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PROPERTIES OF SAND-CAST MAGNESIUM ALLOYS

Part VIII: Foundry Characteristics of Magnesium-Zinc-Silver-Zirconium Casting Alloys

B. LAGOWSKI & J. W. MEIER

PHYSICAL METALLURGY DIVISION

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PROPERTIES OF SAND-CAST MAGNESIUM ALLOYS.

Part VIII: Foundry Characteristics of Magnesium-Zinc-Silver-Zirconium Casting Alloys

by

B. Lagowski* and J. W. Meier**

ABSTRACT

In continuation of earlier work, additional casting alloys were developed in the magnesium-zinc-silver-zirconium system to achieve the optimum combination of mechanical properties and foundry characteristics. In particular, some work was directed to the production of thin-walled premium-quality castings.

The effects of section thickness, heavy chilling, and hot water quenching after solution treatment on the mechanical properties of high-strength magnesium casting alloys were investigated. Results of a study of foundry characteristics, including hot tearing, fluidity (castability), susceptibility to microshrinkage, linear shrinkage and density, are reported.

It was found that alloy ZQ91-T6 shows great promise for applications in more complex, and especially in thin-walled castings.

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Direction des mines

Rapport de recherches R 161

PROPRIÉTÉS DES ALLIAGES DE MAGNÉSIUM COULÉS EN SABLE

8e partie: Caractéristiques de fonderie des pièces moulées en alliages de magnésium-zinc-argent-zirconium

par

B. Lagowski* et J. W. Meier**

RÉSUMÉ

Comme suite à des travaux antérieurs, les auteurs ont mis au point d'autres alliages de fonderie, du système meilleure combinaison de propriétés mécaniques et de caractéristiques de fonderie. Certains travaux ont en particulier visé à la production de pièces moulées à parois minces de haute qualité.

Les effets de l'épaisseur de la paroi, du refroidissement rapide, et de la trempe en eau chaude après homogénéisation sur les propriétés mécaniques des alliages de magnésium à haute résistance pour pièces moulées, ont été étudiés. Les auteurs rendent compte des résultats d'une étude sur des caractéristiques de fonderie, y compris la formation de criques à chaud, la fluidité (coulabilité), la tendance aux micro-retassures, le retrait linéaire et la densité.

Les auteurs ont découvert que l'alliage ZQ91-T6 semble très prometteur pour les pièces moulées très complexes et spécialement celles à parois minces.

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Ce rapport a été présenté comme étude au 69e Congres de l'"American Foundrymen's Society", le 10 mai 1965, à Chicago, Ill.

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INTRODUCTION

The first phases of Canadian work on the development of magnesium-zinc-silver-zirconium casting alloys were reported earlier[1,2] and results of some preliminary work on the application of these alloys to premium-quality castings were presented[3,4]. Silver additions were shown to decrease the solubility of zirconium in molten magnesium without affecting the resultant grain size and some of the alloys showed exceptionally high tensile properties with good ductility.

Further work included a study of properties of additional alloy compositions[5], an investigation on some foundry characteristics of the most promising alloys, and an evaluation of the properties of these alloys in premium-quality castings of various section thicknesses.

PREMIUM-QUALITY CASTINGS

"Premium-quality" implies not only an excellent internal quality of a casting with accompanying high mechanical properties, but most importantly a high product integrity, that is, reliability of properties in designated areas of each and every single casting, which are guaranteed by the foundry[6].

In an earlier investigation[3] some of the factors affecting the achievement of high mechanical properties were reviewed, including the effects of modifications in heat treatments, cooling rate from solution temperature, section size, distance from chill, etc. In the present paper, additional work is reported, which was carried out to extend some of the former results to the ZQ-type alloys; to study further the effect of section thickness and hot water quenching on the mechanical properties of high-strength magnesium casting alloys; and to use some of the ZQ-type alloys in the development of a thin-walled premium-quality test casting.

Plate Castings

Materials and experimental procedures used were the same as described in an earlier paper[3] and only modifications in casting or heat treating conditions, introduced in the present investigation, will be reported.

Heavy chilling was used to obtain favourable solidification conditions to improve mechanical properties in 1- and 2-inch-thick plates cast in various commercial magnesium alloys (Tables 7 and 8, and Figures 7 to 9 in the earlier paper[3]). Similar 2-inch-thick plates were cast in alloys ZK61, ZQ64, ZQ71 and ZQ91, and heat treated using a boiling water quench instead of the standard air blast cooling after solution treatment.

Effect of End-Chilling and of Hot Water Quenching

Tensile properties, obtained using boiling water quench in the heat treatment, at various distances from the chilled end, are presented in Figure 1. Selected experimental ZQ-type alloys show superior properties at short distances from the chill, but somewhat faster ratio of property decrease in the proximity of the riser.

Tables 1 and 2 compare the mechanical properties of alloys ZK61[a] and ZQ64[b] as affected by the difference in cooling rates from solution temperatures, obtained by cooling in a forced air blast and quenching in boiling water. The results obtained on separately-cast test bars are shown in Table 1, and those obtained on test bars cut from end-chilled 2-inch-thick plates are given in Table 2. Although, as would be expected, the improvement in properties is marked, the more drastic quenching should be avoided in complex casting shapes, where introduction of internal stresses or warping may be harmful.

