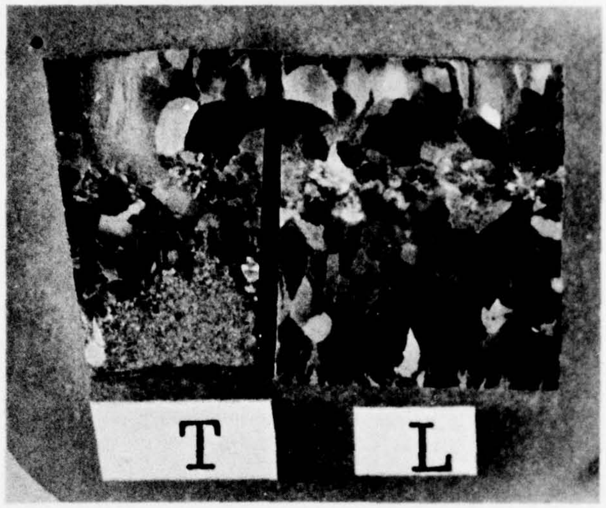
a. 3X

b. 75X c. 250X

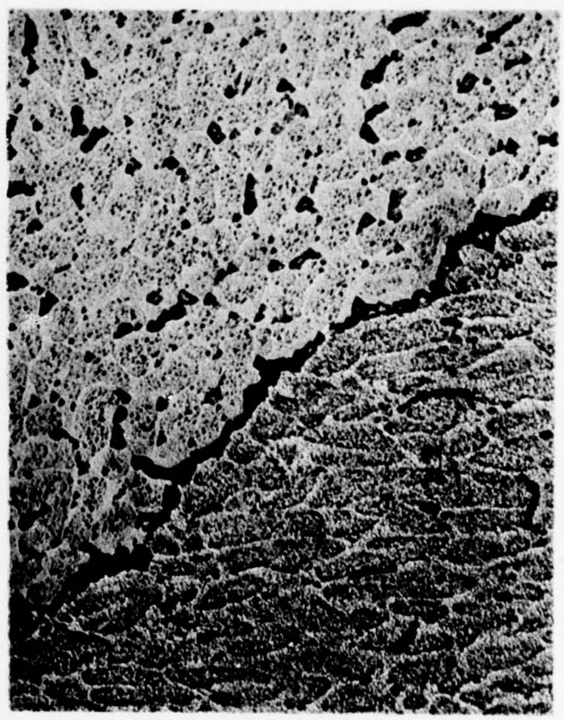
PHD-1421-4-77 NSWC/DL (DG-30)

FIGURE 20. MICROSTRUCTURE OF SQUEEZE CAST 7075 ALUMINUM ALLOY AFTER SOLUTION TREATING AND PRECIPITATION HARDENING.

Specimen SC-10BB solution treated at 870°F for 4 hours and precipitation hardened at 250°F for 24 hours.



a. 3X

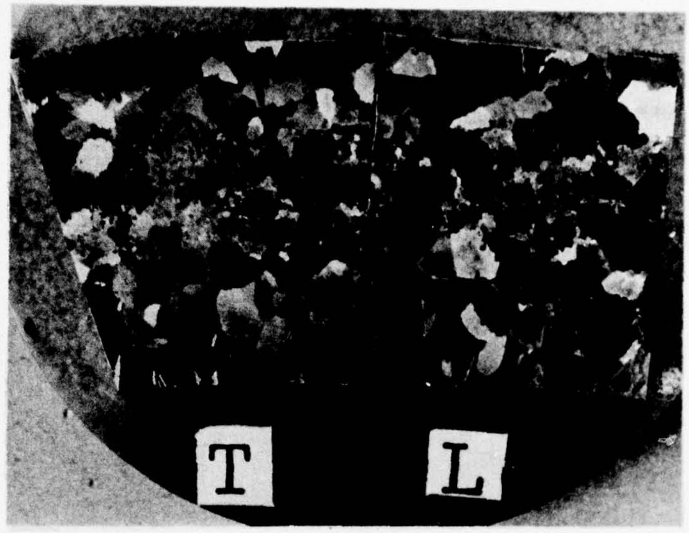


b. 75X c. 250X

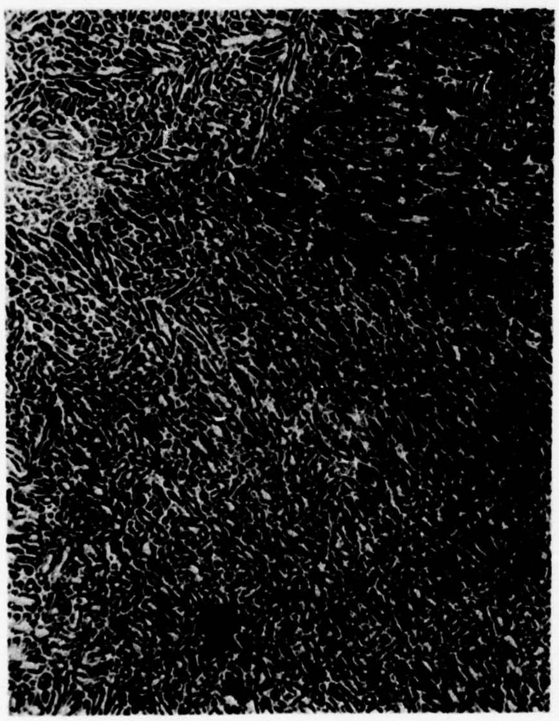
PHD-1422-4-77 NSWC/DL (DG-30)

FIGURE 21. MICROSTRUCTURE OF SQUEEZE CAST 7075 ALUMINUM ALLOY AFTER SOLUTION TREATING AND PRECIPITATION HARDENING.

Specimen SC-10CC solution treated at 870°F for 8 hours and precipitation hardened at 250°F for 24 hours.



a. 3X



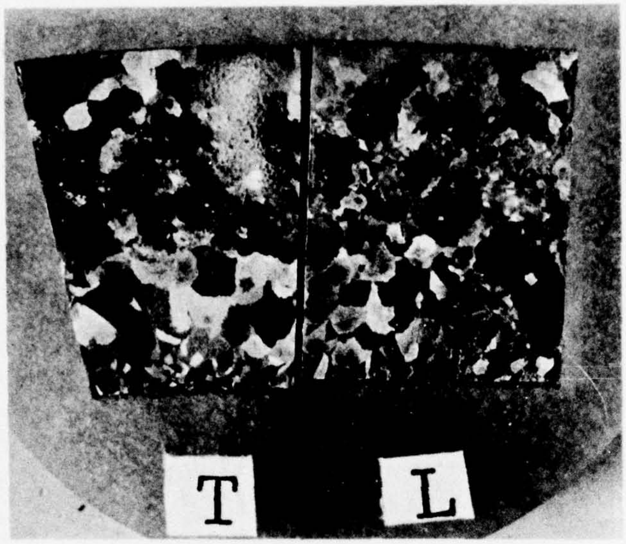
b. 75X

c. 250X

PHD-1423-4-77 NSWC/DL (DG-30)

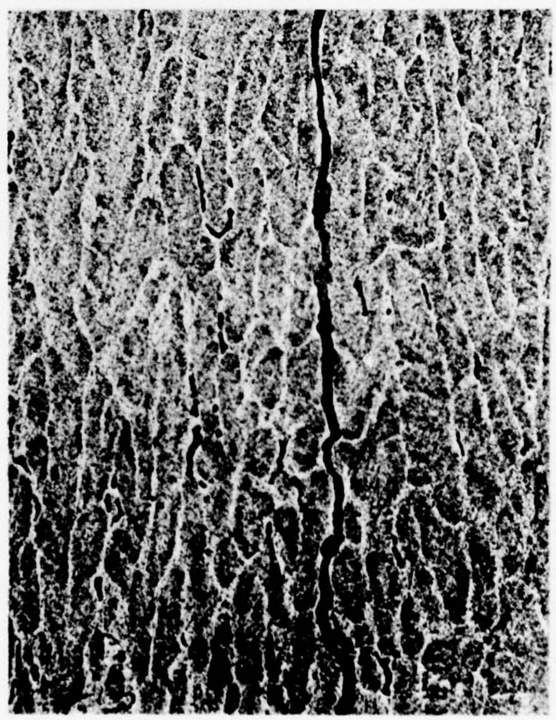
FIGURE 22. MICROSTRUCTURE OF SQUEEZE CAST 7075 ALUMINUM ALLOY AFTER SOLUTION TREATING AND PRECIPITATION HARDENING.

Specimen SC-9CC solution treated at 870°F for 16 hours and precipitation hardened at 250°F for 24 hours.



a. 3X

b. 75X



c. 250X

PHD-1424-4-77 NSWC/DL (DG-30)

FIGURE 23. MICROSTRUCTURE OF SQUEEZE CAST 7075 ALUMINUM ALLOY AFTER SOLUTION TREATING AND PRECIPITATION HARDENING.

Specimen SC-9BB solution treated at 905°F for 4 hours and precipitation hardened at 250°F for 24 hours.

(1) 870°F/4 hrs. + 250°F/24 hrs. (SC-10BB): Some prior cast structure was still evident. Grain boundary phases were present. Uneven etching behavior was noted. A surface contamination in the form of an equiaxed grainy layer was found on the inside edge of the longitudinal section.

(2) 870°F/8 hrs. + 250°F/24 hrs. (SC-10CC): Some retention of cast structure observed. Subgrain and grain structures did not etch uniformly. A zone of heavy precipitates was found at the inside edge of the transverse section; gross segregation was also noted.

(3) 870°F/16 hrs. + 250°F/24 hrs. (SC-9CC): Heavy coring or chemical segregation was noted. Some precipitates were found in structure. This structure was considerably different than the other precipitation hardened structures.

(4) 905°F/4 hrs. + 250°F/24 hrs. (SC-9BB): Cored structure observed. Inside and outside surfaces had equiaxed grain appearances suggesting contamination or unalloyed aluminum. Second phases were noted at grain boundaries and some fine precipitates were observed in transverse sections. Grains were somewhat coarser than SC-9CC.

Primarily because of its slightly higher hardness and its somewhat finer grain size, the solution treatment at 870°F for 16 hours followed by precipitation hardening at 250°F for 24 hours was selected as the heat treatment for developing maximum properties (T6 condition) in the squeeze cast cylinders. It was recognized that this was not the optimum heat treatment practice for the cast 7075 alloy but program restraints prevented further heat treatment optimization at the time.

MATERIALS CHARACTERIZATION

Following heat treatment to the "T6" condition, as indicated above, the two squeeze cast 7075 aluminum alloy cylinders were sectioned in nearly identical fashion to obtain the following specimens for materials characterization:

1 full-length longitudinal section for macrostructure evaluation and hardness profile

3 sidewall tensile specimens, longitudinal

2 base tensile specimens, transverse

3 notched bend bars for fracture toughness, longitudinal

2 chemical analysis samples

3 microstructure samples, longitudinal and transverse

Figure 24 presents the sampling scheme used to obtain these specimens. Slightly less than one-half of each cylinder was retained for historical reference.

Chemical Analysis

Samples noted in Figure 24B were analyzed by wet chemistry methods to determine the chemical composition of the squeeze castings. Results of these analyses, together with the composition requirements for wrought 7075 alloy, are presented in Table 5; the average composition for each casting barely meets the 7075 alloy requirements. The three primary alloying elements exhibited chemical segregation within the castings; all were found in larger quantities near the top of the castings. This chemical segregation was of sufficient magnitude that the zinc content near the top of the cylinders exceeds the wrought alloy specification while the magnesium and copper contents in the base of the castings are below specification. It is thought that these variations are related to the chemical composition of the 7075 alloy bar used for the melting stock, and to non-optimized melting and casting practices.

