TECHNICAL REPORT NO. 11727

CASTING TECHNOLOGY RELEVANT TO THE PRODUCTION OF HIGH STRENGTH ALUMINUM SAND CASTINGS

NOVEMBER 1973

U.S. ARMY TANK AUTOMOTIVE COMMAND LABORATORIES

by ALAN G. FLEMING, G. B. SINGH

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U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan

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CASTING TECHNOLOGY RELEVANT TO THE PRODUCTION OF HIGH STRENGTH ALUMINUM SAND CASTINGS

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MATERIALS BRANCH

ABSTRACT

High-strength aluminum sand casting alloys such as type 201 and 224 offer yield strengths upwards of 55,000 psi on bars cut from castings. The range of properties represented expands the technical base and design strength range of aluminum castings; their utilization will result in longer service life as a consequence of improved heat rejection capability and lowered running temperatures under high ambient temperature operation. Significant weight savings realized in individual applications should enhance vehicle mobility characteristics.

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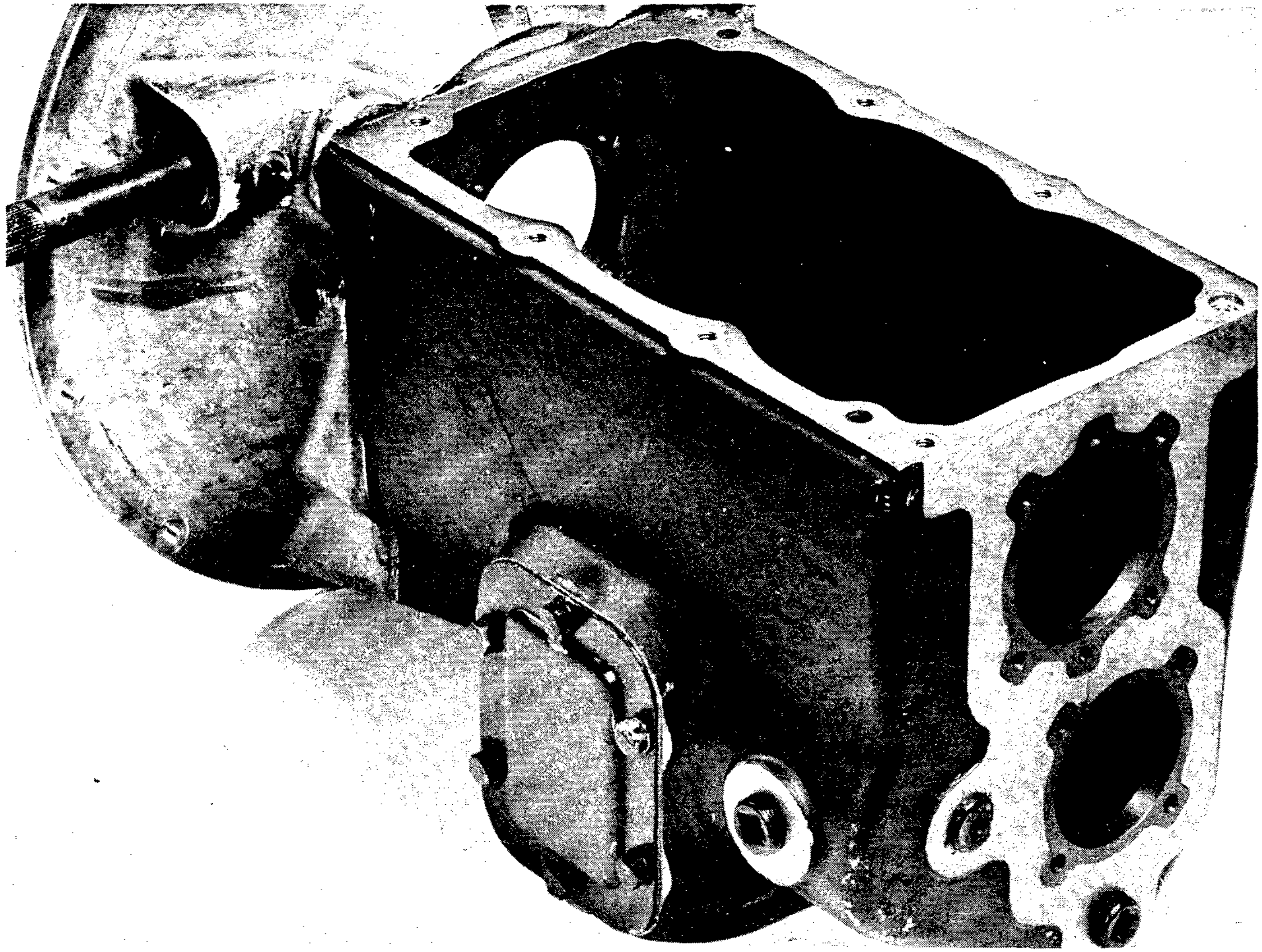
INTRODUCTION

Recent developments in the aluminum casting industry over the past few years have resulted in the development and introduction of a new class of "super-strength" casting alloys with strength levels exceeding 50,000 psi. These strength levels are considerably in excess of commercial materials presented in specification MIL-A-21180. Super-strength alloys as typified by types 201 and 224 alloys, which are utilized in current study, were originally developed to fulfill demands by industry, particularly the aircraft industry, for castings with higher strength levels and reliability. The utilization of super-strength cast aluminum alloys by the military, particularly for tactical and tracked vehicles, presents an opportunity for extended material utilization and engineering application where weight savings, heat rejection capability and higher strength levels will offer relief from field service limitations imposed by iron or steel castings currently in use.

The 2-1/2 ton transmission case, DTA 7520988, and clutch cover, DTA 7520952, were selected as test components. The iron case (ferritic nodular, 30 KSI ultimate strength, Spec QQ-I-653) and clutch cover were re-designed in aluminum to be interchangeable as an assembly. A view of the completed assembly is shown in Figure 1.