(a) The heat treatments for alloy ZK61 were:
T6C - 5 hr at 500 °C (930 °F), air blast cooling, 48 hr ageing at 130 °C (265 °F).
T6E - the same, substituting a boiling water quench for air blast cooling.

(b) The heat treatments for alloy ZQ64 were:
T6A - 5 hr at 450 °C (840 °F), air blast cooling, 48 hr ageing at 130 °C (265 °F).
T6E - the same, substituting a boiling water quench for air blast cooling.

Effect of Section Thickness

Thin section plate castings were prepared (1/8-, 1/4- and 1/2-inch thicknesses) without chilling and the tensile properties obtained are presented in Table 3. This table includes, for comparison, properties obtained on separately-cast test bars and from end-chilled 2-inch-thick plates.

As may be seen from Table 3, the results indicate that, if the metal solidifies under favourable conditions, excellent properties can be obtained in all seven alloys regardless of section size (1/8- to 2-inch thicknesses), and that most results obtained on test bars cut out of castings are equal to, or better than, those obtained on separately-cast test bars.

The results in Table 3 for alloys AZ91, AZ92, QE22 and ZK61 show that the minima for Class 1 areas required in the U. S. Military Specification for High-Strength Magnesium Alloy Castings MIL-M-46062 (MR), dated 25 June 1963, are realistic and can be met if proper solidification conditions are provided.

FOUNDRY CHARACTERISTICS

Since the alloy development phase of the work on the Mg-Zn-Ag-Zr alloy family was carried out on cast-to-shape test bars, detailed foundry characteristics of these alloys could not be determined. Limited data[4] on mechanical properties in some ZQ64-T6 alloy castings were available and additional information on fluidity, hot shortness and susceptibility to microshrinkage was obtained during work on thin-walled premium-quality castings. However, this was based on incidental observation rather than systematic study.

Determination of foundry characteristics is always controversial and many different testing methods have been developed. Thus, in most cases a meaningful comparison of results from different tests, especially in the fields of fluidity (castability) and hot tearing, is difficult if not impossible. It is not the aim of this paper to evaluate critically various testing methods. The only reason for using the particular test methods described here is that they were available from earlier work at these laboratories, where they had been found to give satisfactory results.

Hot Tearing

The evaluation of the hot tearing tendency of the various alloys was carried out as in earlier work[7] at these laboratories. The rating of each particular alloy was based on the length of cracks formed in a cast ring (Design C in the earlier paper) having a constant 8-inch outside diameter and various wall thicknesses. The rings were cast in standard green sand moulds, using CO_2-hardened cores. The pouring temperatures were chosen to achieve a superheat of 125°C (225°F) above the liquidus temperature of each particular alloy. In order to check the present test results with those obtained in the earlier work, three AZ-type alloys and a ZK61 alloy were included in the present series. The results agreed with those of the earlier work.

The present tests showed that the hot-shortness of the three Mg-Zn-Ag-Zr alloys investigated is similar to that of ZK61. The AZ-type alloys and alloy QE22 are much less sensitive to hot tearing, since they are subject to eutectic healing. Based on these tests, the following classification of alloys, in increasing order of susceptibility to hot tearing from Class 1 to 3 (and from left to right in these classes) can be made:

Class 1: A10, AZ91, AZ92

Class 2: QE22

Class 3: ZQ91, ZK61, ZQ71, ZQ64

Fluidity (Castability)

Two methods of measuring the castability, or ability of the metal to flow freely in the mould cavity, were used. The first was based on the conventional fluidity spiral in green sand, as proposed by Saeger and Krynitsky(8) and modified for magnesium alloys by Carapella and Shaw(9); the second was carried out according to Kondic(10).

1. Spiral Fluidity Test. The spiral was gated as described by Carapella and Shaw(9) and a standard green sand mixture for magnesium alloys was used. The pouring temperature for all alloys was arbitrarily chosen at 750 °C (1380 °F). The results are listed in Table 4 in order of increasing fluidity. Alloy ZQ91 showed the best fluidity rating in the group of high-strength alloys.

2. Castability Test According to Kondic[10]. This test determines the fluidity characteristics of the alloy by its ability to fill a mould consisting of a central sprue connected with six flat channels of varying thickness (0.030 to 0.080 in.). The moulds were prepared in CO_2-hardened sand and the pouring temperature was arbitrarily chosen for all alloys at 780 °C (1435 °F).

Each of the alloys investigated entered the thinnest channel (0.030 in.); however, only the most fluid alloys (ZQ91, AZ92 and A10) completely filled the full length of the thickest channel (0.080 in.). The results in Table 5 represent the total length of all channel sections measured from the sprue to the farthest tip of the metal, and again are listed in order of increasing fluidity.