(a) Zinc - Although present at concentrations in general agreement with the specification, zinc would have a strong tendency to vaporize from the molten metal. Because of this evaporation, the upper portions of the melt would contain somewhat less zinc than the bottom of the melt. In the casting operation, the upper part of the melt becomes the base region of the cylinder. The variation of zinc content in the casting can be related to the melting operation.

(b) Magnesium - Magnesium tends to behave in much the same manner as just described for zinc. If the magnesium content of the starting alloy was at the low end of the composition limits, this evaporation could reduce the top of the melt to a level below specification. This would result in a below specification magnesium content in the base of the castings.

(c) Copper - Being the heaviest of the major elements in the alloy, copper would tend to concentrate in the bottom of the melt without adequate stirring. If the initial copper level was on the low end of the composition range, the observed variations in composition would occur. It should be noted that increased stirring of the melt to reduce

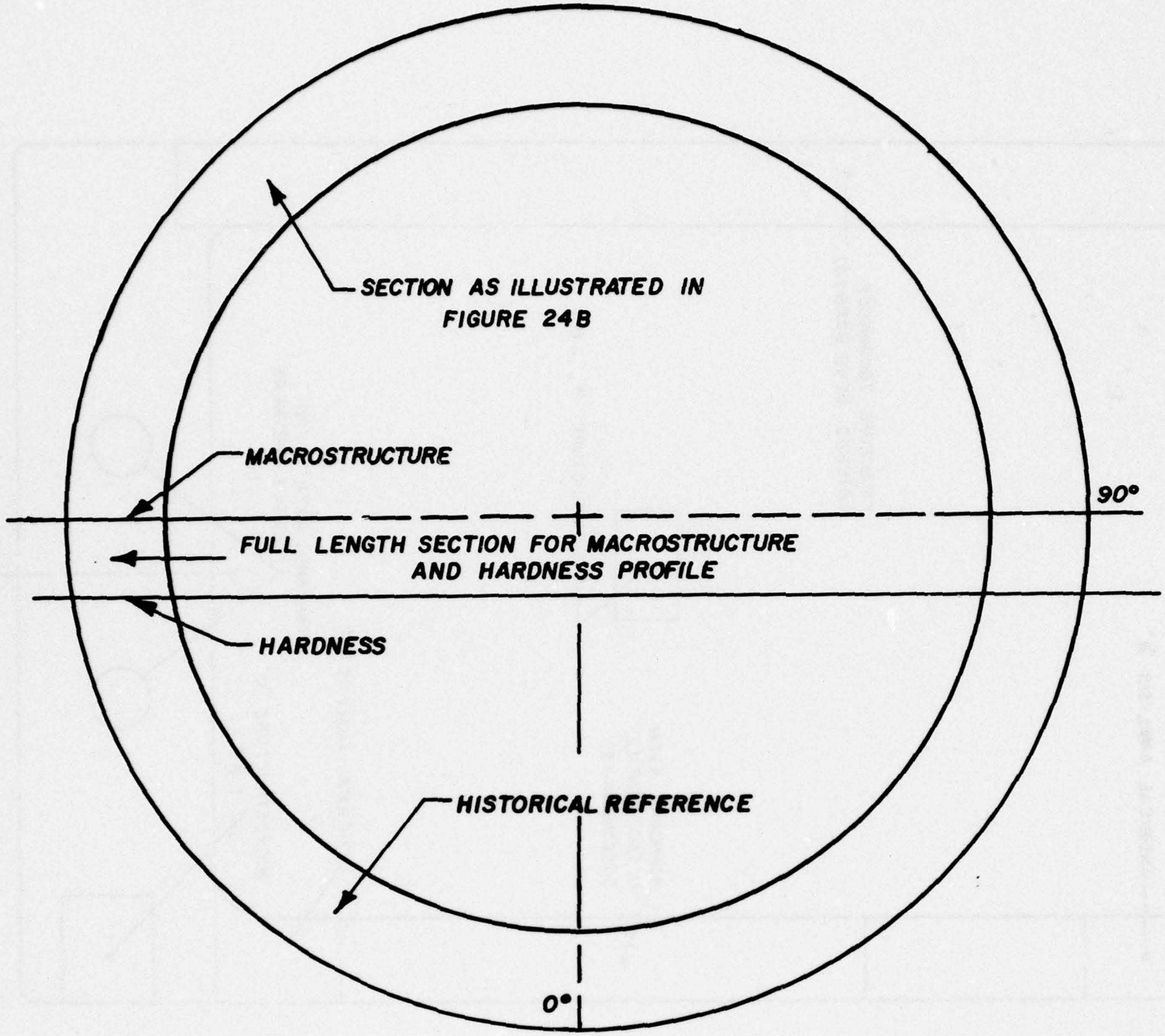


FIGURE 24A. INITIAL SAMPLING OF SQUEEZE CAST 7075-T6 ALUMINUM CYLINDERS SC-9 AND SC-10.
SEE FIGURE 24B FOR FURTHER SAMPLING.

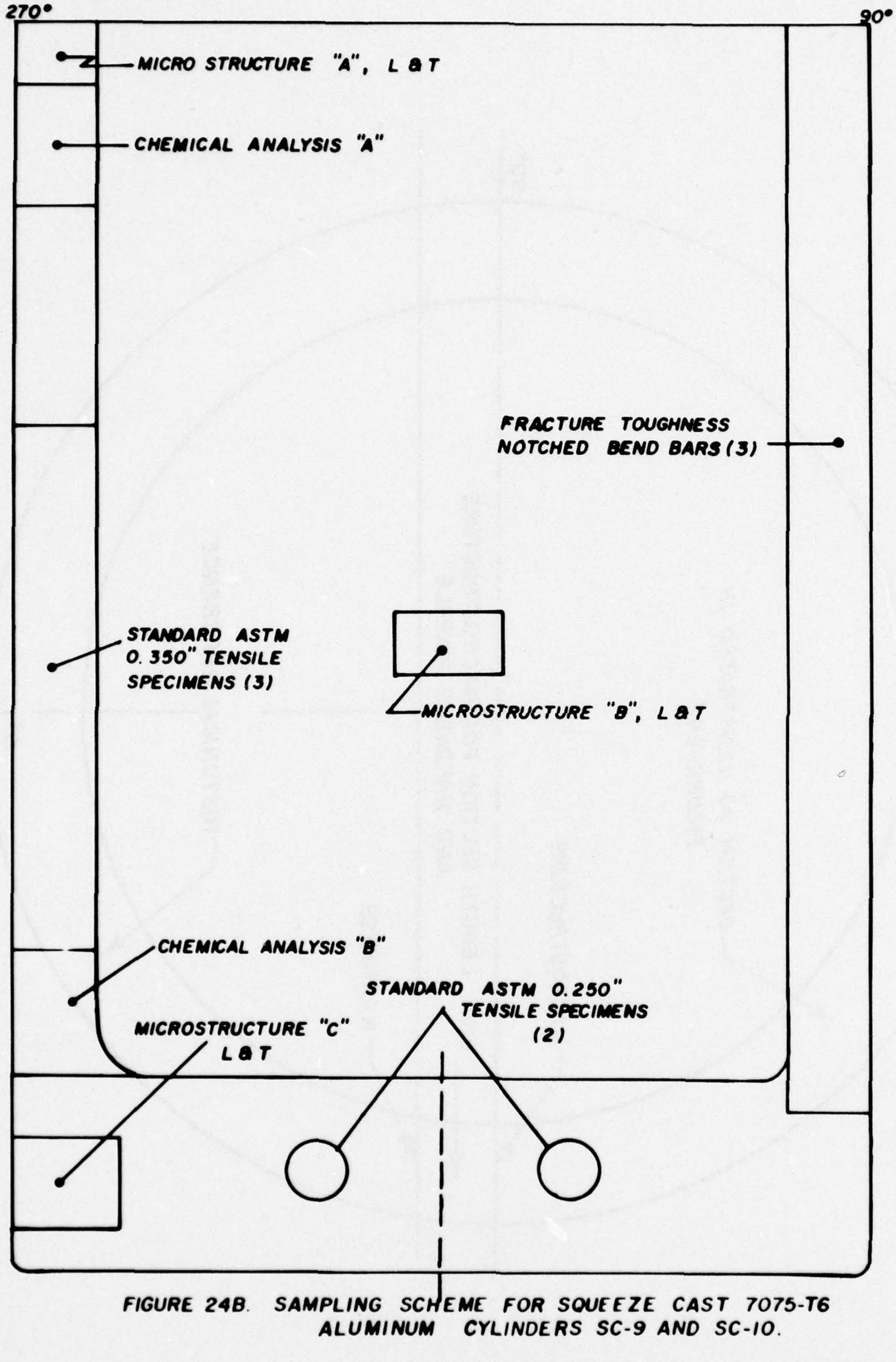


FIGURE 24B. SAMPLING SCHEME FOR SQUEEZE CAST 7075-T6 ALUMINUM CYLINDERS SC-9 AND SC-10.

TABLE 5. CHEMICAL COMPOSITION OF SQUEEZE CAST 7075-T6 ALUMINUM ALLOY CYLINDERS

	Chemical Composition in Percent by Weight[(a)]										
	AA	SC-9A		SC-9B		SC-9	SC-10A		SC-10B		SC-10
Element	7075[(b)]	1	2	1	2	Avg.	1	2	1	2	Avg.
Zinc	5.1-6.1	6.28	6.04	5.32	5.46	5.78	6.10	6.24	5.14	5.26	5.69
Magnesium	2.1-2.9	2.32	2.28	1.92	1.98	2.13	2.42	2.47	1.72	1.79	2.10
Copper	1.2-2.0	1.59	1.44	1.15	1.00	1.30	1.72	1.60	0.99	0.90	1.30
Chromium	0.18-0.35	0.21		0.20		0.21	0.19		0.22		0.21
Iron	0.50 max.	0.05		0.06		0.06	0.04		0.06		0.05
Silicon	0.40 max.	0.10		0.04		0.07	0.07		0.04		0.06
Manganese	0.30 max.	0.04		0.05		0.05	0.04		0.05		0.05
Titanium	0.20 max.	0.03		0.05		0.04	0.04		0.05		0.05

(a) Duplicate analysis performed for major elements. Location A is approximately 3 inches below lip of original casting; location B is at bottom of sidewall near sidewall-base intersection.

(b) Aluminum Association composition limits for wrought 7075 alloy (reference (7)).

this problem would tend to increase zinc and magnesium vaporization losses.

The low levels of magnesium and copper in the castings, combined with the chemical segregation, would have an adverse effect on precipitation-hardening reactions required to strengthen the 7075 alloy.

Additional study to optimize melting and casting practices, as well as optimize chemical composition, is necessary to overcome these problems.

Macrostructure Evaluation

The faces of the specimens illustrated in Figure 24A were machined flat and then etched with 2-HF: 9-HNO_3: 9-H_2O solution in order to show gross inhomogenities, porosity, cracks, and metal flow caused by the squeezing step of the casting process. Photographs of these etched sections are presented in Figures 25 and 26. Both casting sections contain excessive porosity in the base of the cylinder, a very large grain structure, sidewall porosity, and cracks. Some evidence of deformation during "squeezing" can be noted by the transition of the porosity from the base to the sidewall. Grain boundary cracking in the sidewalls of the castings can also be seen. In general, the casting quality is poor. Further process development for the 7075 alloy is required.

