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THE DEVELOPMENT OF IMPROVED ZINC-BASE DIE CASTING ALLOYS. PHASE II: THE EFFECTS OF ADDITION ELEMENTS ON THE MECHANICAL PROPERTIES OF ZAMAK TYPE ZINC-BASE DIE CASTING ALLOYS

by

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THE DEVELOPMENT OF IMPROVED ZINC-BASE DIE CASTING ALLOYS. Phase II: The Effects of Addition Elements on the Mechanical Properties of Zamak Type Zinc-Base Die Casting Alloys

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SUMMARY OF RESULTS

Studies were carried out to determine the effects of small additions of beryllium, titanium, manganese, nickel, zirconium and lithium on the mechanical properties of standard Zamak 3 and Zamak 5 zinc-base die casting alloys. The properties were measured on test pieces die cast on an A.B.C. die casting machine.

It was found that, at the concentrations tested, the above elements cannot be considered as beneficial additives. In some cases they have insignificant effects on the mechanical properties. In others, they have definite harmful effects.

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INTRODUCTION

Research Project Zn-6 has been carried out at the laboratories of the Physical Metallurgy Division, Mines Branch, Ottawa, under the auspices of the Canadian Zinc Research and Development Committee.

Phase I of the project, which dealt with studies to determine methods of introducing the elements beryllium, titanium, manganese, nickel, zirconium, and lithium into standard Zamak-type zinc-base die casting alloys, has been previously reported(1). A second report dealing with the preparatory work required to adapt a model 1000 A.B.C. die casting machine for the production of die cast test pieces has also been issued(2). The purpose of this report is to place on record an outline of the work carried out, and of the results obtained during Phase II of the Project.

Phase II involved examination of the effects of the above mentioned addition elements on the mechanical properties of die cast test pieces. Most of the die casting was done on the A.B.C. die casting machine, although several casts of a confirmatory nature were carried out on a larger (Cleveland 200) die casting machine which had been used for earlier work(3).

The work in Phase I made it possible to establish tentative upper limits on amounts of each of the addition elements which could be retained in zinc-base die casting alloys. Phase II has concentrated mainly on the die casting of Zamak 3 alloys containing varying amounts of the additives within the tentative limits, combined with varying amounts of copper. For each of the addition elements: titanium, manganese, nickel, and zirconium, casting schedules were set up to follow a statistically sound pattern according to the method of Box(4). These were arranged to vary the copper and other additions from cast to cast, as illustrated in Figure 1 of the Appendix. In the case of beryllium and lithium, no attempts were made to establish similar patterns because of the very low retention levels. Instead, a limited number of casts were made to obtain some indication of the effects of the additions.

The earlier work showed that the presence of copper appeared to increase addition-element retention in several cases. Accordingly, additional casts were made using standard Zamak 5 die casting alloy containing titanium, manganese, nickel, and zirconium at concentrations approaching the maximum retention levels.

Table 1 outlines the nominal compositions of all alloys cast on the A.B.C. die casting machine during this phase of the project.

In addition to the die casting work, some rolling tests at the Burgess Battery Company were carried out on the alloys prepared for die casting. These tests were discussed in previous Progress Reports and will not be dealt with further other than to note that the results did not appear promising.

EXPERIMENTAL PROCEDURE AND EQUIPMENT

(a) Alloying

With the exception of lithium, master alloys were used to introduce all addition elements into the zinc-base die casting alloys. Master alloys, alloying materials, production procedures, and concentrations, were generally as previously described(1).

The titanium and zirconium alloys were prepared in the small Lindberg electric furnace by dissolving sponge in a zinc bath protected by a cover flux of boric acid, and maintained at a temperature of approximately 800°C (1470°F). The furnace used is shown in Figure 2. Some melts of the manganese and nickel master alloys were also made in the Lindberg furnace, but it was found expedient to prepare large batches of approximately 200 lb each in the Non-Ferrous Metals foundry. The zinc charge was held in a gas-fired furnace in a tercod crucible at a temperature of approximately 600°C (1110°F), and the addition element, contained in a small perforated crucible, was then agitated through the bath until it dissolved.

Drossing losses were high during this operation, but the oxide dross was readily skimmed, and it was possible to cast slabs with negligible dross contamination. Master alloys containing copper were made in large batches in a similar manner as were also, beryllium-containing master alloys.

In the latter case, preparation of the master alloy was carried out as the first step of an operation to produce beryllium-containing die casting alloy. The entire procedure will be discussed later.

A propane-fired Fisher Sulphur Dome furnace, with the dome removed as shown in Figure 3, was used for the preparation of the die casting alloys. The capacity of the alloying-pot was approximately 400 lb, and batches of this size were generally prepared. Alloying ingredients used included Special High Grade zinc in slab form, 99.5% Al rolled to approximately 1/8 in. thickness, 99.5% Mg cut into blocks, copper, when required, as a 5 to 6% copper-zinc master alloy, and the addition element, when required, as the appropriate master alloy. A typical charge for Zamak 3 alloy production was as follows:

Special High Grade zinc	383.8 lb
99.5% Al	16.0 lb
99.5% Mg	0.16 lb (72.5 g)

When copper, or other addition was required, the Special High Grade zinc plus master alloys used totalled 383.8 lb.

The steps followed during alloy preparation were generally as follows:

(i) Approximately one half of the aluminum required was placed flat on the bottom of the pot. The balance was stacked on edge around the circumference of the pot.

(ii) The zinc slabs were charged to the pot in a manner to hold the aluminum sheets immersed as melting proceeded. In baths requiring copper, the copper master alloy was also added at this time. Generally, approximately two thirds of the zinc and all of the copper master alloy were added to the pot before the furnace was fired.

(iii) The furnace burner and an auxiliary torch were started. The auxiliary torch was directed onto the slab zinc, and was used only until such time as the molten metal level reached the flame zone.

(iv) The balance of the slab zinc was added as melting proceeded and space in the pot became available.

(v) When the total zinc and copper alloy charge was melted down, the bath was stirred manually until all of the aluminum dissolved. Through all stages of melting and casting, the metal temperature was limited to a maximum of 450°C (840°F). The furnace and burner characteristics were such that the alloying temperature range varied generally between 420 and 450°C (790 and 840°F) once the complete charge was molten.

(vi) When the aluminum was completely dissolved, the addition element required was charged as the appropriate master alloy. The bath was then stirred until complete solution was effected.

(vii) The bath surface was skimmed free of dross.

(viii) The magnesium addition was stirred into the bath and was kept fully immersed at all times with a basket-type plunger.

(ix) The bath was again skimmed, stirred, and sampled. Ingot casting was started. A second sample was taken when approximately one half of the charge had been cast.

When lithium additions were made to Zamak 3 alloy, with or without copper, the procedure followed was basically the same as above. At the completion of the magnesium addition, lithium contained in aluminum cartridges was plunged into the bath with the inverted basket type plunger. The cartridges each contained 4 g lithium, and four were generally plunged at a time. The cartridges were kept immersed until all reaction ceased. No attempts were made to dissolve the aluminum of the cartridge, and its weight was not calculated into the charge. Reaction started when once pin hole penetration occurred. There appeared to be negligible aluminum solution from this source.

As previously mentioned, beryllium master alloy production was carried out on a large scale as the first step of a procedure to produce die casting alloy. The complete procedure was as follows:

(i) The required amount of Al- 5% Be hardener pellets was added to a zinc bath held at approximately 450°C (840°F). Enough hardener was added to give an approximate bath composition of 2% Al and 0.15% Be.

(ii) The bath was held at temperature, with little stirring, until most of the aluminum matrix of the hardener dissolved. A flux cover of boric acid was then applied, and the temperature raised to 750 to 800°C (1380 to 1470°F).

(iii) The bath was held at this temperature under quiescent conditions for approximately six hours.

(iv) The burner was shut off, and cooling air was directed onto the crucible. When the temperature dropped to approximately 500°C (930°F), the flux cover was removed.

(v) Following a further drop in temperature to 450°C (840°F), enough aluminum was added to the bath to raise the aluminum content to 4%.

(vi) The required amount of magnesium was stirred into the bath.

(vii) The bath was stirred, skimmed, sampled and cast into slabs.

The alloys prepared as above were used for casting on the A.B.C. die casting machine; several casts were also made on the Cleveland "200" machine. Two of the latter were made with alloy containing beryllium. In the first of these, an attempt was made to introduce the beryllium into standard Zamak 3 alloy held in the machine melting pot by stirring in the required amount of copper-4.83% beryllium hardener. However, the rate of solution was prohibitively slow, and this method was abandoned. Instead, the hardener was used to prepare a zinc-rich master alloy, and this was added to the Zamak 3 in the machine pot. For the second of the large machine casts, the beryllium containing alloy prepared above was diluted with additional Zamak 3 alloy.

Samples for analysis were taken of all die casting alloys prepared. At each sampling a quantity of alloy was granulated into cold water. In addition, three samples were cast in a small iron spectrographic disc mould. When required, metallographic specimens were cut from the cast discs.

(b) Die Casting

A description of the A.B.C. die casting machine and the two cavity test bar die, and a detailed account of the preparatory work required to adapt the machine to this project has already been reported.

