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REPORT R-1785

PROCESS DEVELOPMENT OF SHAPED MAGNESIUM-LITHIUM CASTINGS

by

ANTHONY SAIA
RALPH E. EDELMAN

November 1965

for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
National Aeronautics & Space Administration
Huntsville, Alabama

NASA Defense Purchase Request H-71508

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UNITED STATES ARMY
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Pitman-Dunn Research Laboratories
FRANKFORD ARSENAL
Philadelphia, Pa. 19137

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FOREWORD

This report was prepared at Frankford Arsenal, Philadelphia, Pa., for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration, under NASA Defense Purchase Request H-71508. The work was performed at Frankford Arsenal by Anthony Saia and Ralph E. Edelman, under the technical direction of the Propulsion and Vehicle Engineering Laboratory, Materials Division of the George C. Marshall Space Flight Center, with Mr. Herman L. Gilmore (R-P&VE-MMP MSFC) as Project Manager.

ABSTRACT

A process has been developed for successfully casting a number of prototype aerospace components using the ternary magnesium-lithium-silicon alloy. These components contained many of the design elements anticipated in aerospace hardware of this type.

It was found that conventional magnesium sand foundry practice was not satisfactory. A new molding material, based upon bentonite-bonded graphite powder, was employed. Melting and pouring practice was also modified to cope with the reactive nature of the alloy.

The radiographic quality of the castings and mechanical properties of test bars sectioned from the castings were evaluated and found to be satisfactory and to correspond with earlier experience on separately cast test bars.

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INTRODUCTION

The importance of conservation of weight in castings intended for space applications has properly drawn attention to the family of alloys which are based on the magnesium-lithium system.[1*] Until recently, these materials were available only in the wrought form and, consequently, design possibilities were limited by existing fabrication technology. In order to expand the design possibilities for these materials, a study was undertaken to develop a suitable foundry practice so that shaped components of greater complexity could be produced.

The problems anticipated and encountered were associated with the extremely reactive nature of the alloys. In order to minimize the possibility of mold reaction, the first castings were poured into machined steel or graphite molds. Later, rammed and fired molds, prepared with a special graphite-base molding medium, were used in an effort to broaden the range of shapes that could be cast.[2]

While this latter practice was found to be successful, limitations were evident in the long firing schedules required to bring the mold material to the state where it would not react with the molten alloy. Subsequent attempts, directed toward development of a mold material and molding practice that would more closely approximate conventional sand practice, were successful. This mold material was also of graphite base. It could be handled very much like green sand, required only low temperature baking, and did not react with the molten alloy.

In addition to the mold material development, this prior work included some alloy development which was directed toward compositions more specifically designed as foundry alloys. The most attractive of these were Mg-14 Li-0.5 Si (non-age hardening) and Mg-14 Li-3 Ag-5 Zn-2 Si (age hardening). These alloys were evaluated in comparison with compositions being used for wrought material and were found to exceed the level of stable properties obtained with the existing alloys.[3,4,5] As a result of these developments, the George C. Marshall Space Flight Center at Huntsville, Ala., requested Frankford Arsenal to further develop the casting process so that prototype castings, representing typical space-vehicle requirements, could be produced and tested.

The principal gaps between the then current state-of-the-art and that needed to satisfy the NASA requirement were: (1) capability of producing larger and more complex shapes; (2) improvements required in pouring practice to minimize the possibility for entrainment of oxide formed on the surface of the molten metal stream; and (3) the experience needed with a variety of shape factors. This last consideration required that a study of rigging practice for such castings be included.

*See REFERENCES.

This involved development of gating, risering, and chilling practices necessary to produce high quality castings.

Accordingly, three components, representing typical space-vehicle components, were selected on the basis of their design complexity and pattern availability. The experience with these castings was to be documented on the basis of mechanical properties, processing practice, and metallurgical quality.

Since this was essentially a feasibility type of study, the only alloy tested was the ternary composition. This decision was based upon the fact that this alloy does develop a satisfactory strength level in combination with substantial ductility. Although higher strength magnesium-lithium compositions have been developed, the ternary alloy presented the same challenge to foundry processing practice as did the more complex compositions.

MATERIALS AND METHODS

Casting Alloy

The analyses of the various heats poured are shown in Table I.

TABLE I. Composition of the Alloys

Heat No.	Weight (%) Nominal			Weight (%) Actual Analysis		
	Mg	Li	Si	Mg	Li	Si
1	Bal	14.0	0.50	85.71	13.92	0.28
2	Bal	14.0	0.50	85.93	13.68	0.27
3	Bal	14.0	0.50	85.98	13.58	0.29
4	Bal	14.0	1.0	86.67	12.13	0.92
5	Bal	14.0	1.0	86.85	12.29	0.83
6	Bal	14.0	1.0	87.38	11.72	0.94

Prior experience with this composition, using cast-to-size test bars poured into a permanent steel mold, developed the following properties.

Ultimate tensile strength	19,000 to 20,000 psi
Yield strength (0.2% offset)	15,000 psi
Elongation (2 in. gage length)	10 percent

The melting stock for this alloy is listed below.

Material	Form	Purity
Magnesium	Primary extruded stick	99.0% min (0.006% Na max)
Lithium	Ingot	99.9% min (0.006% Na max)
Silicon	Granules	99.9% min

Mold Material and Method

Three wooden patterns of parts typical of the components used in space vehicles were provided by the George C. Marshall Space Flight Center. These were:

(a) Alignment bracket, part No. GM470051 (Figure 1);

(b) Small box, no part number, with core box (Figure 2);

(c) Mounting case, part No. Gc503517, with core box (Figure 3).