Hardness Profiles

Hardness data were obtained for each heat treated casting using the reverse side of the macrostructure specimens. Hardness measurements were made at 1/2-inch intervals along the centerline of the sidewalls and at several locations across the base. These data are presented in Figures 27 and 28. Average hardnesses for both sections are on the low end of the typical hardness range for wrought 7075-T6 alloy (R_B 85-95). The wide variations in hardness values and the lowness of the values is probably the result of the porosity, cracking, large grain size, and chemical composition variations previously noted. Porosity and cracking contribute to erratic hardness values; large grain structures are softer than fine grain structures for a given composition; zinc, copper, and magnesium are principal solutes in the precipitation hardening reactions and reduced levels of copper and magnesium would inhibit precipitate formation. Optimization of the fabrication processes and the alloy composition should increase the hardness levels of that of the wrought material and reduce the variability.

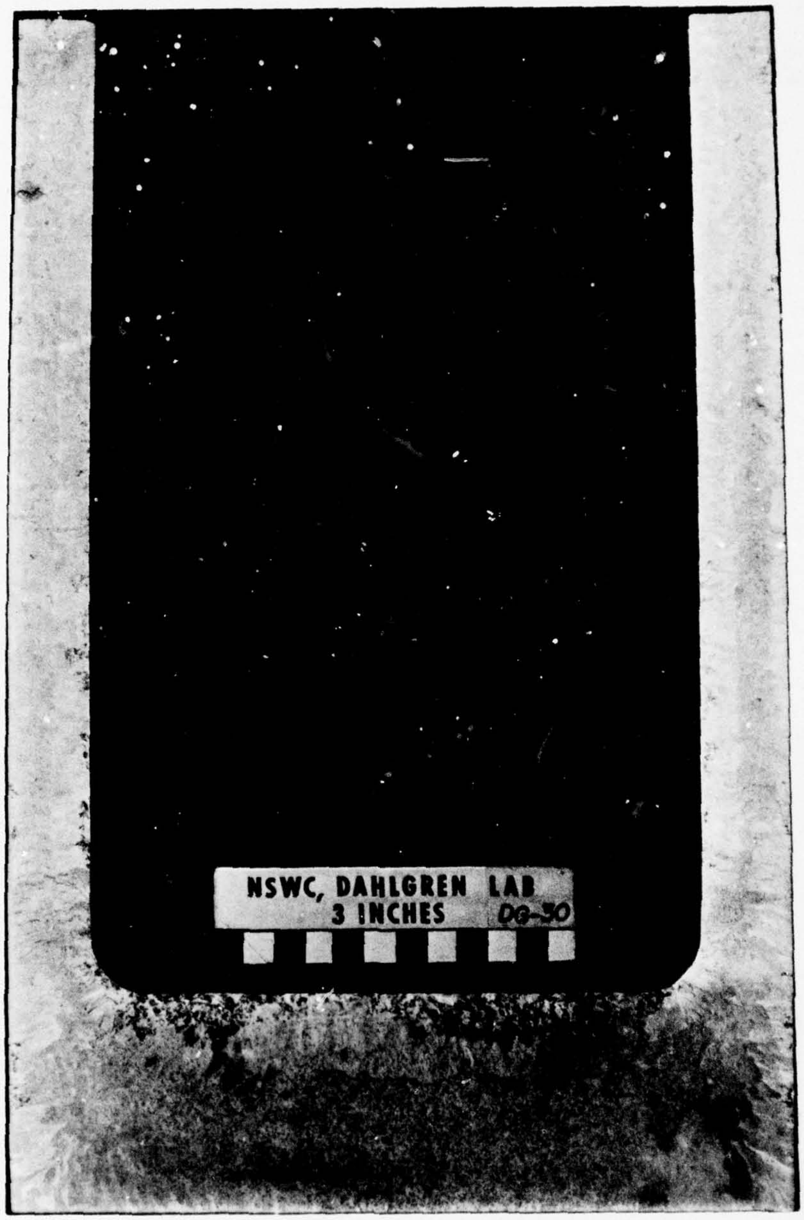


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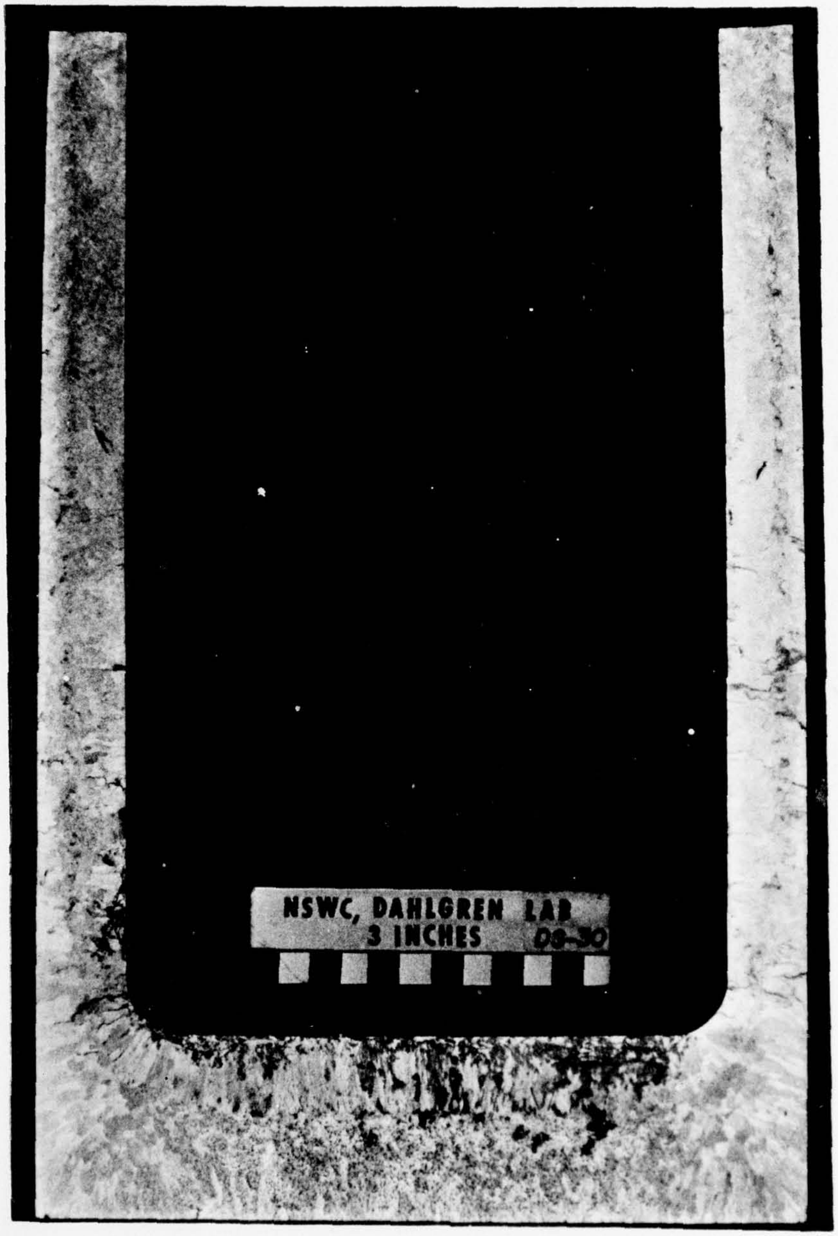
FIGURE 25. MACROSTRUCTURE OF LONGITUDINAL SECTION FROM SQUEEZE CAST 7075-T6 ALUMINUM ALLOY CASTING SC-9.



PHD-1426-4-77 NSWC/DL (DG-30)

FIGURE 26. MACROSTRUCTURE OF LONGITUDINAL SECTION FROM SQUEEZE CAST 7075-T6 ALUMINUM ALLOY CASTING SC-10.

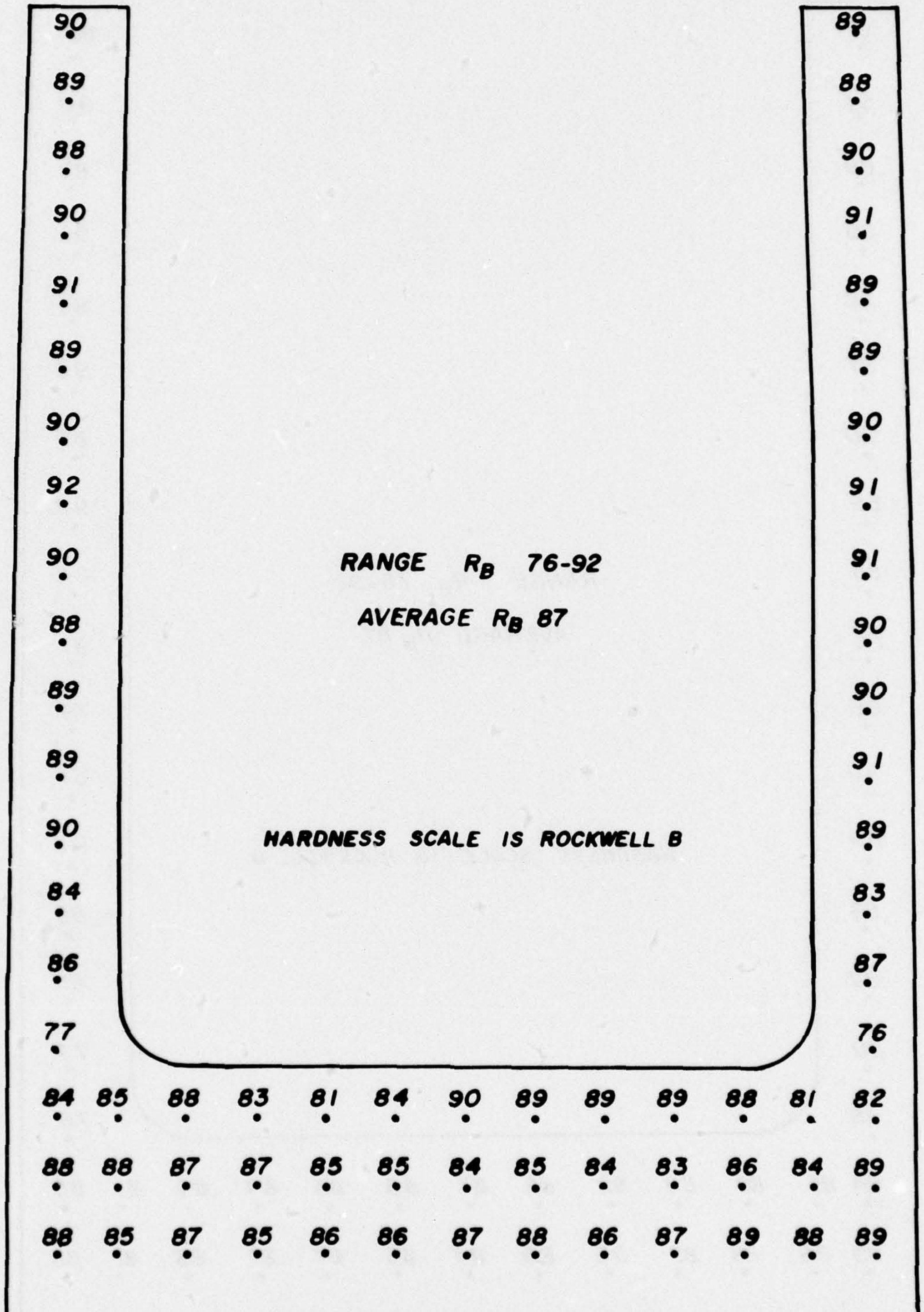


FIGURE 27. HARDNESS PROFILE FOR LONGITUDINAL SECTION FROM SQUEEZE CAST 7075-T6 ALUMINUM CYLINDER SC-9.