Based on the previous work, it was possible to establish a definite operating routine for the casting runs, and the general procedure was as follows:

(i) Alloy in ingot form was charged into the melting pot, and melting started, using the installed burner located in the chamber below the melting pot, and two auxilliary torches. One torch was directed from above onto the alloy ingots, and was used until the molten metal came into contact with the flame. The second was directed onto the underside of the pot during meltdown and until the casting temperature was reached, and also later as required for temperature control.

(ii) Approximately ½ hr after the melting was started, the nozzle burner was turned on. This burner also served to heat up the die blocks to temperatures at or above the operating ranges. During this initial heating up, sprue pin coolant was adjusted to full operating flow. To allow the dies to heat rapidly, coolant flow to the stationery die block was restricted to the point where steam only emmitted from the discharge, and the coolant to the top section of the ejector half was completely shut off.

(iii) As melting proceeded, ingot sections were added until the bath reached the desired operating level. When the bath temperature approached 410°C (770°F), the plunger was inserted.

(iv) The cover-half hold down bolts were tightened after the nozzle burner had been in operation at peak intensity for approximately ½ hr.

(v) The die was opened, and the mid point surface temperatures were measured by means of a surface contact pyrometer. If the cover- and ejector-half temperatures were 250 to 260°C (480 to 500°F) and 190 to 200°C (370 to 390°F) respectively, the machine was checked for die closure. If temperatures lower than those indicated were obtained, the die was closed for further heating. Periodic checks were made until the desired temperatures were reached. The die closure was checked using shim stock material of 0.001 in. thickness. The tie bar nuts were tightened until the shim stock was held firmly between the die halves when the toggles were completely extended. Checks were made at points on both vertical edges of the die.

(vi) The alloy in the melting pot was skimmed, and the casting operation was commenced. The first 20 to 30 castings, which were made to establish uniform operating conditions, were discarded. While making these castings, the nozzle burner was adjusted to give a suitable appearing sprue. It was also necessary to supply coolant to the top section of the ejector-half die, and to adjust coolant flow in all lines in order to maintain the desired die surface temperatures of 240 to to 250°C (460° to 480°F) and 200°C (390°F) on the cover and ejector halves respectively. As operation proceeded and the machine heated up, further die closure adjustments were required because of unequal expansion of the tie bars. During this initial casting stage, die temperature measurements were made at frequent intervals, and the die surfaces were lubricated with "Die Slick No. 11" as required. It was necessary to brush the surface free of flash after every casting.

(vii) When normal operating conditions were attained, the regular test period commenced. During this stage, die temperature measurements were made and die lubricant applied after every ten castings. Two castings were rejected after the lubricant application, since it was felt that the lubricant might cause gross porosity in these two. The die surfaces were brushed free of flash after every casting. Generally, 160 castings were saved for each composition unless operational difficulties necessitated a forced shut down. Casting rates were of the order of 80 shots/hr net. This rate allowed ample time for die temperature control, and was largely dependent on the time required to brush the flash from the die surfaces.

As the castings were removed from the machine, they were laid on a table for cooling. When cool enough to be handled without fear of breakage or distortion, the test pieces were identified as to composition and position in the cast, and the sprues and overflow wells were broken off. The procedure is illustrated in Figure 4.

At all times during casting, the bath level was kept up to the predetermined(2) optimum level in the pot. The bath surface was skimmed free of dross at frequent intervals.

(viii) During the casting period, samples for analyses were taken after the 40th, 80th, 120th, and 160th shots. At each sampling, three spectrographic discs were prepared, and a quantity of metal was granulated in cold water. Analytical samples were taken from each batch of granulated metal. In addition, a composite sample was prepared which represented the bath during the entire run.

(ix) At the end of the casting period, the plunger was removed from the machine, and the melting pot drained, leaving a 5 to 10 lb heel. At the same time, most of the metal was removed from the gooseneck by means of a specially constructed small diameter ladle. When the metal heel solidified and the pot cooled, it was possible to lift the heel and to remove the thin skin of frozen metal on the pot sides, leaving a clean pot with little danger of contamination to the next melt.

(x) When the die casting machine had been shut down and the pot drained, flash was trimmed from the test pieces. Test bars were picked at random for specific mechanical tests and the extra test pieces were packed into compartmented storage boxes. The sprues, trimmings, and all castings made during the warm-up period and those rejected after die lubricant application, were gathered and remelted as scrap.

The procedure outlined above was followed in most cases when casting on the A.B.C. machine. As previously reported(2), some difficulties were encountered in establishing optimum operating conditions, and five casts were carried out in the titanium series with lower operating die temperatures than shown above. Five other casts were carried out following the above detailed procedure but with inadequate level control, which had an adverse effect on the soundness of the castings.

In addition to the A.B.C. machine casting, three casts were carried out on the Cleveland "200" machine. The machine and its operation have previously been described(5,6), and will not be dealt with further. One cast was made using Zamak 3 alloy and two with Zamak 3 containing beryllium.

During the early stages of the casting program, two compositions were cast each week. Later, revisions to the testing schedule made it possible to cast at the rate of three per week.

(c) Preparation and Ageing of Test Bars for Mechanical Testing

At the commencement of the program, the following mechanical testing schedule, requiring the test bars as shown, was drawn up:

(i) Tensile and Elongation Tests:

(1) 20 tensile bars, selected at random, aged 10 days at room temperature.

(2) 20 tensile bars, selected at random, aged 10 days in dry air at 95°C (200°F).

(3) 15 tensile bars, selected at random, aged 10 days in a 95% relative humidity atmosphere at 95°C (200°F).

(ii) Impact Tests:

(1) 20 impact bars, position in cast corresponding to (i)(1), aged 10 days at room temperature.

(2) 20 impact bars, corresponding to (i)(2), aged 10 days in dry air at 95°C (200°F).

(3) 15 impact bars, corresponding to (i)(3), aged 10 days in a 95% relative humidity at 95°C (200°F).

(4) 80 impact bars selected at random, aged 10 days at room temperature, and distributed as follows:

20 tested at 0°C (32°F)
20 tested at -10°C (14°F)
20 tested at -20°C (-4°F)
20 tested at -40°C (-40°F)

(iii) Dimensional Stability Tests:

(1) 5 impact bars, selected at random, aged 10 days at room temperature.

(2) 5 impact bars, selected at random, aged 10 days in dry air at 95°C (200°F).

(3) 5 impact bars, selected at random, aged 10 days in a 95% R.H. at 95°C (200°F).

In all cases except for the zero and sub-zero impact tests, specimens were to be tested at room temperature after the various ageing treatments.

The schedule was adhered to throughout the program with regard to all tensile and elongation tests, the room temperature impact tests, and the dimensional stability tests. After several casts, the number of specimens tested at each of the sub-zero temperatures was reduced to 10. Later, on the recommendation of the Cominco Statistical Group(7), impact testing at 0°C (32°F), -10°C (14°F) and -40°C (-40°F), was eliminated. It was this revision to the testing schedule which allowed time for casting at the rate of 3 casts per week.

All tensile and impact bars to be aged at room temperature and in dry air at 95°C (200°F) were sanded on a high speed sanding wheel to remove any flash left after the preliminary trimming operation. Bars to be aged in the humidity cabinet were not sanded, since it was found that any flash present corroded away during the ageing period. Furthermore it was felt that sanding scratches might act to initiate local corrosion. All impact bars selected for dimensional stability measurements were sanded for flash removal. The gate ends were ground square on a fine grinding wheel to remove any irregularities left when the bar was broken free from the gate runner. The gate ends were ground to well rounded points to facilitate accurate measurement on the micrometer gauge. It should be noted that impact bars cast on the A.B.C. machine measured 6 in. in length. Those cast on the Cleveland machine were 9 in. long, and when prepared for dimensional stability measurements, 3 in. was cut off from the gate end, and the remaining length handled as above.

After preparation, the specimens were aged as follows:

(i) Room Temperature Ageing:

This was carried out in a constant temperature room controlled at 23 ± 2°C (73 ± 3.6°F), for the 10 day period.

(ii) Dry Air, 95°C (200°F) Ageing (High Temperature Treatment):

A standard drying oven maintained at 95 ± 1°C (200 ± 2°F) was used to keep the bars at temperature for the 10 day period. They were removed the night before testing and placed in the constant temperature room.

(iii) Humidity Cabinet Ageing (Steam Treatment):

The equipment as used in previous projects is described elsewhere and illustrated in Figure 5.

Minor modifications were made to facilitate its use for the shorter test bars produced during this project. The modifications, which can be seen in Figure 6, entailed soldering of double hook brackets to the side arms of the racks at the bottom and at approximately 5½ in. from the bottom. The hooks supported a beaded glass rod against which the test bars rested, and a straight rod to hold them in place as a protection against external knocking of the cabinet.

Six racks were used in the cabinet. The specimens were held at an angle of approximately 20° to the vertical and were in contact with only the glass rods of the racks except in some cases where the tops of adjacent pairs of specimens contacted each other. Regular examination revealed that this did not cause excessive condensation or corrosion.

All specimens were vapour degreased in trichloroethylene before being placed in the cabinet. They were arranged on the racks in order of testing, and were handled in and out with degreased tongs. They were removed the night before testing and placed in the constant temperature room.

(d) Mechanical Testing of Test Bars

(i) Tensile and Elongation Testing:

Following the ageing periods, the tensile bars were marked with a 2 in. gauge length punch and tested on a standard Baldwin Southwark, Tate-Emery tensile machine, using wedge grips, 0 to 6000 lb scale, and a cross-head speed of 0.40 in. per min.