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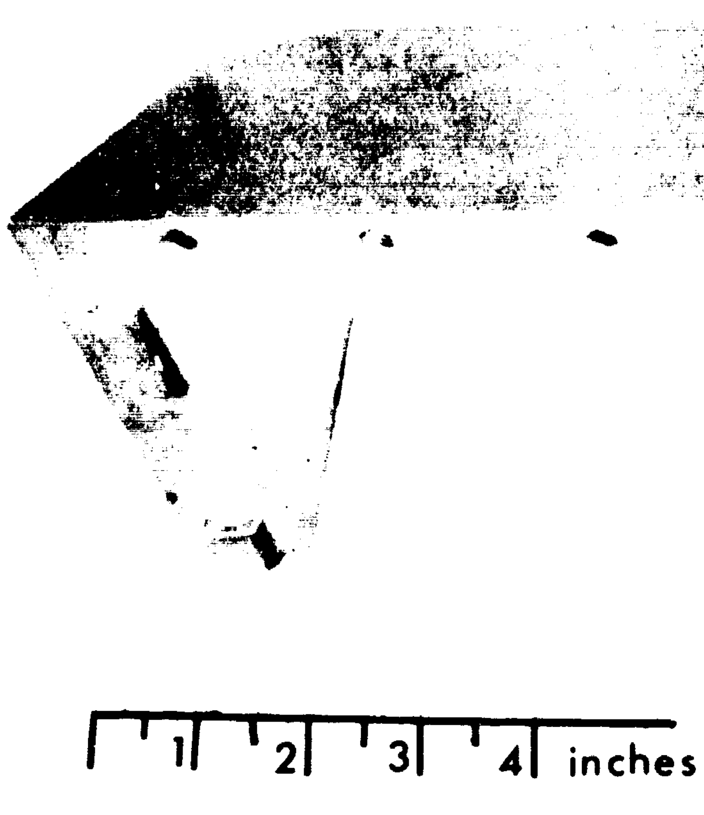

Figure 1. Alignment Bracket Pattern

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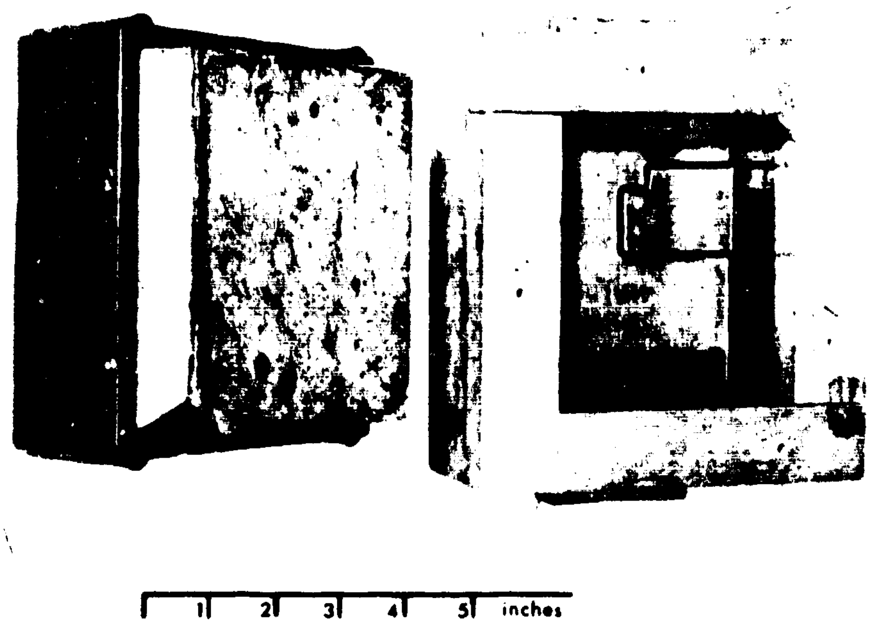

Figure 2. Small Box Pattern and Core Box

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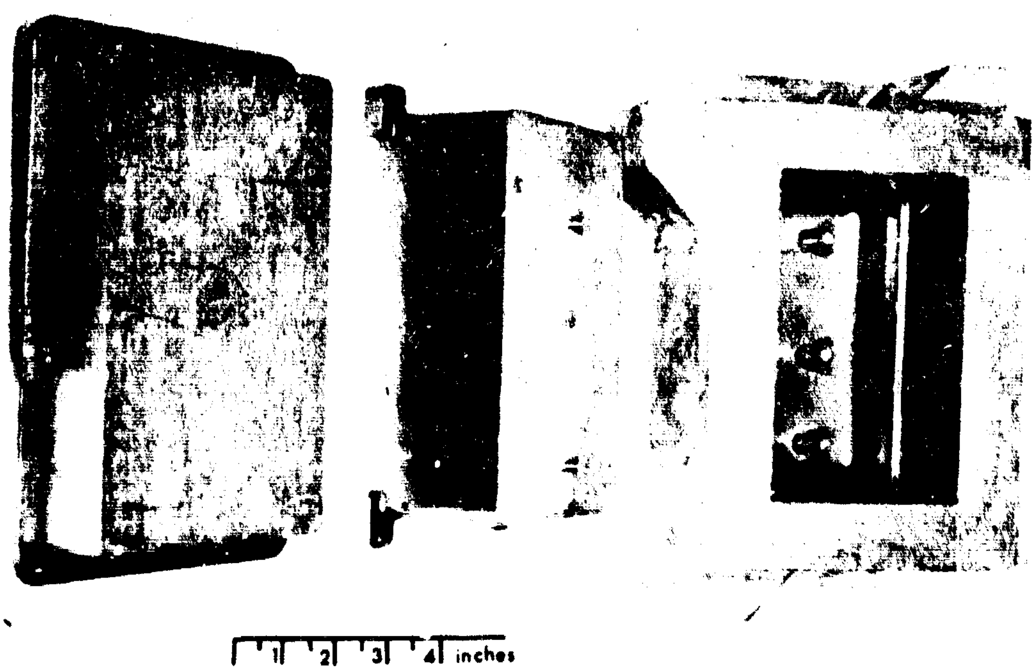

Figure 3. Mounting Case Pattern and Core Box

The first castings were made using an inhibited molding sand which was similar to that used for standard magnesium casting alloys. The castings which were poured into these molds showed evidence of severe metal-mold reaction. An inhibited zircon mold also reacted with the molten metal.

Promising results were finally obtained with a graphite mold material which had been developed concurrently on another program. This material was modified so as to meet the requirements for the magnesium-lithium castings. The final composition was a mixture of electric furnace graphite powder (National Carbon Company No. CPBB4P5, grade 99.9% pure), water, and bentonite. The sieve analysis of the material is given in Table II. The AFS grain fineness number for the graphite particles was approximately 47.