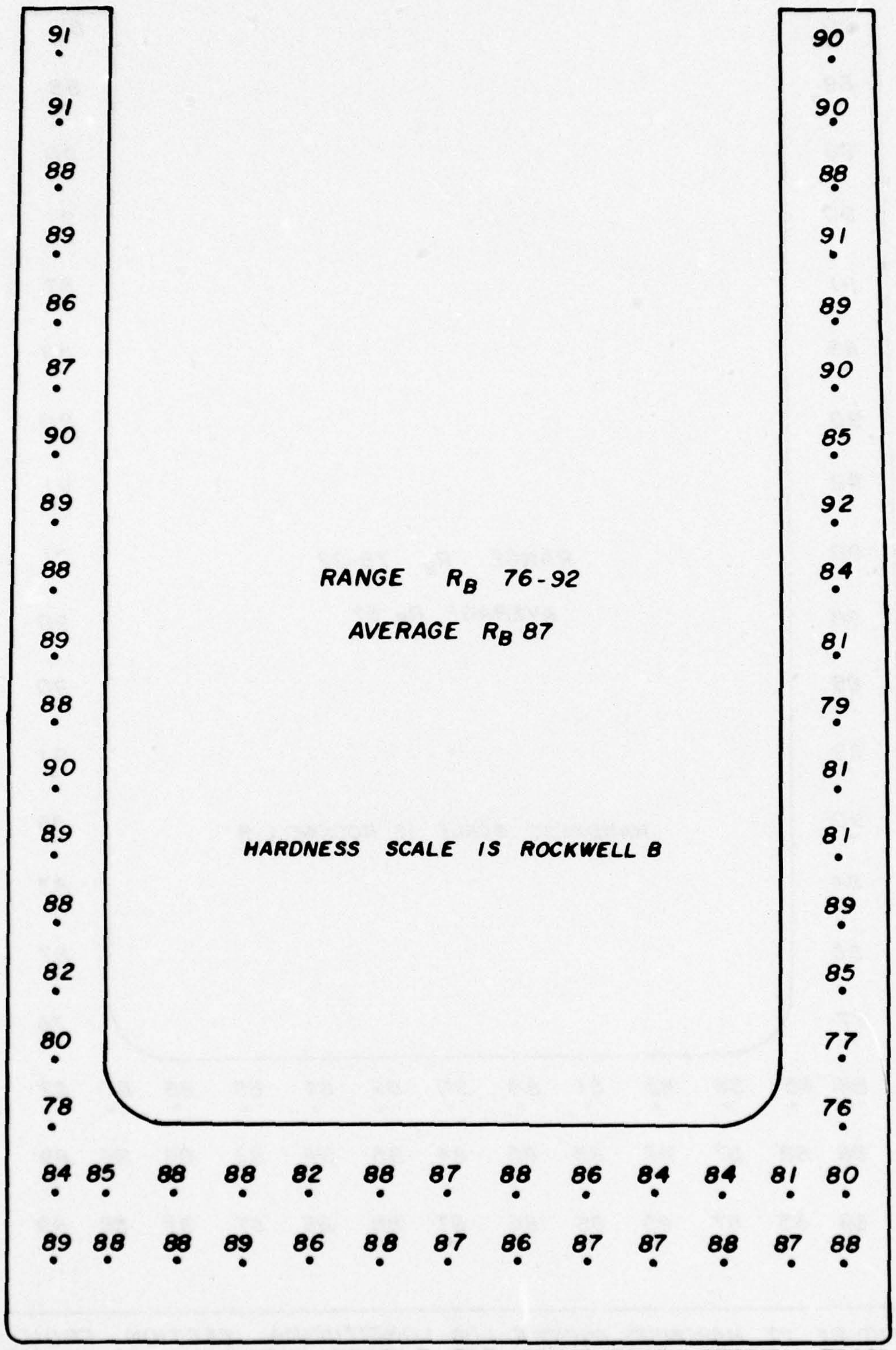


FIGURE 28. HARDNESS PROFILE FOR LONGITUDINAL SECTION FROM SQUEEZE CAST 7075-T6 ALUMINUM CYLINDER SC-10.

Tensile Properties

Specimens for tensile testing were taken from the sidewalls and base of each cylinder as in Figure 24B. Standard ASTM test specimens were machined as indicated in Table 6 and tested at room temperature. Tests were performed on a 10,000 lb. capacity Instron mechanical testing machine at crosshead separation speed of 0.05 inches per minute. The results of these tests are summarized in Table 6; typical and guaranteed properties for wrought 7075-T6 products are included for comparison.

All of the specimens failed prior to achieving the standard 0.2% offset yield point and without any measurable elongation or reduction of area. Yield strength data for the 0.1% offset point were obtained for 3 of the 4 base tensile specimens; the strength data for these specimens approached that for wrought 7075-T6 alloy. All of the fractured surfaces showed a coarse grain structure and some contained casting defects; both of these conditions act to reduce strength and ductility. Melting and casting practice optimization is required to reduce the grain size and eliminate the casting defects. Further development of heat treatment procedures will also be required to increase mechanical properties to the levels of the wrought 7075-T6 alloy.

Modulus of elasticity data were calculated from the tensile curves. The average modulus of elasticity for 10 tests was 10.15×10^6 psi; individual tests ranged from 9.56 to 10.71×10^6 psi. The average modulus is in good agreement with the 10.3×10^6 psi value reported in the Structural Alloys Handbook (Reference (12)) for wrought 7075-T6 alloy. The spread in the individual test data is slightly larger than would be expected for wrought materials and was probably influenced by the large grain size and the casting defects.

Fracture Toughness

Fracture toughness of the squeeze cast 7075-T6 alloys was measured at room temperature using the NSWC/DL fatigue precracked notched bend bar specimen; specimen locations are shown in Figure 24B. Following fatigue precracking to create a sharp crack site, the specimens were tested in three-point bending (bend span = 4.00 inches). The results of these tests are presented in Table 7. These data are in general agreement with fracture toughness data tabulated for wrought 7075-T6 alloy forgings, bars, and extrusions (Reference (13)). The scatter in the data for the cast materials is thought to be related to nonuniform fatigue precracking, large grain size, and inconsistent orientation of the major notch in the bend bars (due to an error in machining, both thru-wall and circumferential fracture were possible).

TABLE 6. ROOM TEMPERATURE TENSILE PROPERTIES OF SQUEEZE CAST 7075-T6 ALUMINUM ALLOY

Casting Identification	Specimen Location	ASTM Specimen Size (a)	Gage Length	0.1% Offset Yield Strength	Breaking Strength	Comment (c)
SC-9	Sidewall	0.357"	1.4"	(b)	57,100 psi	
	Sidewall	0.357"	1.4"	(b)	43,500	Broke outside gage.
	Sidewall	0.357"	1.4"	(b)	51,300	
				Average	50,600	
SC-9	Base	0.250	1.0	65,100	65,800	
	Base	0.250	1.0	65,800	67,800	Broke outside gage.
			Average	65,450	66,800	
SC-10	Sidewall	0.250	1.0	(b)	50,100	
	Sidewall	0.250	1.0	(b)	48,000	Broke outside gage.
	Sidewall	0.250	1.0	(b)	65,200	
				Average	54,400	
SC-10	Base	0.250	1.0	66,000	67,300	
	Base	0.250	1.0	(b)	46,600	Broke on gage.
				Average	56,950	

(Cont.)

TABLE 6. (Cont.)

Wrought Properties	0.2% Offset Yield Strength	Ultimate Strength	Elongation
Aluminum Association Typical Properties - All forms	73,000 psi	83,000 psi	11%
Aluminum Association Guaranteed Properties 0.5-1.0" Plate (Min.)	68,000	78,000	7
Vendor Properties for 8.25 inch dia. bar	55,000	65,000	7
Reynolds Specified Properties Extruded Tube (min.)	72,000	80,000	7

(a) Specimens prepared in accordance with ASTM Standard E8.
(b) Specimens broke before reaching 0.1% offset yield stress.
(c) No measureable elongation or reduction of area for all tests.

TABLE 7. FRACTURE TOUGHNESS EVALUATION OF SQUEEZE CAST 7075-T6 ALUMINUM ALLOY (a)

Specimen Identi-fication	Specimen Dimensions (in.)		Max. Load P_{max} (lbs)	ASTM P_Q(b) (lbs)	K_Q Apparent Fracture Toughness (kpsi x in$^{1/2}$)	ASTM Validity Check (c)		K_{IC} Fracture Toughness (kpsi x in.$^{1/2}$)
	Depth(D)	Width(B)				B, D	P_{max}/P_Q	
SC-9-1	0.502	0.501	860	860	25.0	0.61	1.0	Invalid
SC-9-2	0.500	0.501	580	560	19.7	0.38	1.04	19.7
SC-9-3	0.501	0.501	575	530	15.9	0.25	1.08	15.9
SC-10-1	0.501	0.502	650	650	22.6	0.43	1.0	22.6
SC-10-2	0.502	0.502	610	610	20.5	0.36	1.0	20.5
SC-10-3	0.502	0.503	680	580	21.0	0.52	1.17	Invalid

(a) Three-point slow bend test of notched specimens; bend span = 4.00 in.
(b) Maximum load determined for 95% secant method per ASTM Standard E-399.
(c) ASTM apparent fracture toughness validity check per ASTM Standard E-399. For valid tests,
(1) B and D $\geq 2.5 (K_Q/\sigma_{ys})^2$ where σ_{ys} assumed as 50,600 psi for SC-9 specimens and 54,400 psi for SC-10 specimens and
(2) $1.0 \leq P_{max}/P_Q \leq 1.10$

Figures 29 and 30 show the fracture appearance of the broken bend bar specimens. It can be seen that only specimen SC-10-1 had a uniform fatigue precrack and that, contrary to pretest inspection, specimen SC-9-1 had no fatigue precrack.

Microstructure

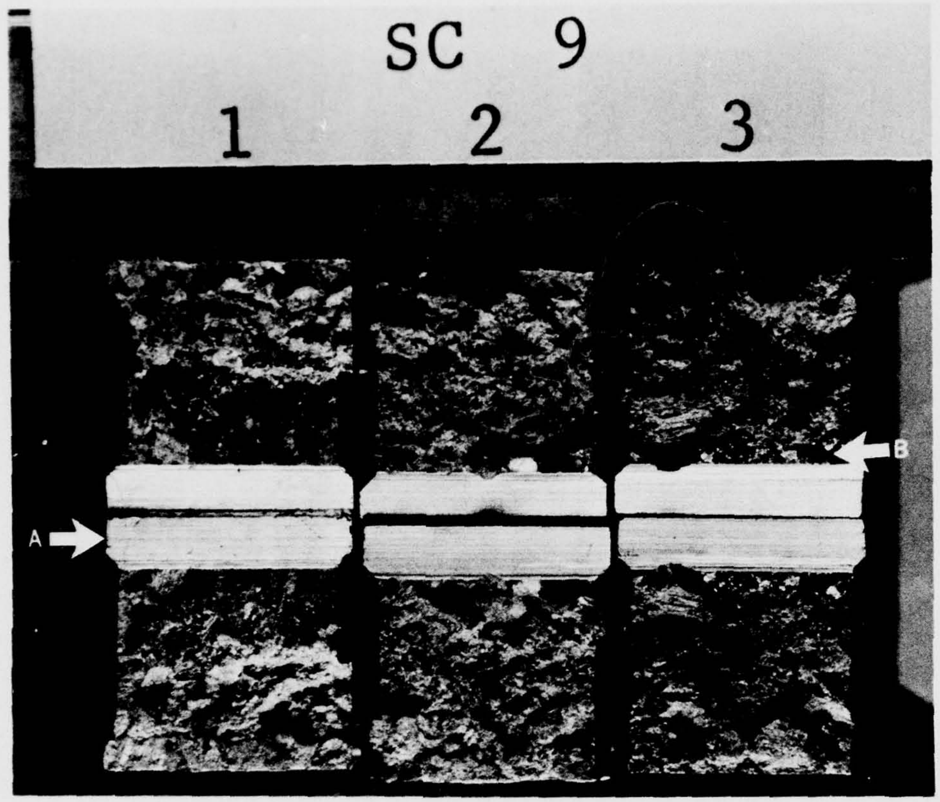
Samples for evaluation of the heat treated squeeze cast cylinders were obtained from each cylinder as shown in Figure 24B; both longitudinal and transverse specimens were metallographically prepared for each location. Figures 31 and 33 show the overall microstructure for each of the sections evaluated. The large grain size of these materials and the mixed microstructures are readily apparent.