CAST ALUMINUM 2-1/2 TON TRANSMISSION ASSEMBLY

FIGURE 1

OBJECTIVE

Establish parameters for proper foundry technology in aluminum sand casting production for high-strength aluminum alloys 201 and 224. Determine quality control procedures related to melt-down procedures, temperature control apparatus, additives, ranges of chemical analysis and heat treatment of castings.

BACKGROUND

The development of uniform cross-sectional density and metal soundness in walls of a given casting on a production basis with minimum scrap loss is the summation of close control of design configuration, metal melting, foundry practice and final heat treatment. The correlation of all of these parameters will establish proper chemical composition, gas content and grain size. Optimum mechanical properties will not be realized unless such undesirable defects as voids (solidification shrinkage), gas and metal oxides are minimized[1].

Common causes of high scrap losses for "super-strength" castings, such as hot tears, can be minimized by application of principles in original design and casting configuration as outlined in AFS "Hot Tear Control Handbook"[2].

The presence of dispersed discontinuities such as voids (from hydrogen gas dissolved in molten aluminum), dissolved oxides and metal impurities have quantitative detrimental effects on such mechanical properties as elongation, ultimate tensile strength and yield strength[3]. Defects in this category are directly related to mechanism of metal solidification for any given alloy system. Remedial measures for removal of residual gases for alloys such as 201 and 224 include flushing molten aluminum at controlled temperature with Nitrogen and/or Chlorine gas[4].

CONCLUSIONS

Commercial aluminum sand casting alloys such as type 201 and 224 will satisfactorily produce quality castings with conformance to established radiographic soundness standards having yield strength capabilities exceeding 55,000 psi. The mechanical properties are reproducible from heat to heat as long as routine quality control procedures relating to metal segregation, cleanliness, degassing and inoculation procedures are adhered to.

TEST MATERIALS AND EQUIPMENT

The aluminum alloys selected for evaluation were types 201 and 224. A tabulation of nominal heat analysis and specified alloy content ranges and recommended heat treat are shown in the Appendix. In addition to foundry equipment normal to the production of castings, the following items were employed:

a. Foundry:

(1) Degassing equipment including carbon lance, gauging control lines, Chlorine gas storage tank and controls.

(2) Vacuum equipment for residual gas check prior to metal pouring.

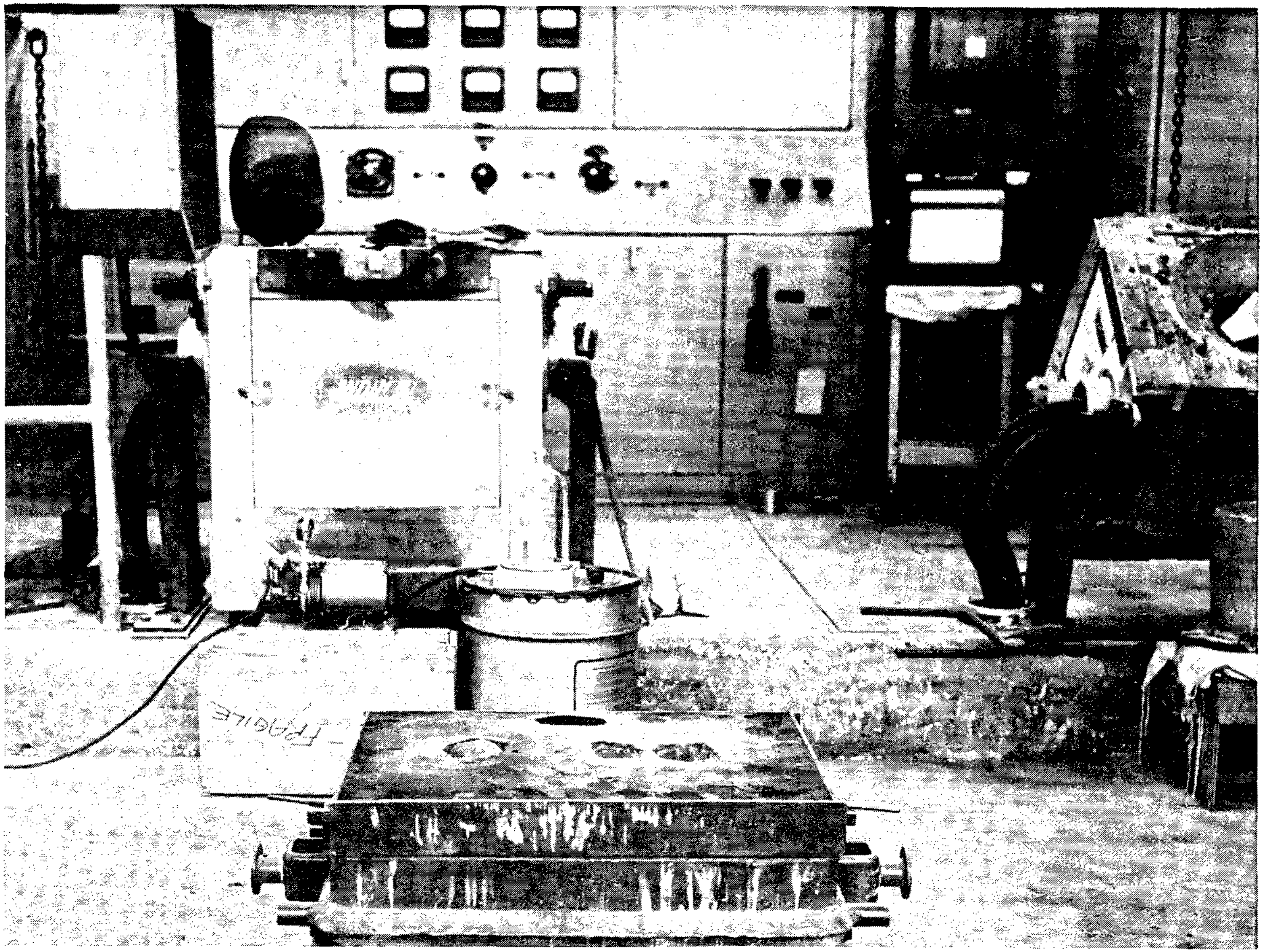
b. Laboratory:

(1) ARL Spectrograph

(2) Tensile test equipment

(3) Metallographic equipment, microprobe analyzer

A view of the foundry layout, including induction melting furnaces, holding ladles and other production equipment, is shown in Figure 2.