TABLE II. Sieve Analysis of Graphite Molding Material[a] (100-gram sample; shaker time, 15 minutes)

U.S. Std Sieve No.	Weight Grams	Weight Cumulative %	Mesh	Sieve Opening (microns)
30	-	-	28	590
40	4.0	4.0	35	420
60	71.0	75.0	60	250
80	18.0	93.0	80	177
100	2.8	95.8	100	149
140	1.3	97.1	150	105
200	0.6	97.7	200	74
270	0.3	98.0	270	53
Pan	0.4	98.4	-	-

[a]Equivalent to AFS grain fineness No. 47

A brief investigation was made to determine the green compressive strength and permeability of the mold material with different water contents. From these limited data it was determined that the mold material had an AFS permeability value of 150 and a compressive strength of 3 psi. Optimum composition corresponded to the following.

Material	Weight %
60 mesh graphite	90.0
Western bentonite	5.0
Tap water	5.0

Mixing procedure consisted of mulling the dry ingredients for five minutes, adding water, and mulling for an additional five minutes.

This material behaved like ordinary foundry sand when it was hand rammed around the pattern. The molds were baked at 250° F for 24 hours to remove moisture. Cores were of the same composition and were baked in the same way as the molds.

Because a new technique of pouring (described later in the section "Melting and Casting") was employed to make the castings, a new system of gating and risering had to be developed. The gating system was designed to minimize turbulence in the molten metal by a slow uniform flow of molten metal from the bottom to the top of the casting. This gating system consisted, essentially, of a relatively large sprue, a sprue basin to catch the first metal into the casting, and a fan-shaped runner which fed into a ring gate around the casting. To prevent gas entrapment in the mold, extensive venting was used on the top of the mold. A description of the gating and risering of each casting follows.

Alignment Bracket (Figure 4). This bracket had approximate dimensions of 7 by 4 by 4 in., and weighed 1-1/4 lb. The wall thickness varied from 1/2 to 1/4 inch. Figure 5 (A and B) shows the rigging employed. It should be noted in Figure 5B that the pouring gate extended past the casting to form a sprue basin. This extension provided both a "cushion" to take the initial impact of the molten metal and a basin to hold the first metal into the casting. From the pouring gate, a tapered fan-shaped runner led into a gate which was attached to the entire bottom of the casting.

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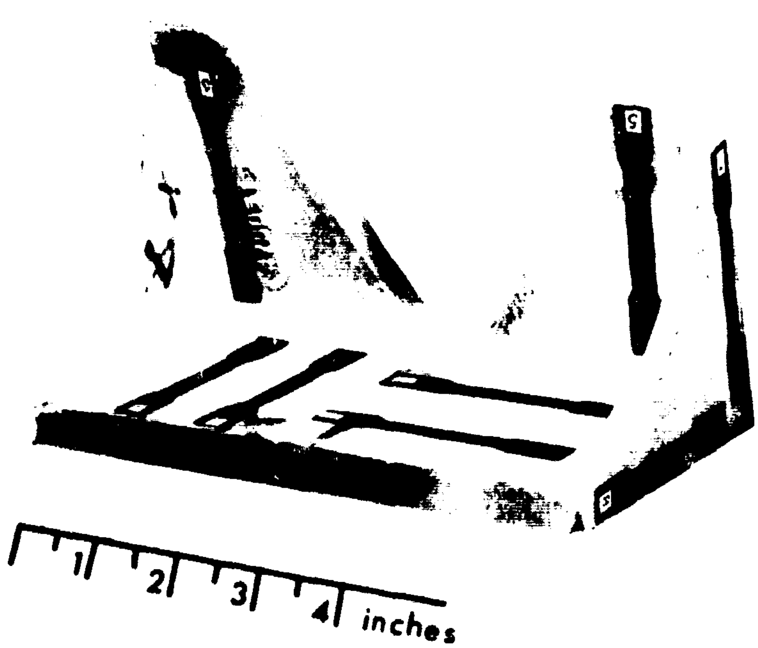

Figure 4. Test Bar Locations in Alignment Bracket Casting

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A

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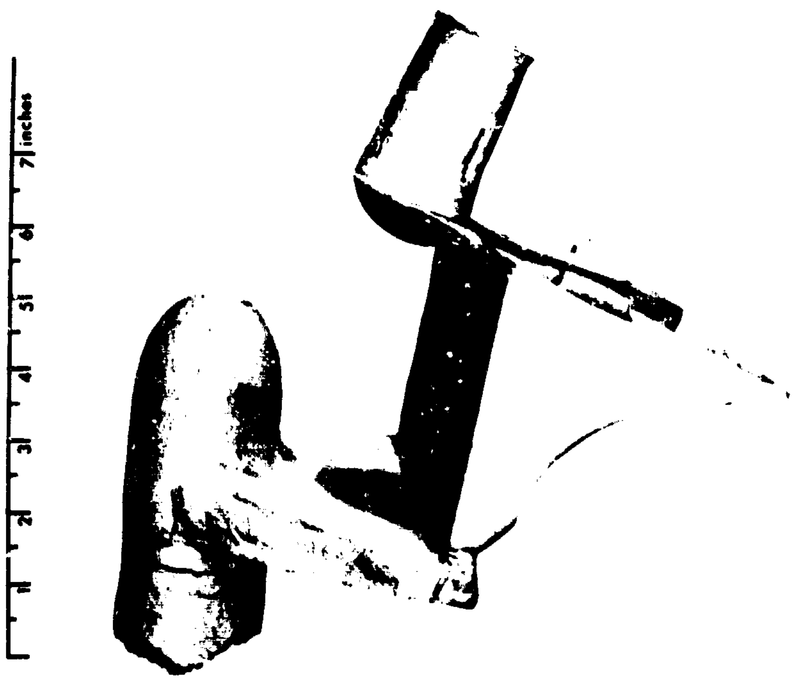

B

Figure 5. A - Mold for Producing Alignment Bracket Casting with Insulating Riser Sleeve
B - Rigging Employed to Produce Alignment Bracket Casting

The major problem with this part was the entrapment of gas and the occurrence of shrinkage at the top of the casting. By carefully venting the top and using an insulated blind riser, the problem was corrected. The insulated riser sleeve was prepared with a gypsum-bonded investment material, using boric acid (1 percent of investment by weight) as the inhibitor. Eight test bars were cut from one casting. These locations are shown in Figure 4.