(ii) Impact Testing:

After ageing, the impact bars were cut into 3 in. lengths (2 from the A.B.C. machine and 3 from the Cleveland machine bars) and tested on a Tinius Olsen impact testing machine of 0 to 60 ft-lb range.

All specimens were tested in the unnotched condition, and were always set in the sample support anvil with the ejector surface facing the striking tup. For each ageing condition the vent and gate end sections (and middle section for the large machine bars) were tested as separate groups.

Specimens tested at sub-room temperatures were laid on glass rods in a Pyrex glass tray and covered with acetone. Dry ice was added to the acetone to lower the bath temperature to the desired testing temperature. The specimens were held at temperature for at least ½ hr transferred quickly to the support anvil by metal tongs, and broken before the temperature changed appreciably.

(iii) Dimensional Stability:

The micrometer gauge used in determining the dimensional stability has been previously described(6). The initial length of the specially prepared impact bar specimens was measured after the bars were held at room temperature for at least 1 hr following completion of the necessary grinding operation. Final length measurements were made after the ageing periods.

Before measurements started, a standard 6 in. gauge block stored in the constant temperature room, was used to check the micrometer setting. This check measurement and all test measurements were made by two observers and the results averaged. Generally, agreement was good with the measurements usually checking to ± 0.0001 in.

(e) Radiography

The test bars chosen for room temperature ageing from each cast were examined radiographically. This was done with a Philips "Searchray", 150 kV instrument. Exposure data were as follows: 80 kV; 700 ma sec; 48 in. focal film distance; Kodak type M film; Kodak developer 8 min at 20°C (70°F).

The bars were examined shortly after the preliminary trimming and before being prepared for ageing. Results were generally available before the end of the day, and in some instances confirmed the presence of broken piston rings and/or other die casting machine operational difficulties. If this was the case, the cast was limited to cover the best part of the run.

(f) Analyses

Granulated and spectrographic disc samples were submitted to the analytical laboratories of the Mines Branch, The Consolidated Mining and Smelting Company of Canada Limited, and the Hudson Bay Mining and Smelting Company, Limited.

At the start of this project, a program on the development of solution methods of spectrographic analysis, to deal with the alloys to be encountered, was undertaken in the Metals Physics Section, Physical Metallurgy Division, Mines Branch. Satisfactory methods were developed for handling additive-free Zamak-type alloys and the alloys of the titanium series. However, circumstances necessitated the termination of the work at this point. As a result, routine chemical analyses, which served as operational controls, were done at the Mines Branch. Check analyses and most of the spectrographic analyses were done at the laboratories of the member firms noted above.

As reported later, aluminum, copper when present as an addition, in most cases the addition element, and iron, were determined by standard wet methods using the granulated samples. Lead, tin, cadmium, copper when present at the impurity level, and the addition element, when possible, were determined spectrographically using the disc samples. Aluminum, copper at all levels, and iron, were also determined spectrographically, but these results have not been included in this report.

In cases where check analyses were made with proper standards, agreement was generally good. The analyses reported later are considered to be representative and are based on the work of all laboratories concerned.

(g) Metallography

Routine metallographic examination was done on specimens prepared from impact and tensile test bars of all alloys. The etchant generally used was a solution of 50 g CrO_3, 4 g Na_2SO_4 and 2000 ml H_2O (a dilute solution No. 2, ASM Metals Handbook 1948, p. 1086).

(h) Hardness Testing

Rockwell "E" hardness measurements were made on die cast specimens of all alloys. The measurements were made on randomly selected vent-end sections of impact bars which were mounted in bakelite, and given a rough polish before testing.

RESULTS

Radiographs and photomicrographs, and numerical data and results are appended to this report. A die casting log sheet and mechanical testing data sheets of a typical cast are also included.

(a) Mechanical Testing of Test Bars

The average test results for each composition cast during the project are presented in Tables 2 to 8. Tables 2 to 5 deal with the titanium, manganese, nickel and zirconium series respectively. The beryllium, lithium, and the Zamak 5 series are dealt with in Tables 6 to 8.

The casting of the titanium, manganese, nickel and zirconium series was carried out according to statistically-planned patterns. The results of the statistical analyses of the test data are presented in Tables 9 and 10. In order to develop these tables, equations of the type

$$Y = b_o + b_1x_1 + b_2x_2 + b_{12}x_1x_2 - - - - - -$$

were fitted to the mechanical testing results of these four series. In the equation,

Y = the mechanical property of interest

x_1 = (% Cu-0.2)/0.2

x_2 = (% Ti-0.05)/0.05

or = (% Mn-0.03)/0.03

or = (% Ni-0.03)/0.03

or = (% Zr-0.05)/0.05

b's = regression coefficients

In the tables, S_s is the standard deviation of the variation within casts, S_r is the standard deviation of the variation about regression. S_c, which is given only for the zirconium series, is the standard deviation of the variation between duplicate casts, N is the average number of specimens per cast for each specific mechanical test, and SE_b which is shown below each regression coefficient, is the standard error. Where the regression coefficients are not significant, this is indicated by the letters NS.

(b) Radiography

The groups of test bars chosen for room temperature ageing from each cast were examined radiographically. Radiographs of specimens from casts CM and CN only are appended as Figures 7 and 8. These are not typical, but have been chosen to illustrate a special point. Typical radiographs have been dealt with in a previous report$^{(2)}$.

(c) Analysis

Representative analyses of all compositions prepared and cast are presented as Tables 11 to 17, which deal with the titanium, manganese, nickel, zirconium, beryllium, lithium, and Zamak 5 series respectively.

(d) Metallography

Die cast specimens of all compositions cast were examined metallographically. Photomicrographs have been selected of the compositions of the manganese series as being representative of most compositions with regard to dispersion and quantity of constituent present, and are presented as Figures 9 to 12. Figures 13 to 16 show the nature and distribution of constituent in the Zamak 5 series alloys.

Metallographic examination was also done on specimens from a beryllium cast in an effort to determine the cause of a characteristic flow which became evident on mechanical testing. Figures 17 to 19 show the results of these examinations.

(e) Hardness Testing

The Rockwell E hardness results for the die cast impact bars are presented in Table 18.

DISCUSSION OF RESULTS

(a) Mechanical Testing

The statistical study of the mechanical testing data of the titanium, manganese, nickel and zirconium series showed the following:

(i) Copper additions within the limits studied tended to improve the ultimate tensile strength, increase the impact strength, reduce the elongation, and increase the amount of shrinkage. All of these effects were minor, the increase in the amount of shrinkage being the least significant.

(ii) Titanium additions within the limits studied tended to decrease the impact strength, reduce the elongation, and increase the amount of shrinkage of steam treated specimens. The effect of titanium on the impact strength is major. All other effects are of minor significance.

(iii) Manganese additions within the limits studied tended to reduce the impact strength a significant amount. The effects on other properties were not significant. Manganese and copper showed a joint effect (interaction) in reducing elongation.

(iv) Nickel additions within the limits studied tended to increase elongation a minor amount, and to reduce the impact strength to a more significant degree. Nickel and copper showed a joint effect (interaction) on elongation.

(v) Zirconium additions within the limits studied tended to reduce the ultimate tensile strength, elongation and impact strength. Zirconium also increased the amount of shrinkage on steam aged specimens. None of these effects were major in nature.

(vi) For each series, the relationships were checked for curvature, but nothing of note was found. Thus, indications of an approach to optimum concentrations of copper plus addition element, which was of primary interest were not evident. The magnitude of the various effects mentioned above is evident on reference to the mechanical testing results of Tables 2 to 5, and the statistical analysis results of Tables 9 and 10.

Generally, the effects of the four addition elements on the ultimate tensile strength were not significant. The zirconium addition did lower the ultimate tensile strength slightly, but only to the extent of approximately 1%. The effects on the elongation were also mainly insignificant. Zirconium appeared to lower it approximately 10 to 15% on the high-temperature and room-temperature aged specimens but had no effect on the steam-aged specimens. Nickel tended to improve the elongation of the steam-aged specimens by approximately 10%.

Changes in dimensional stability were also of minor significance in most cases. Titanium and zirconium caused a small increase in the amount of shrinkage as measured on the steam-aged specimens. In this regard, it should be pointed out that the conventional zinc-base alloys undergo shrinkage on ageing under normal conditions due to structural changes which occur while phase equilibria are being attained. The accelerated test condition used (ageing at 95°C (200°F) for ten days) is considered sufficient to cause the maximum shrinkage. In alloys containing more than 1% Cu, this initial shrinkage is followed by an expansion of sufficient magnitude to result in a net expansion. The levels of copper examined did not appear to be high enough to cause this subsequent expansion. Where specimens are subjected to the humid atmosphere and high temperature of the steam treatment, the initial shrinkage is followed by an expansion due to an intercrystalline type of corrosion. In the case of the titanium- and zirconium-containing alloys, such corrosion appeared to be inhibited to a minor extent, as is indicated by the net shrinkage being slightly greater than in the alloy without each of these additions.