FOUNDRY FLOOR LAYOUT

FIGURE 2

FOUNDRY PROCEDURE

In order to consistently produce high quality castings of uniform cross-sectional density, all phases of the operation from melt-down of ingot and ingot returns, through analysis and temperature control to pouring must be closely controlled. Other than gating and feed characteristics, which are unique to a given casting, there are three attributes of any molten casting alloy that will largely determine the quality of the casting. These are chemical composition, gas content and grain size.

Accurate analysis of each heat of aluminum casting alloy should be made. Preferentially, this should be done prior to pouring. If this is not possible, a sample poured from the furnace should be analyzed later and conformance to the specifications (given in the Appendix) should be noted before the castings are processed further.

Careful attention should be given to the content of silicon, particularly for 201 alloy. Silicon is a very harmful impurity and can intrude from contamination with other aluminum casting alloys where silicon is a common alloying element.

The content of magnesium is also very important, since this element is responsible along with copper and silver for the hardenability of the alloy when given a solution and aging heat treatment. Since magnesium is somewhat volatile and is removed by reacting with chlorine gas, additions of magnesium to the melt may be necessary to maintain the specified content.

A recommended total procedure for 201 and 224 alloys relating to melt size and time flow for additives is shown in the Appendix.

To minimize scrap losses and insure maximum physical properties on bars cut from castings (as required under specification MIL-A-21180), the following minimum procedure is recommended for hydrogen degassing. The practice in a given foundry operation must be circumscribed.

a. Clean and preheat all degassing tubes before using.

b. Turn gas on slightly before inserting carbon lance in molten metal.

c. Lance should clear bottom of crucible; gas flow should be adjusted to insure maximum mixing which is a function of position and size of orifice (side or bottom) and gas pressure.

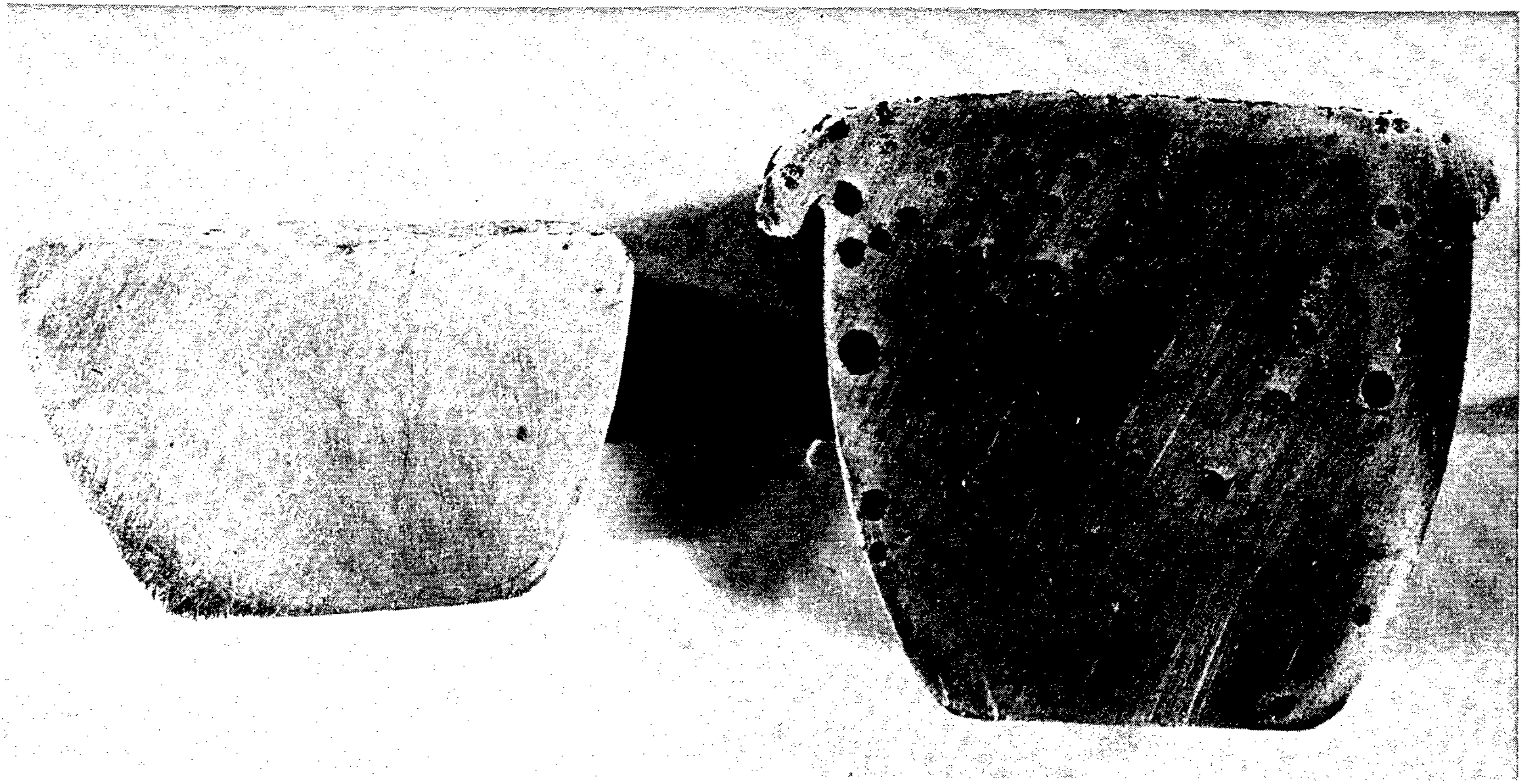
d. The degassing time should be measured accurately.

e. The temperature of the molten metal should be maintained within the range of 1350°F to 1450°F for both 201 and 224 type alloys.

f. The gas should be flowing slightly through the degassing tube during removal from the molten metal and turned off after complete removal from the bath.

g. Cleanliness of all equipment (cleaning and precoating with "wash" prior to skimming, etc.) is mandatory.