Small Box (Figure 6). This item had approximate dimensions of 8 by 7 by 3 in. and weighed 2 lb. The wall thickness varied from 1/8 to 3/4 inch. Figure 7 (A, B, and C) shows the rigging employed.

This casting presented a problem in feeding because three of the side walls were 1/8 inch thick, while the fourth was 1/2 inch thick. On the three thin sides, there was also a 1/2 inch flange to which the ring gate was attached.

To insure proper solidification in this casting, insulated blind risers and chills had to be utilized. Two heavy insulated blind risers were used to feed the thick side of the casting. Opposite the entrance of these gates, graphite chills were used.

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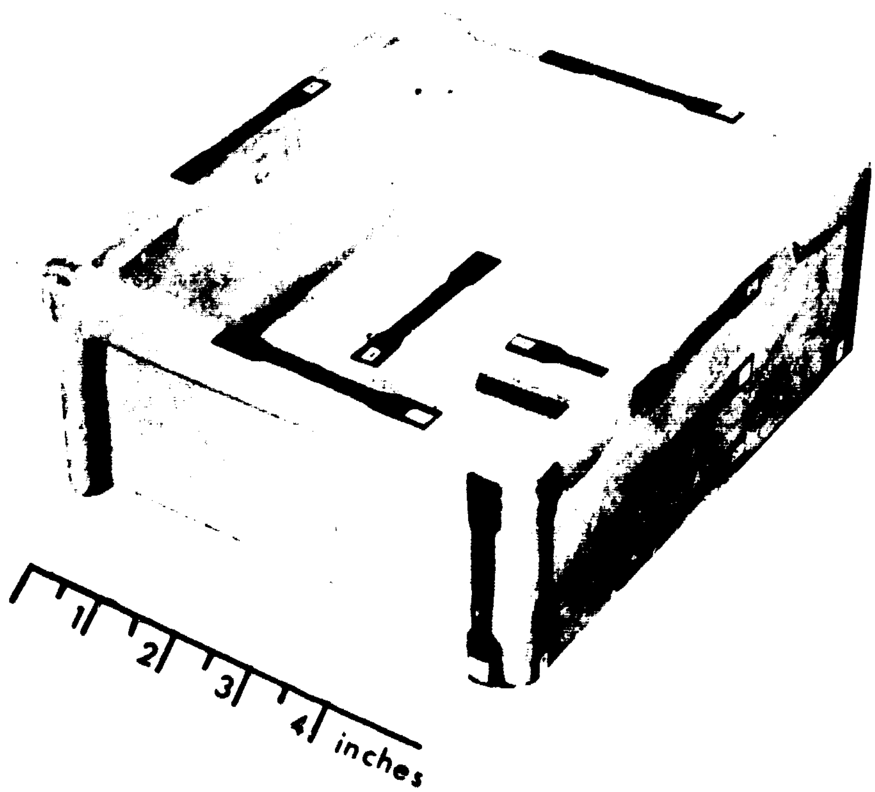

Figure 6. Test Bar Locations in Box type Casting

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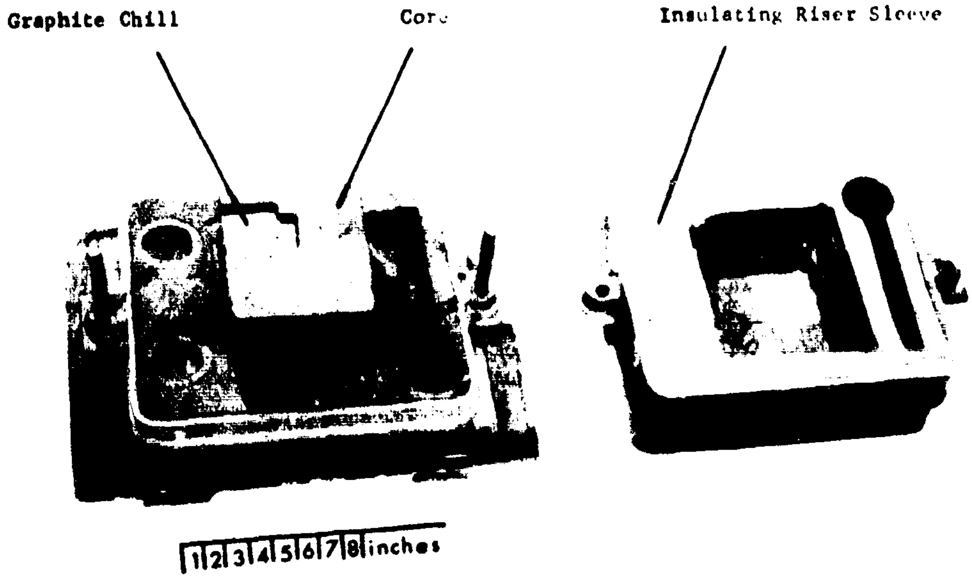

A

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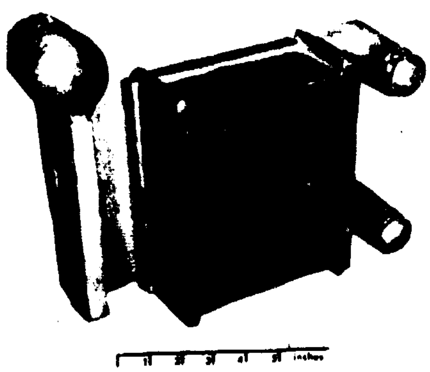

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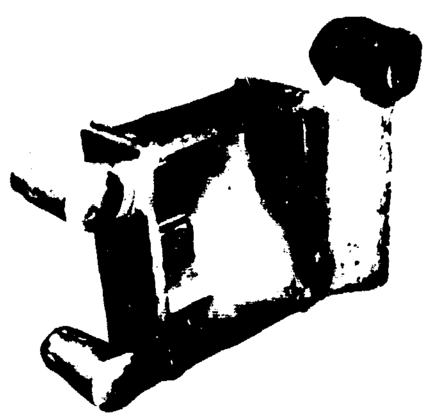

C

Figure 7. A - Mold for Producing Box type Casting with Core, Chills, and Insulating Sleeves
B - Cope view of Box type Casting showing the Rigging employed
C - Drag view of Box type Casting showing Gating and Risering employed

A mounting pad on the inside of the casting was subject to both internal and external shrinkage. This problem was alleviated by means of a graphite chill shaped to the same area as the pad. Alone, this chill was not fully successful; therefore, the outer surface of the casting in this area was thickened, as shown in Figure 7B. Both of these measures completely eliminated this problem. The top surface of the mold was generously vented to prevent the entrapment of gas on the upper surfaces. Ten test bars were cut from the casting. Their locations are shown in Figure 6.