The behaviour of the various alloys in this test is similar to that in the spiral fluidity test, with the exception of the very much poorer performance of alloy ZQ64 and the somewhat inferior position of alloy ZQ71. This apparent discrepancy in the "fluidity" results could be explained by the difference in the nature of the two tests. Again the favourable performance of alloy ZQ91 should be noted.

X-Ray Soundness Rating

One of the most desirable characteristics of an alloy is its ability to solidify without the occurrence of microshrinkage. This characteristic is generally assessed by actual foundry experience with castings of various shapes and sizes. The extent of unsoundness in various casting sections is determined by X-ray examinations. However, it is important to realize that a clear radiograph (no visible defects) does not guarantee highest premium-quality properties, which can be obtained only when the proper solidification (grain size, dendritic cell size, micro-constituents) and heat treating (microsegregation) conditions prevail(6). Very fine porosity can escape detection by radiography, in which case fracture tests and/or metallographic examination are a very useful supplementary check on quality.

The occurrence of microshrinkage is, as stated above, dependent on solidification conditions and particularly on thermal gradients. Thus, an "X-ray soundness" rating based on casting a simple shape entailing gradually decreasing thermal gradients, with radiographic determination of the amount of "visible" microshrinkage, was adopted. An end-chilled 6 x 12 x 1 in. plate was chosen for this purpose, gated and risered as described by Flemings et al(11). A typical reproduction of a radiograph of the plate is shown in Figure 2.

The distance between the chilled end of the plate and the start of microshrinkage, measured on the radiograph, is given as the rating of the alloy. Thus the higher the value of the rating (to a maximum of 12) the less susceptible is the alloy to microshrinkage. The results of the determinations are presented in Table 6 in order of decreasing susceptibility to microshrinkage. It should be noted that these ratings are based on average results obtained in repeated tests, which were, in general, very reproducible for any given alloy.

It is realised that the "X-ray soundness" rating is not an absolute value, but only a relative assessment of the alloys based on the evaluation of the radiographs. The zirconium-containing alloys show a high X-ray density contrast, which enables the onset of microporosity to be readily detected. In aluminum-containing alloys, this contrast is lower and the picture is obscured by mottling effects in the area of larger grain size (adjacent to the riser).

Nelson[12] divides magnesium alloys into four groups in increasing order of microshrinkage tendency: (1) AZ91C, AZ92A; (2) ZH62A, HK31A; (3) EK31A, QE22A; and (4) ZK51A, ZK61A. The present ratings (see Table 6) confirm his findings.

The results of this test confirm the known insensitivity to microporosity of alloys A10 and AZ91, the good behaviour of QE22, and the known susceptibility to microporosity of ZK51 alloy. Alloy ZQ91 rates the highest of any of the high-strength zirconium-containing alloys.

When discussing "unsoundness" it should be realized that there are two factors: one is the susceptibility of the alloy to unsoundness, and the other is the effect of a certain degree of unsoundness on the mechanical properties of the alloy, which may be termed the sensitivity to unsoundness. Burns[13] showed on AZ-type alloys examples in which these two factors are to some extent compensating. The "sensitivity to unsoundness" was not investigated in this phase of the work.

Linear Shrinkage

Linear shrinkage (or pattern shrinkage) of the alloys was measured, at room temperature, on sand-cast tapered bars, 48-in. long, as described by Busk and Marande(14). The results obtained for the various alloys are listed in Table 7.

The high value obtained for alloy QE22 is in agreement with the known behaviour of rare earths-containing magnesium alloys that show higher shrinkage than those containing aluminum or zinc as their main alloying elements(15). Linear shrinkage figures for ZQ-type alloys are very similar to those of the AZ-type alloys. The lowest shrinkage is shown for alloy ZQ91.

Density

Although density is hardly a foundry characteristic, average density values are listed because of their possible importance to the designer and user of castings. The results given in Table 8 were determined on sound casting sections. As expected, alloys with the higher total alloying content of heavy metals, such as zinc and silver, show the highest density.

THIN-WALLED TEST CASTING

To check the results obtained on separately-cast test bars and plate castings, some additional work was carried out on a thin-walled test casting, designed and used by Iler[16]. This test casting incorporates various cross-sections from 1/8 to 3/4 inch. Figures 3 and 4 show the casting with gates and risers developed at our Experimental Foundry. Alloys used in this part of the investigation were: ZK61-T6, QE22-T6 and several experimental alloys of the Mg-Zn-Ag-Zr system: ZQ52-T6A, ZQ64-T6A, ZQ71-T6A, ZQ91-T6A and ZQ101-T6A.

Experimental Procedures

Melting and alloying procedure for the above test castings was carried out as described earlier[3]. The metal was poured into heavily chilled green sand moulds at temperatures from 830 to 850 °C (1525 to 1560 °F). Burning of metal at these high temperatures was controlled by dusting of a sulphur-boric acid-fluoborate mixture.

The test castings and separately-cast control test bars were heat treated at temperatures indicated in Table 9. The castings and the test bars were separately suspended in the furnace and solution heat treatment was carried out under the protection of at least 1% SO_2 atmosphere. Cooling from the solution temperature was carried out by uniformly directed air stream from a high-speed electric fan.