In addition to the large grain size, this investigation also revealed the formation of subgrains, the remains of the cored structure due to chemical segregation during solidification, both general and boundary precipitates, and a copper colored deposit at some of the grain and subgrain boundaries. The inside surface of cylinder SC-9 had a distinctive fine-grained layer which was believed to be oxide contamination. An indication of metal flow in the base during the "squeezing" operation was found in cylinder SC-10. These microstructure details are illustrated in Figures 32 and 34.

The large grain size, chemical segregation, and mixed microstructures all contribute to the reduced mechanical properties previously noted. Additional alloy composition and process optimization are required to eliminate these undesirable occurences.

CONCLUSIONS

In general, the mechanical properties developed in the squeeze cast 7075 alloy by heat treatment to the T6 condition were lower than comparable properties for the wrought alloy. However, the tensile properties developed in the closed base of the squeeze cast cylinders and the sidewall fracture toughness data did approach reported properties for wrought 7075-T6 material. Chemical segregation during melting and casting, excessive grain size, low casting soundness, and incomplete heat treatment response are thought to be the causes for the reduced mechanical properties.



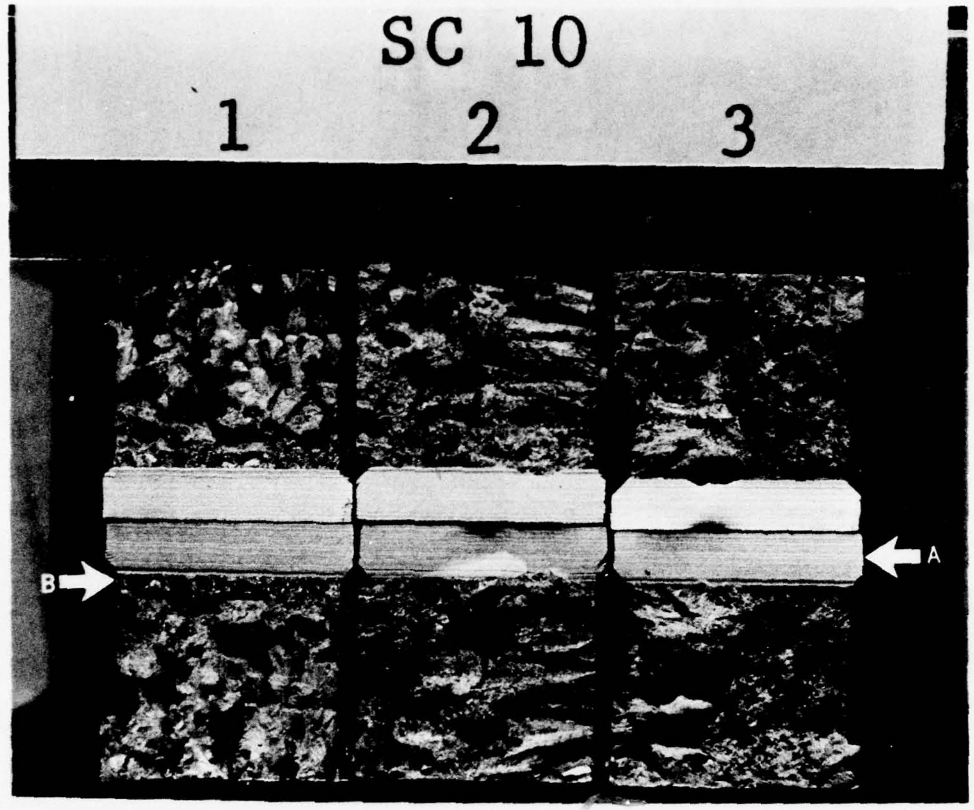
PHD-1427-4-77

NSWC/DL (DG-30)

FIGURE 29. FRACTURE APPEARANCE OF NOTCHED BEND BARS FROM SQUEEZE CAST 7075-T6 ALUMINUM CYLINDER SC- 9.

a - major machined notch

b - fatigue precrack



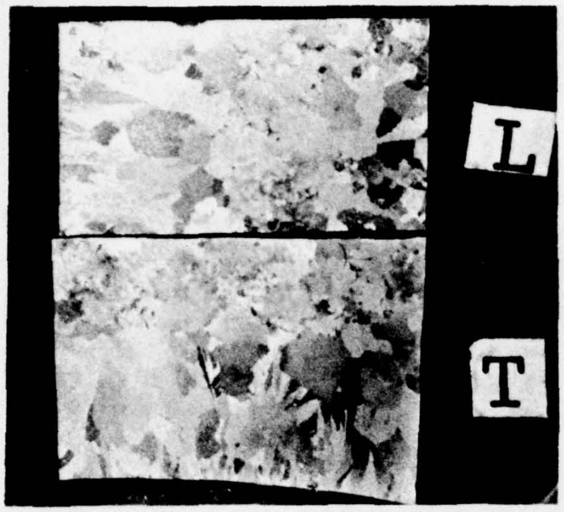
PHD-1428-4-77

NSWC/DL (DG-30)

FIGURE 30. FRACTURE APPEARANCE OF NOTCHED BEND BARS FROM SQUEEZE CAST 7075-T6 ALUMINUM CYLINDER SC-10.

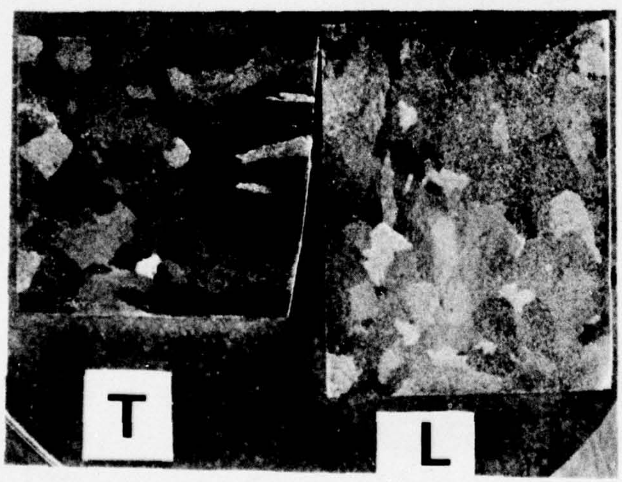
a - major machined notch

b - fatigue precrack



SC-9A Upper Sidewall

SC-9B Sidewall Mid-Length

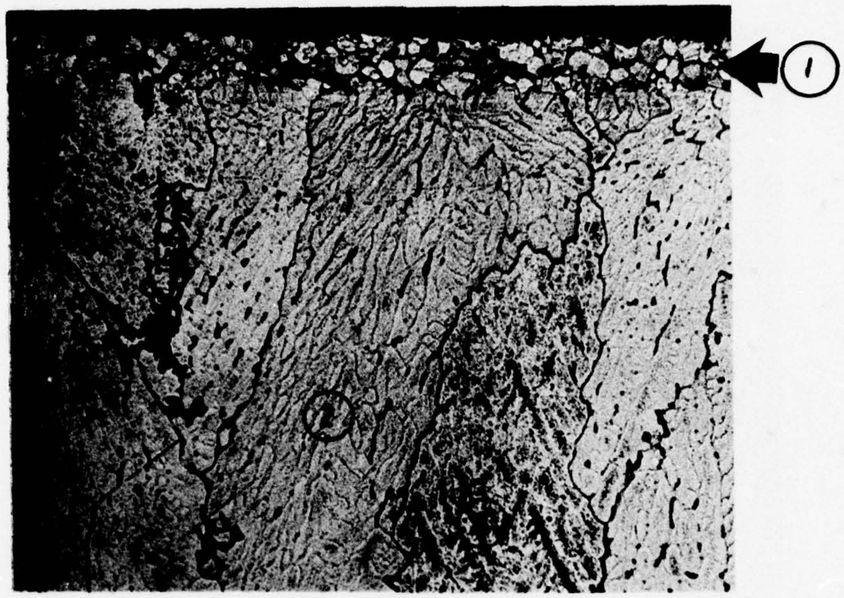


SC-9C Base

PHD-1429-4-77 NSWC/DL (DG-30)

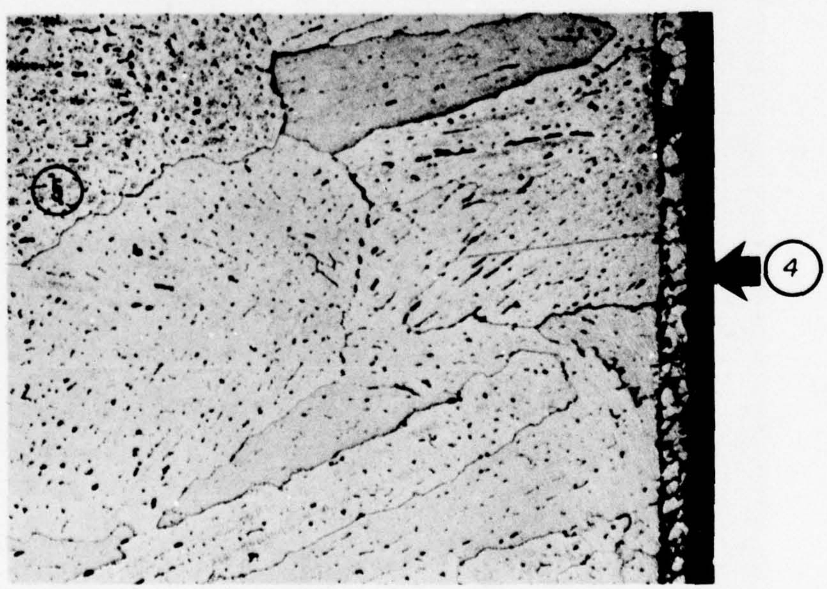
FIGURE 31. GENERAL STRUCTURE OF SQUEEZE CAST 7075-T6 ALUMINUM CYLINDER SC-9.

Approx. 3X



a. Transverse 100X

ID Surface Layer (1), Substructure (2), and Coring (3).

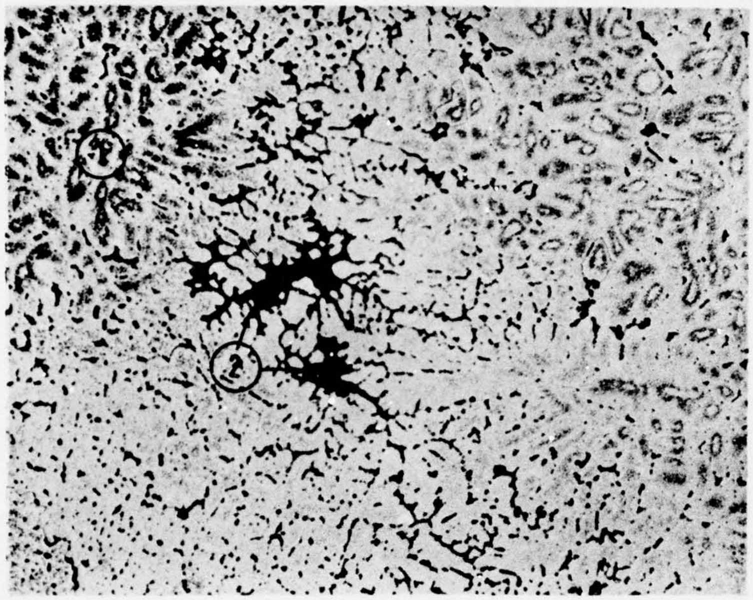


b. Longitudinal 100X

ID Surface Layer (4) and Coring (5)

PHD-1430-4-77 NSWC/DL (DG-30)

FIGURE 32. REPRESENTATIVE MICROSTRUCTURAL FEATURES OF SQUEEZE CAST 7075-T6 ALUMINUM CYLINDER SC-9.