<u>Mounting Case</u> (Figure 8). This case had approximate dimensions of 10 by 7 by 6 inches, and weighed 2-1/2 pounds. The wall thickness varied from 1/8 to 1 inch. Figure 9 (A, B, and C) shows the rigging employed. A sprue basin and fan-shaped runner, similar to those in the other castings, were employed for this part. A ring gate was used which went around the entire circumference of the casting. This casting was complicated by the presence of three "fingers," roughly three inches long by 1/2 inch diameter, projecting down from the top surface of the casting (Figure 9B). To insure proper solidification, graphite sleeves, machined to the same contour as the "fingers," were inserted into the core. The machined graphite acted as a chill, and good directional solidification was obtained in the projections.

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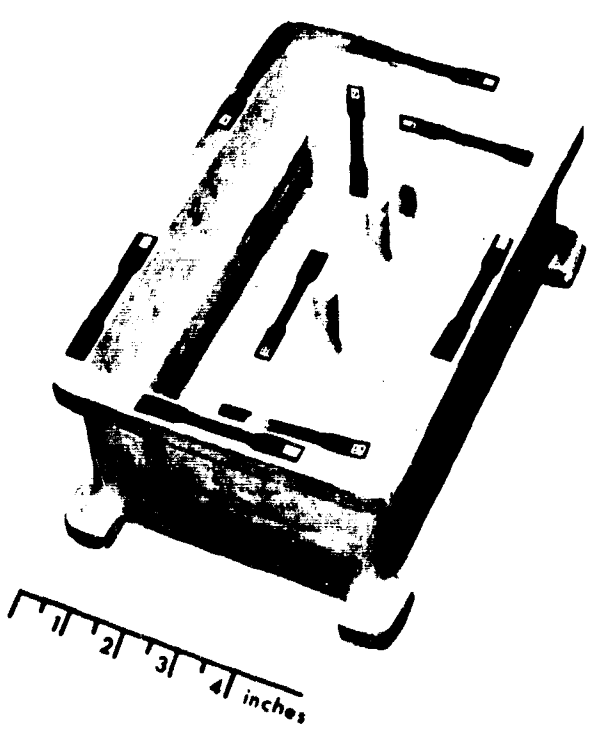

Figure 8. Test Bar Locations in Mounting Case Casting

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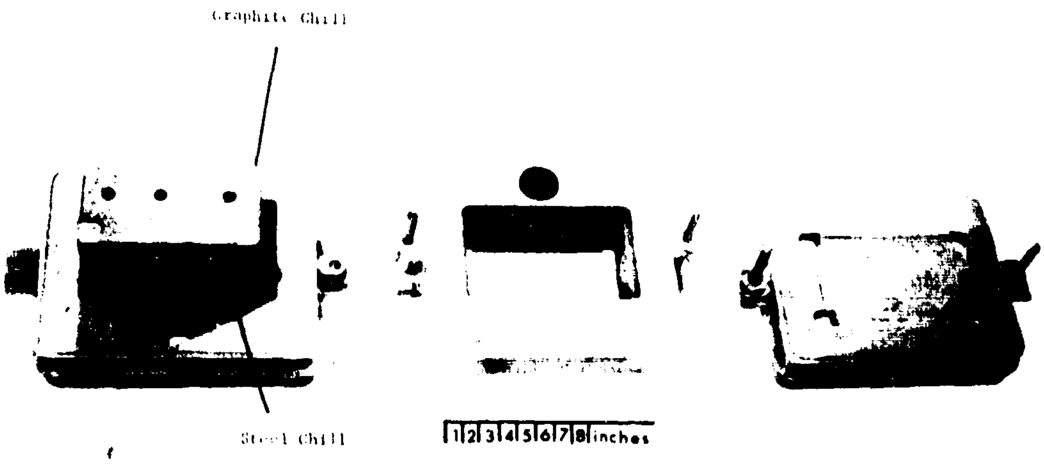

A

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Neg: 36.231.S1478/ORD.65

B

C

Figure 9. A - Mold for producing Mounting Case Casting with Core, Chills, and Insulating Riser Sleeves
B - Drag view of Mounting Case Casting showing Gating and Risering employed
C - Cope view of Mounting Case Casting showing the Rigging employed

This particular box had lugs on each corner. Unsoundness in the lugs was an anticipated problem. Several methods were used to correct this problem. The final solution was to use four blind risers, one set directly above each lug. Each riser had an insulating sleeve. In addition, machined graphite chills were inserted on the inside corners, opposite each lug, to provide directional solidification.

Two other areas in this casting presented problems. These were the heavy sections running along the middle section of the two long walls (Figure 9B). Again, to promote directional solidification, thin metal straps were inserted in the core along the entire area of the heavy section. No additional feeding was needed, and these areas were found to be sound. Ten test bars were cut from one casting. Their locations are shown in Figure 8.

Melting and Casting

To minimize turbulence caused by lip pouring, a counter-gravity pouring technique was employed. The method was a modification of a principle developed at Frankford Arsenal.[6]

A 75-lb capacity furnace was modified to accommodate the counter-gravity pouring apparatus. The crucible was a mild steel pot of the type commonly used for melting magnesium. The required weight of the alloy was charged into the crucible and a small positive argon pressure was maintained during the melting cycle. No fluxes were used. All the molds were cast by pumping the liquid metal up into the molds.