Evaluation of Test Castings

Table 10 lists the results of chemical analyses for the alloying elements and the average results of tensile tests carried out on separately-cast test bars, cast and heat treated in each melt with the test castings for evaluation of the melt quality.

All test castings were radiographed, using three exposure times to obtain maximum contrast in each section thickness. All castings (in each alloy) showed freedom of porosity in locations 1 to 5 (see Figure 5). Table 11 shows the amount of porosity observed in locations 9 and 10 (3/4 in.-thick section next to the risers), and in the 1/8 in. section (locations 6 to 8). No hot tearing or cracking was observed in any of the castings. All test castings were cut into test bar coupons according to Figure 5 and Table 12 shows the dimensions of machined test bars.

The results of tensile tests carried out on the test bars cut out of the castings are listed in Table 13. The results of some test bars, showing small flaws in the fracture, were discarded. This was done to avoid misrepresentation of the effect of tiny defects that significantly affect properties of sub-standard size test bars but would not necessarily affect the results of a break-down (or other simulated service) test of the whole casting. The properties for alloy QE22-T6 were not included in Table 13 because they were rather low and not typical for this alloy* and the time allotted to this investigation was not sufficient to duplicate the castings.

*It is suspected that the response to ageing was at fault, as indicated by low yield strength and high elongation values.

Discussion of Results

In the design of gating, risering and chilling, an attempt was made to secure optimum solidification conditions, particularly for heavier sections. The large chill in the middle of the casting (Figure 4) and the two risers help to establish high thermal gradients for Sections 1 to 5. Two small chills at the end of Sections 9 and 10 increase the thermal gradients with the predominant solidification direction being perpendicular to that for Sections 1 to 5. A well at the end of the 1/8 in. section is beneficial to the establishment of a directional solidification pattern a difficult thing to achieve in such thin and relatively large sections.

Alloys ZK61 and ZQ71 showed the greatest tendency to form microporosity in the test casting, as revealed by radiographic examination; QE22 was porosity-free with the exception of the 1/8 in. section; alloys ZQ91 and ZQ101 showed complete freedom from porosity. Alloy ZQ91 also indicated the best fluidity of these alloys.

Tensile properties obtained on test bars cut from castings (listed in Table 13) show that, although the material is free from defects visible under radiographic examination, the fractures of test bars sometimes show minute inclusions, mostly oxide skins, which may lower the properties of the test bar to a much greater degree than they would affect the properties of the whole casting.

The highest properties were obtained in locations 1, 2, 3, 4 and 5 (in section thicknesses of 3/4, 1/2, 3/8 and 1/4 in.), followed by those in locations 9 and 10 (3/4 in. section); the lowest results were obtained in

1/8 in. sections, with the exception of alloy ZQ91, which showed exceptionally high properties in these sections. The level of properties seems to depend on solidification conditions, if the material is sound, and on the distribution and amount of microporosity, if it is unsound.

It is interesting to note that the yield strength in location 7 (middle of 1/8 in. section) is very high in alloys ZK61, ZQ64, ZQ91 and ZQ101 (43.2 kpsi for ZQ64 alloy). It should also be noted that the values for yield strength are the highest and most uniform in alloys ZQ71. ZQ91 and ZQ101.

The highest ultimate tensile strength values were obtained in ZQ 64, ZQ91 and ZQ71 alloys. The highest ductility was obtained in ZQ52, ZQ64 and ZK61 alloys, followed by ZQ71 and ZQ91 alloys.

In the general analysis of results obtained in various alloys, three alloys seem to warrant special attention: alloys ZQ64 and ZQ71 for castings where very favourable solidification conditions are easily secured, and alloy ZQ91 when excellent properties are required in thin (1/8 in.) sections. If further work confirms these characteristics, ZQ91 alloy could be an excellent choice for difficult castings, particularly with thin sections.

CONCLUSIONS

1. The use of boiling water quenching in ZK61 and ZQ-type alloys increases the strength of these alloys without affecting their ductility.

2. Results of tensile tests carried out on cast plates of different thickness show that, if the metal solidifies under favourable conditions, excellent properties can be obtained regardless of section size.

3. A limited study of foundry characteristics of some Mg-Zn-Ag-Zr alloys showed very promising fluidity and X-ray soundness ratings for alloy ZQ91.

4. Development work on a thin-walled test casting showed good adaptability of the Mg-Zn-Ag-Zr alloys to their use in premium quality castings, and especially confirmed the remarkable properties obtained in thin casting sections in alloy ZQ91-T6.