The gas content of molten bath is regulated by checking of samples cooled under vacuum. Figure 3 depicts differences between "gassed" and "degassed" materials.



AFTER BEFORE

VACUUM DEGAS SPECIMENS

FIGURE 3

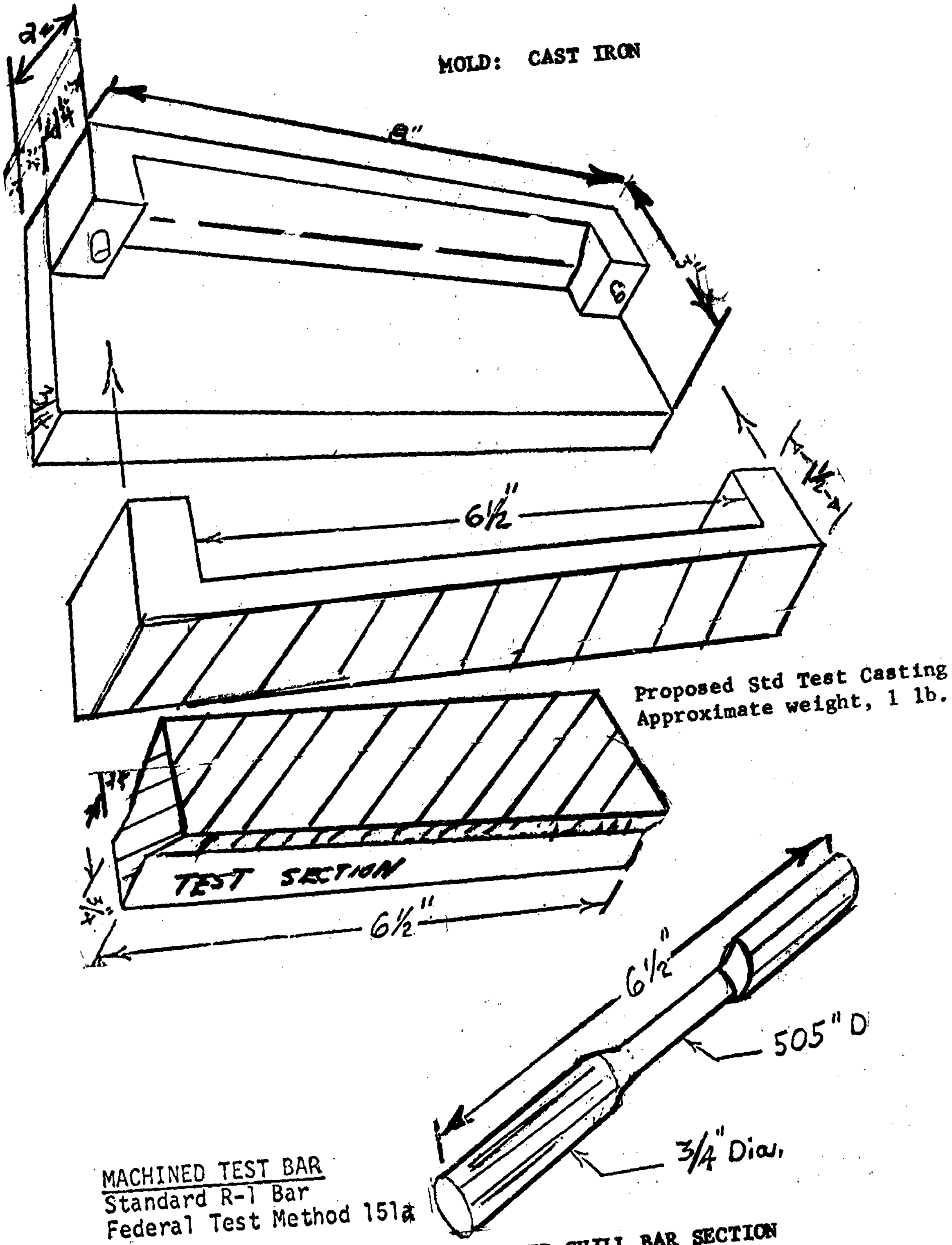
TEST RESULTS

The initial phase of the foundry production program was related to the establishment of proper foundry techniques, pouring of simulated test sections, checking variations in chemical analysis of castings due to melt losses and verification of heat treat and instrumentation parameters. Figure 4 shows a schematic diagram of a proposed "chill" bar submitted to Mil Handbook IV Committee (courtesy A. Kearney, Olin Ingot). Test plates in conformation of the type presented by Owen and Marsh are shown in Figure 5. Figure 6 presents an "as cast", 0.505" diameter test bar configuration (specification QQ-A-601). Compiled mechanical strength properties for bars in this group are presented in the Appendix.

The final phase of the foundry production study consisted of pouring castings in patterns developed from drawings established on engineering study.