Figure 10 is a schematic illustration of the furnace. In practice, the mold was assembled on the lid of the furnace and clamped tightly in place with two mold clamps after the metal reached pouring temperature. The mold was flushed with argon gas for about five minutes, and then the flushing hole in the mold was sealed; the gas release valve was closed; the argon pressure was increased; and the molten metal was forced into the mold.

With the mold geometry, sprue opening, and furnace design employed in this investigation, it was found that a pressure of approximately two psi was necessary to provide the pressure head to completely fill the mold cavity. The pouring rate of the metal stream which enters the mold cavity is determined by the flow control valve which admits argon into the furnace. The pouring rate is controlled, to avoid turbulence, but the flow must be great enough so that the mold cavity can be completely filled before premature freezing. The pressure is maintained on the metal in the furnace for sufficient time for the casting to solidify (dwell time). The geometry of the system was arranged so that

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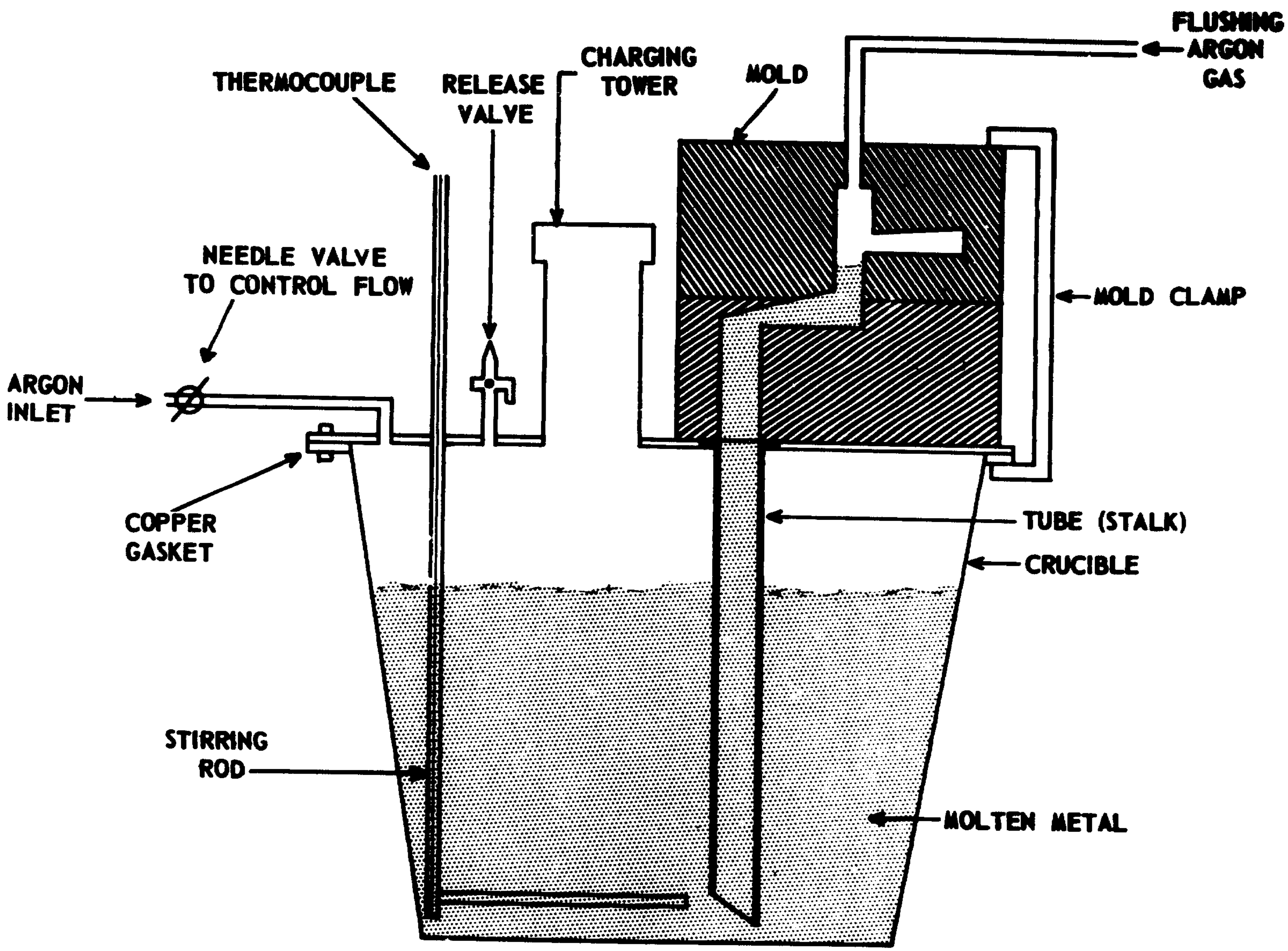


Figure 10. Schematic illustration of the Counter-gravity Pouring Apparatus with Partially Filled Mold

the metal in the stalk and in the sprue cavity of the mold would be the last to freeze. The pressure release valve is opened while the metal in these regions is still liquid and, therefore, the metal can drain back into the furnace. This permits easy separation of the mold from the furnace lid.

The drained sprue cavity may be observed in Figure 9B. The dwell time is empirically determined for each casting configuration. For these castings, a pressure of two psi, held for approximately two minutes, was found to be satisfactory for filling the mold and insuring mold-furnace separation.

To minimize turbulence, it was desirable to use the lowest pouring rate necessary to avoid misruns. The time of pour corresponding to this rate was found to be approximately six seconds, at a pouring temperature of 1350° F.

One of the major advantages of the casting technique was the fact that no fluxes were used. As a result, there was no flux entrapment in the final castings. The argon shield which protected the molten metal also served to force the metal into the mold.

Test Procedure

Mechanical properties were determined on machined standard 0.252 inch diameter tensile specimens taken from typical castings and compared with separately cast 0.505 inch diameter tensile specimens taken from the same heat of metal. The tensile specimens were tested at room temperature, using a crosshead speed of 0.05 inch/minute. Tensile strength, 0.2 percent offset yield strength, and percent elongation were measured.

Representative specimens were removed from the castings and examined metallographically. All the castings were radiographed completely. Where defects were noted on the film, sections were removed from the castings and fractured through the defects. An examination was then made of the fractured surface to determine the cause of the defect; i.e., gas, oxide, or shrinkage.