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TABLE 1

Effect of Cooling Rate from Solution Temperature on Properties of Separately-Cast Test Bars

Alloy Designation	UTS, kpsi	0.2% YS, kpsi	El,% in 2 in.	Cooling Rate
ZK61-T6C	46.8	32.5	11.0	Cooled in air blast
ZK61-T6E	48.2	35.0	10.0	Quenched in boiling water
ZQ64-T6A	48.9	34.3	10.5	Cooled in air blast
ZQ64-T6E	50.6	36.2	10.0	Quenched in boiling water

TABLE 2

Effect of Cooling Rate from Solution Temperature on Properties of Castings*

Alloy Designation	UTS, kpsi	0.2% YS, kpsi	El% in 2 in.	Cooling Rate
ZK61-T6C	46.5	31.3	18.0	Cooled in air blast
ZK61-T6E	47.5	33.2	15.0	Quenched in boiling water
ZQ64-T6A	50.1	33.8	7.0	Cooled in air blast
ZQ64-T6E	50.8	35.4	10.0	Quenched in boiling water

* Test bars cut from end-chilled 2-inch-thick plates (adjacent to chill).

TABLE 3

Properties of Premium-Quality Magnesium Alloy Castings

(Effect of section thickness)

Alloy Designation	Test Casting*	UTS, kpsi	0.2% YS, kpsi	El,% in 4D
AZ91-T6	A	42.2	21.1	4.5
	B	41.2	23.8	6.5
	C	41.4	22.4	5.0
	D	41.3	21.0	5.5
	E	44.9	21.1	6.5
AZ92-T6	A	43.7	24.8	2.5
	B	45.1	27.5	4.0
	C	42.9	26.8	3.5
	D	45.1	25.7	3.0
	E	46.3	29.1	3.0
QE22-T6	A	40.7	31.3	3.5
	B	38.8	31.0	2.0
	C	38.8	31.1	2.0
	D	40.3	29.9	4.5
	E	42.3	30.8	4.5
ZK61-T6	A	46.8	32.5	11.0
	B	46.6	33.6	8.0
	C	47.4	31.4	7.5
	D	46.4	31.3	15.0
	E	46.5	31.3	18.0
ZQ64-T6	A	48.9	34.3	10.5
	B	49.9	35.6	12.5
	C	47.8	34.5	7.5
	D	50.7	33.7	9.5
	E	50.8	35.4	10.0
ZQ71-T6	A	49.2	36.9	7.5
	B	47.8	36.7	7.0
	C	48.9	35.0	8.0
	D	49.3	34.4	10.0
	E	50.0	36.0	13.5
ZQ91-T6	A	49.8	36.7	9.0
	B	49.9	34.8	8.5
	C	48.2	33.9	5.5
	D	48.4	33.8	7.5
	E	50.9	34.9	13.5

* A - Cast-to-shape test bar (0.5 in. diameter).
B - 1/8 in.-thick unchilled plate.
C - 1/4 in.-thick unchilled plate.
D - 1/2 in.-thick unchilled plate.
E - 2-inch-thick end-chilled plate.

TABLE 4

Results of Spiral Fluidity

Alloy	Length of Spiral, inches
ZK61	16.3
QE22	16.8
ZQ64	21.0
AZ91	22.7
ZQ71	23.3
ZQ91	24.4
AZ92	25.4
A10	25.8

TABLE 5

Results of Mould Filling Test

Alloy	Total Length of Cast Sections, inches	Remarks
ZQ64	14	
ZK61	14.3	
QE22	14.3	
ZQ71	15.4	
AZ91	16.2	
ZQ91	16.3	0.080 in. channel filled completely
AZ92	17.4	" " "
A10	17.8	" " "

TABLE 6

X-Ray Unsoundness Rating

Alloy	Microporosity Rating, inches
ZK61	2.5
ZQ71	3.8
ZQ64	7
ZQ81	7
AZ63	7.7
QE22	8
ZQ91	8.6
AZ92	10.5
AZ91	12
A10	12

TABLE 7

Linear Shrinkage

Alloy	Linear Shrinkage	
	%	in./ft
QE22-F	1.50	0.180
ZK61-F	1.30	0.156
AZ91-F	1.20	0.144
AZ92-F	1.17	0.140
ZQ64-F	1.17	0.140
ZQ71-F	1.14	0.137
ZQ91-F	1.11	0.133

TABLE 8

Density of Sand-Cast Magnesium Alloys

Alloy	g/cm^3	lb/in.^{3}
ZQ64	1.91	0.0690
ZQ91	1.90	0.0687
ZQ71	1.87	0.0676
ZK61	1.83	0.0661
AZ92	1.83	0.0661
QE22	1.82	0.0658
AZ91	1.82	0.0658

TABLE 9

Heat Treatment of Test Castings

Alloy	Solution Heat Treatment			Ageing		
	Temperature		Time, hr	Temperature		Time, hr
	°C	°F		°C	°F	
QE22-T6*	535	995	8	200	390	8
ZK61-T6	510	950	2	130	265	48
ZQ52-T6	500	930	5	130	265	48
ZQ64-T6	450	840	5	130	265	48
ZQ71-T6	470	880	5	130	265	48
ZQ91-T6	405	760	5	130	265	48
ZQ101-T6	385	725	5	130	265	48

* Quenched in water at 60°C (140°F); all other alloys were cooled by air blast.