The additives appeared to exert their greatest effect on the impact strength. In this respect, it should be noted that the reduction in the impact strength of the gate- end specimen was considerably greater than that of the vent-end specimens. This was associated with the relatively porous nature of the gate end, and was an apparent indication of the castability of the various addition-element-containing alloys. The addition of titanium appeared to be particularly harmful. In the range tested, it caused reductions in impact strength of up to approximately 35% on the gate end, and 15% on the vent-end specimens. Zirconium additions resulted in reductions of up to 20% on the gate end and less than 10% on the vent-end specimens. The effects of manganese and nickel were considerably less.

The results of the mechanical testing of the beryllium series test bars are tabulated in Table 6(a). Three casts were attempted on the A.B.C. die casting machine. However, the alloy of cast BA (nominally 0.08% Be) was extremely drossy and it was possible to produce only a few test bars. These were not tested. Excessive drossing was also encountered while casting BB (0.005% Be nominal); and the effects of this dross were evident in the test results.

The ultimate tensile strength, elongation and impact strength were considerably lower than those for Zamak 3 test bars cast on the small machine. For cast BC, the nominal beryllium content was reduced from 0.005% to 0.001%, and the results obtained compared favourably with the Zamak 3 casts. Elongation appeared to be improved markedly by the presence of beryllium, particularly for the heat treated specimens. A single value of 21.5% was obtained and several were above 10%. Because of this apparent improvement in ductility, it was decided to carry out several check casts on the large Cleveland "200" machine. A Zamak 3 cast (DD), a Zamak 3 plus 0.001% Be cast (DE), and a Zamak 3 plus 0.0005% Be cast (DF) were attempted. Unfortunately, alloy preparation difficulties were encountered, and 0.0004% Be was reported for both casts DE and DF. At this level, beryllium appeared to have no effects on the ultimate tensile strength, elongation, impact strength, or the dimensional stability. As shown in Table 6(b) the 0.2% yield stress for bars from all three casts was lowered slightly.

Four casts were made in the lithium series. The alloys for these casts were treated with 0.05 to 0.1% Li, but only $<$ 0.001% was retained. The mechanical testing results in Table 7 indicate that the lithium treatment had negligible effects on the properties of Zamak 3 and Zamak 3 plus 0.4% Cu.

The mechanical testing results of the five casts of the Zamak 5 series are given in Table 8. Tensile and impact properties for the additive-free Zamak 5 specimens were considerably lower than expected, presumably because effects of the inherent flaws in castings from the A.B.C. machine die were magnified by the increased hardness of the Zamak 5 alloy, and properties lower than those for Zamak 3 cast on the same machine resulted. The added amounts of titanium, nickel and manganese caused a significant reduction in the ultimate tensile strength and the elongation, and greatly reduced the impact strength. The effects of zirconium were similar, but of much smaller magnitude. The Zamak 5 alloys appeared to undergo greater shrinkage on high temperature ageing. The previous indication that titanium and zirconium inhibit intercrystalline corrosion of steam-aged specimens was not substantiated with alloys of this series. However, the quality of the test pieces of this series was inferior to that of the Zamak 3 type alloys with regards to soundness, and it is felt that this may have had an appreciable effect on dimensional stability measurements, making them unreliable. (The dimensional stability measurements of the first ten casts of the titanium series, as given in Table 2, were erratic. During these casts, bars of very poor quality were also produced).

(b) Radiography

The radiography of the test bars produced on the A.B.C. die casting machine during the die break-in period was discussed at length in a previous report(2). Radiographs were presented which included those of cast 24 of the break-in series, cast TI and cast ZA. These are considered to be typical of Zamak 3 type alloy specimens produced during this phase of the project.

Referring briefly back to these radiographs, the following points were noted:

(i) The test bars of cast 24 were produced from the test bar die of the final design. The radiograph showed fine center-line porosity over the entire length of the impact bar, with some scatter away from the center-line at the gate end. In some cases the scattered porosity extended along the bar to the point of contact with the impact tup. Porosity in the tensile bars was confined largely to the gate-end grip section. In some cases it extended into the tapered shoulder section and into the gauge-length section as center-line porosity.

(ii) Cast TI was one of the first ten casts of the titanium series and radiographically was typical for the series. All casts were carried out under conditions of inadequate level control in the machine pot, and as a result, gross porosity was present in the test bars.

(iii) Cast ZA was carried out with proper level control during the run, and sound test bars of similar quality to those of cast 24 were produced.

With few exceptions, radiographs of cast 24 and of cast ZA were of similar quality to the last five casts of the titanium series and all casts of the manganese, nickel, zirconium and lithium series. A considerable increase in porosity was evident in the radiographs of specimens from casts BB and BC. This porosity was present with a similar distribution to the others, and was associated with the drossy nature of the bath metal. Castings from the large machine runs were also radiographed, and these showed virtually no porosity in the tensile bars, very fine center-line porosity in the middle and vent sections of the impact bars, and some scatter at the impact bar gate ends. Marked differences from the above showed up in the radiographs of the additive-containing Zamak 5 test bars, and typical radiographs of casts CM and CN are appended as Figures 7 and 8, respectively. The tensile bars in both cases contained considerable porosity in the gauge-length section, and many showed internal cracks. The position of these cracks are marked by arrows. Examination of the tensile fractures, which generally occurred at cracks when present, appeared to indicate the presence of drossy material. Apparently the dross particles were sufficiently large in size to cause separation at the metal-dross interface on freezing. The impact bars appeared to be radiographically similar to all others.

(c) Analysis

Tables 11 to 17 show the compositions of the various alloys dealt with during this phase of the project; the alloys are listed in consecutive pairs. In all series, the first sample listed is designated by a number and represents the specific alloy on preparation or in ingot form. The second sample is designated by the cast letters and represents the same alloy in the melting pot during casting runs. This procedure has been followed to facilitate detection of any drossing-off of particular alloying ingredients which might have occurred during the alloy preparation, ingot casting, remelting, and casting stages. Comparing the results with Table 1, which gives the nominal compositions, shows that in some cases the addition elements were retained, whereas, in others drossing-off did occur.

The titanium- and zirconium-containing alloys appeared to be quite stable with regard to additive retention. Some losses occurred on preparation of the alloys containing nominally 0.10% Ti and Zr, but this may have been associated with master alloy analytical discrepancies. There is little indication that removal after preparation occurred. The manganese- and nickel-containing alloys did not appear to be as stable. Noticeable losses occurred during the various handling stages, particularly of nickel, in which case retention was relatively poor, even in the alloys containing 0.03% nominally.

No compositions are given for the alloy used for cast BA of the beryllium series. This alloy was prepared by mixing relatively small lots which contained from 0.05 to 0.15% Be. A composition of 0.08% Be was calculated for the mixture. Because of casting difficulties due to the extremely drossy nature of this alloy, no samples were taken during the casting run. Alloy 198 was prepared from this alloy by dilution with Zamak 3. Alloy 200 was similarly prepared using alloy left after casting run BB and Zamak 3. Nominal compositions of 0.005 and 0.001% Be respectively were aimed for, and actual compositions of 0.007 and 0.002% were obtained. It is felt that these differences are due to the relatively uncertain composition of the alloy prepared for cast BA. The analyses of Table 15 indicate that no beryllium losses occurred at these two levels. Discrepancies are apparent in the analyses of the alloys for the two Cleveland die casting machine casts. For cast DE, beryllium was introduced into Zamak 3 alloy in the machine pot in the form of a molten zinc-copper-beryllium master alloy. For cast DF, alloy remaining from DE was diluted with Zamak 3. A nominal composition of 0.001% Be was aimed for with the alloy of DE, and 0.0005% Be with that of DF. Enough copper was added with the master alloy to give an analysis of approximately 0.02% Cu in DE, which would be reduced to 0.01% Cu on dilution. However, the analyses obtained, as tabulated in Table 15, were 0.0004% Be, 0.011% Cu in the sample of DE and 0.0004% Be, 0.015% Cu in the sample of DF. A possible reason for the discrepancies is that when the molten master alloy (at approximately 550°C (1020°F)) was added to the relatively cold bath (420°C (790°F)), it solidified into metallic prills which sank to the bottom of the pot. The gooseneck hindered stirring of the bath metal and undissolved master alloy remained at the bottom during cast DE. Between casts, a small heel of metal was left on the pot bottom, and when the alloy for cast DF was melted down in the pot, this remaining master alloy was taken into solution.

In preparing the alloys for the lithium series casts, the equivalent of approximately 0.10% Li was used as a treatment material. During runs LA and LB a further addition of 0.05% Li was made. The analytical results in Table 16 show that in all cases, the lithium retention was low and of the same order.

Several discrepancies were apparent in the analytical results of the Zamak 5 series of alloys (Table 17). The titanium-containing alloys analysed 0.38% Ti as against the nominal value of 0.30% aimed for. This high value suggests that drossy material was entrapped in the samples. However, the aluminum analysis did not indicate such dross contamination. With the manganese-containing alloys, the nominal manganese content of 0.35% was appreciably higher than the analyses of 0.30 and 0.29% which indicates that considerable dross losses occurred on preparation but that the dross formed was readily removable. The minor difference between the as-prepared sample and the casting-run sample suggests that the alloy rapidly drossed down to a manganese content which was retainable. Check analyses for the nickel-containing melt 194 were markedly different and two analyses were run. From the results in Table 17 it appears that a considerable amount of drossy material (probably Al_3Ni and a copper-containing ternary compound) was present in the first sample. Several samples of CN were also analysed. All were consistently uniform. From these various analyses it was concluded that a relatively small portion of the nickel was retained in solution, with the balance present as aluminum- and/or copper-containing compounds. The analyses of the zirconium-containing alloys showed minor differences only, possibly due to sampling and/or analytical discrepancies. There was little evidence to indicate that zirconium was lost to dross from Zamak 5 alloy at the 0.10% Zr nominal level.