RESULTS AND DISCUSSION

Molding and Rigging

The 60-mesh graphite powder-5 percent Western bentonite-water mixture was used, without inhibitors, to form a mold into which the magnesium-lithium alloy could be cast successfully. The molding characteristics of the graphite material were similar to "green" sand. The gating system developed during this investigation was different from that used in the gravity pouring of magnesium into sand molds. This difference was not unexpected, considering the difference in pouring and the wide disparity in heat conductivity between the two types of mold. The ratio of the cross-section area of the sprue to that of the fan-shaped runner to that of the ingate was approximately 1 : 1-1/2 : 2. This ratio was arrived at empirically, but it did provide a reasonably nonturbulent flow of metal into the mold cavity.

Meting and Casting

After development of proper pressure, flow rate, and holding time, little difficulty was encountered in the production of castings by means of the counter-gravity pouring technique. The castings broke out cleanly from the mold, and there were no signs of mold-metal reaction.

Chemical analyses of the first heats of the metal showed that the silicon level was 0.29 percent Si, rather than 0.5 percent. Therefore, on subsequent heats, additional silicon was added to compensate for the losses. On the second heats, however, the silicon content was 0.94 percent. Past experience has shown that through a sufficient number of heats, the chemistry can be carefully controlled. Therefore, since the chemistry did not affect the foundry characteristics, no further time was spent on this phase of the program. Also, it has been shown that 0.5 percent Si and 0.9 percent Si magnesium-lithium alloys have approximately the same ultimate and yield strengths, although in the latter, the elongation is reduced.[3]

Test Properties

The results of the mechanical tests are shown in Tables III, IV, and V. There was little variation in the ultimate strength, yield strength, or percent elongation from casting to casting. Within the same casting, where the test bars were taken from areas of different cross section, the mechanical properties were similar. This similarity was probably due to the fact that the graphite mold material had such a high heat conductivity that the molten metal froze quickly in all the tested section sizes.

TABLE III. The Mechanical Properties of Test Bars Cut from the Alignment Bracket

Test Bar No.[a]	Strength (psi) Yield 0.28 Si	Yield 0.92 Si	Ultimate Tensile 0.28 Si	Ultimate Tensile 0.92 Si	Elongation (%) 0.28 Si	Elongation (%) 0.92 Si
1	9,100	12,800	14,500	18,300	16.0	6.4
2	b	13,200	14,400	18,700	c	5.5
3	9,300	13,200	12,200	18,700	c	7.2
4	b	12,900	14,400	18,300	15.0	5.2
5	9,900	12,600	14,100	17,300	9.0	5.5
6	b	12,700	14,200	18,400	10.0	6.5
7	9,900	13,000	15,200	18,000	15.0	6.5
8	b	13,000	15,600	19,300	23.0	6.5
d	9,800	12,900	15,100	18,500	14.0	7.0

[a]Test bar locations as shown in Figure 4..
[b]Yield strength not obtained.
[c]Broke outside gage marks.
[d]Separately cast test bars.

TABLE IV. The Mechanical Properties of Test Bars Cut from the Box type Casting

Test Bar No.[a]	Strength (psi) Yield 0.27 Si	Yield 0.83 Si	Ultimate Tensile 0.27 Si	Ultimate Tensile 0.83 Si	Elongation (%) 0.27 Si	Elongation (%) 0.83 Si
1	9,400	13,300	14,800	18,800	22.0	5.5
2	b	13,200	15,400	18,300	26.0	6.0
3	9,200	13,200	14,900	18,500	26.0	7.0
4	b	12,900	14,900	18,400	26.0	6.5
5	9,300	12,800	15,200	18,200	29.0	6.5
6	b	13,000	15,100	18,700	26.0	6.5
7	9,200	13,200	14,700	18,300	27.0	7.0
8	b	13,400	14,700	18,500	12.0	5.5
9	9,400	13,000	14,800	18,800	27.0	6.0
10	b	13,200	15,400	18,500	25.0	6.0
c	9,500	13,200	15,100	18,300	20.0	6.5

[a]Test bar locations as shown in Figure 6.
[b]Yield strength not obtained.
[c]Separately cast test bars.

TABLE V. The Mechanical Properties of Test Bars Cut from the Mounting Case

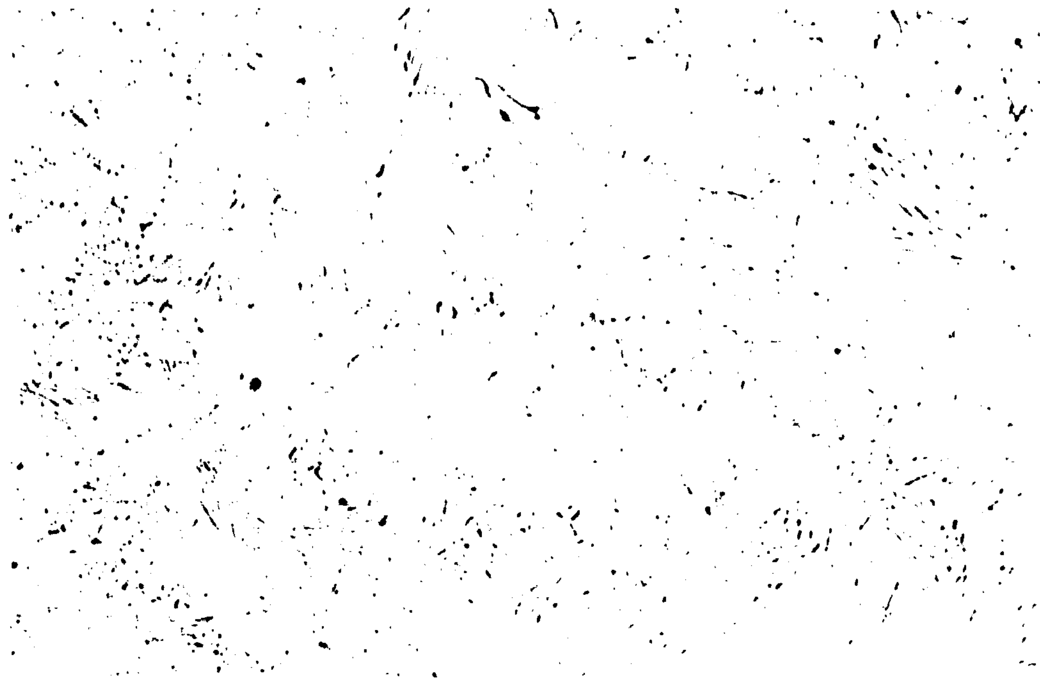
Test Bar No.[a]	Strength (psi) Yield 0.29 Si	Strength (psi) Yield 0.94 Si	Strength (psi) Ultimate Tensile 0.29 Si	Strength (psi) Ultimate Tensile 0.94 Si	Elongation (%) 0.29 Si	Elongation (%) 0.94 Si
1	9,600	13,100	15,500	18,400	24.0	6.0
2	b	13,300	15,200	18,300	17.0	6.5
3	9,600	13,100	15,300	18,400	19.0	6.0
4	b	13,400	15,400	18,500	19.0	6.0
5	9,500	13,000	15,400	18,200	34.0	6.0
6	b	13,100	15,000	18,200	26.0	6.5
7	9,600	13,300	15,500	18,500	36.0	6.5
8	b	13,200	15,400	18,600	29.0	5.5
9	9,600	13,300	15,500	13,500	30.0	6.5
10	b	13,300	15,100	18,400	36.0	6.0
c	9,700	13,600	15,400	18,700	19.0	6.5