TABLE 10

Chemical Composition and Tensile Properties of Separately-Cast Test Bars

Melt No.	Alloy	Zn, %	Ag, %	RE, %	Zr sol., %	Averages of 4 bars UTS, kpsi	0.2% YS, kpsi	El, % in 2 in.
5104	QE22	-	2.34	2.08	0.52	41.0	29.4	8.0
5111	ZK61	6.24	-	-	0.76	46.9	32.8	10.5
5121	ZQ52	4.95	2.11	-	0.84	46.8	31.6	14.5
5115	ZQ64	5.86	4.24	-	0.79	49.9	35.1	9.0
5117	ZQ64	5.86	4.17	-	0.79	49.4	35.4	8.0
5122	ZQ71	7.03	1.11	-	0.88	50.0	35.3	8.5
5124	ZQ91	8.77	1.26	-	0.83	49.0	34.9	8.0
5132	ZQ91	9.01	1.04	-	0.84	47.6	34.5	6.0
5139	ZQ101	9.82	1.03	-	0.72	46.7	35.1	3.0

TAPLE 11

Amount of Porosity in Test Castings

Alloy	Porosity in Locations 9 and 10	Porosity in Locations 6, 7 and 8
ZK61	Very light	Moderate
ZQ71	Very light	Moderate
ZQ52	Faint	Light
ZQ64	Faint	Light
QE22	None	Light
ZQ91	None	None
ZQ101	None	None

TABLE 12

Dimensions of Machined Test Bars

Test Bar Location	Test Coupon: Wall Thickness, in.	Test Coupon: Total Length, in.	Grips: Section, in.	Gauge: Section, in.	Gauge: Length, in.
1, 9, 10	3/4	7	0.75 dia.	0.505 dia.	2
3	1/2	3-3/4	0.5 "	0.313 "	1-1/4
5	3/8	3	0.375 "	0.250 "	1
2,4	1/4	5-1/2	0.75x0.25	0.5x0.25	2
6, 7, 8	1/8	5-1/2	0.75x0.125	0.5x0.125	2

TABLE 13

Tensile Properties of Test Bars Cut from Castings

Alloy		UTS, kpsi	0.2% YS, kpsi	El, % in 4D
ZK61-T6C	Ave (18)	44.6	32.3	9.0
	Max	47.4	38.6	20.0
	Min	42.6	29.6	5.0
ZQ52-T6A	Ave (8)	43.7	28.2	12.0
	Max	45.1	31.5	17.0
	Min	42.0	24.8	7.5
ZQ64-T6A	Ave (16)	48.1	34.3	9.5
	Max	51.2	43.2	16.0
	Min	44.4	28.1	5.0
ZQ71-T6A	Ave (9)	46.3	33.4	8.0
	Max	49.3	35.0	16.5
	Min	41.8	31.8	2.0
ZQ91-T6A	Ave (16)	48.0	34.9	6.5
	Max	50.6	39.9	10.5
	Min	43.1	32.6	5.0
ZQ101-T6A	Ave (10)	44.8	36.0	4.5
	Max	47.8	39.7	8.0
	Min	41.6	32.5	2.0