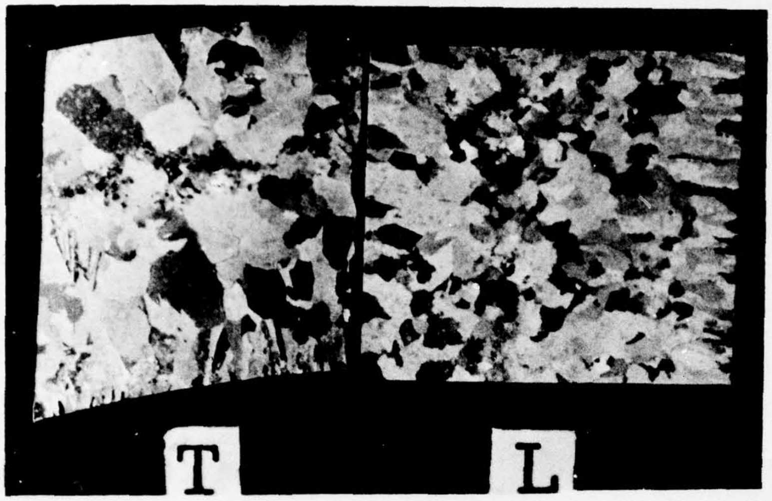
c. 100X

Coring (1) and Copper Colored Deposit (2)

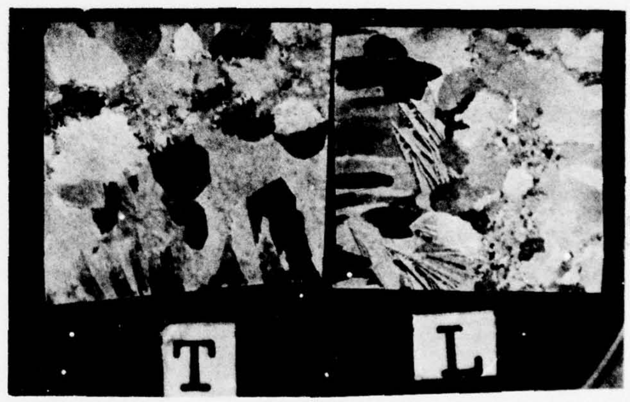
d. General and Boundary Precipitation 400X

PHD-1431-4-77 NSWC/DL (DG-30)

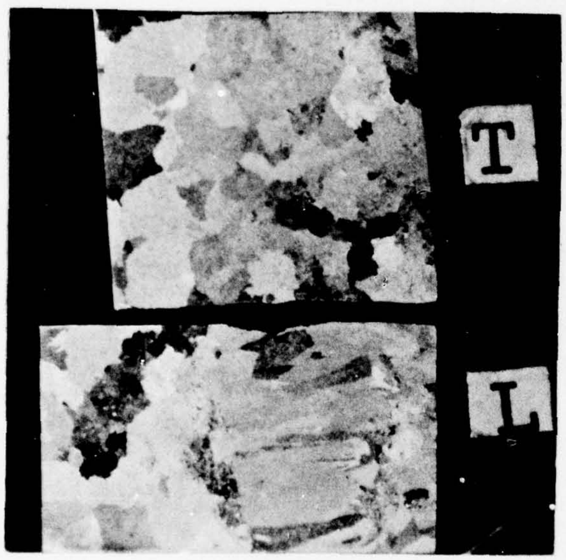
FIGURE 32. (CONTINUED). REPRESENTATIVE MICROSTRUCTURAL FEATURES OF SQUEEZE CAST 7075-T6 ALUMINUM CYLINDER SC-9.



SC-10A Upper Sidewall



SC-10B Sidewall Mid-Length

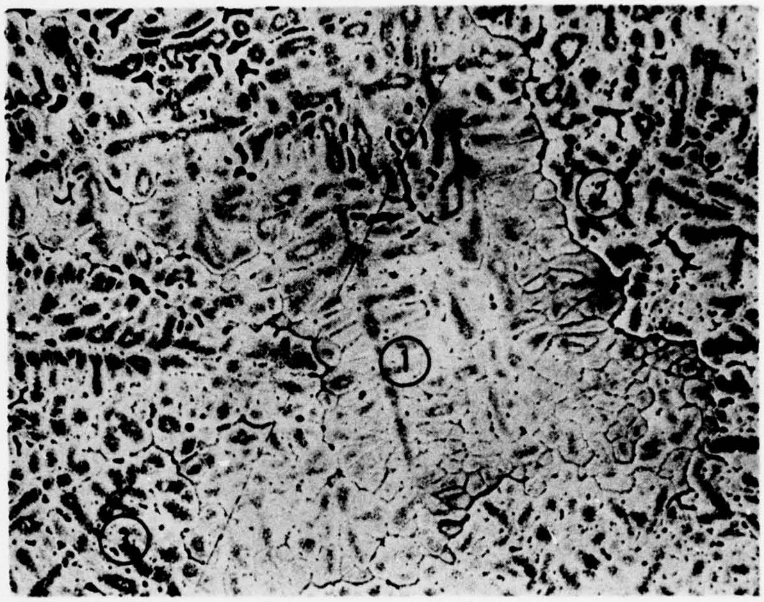


SC-10C Base

PHD-1432-4-77 NSWC/DL (DG-30)

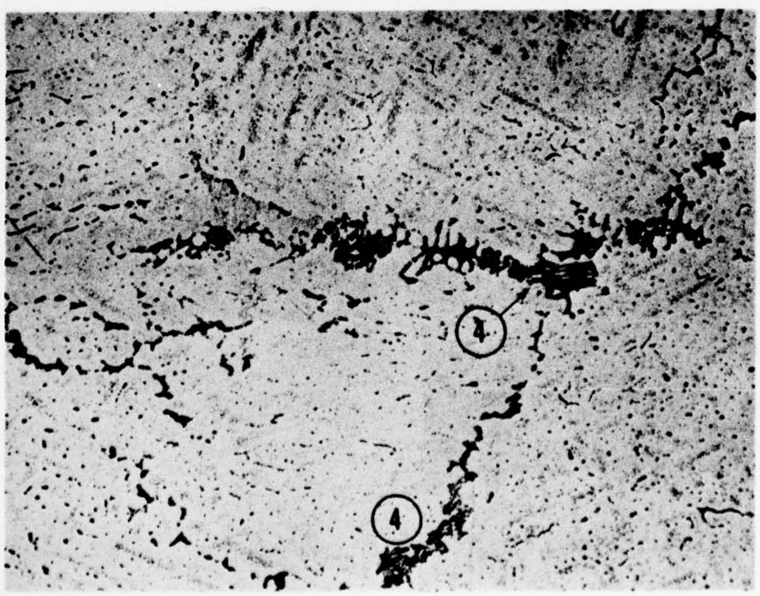
FIGURE 33. GENERAL STRUCTURE OF SQUEEZE CAST 7075-T6 ALUMINUM CYLINDER SC-10.

Approx. 3X



a. 100X

Substructure (1), Coring (2), and Residual Cast Structure (3).

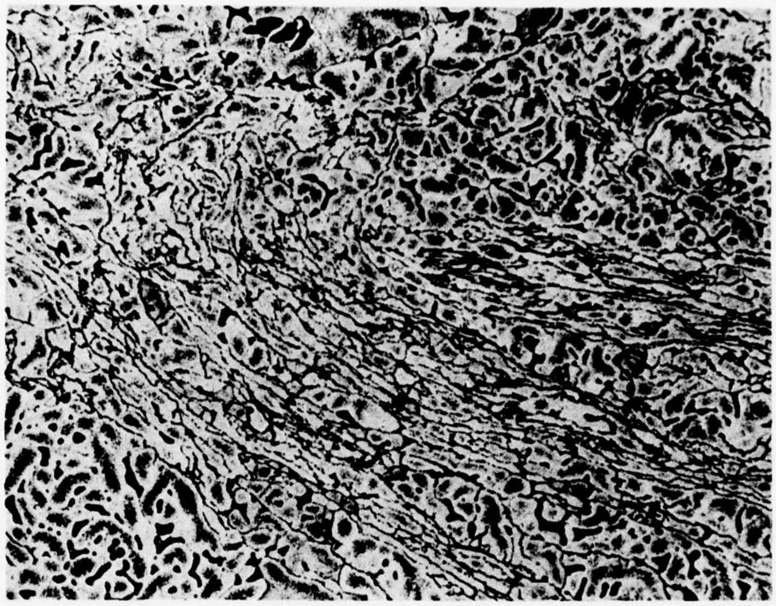


b. 100X

Copper Colored Deposit at Boundaries (4)

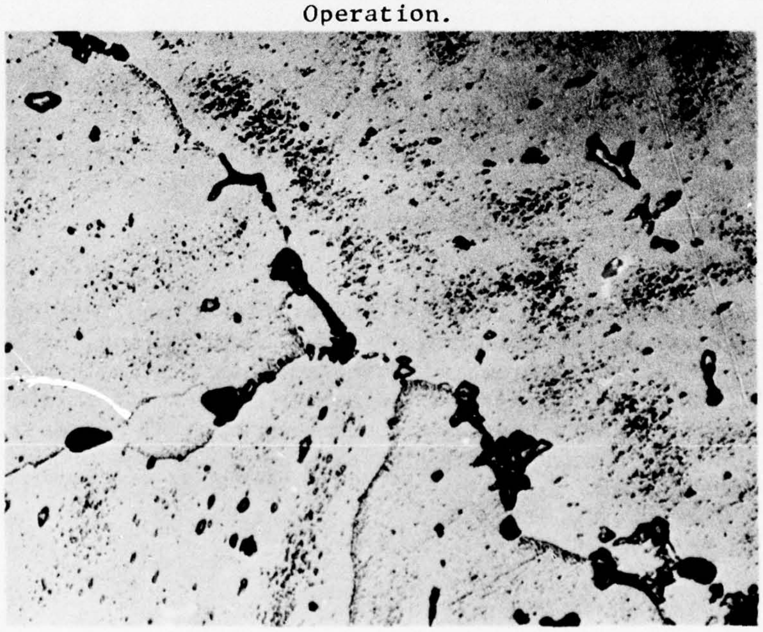
PHD-1433-4-77 NSWC/DL (DG-30)

FIGURE 34. REPRESENTATIVE MICROSTRUCTURAL FEATURES OF SQUEEZE CAST 7075-T6 ALUMINUM CYLINDER SC-10.



c. 100X

Metal Flow in Base Section From "Squeezing" Operation.



d. 400X

General and Boundary Precipitation

PHD-1434-4-77 NSWC/DL (DG-30)

FIGURE 34 (CONTINUED). REPRESENTATIVE MICROSTRUCTURAL FEATURES OF SQUEEZE CAST 7075-T6 ALUMINUM CYLINDER SC-10.