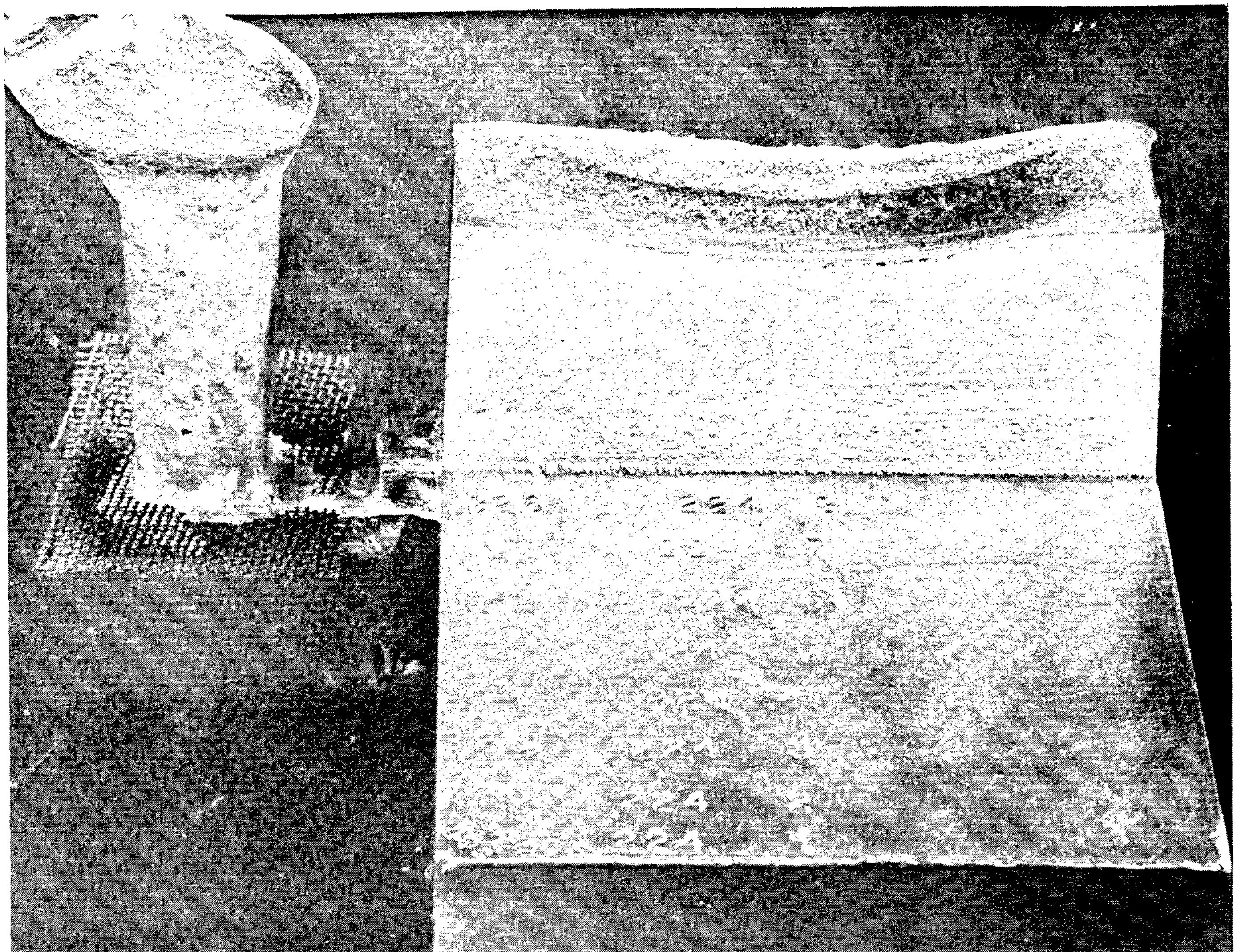
The aluminum transmission case and clutch cover interchange is an assembly with the conventional 2-1/2 ton transmission. A view of the casting transmission case casting is shown in Figure 7. The open side is in the bottom foreground, with risers and a portion of the feeding system in the upper background. Note interior ribbing and cast inserts. Cast-in bearing inserts and use of helicoil stud inserts were incorporated in redesign. Figure 8 shows the finalized transmission case casting with pattern changes necessary to meet required metal soundness in insert and boss areas to conform to Std 1 and 2, ASTM-E-155, in critical and non-critical design areas. The view in Figure 8 shows the reverse side of the casting presented in Figure 7. Note modifications in risers, gate and bosses to insure proper metal feeding. The finalized version of clutch cover casting, Figure 8, also incorporates changes in gates and risers to insure uniform cross-sectional density and freedom from internal defect for minimum scrap losses. Strength values for test bars representative of these procedures are shown in the Appendix.

Approximately 45 rough castings were poured to establish and verify parameters involved in the program. Total gross amount of metal poured for castings test bars and test plates exceeded one ton. Finalized assemblies sent to Yuma test site for vehicular test conformed to Radiographic Standard I in critical areas and Standard 2 in non-critical areas (ASTM-E-155). These results were achieved with melt ratios of one part fresh ingot and two parts returns. Magnesium loss for 201 alloy was controlled with melt additions. No melt additions were required with 224 alloy.