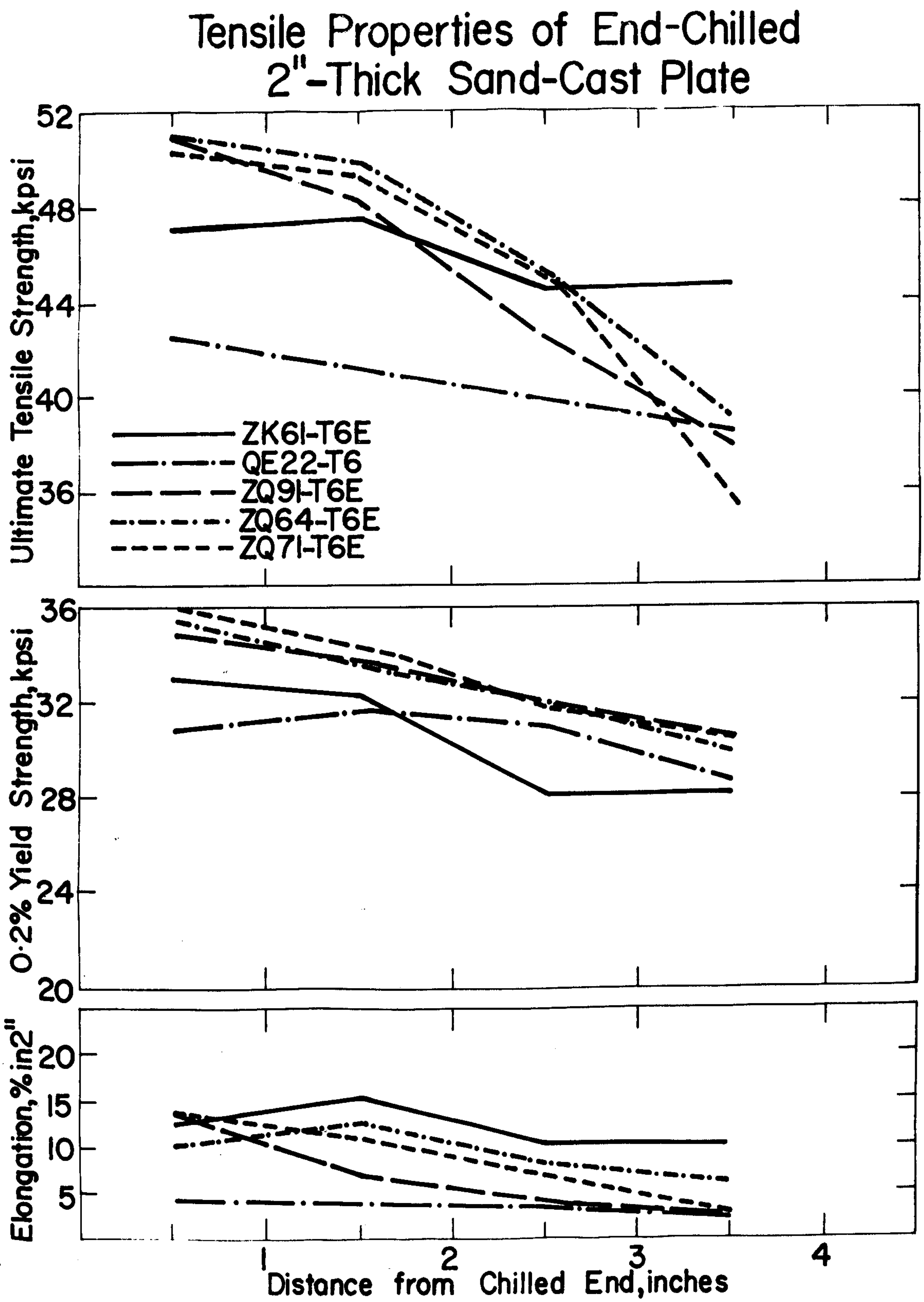
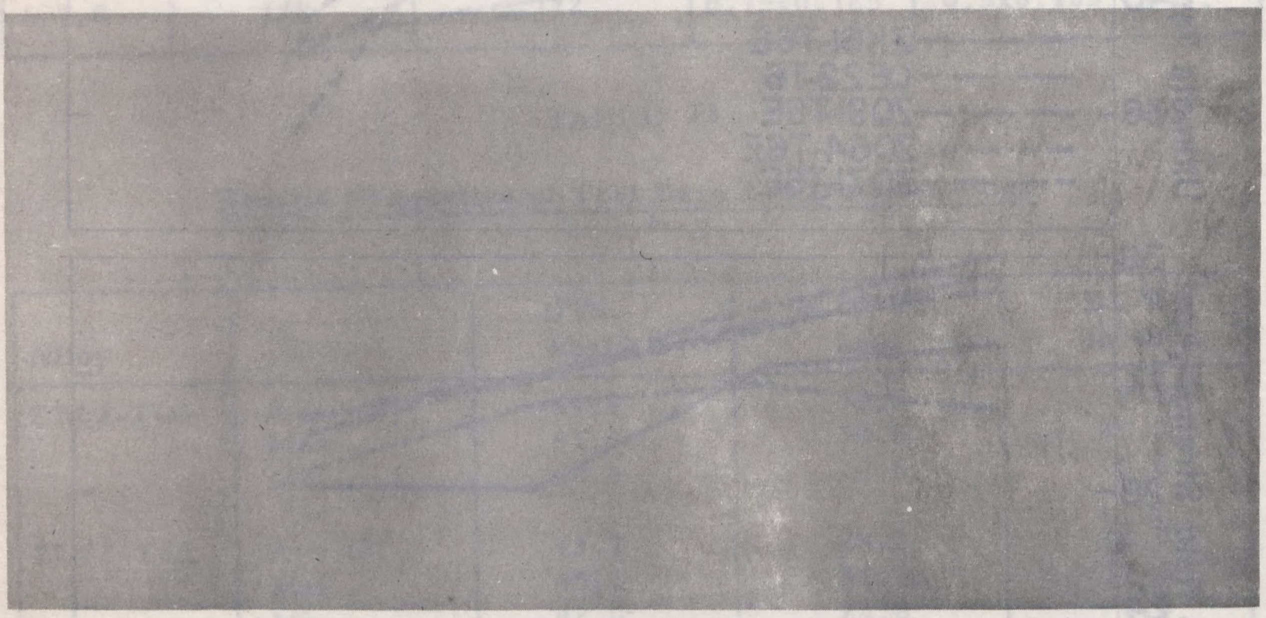


Figure 1. Tensile properties of end-chilled, 2-inch-thick sand-cast magnesium alloy plates.



Chill Riser

Figure 2. Typical reproduction of radiograph (QE22 alloy), approx. 1/2 size.