Reduction of chemical segregation during melting and casting might result from increased mixing during melting, decreasing the melting time and temperature, decreasing the casting temperature, reducing the time between casting and squeezing, and perhaps by modification of the alloy composition. The development of a fine grain structure (normally required for increased strength) could be achieved by reducing the melting and casting temperatures, by decreasing the solidification time prior to pressure application, by increasing the solidification rate, or through the addition of grain-refining elements such as titanium, boron, or zirconium to the molten metal. Increased casting soundness will require closer control of casting temperature, reduced turbulence during pouring, improved casting and tooling design, and optimization of the "squeezing" conditions. If these above factors can be adequately controlled to eliminate the described problems, optimization of the heat treatment to develop the T6 properties should only require a definition of solution treatment temperature and time combinations necessary to convert the cast microstructure into an equiaxed, supersaturated, single phase microstructure suitable for precipitation hardening.

RECOMMENDATIONS

Based upon the results obtained in this study and the identification of approaches to overcome the observed shortcomings, it is recommended that efforts to optimize the squeeze casting process for attainment of the study objectives be continued. It is further recommended that recently developed processes such as rheocasting be considered and that future efforts in this area include production oriented organizations.

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APPENDIX A

IIT RESEARCH INSTITUTE REPORT IITRI-B6140-1

on

SQUEEZE CASTING OF TWO LARGE 7075 ALUMINUM ALLOY SAMPLES

Contract N60921-76-M-E701

Report No. IITRI-B6140-1

SQUEEZE CASTING OF TWO LARGE 7075 ALUMINUM ALLOY SAMPLES

Naval Surface Weapons Center
Dahlgren Laboratory
Dahlgren, Virginia 22448

Attention: Dr. John Thompson

Prepared by

N. C. Birla and K. M. Kulkarni

IIT Research Institute
10 West 35 Street
Chicago, Illinois 60616

28 July 1976

Final Report for Period
15 June to 28 July 1976

FOREWORD

This final report describes the work conducted by the Metalworking Group of IITRI's Metals Research Division for Dahlgren Laboratory to squeeze cast two large 7075 aluminum alloy samples. This work was performed under contract No. N60921-76-ME701 over the period of 15 June to 28 July 1976. This report has been designated at IITRI as IITRI-B6140-1.

Dr. K. M. Kulkarni, Manager of Metalworking, had the overall responsibility for the project and Dr. N. C. Birla, Research Metallurgist, was the Project Engineer. Significant contributions were also made by Mr. J. Dorcic, Technical Assistant; Mr. S. Rajagopal, Assistant Metallurgist; and Mr. A. Hudson and Mr. A. Means, Technicians.

N C Birla

N. C. Birla
Research Metallurgist

Roy E. Beal

Roy E. Beal
Assistant Director
Metals Research

ABSTRACT

SQUEEZE CASTING OF TWO LARGE 7075 ALUMINUM ALLOY SAMPLES

Two 7075 aluminum alloy samples of cylindrical shape were produced utilizing the squeeze casting process actively being developed at IITRI. The castings had nominal dimensions of 6.6 in. diameter x 12 1/2 in. length x 3/4 in. wall thickness, and were made using IITRI's technology and existing tooling. A limited range of processing parameters was encompassed in the experimental work. These parameters include casting temperature, forging load, duration of load, and molten metal weight. On the basis of visual inspection, the castings have clearly established the potential for squeeze casting large 7075 aluminum alloy components.

The squeeze casting process offers a great potential for producing near-net or net components having a high degree of integrity and structure and optimum mechanical properties. It is anticipated that the extensive evaluation by NSWC/DL will confirm these advantages. It is recommended that after such evaluation squeeze casting of even larger 7075 castings of specific interest to the Navy be undertaken.

SQUEEZE CASTING OF TWO LARGE 7075 ALUMINUM ALLOY SAMPLES

1. INTRODUCTION

Many large projectiles and similar ordnance components utilized by the Navy are produced from high-strength aluminum alloys such as 7075. Because of the difficulty of processing such materials by conventional techniques, only oversize forgings can be obtained and these then require extensive finish machining. This sequence results in high end-item cost. The objective of this program was to investigate, on a preliminary basis, the feasibility of producing such ordnance components by the squeeze casting process developed by IITRI.

Basically, the squeeze casting process comprises metering of molten work material into the dies, allowing the melt to solidify partially, closing the dies, and applying the pressure and maintaining it until the solidification is complete. IITRI's work has well established the process for a large variety of ferrous and nonferrous materials. However, prior to using it for large ordnance components, it was necessary to investigate if the process would be suitable for large castings from 7075 alloy which is normally used in the wrought condition. This program was aimed at such preliminary feasibility study using IITRI's technology and existing dies suitable for making a 6 in. diameter cylindrical shape with one closed end.

During the course of this work, the existing IITRI dies were installed in the 1000-ton hydraulic press. Approximately 22 lb of wrought 7075 aluminum alloy (4 in. diameter bar) was melted in an induction furnace and used to produce squeeze castings. The squeeze casting was approximately 12 1/2 in. long, with 6.6 in. outside diameter and a wall thickness of approximately 3/4 in.

Two squeeze castings were produced after optimization of processing parameters like temperature of melt, load and time of its application, and die temperature. While thorough examination of mechnical properties is planned by NSWC/DL, the visual examination indicates that this process has an excellent potential for producing large parts from this alloy.

2. EXPERIMENTAL WORK

2.1 Die Design

Figure 1 is a schematic illustration of the die assembly which is suitable for the closed-end squeeze cast cylinders. The lower die consisted simply of a 1020 carbon steel tube to which two retaining collars were welded. The bottom collar was used to position the die on the bolster plate of the press and form the bottom face of the casting, and the upper collar was used to hold down the cover plate. The cover plate was produced from 1045 steel. The upper die or punch consisted of a 1020 hot rolled round, machined down to appropriate dimensions and welded to a 1020 plate which in turn was bolted to the upper bolster of the press. An ejection pin was contained in the lower die, and its position is shown in Figure 1. A half-degree draft was employed on the punch and the die to insure ease of stripping of the casting. The die and punch were heated by gas-fired radiant burners to temperatures ranging from 500 to 650°F.

2.2 Work Material Melting and Melt Transfer

Since 7075* aluminum is not a casting alloy, it was not available as melt stock. Instead it was bought in 4 in. diameter wrought form (7075-T651). For each squeeze casting, 22-23 lb of 7075 alloy bar was melted in a clay graphite crucible, installed in a high-frequency induction furnace. Melt time ranged from 20-30 min, and the melt was superheated to 1300-1700°F. Power was turned off, then molten metal was brought to the press and poured into the preheated die through a

---

*The nominal composition of 7075 alloy by weight percent is 1.6 Cu, 2.5 Mg, 0.30 Cr, 5.6 Zn, and balance Al.

pouring spout. Temperature of molten metal was monitored in the die before lowering the punch into the die.

2.3 Squeeze Casting Procedure

All squeeze casting experiments were performed with the die mounted in the IITRI 1000-ton hydraulic press shown in Fig. 2. This press was used because it had available the press daylight (42 in.) and ram travel (24 in.) required to produce the long (approximately 12 in.) cylinder.

The typical sequence of events in squeeze casting or liquid metal forging is to admit the molten metal into the lower die cavity where it forms a pool. The preheated punch or upper die is then lowered into the preheated female die cavity as schematically illustrated in Fig. 1. It can be seen that the punch displaces the molten or solidifying metal into the die cavity to give the desired casting shape. Controlled pressure is applied for a predetermined time during and after solidification. After this time interval the upper die is retracted and the squeeze-cast form is ejected from the lower die.

For the subject castings the general sequence of events was as follows:

Approximately 22 lb of molten 7075 aluminum alloy was poured into the lower die and formed a pool approximately 6 in. deep in the lower die. Immediately after pouring the molten metal into the lower die and removal of the crucible the press was activated to lower the punch into the bottom die and contact the upper surface of the pool of molten metal. This typically required 20 sec. Then the punch was further lowered to displace the molten metal around the punch to fully occupy the annulus formed by the die wall and the punch and thereby form a tube. The cover plate effectively prevented the molten metal from being displaced and allowed for the application of the required pressure within the die cavity. This displacement of molten metal required about 10 sec. As previously indicated, the wall of the 7075 aluminum