The nominal magnesium content of all alloys prepared was 0.04%. The analyses in all cases were reasonably close to this value, showing that the various addition elements did not preferentially remove magnesium from the bath.

Impurity levels in all alloys remained well below the tolerable limits. Values for tin have not been tabulated because in all cases the amount present was < 0.0005%.

(d) Metallography

Metallographic examination was carried out on die cast specimens of each of the compositions cast. Intermetallic compounds were present in all specimens containing titanium, manganese, nickel and zirconium, and their physical appearance was as noted earlier(1). Specimens cast from alloys of the beryllium and lithium series generally contained fine dross-type segregates which were too small in size to enable qualitative identification.

The photomicrographs of the manganese-containing alloys (Figures 9 to 12) were included for the purpose of indicating constituent size and manner of dispersion. In these respects the structures shown were typical of the alloys containing titanium, manganese, nickel and zirconium. The amount of constituent present in the Zamak 3 type alloys was relatively small. In the Zamak 5 type alloy, constituent concentration was significant but this is understandable in view of the fact that a relatively large amount of manganese was contained in the alloy of cast CM (Figure 12).

The nature of the constituents present in the Zamak 5 alloys is better defined in Figures 13 to 16 which show the structures of the alloys of casts CT (titanium-containing), CM (manganese-containing), CN (nickel-containing) and CZ (zirconium-containing) respectively. The constituents present corresponded to those found in similar alloys reported previously(1) with the exception of alloy CZ. In this case the constituent appeared to be the zinc-zirconium compound present in the master alloy, (based on its physical appearance). The melt metal apparently attacked the compound particles to a minor extent only. In the previous work, where the alloys were held in the molten condition for a much longer period, complete solution of the compound occurred and new constituents with a different appearance were formed.

As previously mentioned, a characteristic flaw was noted during impact testing on some of the test pieces from cast BC of the beryllium series. On fracture or bending of some of the vent-end impact bars, the presence of a non-adherent skin was evident as shown in Figures 17 and 18. The photomicrograph of Figure 19, which is of a section adjacent to the break shown in Figure 17, clearly defines the skin boundary, and indicates the porosity and dross contamination present on either side of the boundary. It is considered that the skin formation was probably caused by dross particles in the metal affecting the cavity filling process.

(c) Hardness Testing

The Rockwell "E" hardness determinations were made on the vent-end sections of impact bars chosen at random from each cast. The vent ends were selected for testing because of the inherent porosity present in the opposite gate end. No results are included for the first ten casts of the titanium series because it was felt that the gross porosity present in the bars of these casts would seriously affect the hardness readings.

The results as presented in Table 18 have been grouped into Zamak 3, Zamak 3 + 0.4% Cu, and alloys of similar composition for each of the series considered. They show the marked hardening effect of copper additions to the Zamak-type alloys and the less significant effects of the other addition elements. Briefly, the effects of these addition elements are as follows:

(i) The addition of 0.10% Ti had negligible effects on the hardness of Zamak 3 alloy, but it slightly increased the hardness of Zamak 3 + 0.4% Cu. The addition of 0.3% Ti to Zamak 5 had little effect on its hardness.

(ii) Manganese additions appeared to lower slightly the hardness of Zamak 3, Zamak 3 + 0.4% Cu and Zamak 5.

(iii) Nickel additions tended to harden Zamak 3 and Zamak 3 + 0.4% Cu slightly but the hardness of Zamak 5 was reduced. This appears to confirm a previously made suggestion(1) that above a specific copper content, copper-containing nickel-rich compounds are formed which result in a reduction in hardness due to copper.

(iv) Zirconium additions did not appear to affect the hardness of the Zamak 3 and Zamak 5 alloys.

(v) Lithium treatment and the addition of beryllium appeared to harden Zamak 3 alloys. This effect was possibly due to a grain refining action or may be due to some cleaning or degassing action in the case of lithium or the presence of dispersed oxide with beryllium.

MISCELLANEOUS OBSERVATIONS

The work in Phase I of the project indicated that compound formation could be expected from the addition of the various elements studied to the die casting alloys, and that constituent particles would be present in the die cast test pieces. At the start of the casting phase it was felt that the constituents would adversely affect the castability of the additive-containing alloys. However, with the exception of the beryllium-containing alloys cast on the A.B.C. machine and the additive-containing Zamak 5 alloys, harmful effects were generally not evident from an operational point of view.

The beryllium series, when cast on the small machine, was the most troublesome of the Zamak 3 type alloys. The drossy nature of the baths resulted in dross particle inclusion in the shot metal, thus causing weakened castings and frequent sprue breakages. Similar difficulties were encountered with the additive-containing Zamak 5 alloys. Minor effects only were noted while casting the Zamak 3 alloys containing titanium, manganese, nickel and zirconium and those treated with lithium. Slightly more dross formation occurred at the surface of the metal in the casting machine pot, and it was necessary to skim the surface more often than with additive-free Zamak 3 or 5 alloys.

The X-Ray examinations indicated some differences in test piece structure, which could possibly be attributed to differences in castability. Although not marked, the defects were evident as variable scatter of porosity away from the centre line of the vent ends of the impact bars, and as an extension of the porous zone into the gauge length of the tensile bars. This scatter, etc., was difficult to evaluate visually but was responsible for an increase in the number of rejects encountered during testing. It was necessary to reject significantly larger numbers of results because of fracture flaws from the manganese and lithium series than from any of the other additive-containing or additive-free melts. Generally, the additive-free castings were radiographically superior and as good or slightly better than most additive-containing castings on the basis of acceptability of test results.

SUMMARY

The work described in this report represents the second phase of a project carried out on the development of improved zinc-base die casting alloys. The purpose in this phase was to evaluate the effects of additions of small amounts of beryllium, titanium, manganese, nickel, zirconium and lithium on the mechanical properties of die cast test pieces.

Die casting alloy preparation followed procedures developed in Phase I of the project. Most of the die casting runs were made on a small A.B.C. die casting machine. Three casts were done on a large Cleveland "200" machine.

The results of mechanical testing on die cast test pieces indicate that at the levels used, the additives had the following effects on the properties:

(a) Tensile Strength

Beryllium, titanium, manganese, nickel, zirconium and lithium had insignificant effects on the ultimate tensile strength of Zamak 3 alloy.

Titanium, manganese, nickel and zirconium significantly lowered the tensile strength of Zamak 5 alloy, zirconium being the least deleterious. Additions of beryllium and lithium were not made to Zamak 5 alloys.

(b) Elongation

All additives tested had minor effects only on the elongation of Zamak 3 alloy. There was some indication that beryllium might improve the elongation of test pieces cast on the A.B.C. machine, but no improvement was noted with those cast on the Cleveland "200" machine.

Titanium, manganese, nickel and zirconium additions significantly reduced the elongation of Zamak 5 alloy.

(c) Impact Strength

Beryllium and lithium additions had negligible effects on the impact strength of Zamak 3 alloy. Manganese and nickel lowered it slightly and titanium and zirconium reduced it appreciably. The addition of titanium appeared to be particularly harmful.

All additions tested greatly reduced the impact strength of Zamak 5 alloy.

(d) Dimensional Stability

All additives tested had only a minor influence on the dimensional stability of Zamak 3 and Zamak 5 alloys.

(e) Hardness

The alloying elements considered had minor effects on the hardness of Zamak 3 and Zamak 5 alloys. These effects were quite similar to those noted previously in Phase I of the project.

X-Ray examination, done as a routine test, failed to reveal significant differences in the castability of alloys containing the various additives. Castability variations were observed during mechanical testing (on the basis of acceptance or rejection of test results due to fracture flaws), and during the actual casting. Manganese and lithium additions to Zamak 3 alloy had a slight adverse effect on castability. Beryllium, above a low level of approximately 0.001%, seriously affected castability, presumably because of the continuous formation of a fine powdery dross. All additives tested in Zamak 5 alloy seriously affected castability.

Routine metallographic examination indicated that compound formation occurred when titanium, manganese, nickel and zirconium were added to the die casting alloys, and in much the same manner as noted in Phase I.

The extensive analytical studies carried out indicated that the additions of the various elements to the die casting alloys did not affect the impurity levels and that there was no tendency for the additions to remove magnesium preferentially from the bath as a dross constituent. Evidence of some aluminum-additive compound formation was noted as a result of the analytical work. However, the aluminum content in all cases remained within the range specified for Zamak type alloys.

CONCLUSIONS

Mechanical testing results obtained in die cast test pieces have been used as the basis for evaluating the effects of the additives tried on Zamak 3 and Zamak 5 die casting alloys. Most of the casting was carried out on the A.B.C. die casting machine, and although quality of the test pieces with regard to soundness was not as good as for those cast on the larger machine, reproducibility of the results was sufficiently good to enable adequate evaluation by statistical methods. It is concluded that the elements tested are not beneficial additives to the Zamak-type alloys. In some cases, they definitely have harmful effects on the mechanical properties. In others, the effects are not significant.