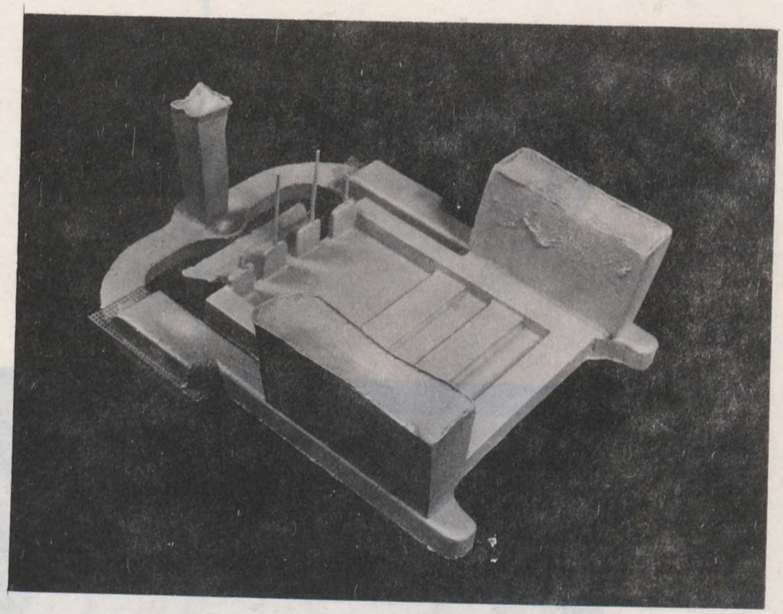


Figure 3. Top view of test casting.

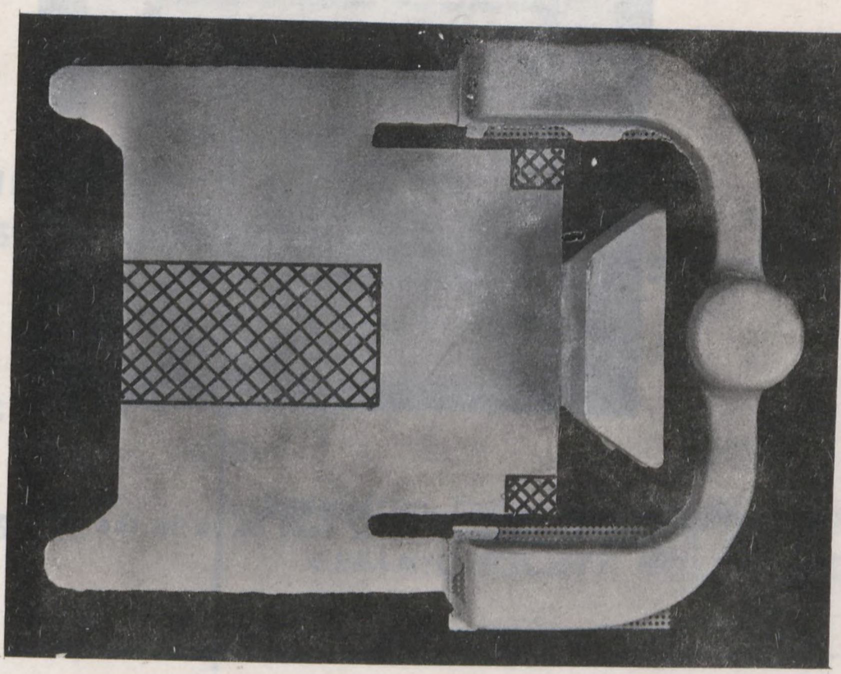


Figure 4. Bottom view of test casting.

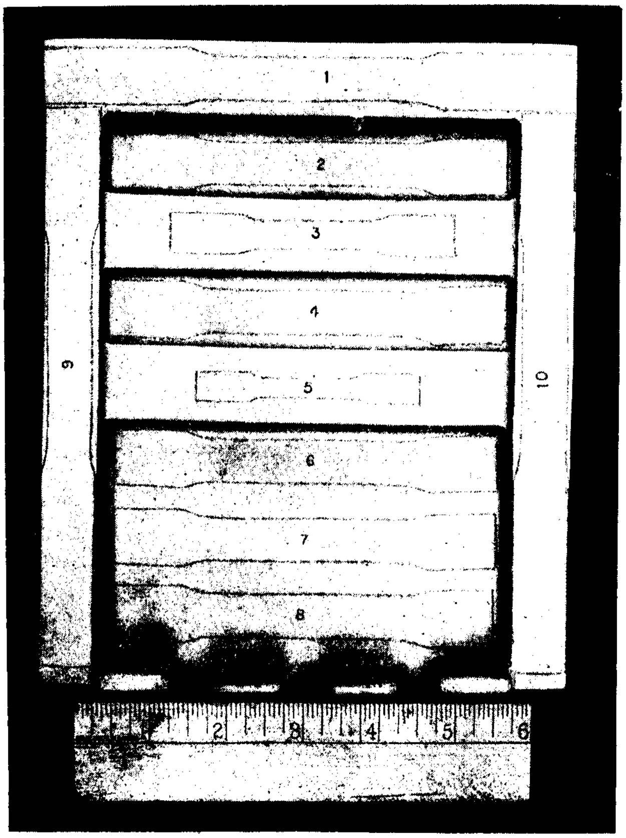


Figure 5. Location of test bars in the casting.