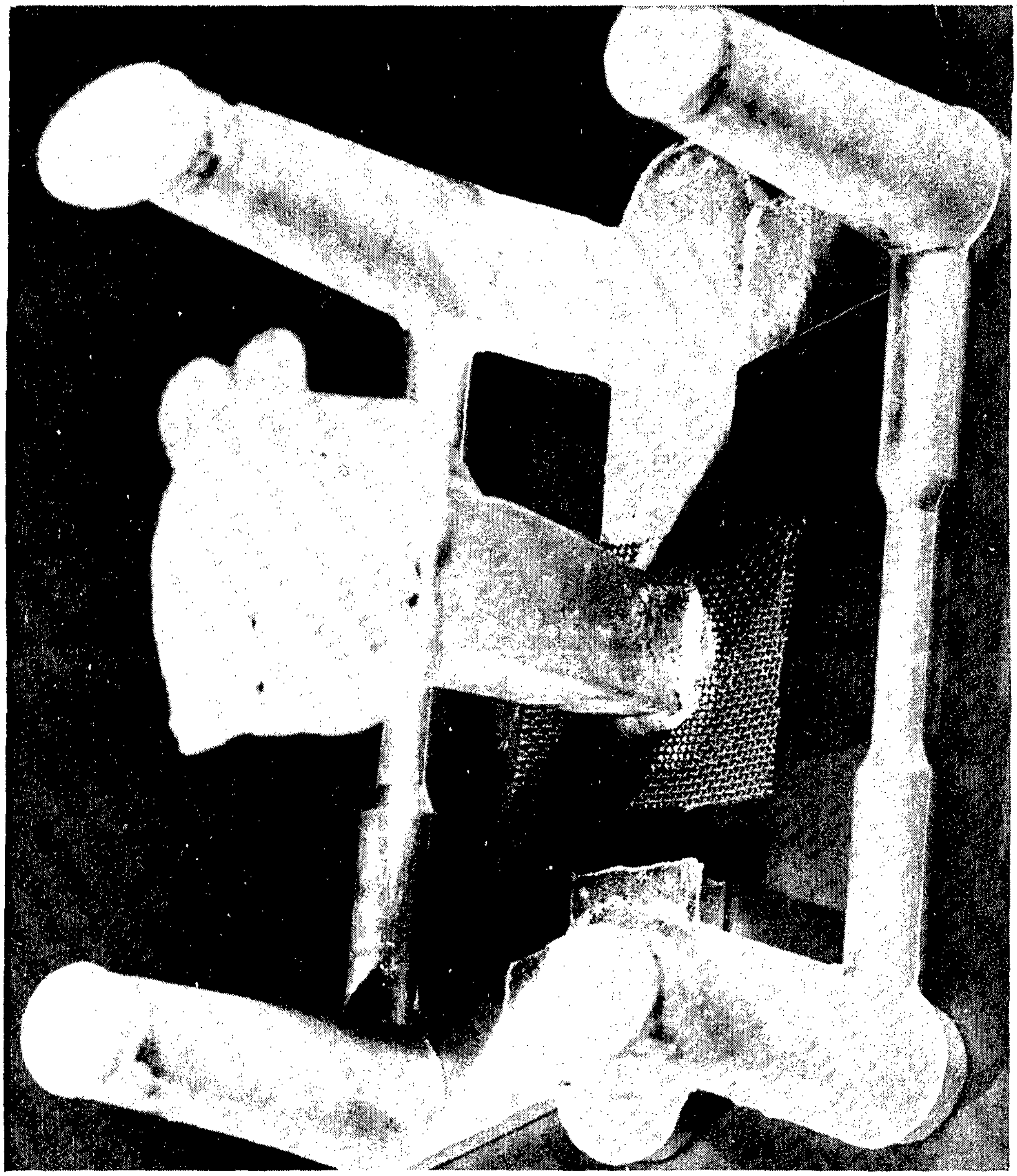
SCHEMATIC OUTLINE: PROPOSED CHILL BAR SECTION

FIGURE 4



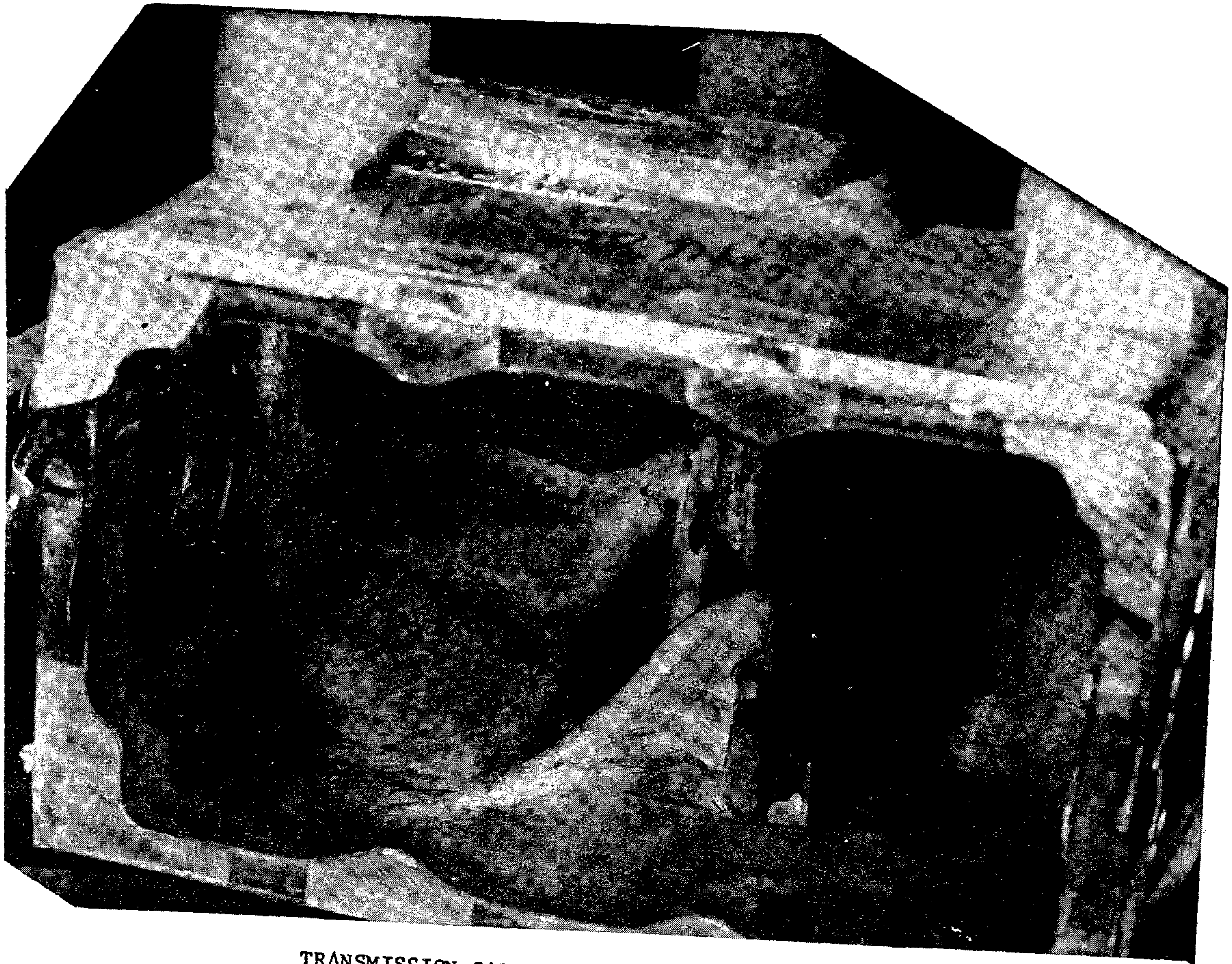
CHILL PLATE SECTION

FIGURE 5