[a]Test bar locations as shown in Figure 8.
[b]Yield strength not obtained.
[c]Separately cast test bars.

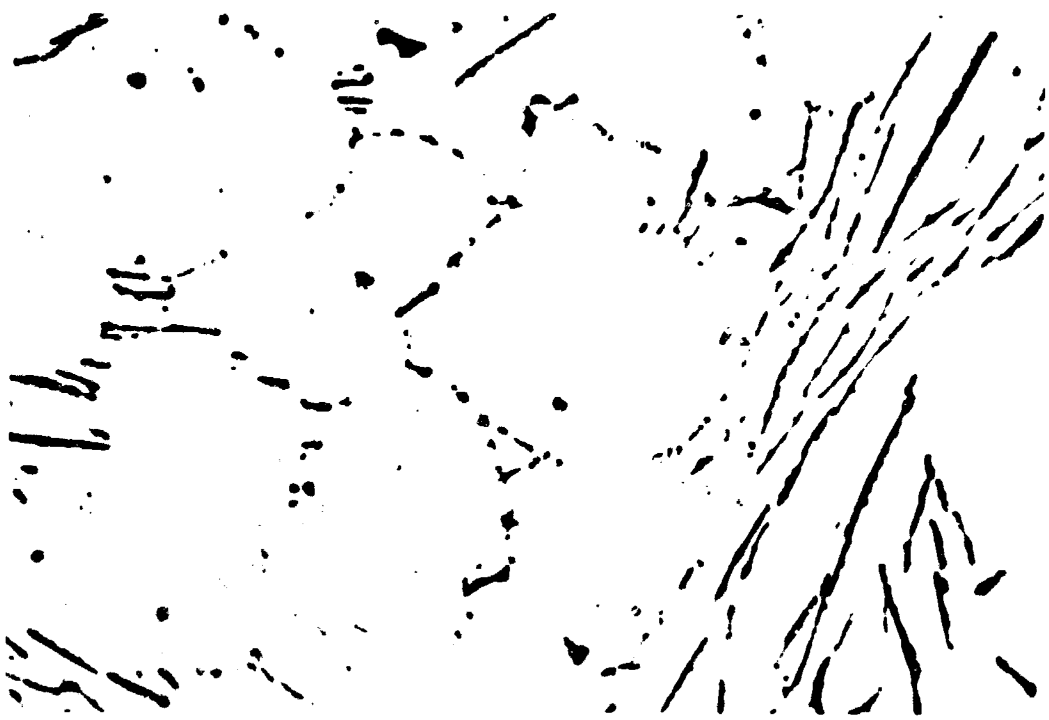
Separately cast test bars, made from the same heats as the castings, exhibited similar properties to bars cut from the castings. This condition would indicate that there was no deterioration of quality of the metal because of the casting technique. A comparison of separately cast test bars using expendable graphite molds with those made in permanent steel molds under optimum conditions showed that the latter had slightly higher properties (see "Casting Alloy"). It should be noted, however, that the permanent mold bars were not made from the same heats as the castings.

Radiographic inspection showed that the finished castings, inspected in accordance with ASTM 155-60T, equalled or exceeded Grade B of Specification MIL-M-46062(MR), 25 June 1963. Subsequent fracture tests indicated that the two major defects were entrapped gas (usually found at the top of the casting) and oxides (which were located randomly in the casting.)

All the castings exhibited the same microstructure and there was little structural change noted in the different section sizes found in the castings. A typical cast structures of Mg-14 Li-1.0 Si is shown in Figure 11. This photomicrograph shows a radiating eutectic phase. This is believed to consist mainly of Mg_2Si.



100X Nital etch



500X Nital etch

Figure 11. Typical Microstructures of the Casting investigated in the As-cast Condition

CONCLUSIONS

1. Shaped castings of magnesium-lithium components (with design features anticipated in space vehicles) can be produced in an expendable noninhibited mold made of graphite particles bonded with bentonite and water.

2. Castings can be produced relatively free of inclusions and entrapped gas bubbles by means of the counter-gravity technique of pouring.

3. A high and uniform level of mechanical properties was obtained in test bars cut from castings. These sound castings were produced by using conventional risering and chilling practices in combination with the counter-gravity pouring technique.

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13. ABSTRACT

A process has been developed for successfully casting a number of prototype aerospace components using the ternary magnesium-lithium-silicon alloy. These components contained many of the design elements anticipated in aerospace hardware of this type.

It was found that conventional magnesium sand foundry practice was not satisfactory. A new molding material, based upon bentonite-bonded graphite powder, was employed. Melting and pouring practice was also modified to cope with the reactive nature of the alloy

The radiographic quality of the castings and mechanical properties of test bars section from the castings were evaluated and found to be satisfactory and to correspond with earlier experience on separately cast test bars.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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