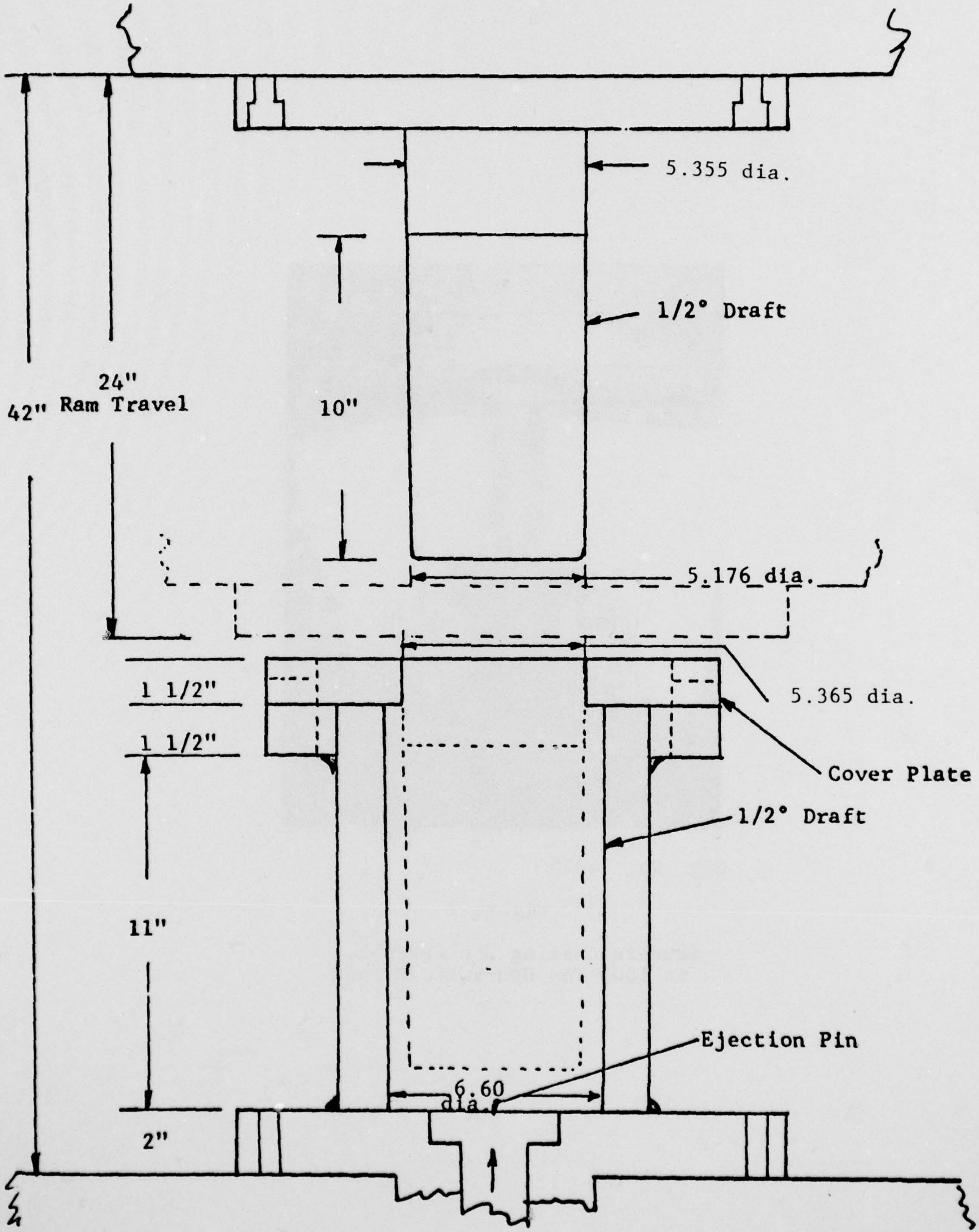

Figure 1
Schematic Illustration of Die Set

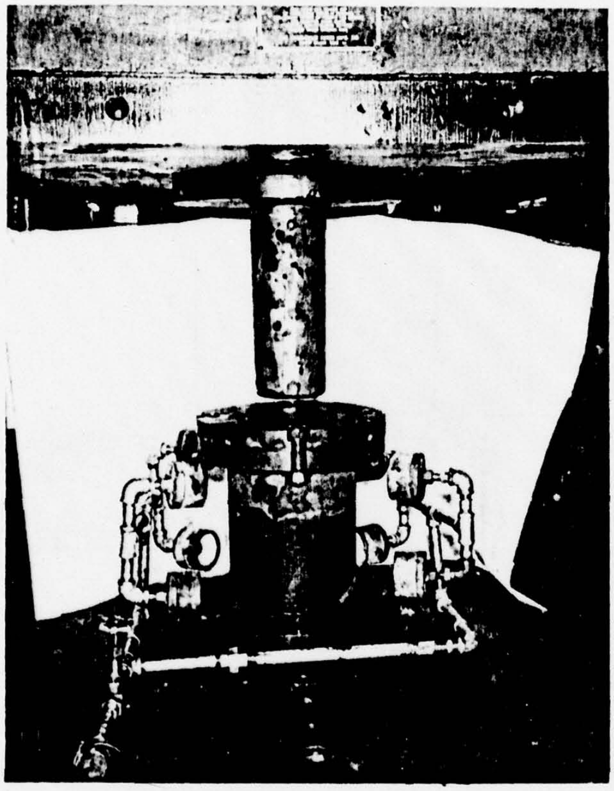

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Figure 2

Squeeze Casting Die Assembly
in 1000-Ton Hydraulic Press

cylinder was approximately 3/4 in. thick, and the thickness of the lower closed-end portion of the tube ranged from 1 to 2 in. depending upon the amount of molten metal used in the particular experiment. The time of pressure application was typically 20 sec. The fact that a close fit existed between the punch and the cover plate allowed for the full application of pressure to all parts of the casting during solidification.

Casting temperatures ranged from 1150° to 1400°F, squeezing loads were varied from 100 to approximately 450 tons, and the time of pressure application was also controlled varying between 20 and 60 seconds. Die temperatures were monitored, and the temperature of selected castings was determined immediately after stripping from the die.

3. EXPERIMENTAL RESULTS

For optimization of processing parameters, the ranges of parameters were as follows:

Melt temperature after transfer in the die	1150°-1400°F
Bottom die temperature	500°-650°F
Weight of bar stock	20.5-23 lb
Load	100-400 tons
Time of load application	20-60 sec

Lower temperatures were found to be unsuitable because of fast freezing of the alloy, required very high retracting force on the punch, and caused stripping and ejection problems. Smaller quantity of molten metal gave incomplete filling of the cavity. With this limited study for optimization of parameters, the following parameters were found to be quite suitable for squeeze casting:

Temperature of molten metal in die	1400°F
Temperature of bottom die	650°F
Temperature of punch	500°F
Load	200 tons

Time of load application	30 sec
Weight of bar stock	22 lb

The data on the squeeze castings delivered are given in Table 1, and the castings are shown in Fig. 3. The castings delivered have been mildly sand blasted. The visual examination showed the surfaces to be of a high quality and free of cracks. The temperature measured on castings soon after ejection was found to be approximately 800°F, i.e., it was fully solidified.

4. SUMMARY AND RECOMMENDATIONS

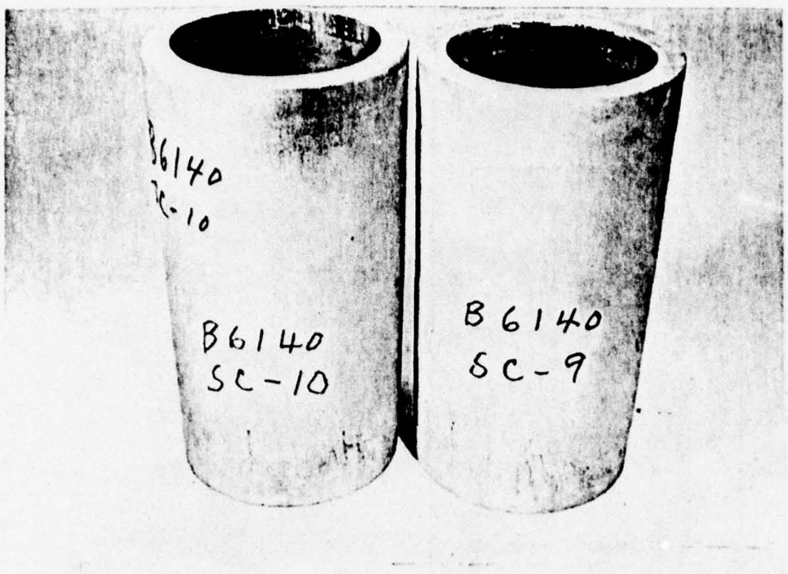
Two 7075 aluminum alloy cylinders were produced and delivered utilizing the squeeze casting process which is being actively developed at IITRI. Visual examination of the castings has indicated the feasibility of applying the squeeze casting process for heavy components of 7075 aluminum. (Further extensive evaluation is planned by NSWC/DL.) A limited range of processing parameters was encompassed in the experimental work. These included casting temperature, load, duration of load, and molten metal weight.

Cylindrical castings of the general type produced in this program pave the way for producing larger castings of 7075 aluminum. With this feasibility study providing the basis, it is recommended that work be continued to further optimize processing parameters to ensure an economic method of producing large 7075 aluminum alloy castings having a high degree of integrity and structure, optimum mechanical properties, and little need for finish machining.

Table 1

PROCESSING PARAMETERS FOR 7075 ALUMINUM SQUEEZE-CAST CYLINDERS

Casting No.	Molten Metal Temp., °F		Wt. of Metal in Squeeze Casting, lb		Die Temp., °F		Load, tons	Duration of Load, sec	Results
	Crucible	Die	Before	After	Die	Punch			
B6140SC-9	1700	1400	22.1	21.73	650	500	200	30	Excellent
B6140SC-10	1700	1400	21.96	21.43	670	520	200	30	Excellent



Neg. No. 44517

Figure 3

Squeeze Castings Selected for Delivery to NSWC/DL

IIT Research Institute
10 West 35 Street, Chicago, Illinois 60616
312/567-4000

30 September 1976
IITRI-B6140-1 (Suppl.)

Receiving Officer
Naval Surface Weapons Center
Dahlgren Laboratory
Contract No. N60921-76-ME-701
Dahlgren, Virginia 22448

Subject: Supplement to the Report Entitled "Squeeze Casting of Two Large 7075 Aluminum Alloy Samples," Project No. IITRI-B6140, Prepared Under the Subject Contract and Task Order

Gentlemen:

This supplement provides information in response to Section F, Description/Specification, Item F11.2, Producibility Information. It was inadvertently left out of the subject report.

IIT Research Institute has pioneered the work on the squeeze casting process in the USA. At this stage, it is the prime source for squeeze castings. But in addition, many of the organizations have worked with IITRI or independently in developing capability for this process. The various organizations and the known status of their capabilities are discussed below.

1. IIT Research Institute
   10 West 35 Street
   Chicago, Illinois 60616

   Contact: Dr. K. M. Kulkarni, Manager
   Metalworking Research

   Phone No.: 312/567-4179

IIT Research Institute has produced squeeze castings in both ferrous and nonferrous materials including aluminum alloys, brasses, carbon steels, cast iron, nickel-base superalloys, and stainless steels. The parts made have ranged in weight up to 20 lb and have ranged in complexity from relatively simple shapes to a difficult aluminum alloy wheel hub and a very complex 8630 steel barrel support with thin tubular sections. On current programs we anticipate making parts weighing up to 100 lb. The facilities include a number of different presses, the largest of which is a 1000-ton hydraulic press. Associated melt handling and control equipment is also available.

2. Perfect Circle Division of Dana Corporation
P.O. Box 1166
Richmond, Indiana 47374

Contact: Mr. William Young, Chief Engineer
Materials Science Department

Phone No.: 317/966-8111

Dana has sponsored two different programs at IITRI on squeeze casting of aluminum alloy components. They are greatly interested in the technology and are currently in the process of developing prototype facilities in their plant. They have already obtained a 150-ton hydraulic press which is being specially fitted for this process. Eventually, they anticipate going into large-scale production with aluminum alloy components.

3. Consolidated Metco, Inc.
P.O. Box 03201
Portland, Oregon 97203

Contact: Mr. Ed Ambrose, Corporate Chief Engineer

Phone No.: 503/286-5741

This company sponsored the development work on the aluminum alloy truck wheel hub at IITRI. They are interested in the process for aluminum alloys and have conducted work on small aluminum alloy parts. They have a 600-ton press.

4. Rodman Laboratories
Rock Island Arsenal
Rock Island, Illinois 61201

Contact: Mr. Dick Miclot

Phone No.: 309/794-5363

The Rock Island Arsenal sponsored the squeeze casting of 8630 type of receiver base and barrel support castings at IIT

Research Institute. IITRI has made recommendations on how the Arsenal can set up a production facility for squeeze casting a variety of ferrous and nonferrous components required by the Army. It is not known if they have reached any decision concerning setting up the facility.

5. Doehler-Jarvis Division of NL Industries, Inc.
1945 Snead Avenue
Toledo, Ohio 43691

Contact: Dr. Richard Lynch
Manager of Marketing

Phone No.: 419/244-9521

NL Industries has done some work on their own on developing the squeeze casting production capability. Apparently they have some small components in small lot production. Their current press size is 500 tons.

6. Babcock & Wilcox
1562 Beeson Street
Alliance, Ohio 44601

Contact: Mr. Dale LeCount
Central R&D

Phone No.: 216/821-9110

The company sponsored work on squeeze casting of cast irons at IITRI. They are seriously interested in the process and have developed their own production capability. They have a 250-ton press suited for squeeze casting and are planning to build a plant for squeeze casting. Their current work is limited to ferrous parts which must be hard and wear resistant. They are experimenting with a 15 lb part in the pilot production stage.

The squeeze casting process is gaining quick support in industry and the production base is expected to increase rapidly in the next five to ten years. However, accurate estimation of the production base expansion is extremely difficult to make at this stage. The work thus far has amply demonstrated the capability of the process and its potential for cost reduction and quality improvement in many different applications. The expansion of the production base will depend on how quickly new applications are identified and the aggressiveness with which the various interested companies pursue the technology. IITRI is constantly getting new inquiries to investigate a variety of different components for their suitability for production by the squeeze casting process. It is likely that in the next decade the industry could develop into a $100,000,000 a year size or larger. The recent concern about energy usage and material consumption may both boost the process tremendously since the squeeze casting process cuts down the material usage significantly, thus reducing the machining cost also, and both of these steps in turn substantially reduce the energy requirements.

We trust that this information will be useful to the Navy and regret any inconvenience caused by its being left out of the original report. Please contact me if there are any questions.

Sincerely,

K. M. Kulkarni

K. M. Kulkarni, Manager
Metalworking Research

KMK:md

Approved by

M.A.H. Howes

M.A.H. Howes, Director
Metals Research

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