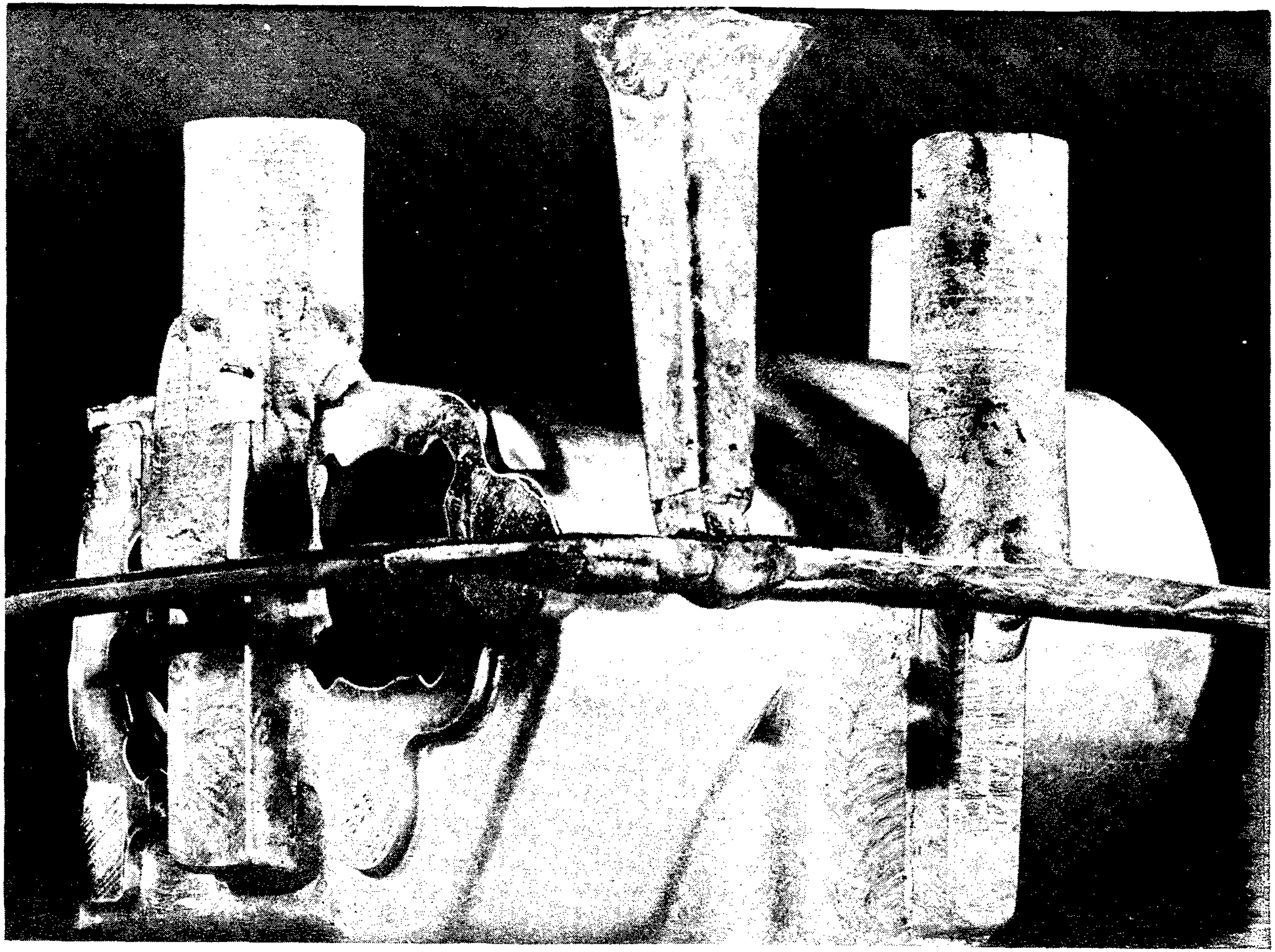
TEST BAR CONFIGURATION: QQ-A-601

FIGURE 6



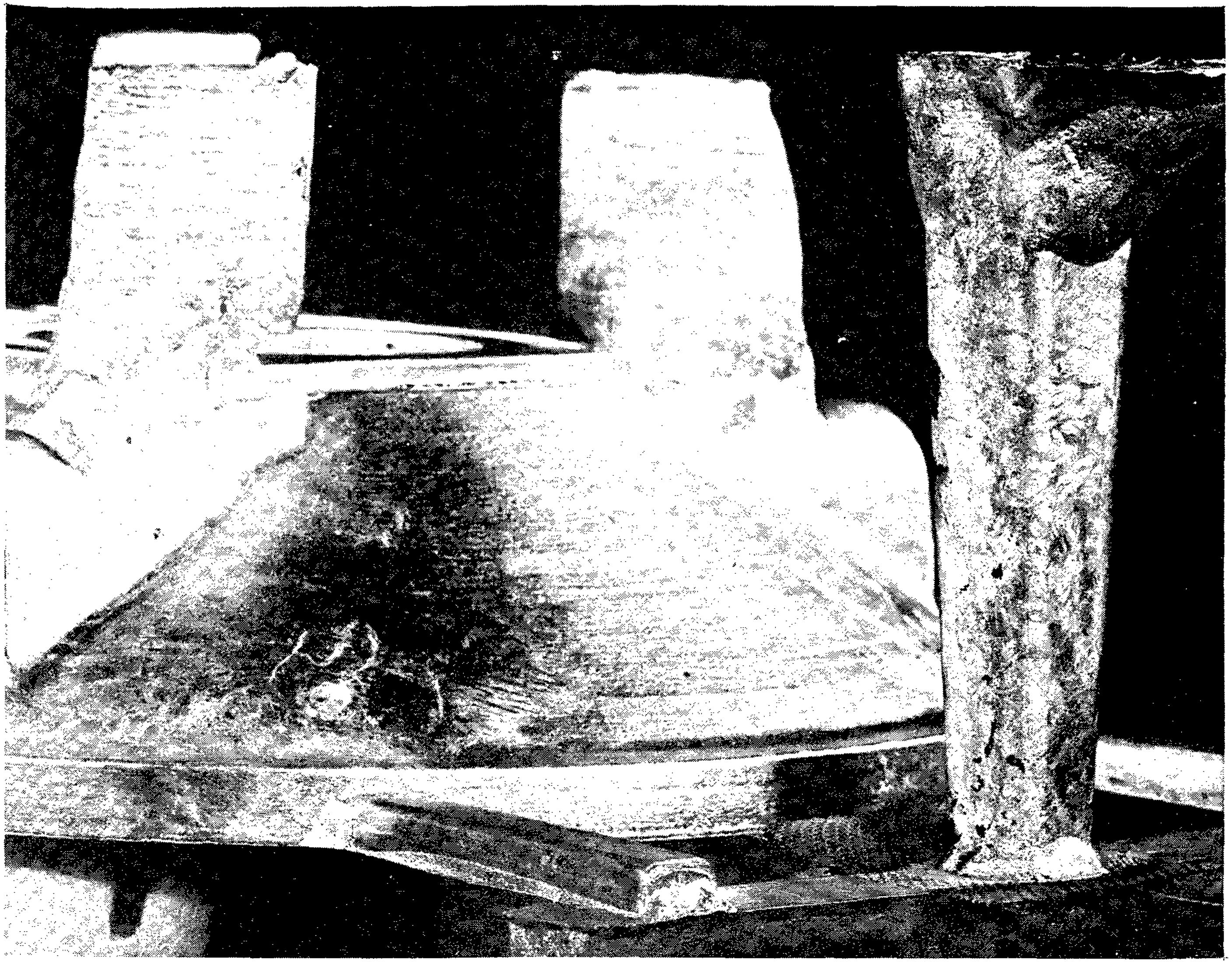
TRANSMISSION CASE, INTERIOR VIEW: DTA 7520988