Beryllium and zirconium were chosen as test elements because of claims made in patent literature wherein specific reference was made to die casting alloy, (8), (9), (10). None of the claims made have been substantiated by this work. Other addition elements were tested because of potential value as implied in the literature with respect to related fields of zinc-base alloy utilization. Anticipated improvements in the properties of the die casting alloys were not attained.

It is felt that in order to improve the properties of zinc-base die casting alloys significantly, it will be necessary to depart from the composition field of the Zamak-type alloys. Fruitful areas of investigation appear to be in the alloys of higher aluminum content. It may be necessary to study these alloys with and without copper additions in order to expand the range while still maintaining molten alloy temperatures below the upper limits of hot-chamber machine casting. It is possible that some of the addition elements tested during this project will help to overcome shortcomings of alloys containing relatively large amounts of aluminum and copper.

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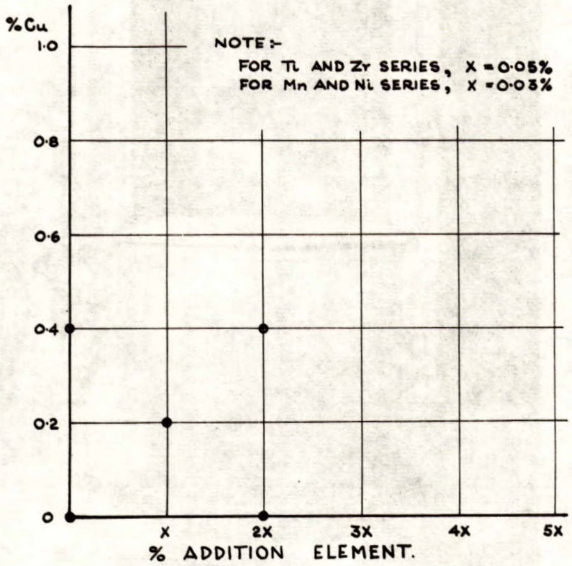


Figure 1. Layout of statistical test pattern.

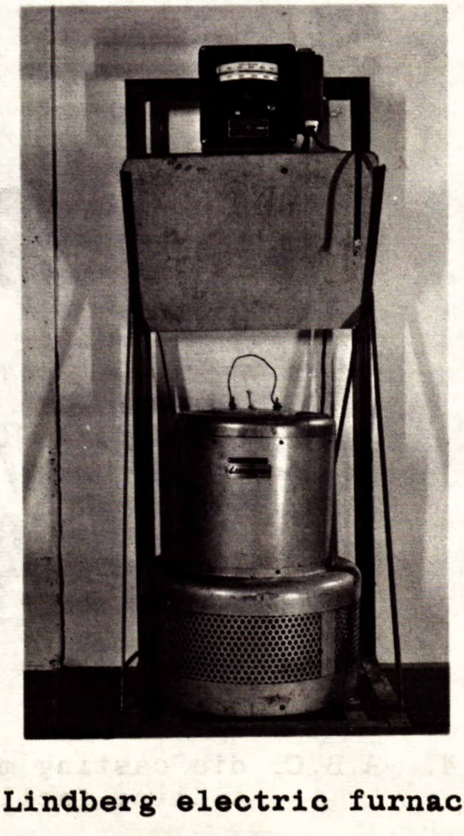


Figure 2. Lindberg electric furnace.

Figure 3. Fisher sulphur dome furnace (Dome removed).

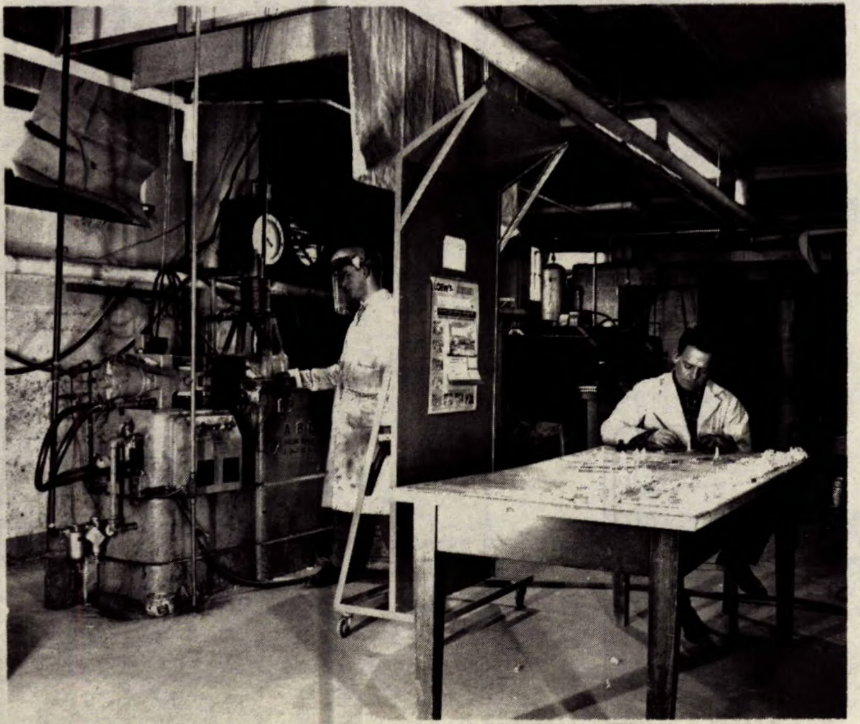


Figure 4. A.B.C. die casting machine and casting handling facilities.

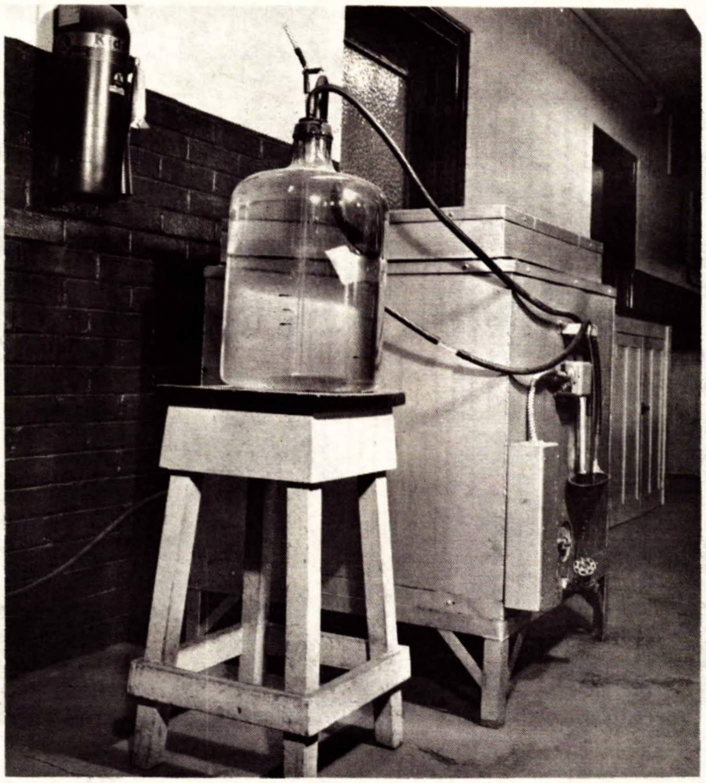


Figure 5. Exterior view of humidity cabinet.

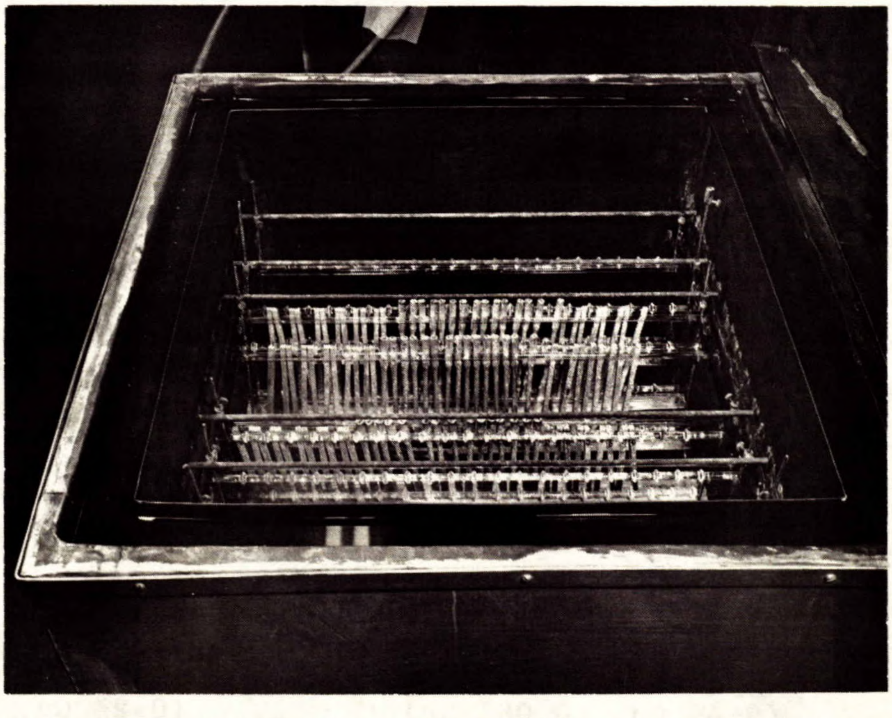


Figure 6. Interior of humidity cabinet showing positioning of specimens during ageing.