FIGURE 7



TRANSMISSION CASE, REAR CONFIGURATION: DTA 7520988

FIGURE 8



CLUTCH COVER, AS-CAST LAYOUT: DTA 7520952

FIGURE 9

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APPENDIX

A. Chemical Analysis

	201 Al Alloy*		224 Al Alloy	
	Specified	Reported	Specified	Reported
Silicon	0.05 max	0.01	0.06 max	0.02
Iron	0.10 max	0.01	0.10 max	0.05
Copper	4.00-5.00	4.65	4.5-5.5	5.00
Titanium	0.15-0.35	0.18	0.35 max	0.21
Mangenese	0.20-0.30	0.19	0.20-0.60	0.26
Magnesium	0.18-0.35	0.29	--	--
Silver	0.4-1.0	0.62	--	--
Vanadium	--	--	0.05-0.15	0.08
Zirconium	--	--	0.10-0.25	0.12

* AMS 4228

B. Recommended Heat Treatment:

(1) 201 Aluminum Alloy

T4 - Two hours at 940-978°F and 14 hours at 985°F then boiling water quench.

Age 24 hours at room temperature.
T6 - 20 hours at 310°F
T7 - 5 hours at 370°F
T42 - 45 minutes at 310°F

(2) 224 Aluminum Alloy

T7 - 5 hours at 930 ± 10°F
24 hours at 1000 ± 10°F
Water quench at 150°F
Age 24 hours at 375 ± 10°F

C. Recommended Additive Control and Degas Procedure[1]

FORMULA	MELT SIZE, LBS.			
	550-600	380-400	275-300	190-200
1. Charge and melt alloy with clean returns. Adjust metal temperature, 1320-1360°F. Skim pot clean.				

FORMULA	MELT SIZE, LBS.			
2.* Sprinkle flux on surface; apply uniformly, but keep away from side of crucible.	10/16	6/16	5/16	3/16
3.** Alloy with magnesium. Allow to react until solid (maximum time). Do not disturb for four minutes.	4/16	2.5/16	2/16	1.125/16
4. Without skimming, degas for (minutes): Chlorine degas for two minutes (see procedure).	10	9	8	7
5. Test for gas (see Figure 3).				

* Grain refining additives in furance are of the Ti-Boron type to minimize grain coarsening as commonly used in the control of aluminum throughout the industry.

** For induction melting, magnesium is added with melt down. Initial degas cycle done in furnace. Transfer to pre-heated holding ladle and repeat degas cycle, if required, from observation of vacuum test.

D. Physical Test Results

(1) 201 Aluminum Alloy - T6

Machined Test Bars from Chill Plate Sections (Figure 5)

SAMPLE NO.	ULTIMATE TENSILE STRENGTH, KSI	YIELD STRENGTH, KSI	ELONGATION %
1	70.3	53.3	16.3
1A	65.4	53	13
2	62.8	52.7	9.2
3	61.6	52.2	7.5
4	61.4	52.2	7
5	62	52.4	9
6	61.8	51.7	10
7	62	46.8	11

Cast Test Bars (Figure 6)

SAMPLE NO.	ULTIMATE TENSILE STRENGTH, KSI	YIELD STRENGTH, KSI	ELONGATION %
4	64.4	53.3	7
5	64.8	54.2	8
7	65.6	54.3	8
8	65.9	54.2	8.8

Separately Cast 0.505" Dia Bars

SAMPLE NO.	ULTIMATE TENSILE STRENGTH, KSI	YIELD STRENGTH, KSI	ELONGATION %
1	68.6	62.75	4.5

Bars from Casting, Heavy Section

1	66.3	60.5	5.5

Bars from Casting, Wall Section

1	67.5	60.8	8

(2) 224 Aluminum Alloy - T7

Machined Test Bars from Chill Plate Sections (Figure 5)

1	58.05	45.5	11
2	59.1	46	11
3	56.5	35	9.5
4	61.5	46	11
5	55.2	40	8
6	54.1	28	7

Cast Test Bars (Figure 6)

1	54.98	51	8
2	55	41	4
3	55.8	41.1	6
4	53.4	49.8	8

Bars from Casting, Heavy Section

1	60	50	9.5
2	54	46	8.6

Bars from Casting, Thin Section

1	61	52	10
2	55	47	9

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13. ABSTRACT

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MICRO-SHRINKAGE						
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YIELD STRENGTH						