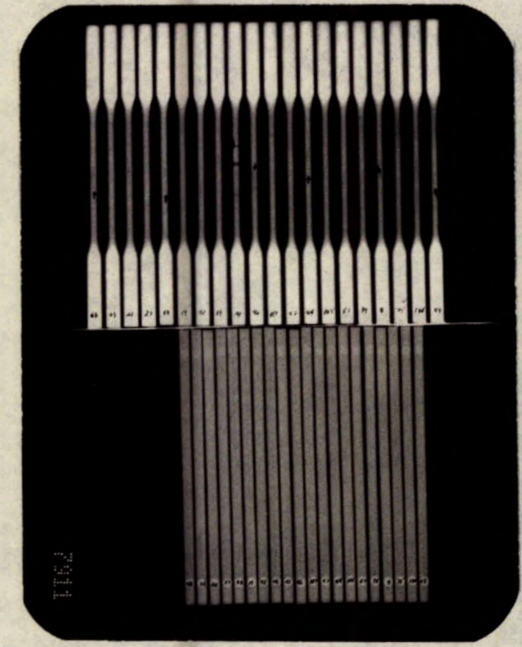


Figure 7. Radiograph of test pieces from cast CM.

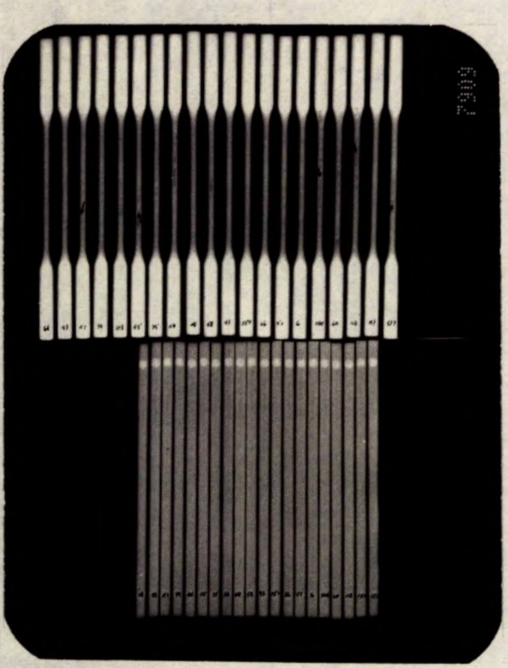
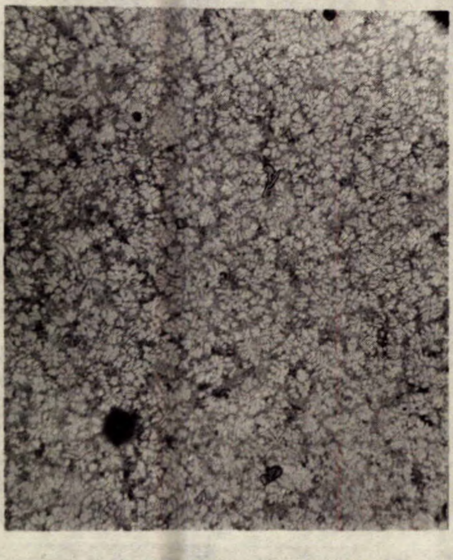
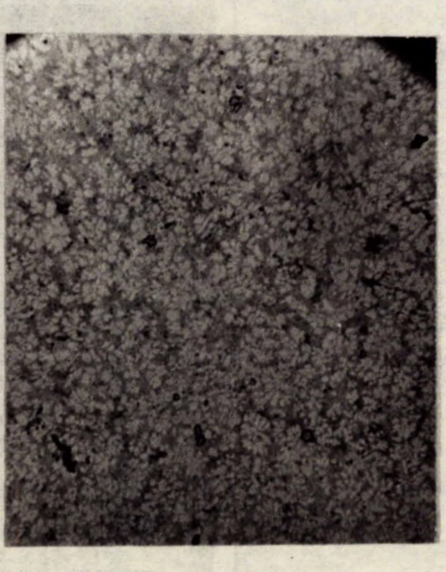


Figure 8. Radiograph of test pieces from cast CN.



X100

Figure 9. Structure of impact bar from cast MB. (0.4% Cu, 0.06% Mn)

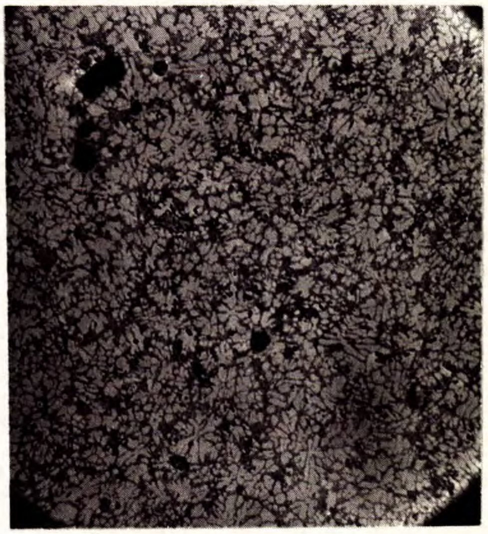


X100

Figure 10. Structure of impact bar from cast MC. (0.2% Cu, 0.03% Mn)

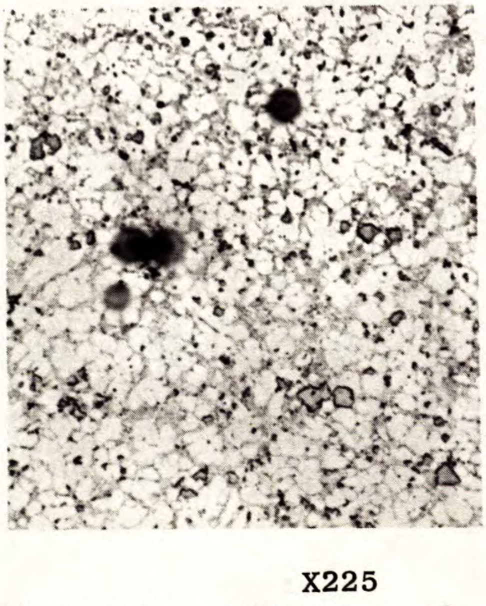
X100

Figure 11. Structure of impact bar from cast MD. (0.06% Mn)



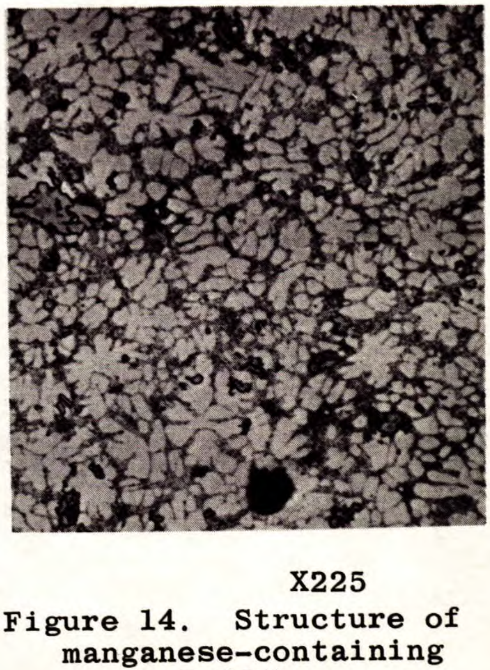
X100

Figure 12. Structure of impact bar from cast CM. (1.0% Cu, 0.35% Mn)



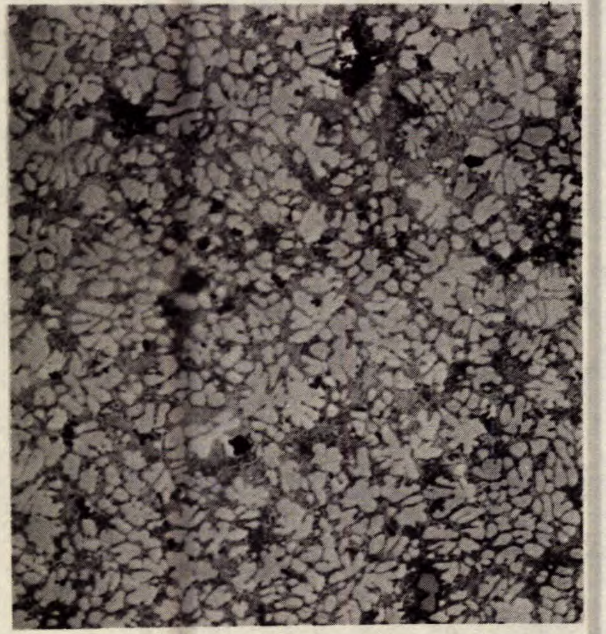
X225

Figure 13. Structure of titanium-containing Zamak 5. (CT).



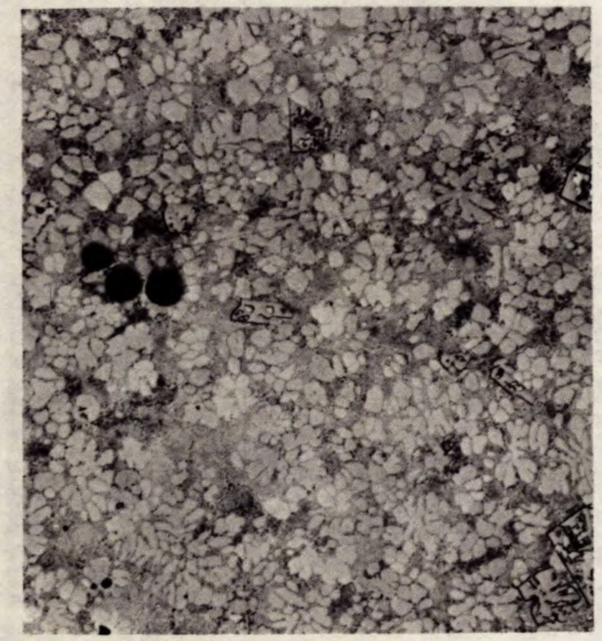
X225

Figure 14. Structure of manganese-containing Zamak 5 (CM).



X225

Figure 15. Structure of nickel-containing Zamak 5 (CN).



X225

Figure 16. Structure of zirconium-containing Zamak 5 (CZ).

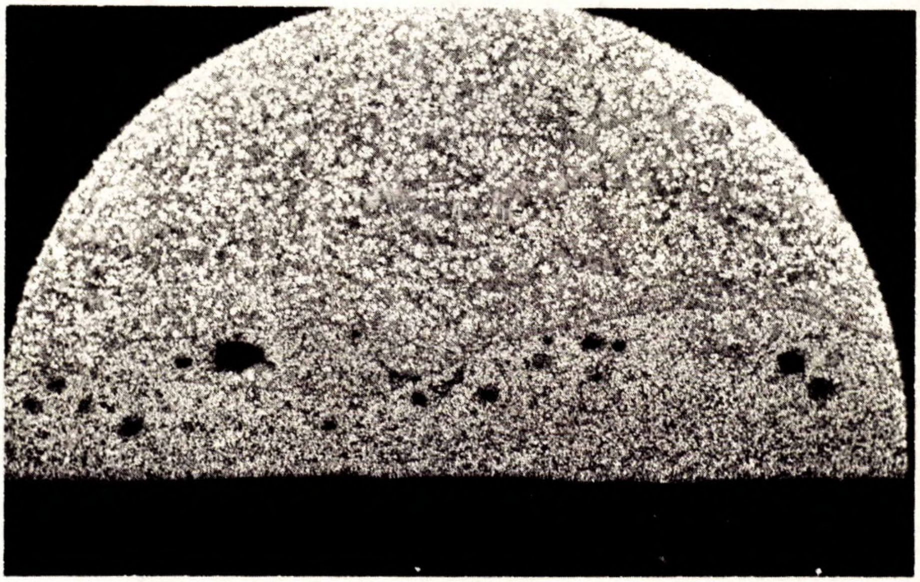
X1½

Figure 17

X1½

Figure 18

Both figures illustrate non-adherent skin evident on bars of cast BC after impact testing.



X100

Figure 19. Structure of impact bar from cast BC (section adjacent to break shown in Figure 17).

TABLE 1

Nominal Composition of Alloys Cast on the A.B.C. Die Casting Machine

Cast No.	Nominal Composition - % -			
	Cu	Be	Ti	Mn
BA	-	0.08		
BB	-	0.005		
BC	-	0.001		
TA	0.4		-	
TB	-		0.1	
TC	0.2		0.05	
TD	0.4		-	
TE	-		-	
TF	0.2		0.05	
TG	-		-	
TH	0.4		0.1	
TI	0.4		0.1	
TJ	-		0.1	
TK	0.2		0.05	
TL	-		0.1	
TM	0.4		-	
TN	0.4		0.1	
TO	-		-	
MA	-			-
MB	0.4			0.06
MC	0.2			0.03
MD	-			0.06
ME	0.2			0.03
MF	0.4			0.06
MG	0.4			-
MH	-			-
MI	-			0.06
MJ	0.4			-

Cast No.	Nominal Composition - % -					
	Cu	Ni	Zr	Li	Ti	Mn
NA	-	0.06				
NB	0.2	0.03				
NC	0.4	0.06				
ND	-	0.06				
NE	0.4	0.06				
NF	0.2	0.03				
ZA	-		-			
ZB	0.4		-			
ZC	0.4		0.1			
ZD	-		-			
ZE	-		0.1			
ZF	0.4		-			
ZG	-		0.1			
ZH	0.2		0.05			
ZI	0.4		0.1			
ZJ	0.2		0.05			
ZK	-		-			
LA	-			*		
LB	0.4			*		
LC	0.4			*		
LD	-			*		
CA	1.0					
CT	1.0				0.30	
CM	1.0					0.35
CN	1.0	0.30				
CZ	1.0		0.10			

NB: All alloys contain nominally 4.0% Al, 0.04% Mg.
Series designated by first letter of cast no. as follows:

B - Beryllium; T - Titanium; M - Magnesium; N - Nickel;
Z - Zirconium; L - Lithium; C - Zamak 5.

*Lithium treated.

TABLE 2(a)

Mechanical Testing Results: Titanium Series

Cast No.	Nominal Composition %			Ultimate Tensile Strength - psi -			Elongation % in 2 in.			Impact Strength - ft-lb -							Dimensional Stability - in./in. x 10-4 -		
	Al	Cu	Ti	RT	ST	HT	RT	ST	HT	RT	ST	HT	0°	-10°	-20°	-40°	RT	ST	HT
TE	4.0	-	-	38,700	32,800	33,100	2.5	3.4	4.8	G. 26.1 V. 34.1	17.0 31.3	24.9 38.4	2.71 3.60	2.12 2.61	1.71 2.01	1.38 1.42	-5.11	-3.53	-7.89
TG	4.0	-	-	39,100	32,600	32,100	3.4	4.9	7.2	G. 30.6 V. 27.8	30.5 22.2	33.0 26.1	2.91 3.15	2.43 2.55	2.00 1.93	1.50 1.50	-1.73	0.00	-5.47
TA	4.0	0.4	-	36,200	31,900	33,200	1.6	2.6	2.5	G. 26.7 V. 34.7	21.2 39.8	26.8 36.1	3.20 5.25	2.18 2.78	1.89 2.23	1.35 1.66	-2.50	-3.86	-7.03
TD	4.0	0.4	-	38,700	35,100	34,400	2.1	3.1	3.4	G. 21.8 V. 33.0	17.6 36.7	24.3 37.4	2.95 5.23	2.08 3.18	1.81 2.08	1.29 1.45	-4.86	-4.67	-8.52
TH	4.0	0.4	0.1	39,100	33,900	33,600	2.3	2.9	3.7	G. 13.6 V. 23.5	10.0 18.5	12.0 19.4	2.49 3.26	1.90 2.43	1.73 1.98	1.38 1.48	-3.00	-4.60	-6.90
TI	4.0	0.4	0.1	38,500	34,100	34,200	2.0	3.0	3.5	G. 11.2 V. 17.0	7.9 19.0	9.9 22.0	2.31 2.89	2.00 2.45	1.55 1.80	1.25 1.53	-3.40	-5.43	-7.27
TC	4.0	0.2	0.05	37,700	33,100	32,900	2.1	2.8	3.2	G. 10.9 V. 26.5	6.4 27.5	9.1 32.8	2.14 3.28	1.90 2.38	1.51 1.84	1.34 1.45	-4.57	-3.93	-7.53
TF	4.0	0.2	0.05	39,400	33,900	33,700	2.4	3.9	4.2	G. 18.6 V. 25.5	15.0 26.7	16.3 28.1	2.44 4.04	2.01 2.83	1.78 2.11	1.35 1.61	-2.87	-3.93	-6.03
TB	4.0	-	0.1	37,100	31,700	31,200	2.3	3.4	2.7	G. 6.2 V. 21.4	5.5 18.5	6.5 24.5	2.00 2.82	1.83 2.30	1.58 1.90	1.33 1.60	-3.89	-1.22	-7.05
TJ	4.0	-	0.1	37,500	31,400	31,500	2.4	3.3	4.2	G. 8.9 V. 15.1	5.3 7.7	7.2 18.1	2.13 2.74	1.83 2.13	1.55 1.75	1.30 1.50	-3.27	-4.63	-6.10

RT - Room Temp Aged ST - Steam Aged HT - High Temp Aged G - Gate End V - Vent End

TABLE 2(b)

Mechanical Testing Results: Titanium Series

Cast No.	Nominal Composition - % -			Ultimate Tensile Strength - psi -			Elongation % in 2 in.			Impact Strength - ft-lb -							Dimensional Stability - in./in. x 10^{-4} -		
	Al	Cu	Ti	RT	ST	HT	RT	ST	HT	RT	ST	HT	0°	-10°	-20°	-40°	RT	ST	HT
TO	4.0	-	-	39,100	32,800	32,400	3.4	6.1	7.8	G. 34.1 V. 45.7	30.1 35.0	39.7 43.5	2.84 5.81	2.03 3.72	1.75 2.53	1.30 1.95	-2.23	-3.67	-5.33
TM	4.0	0.4	-	40,400	35,300	35,400	2.9	4.0	5.7	G. 36.9 V. 45.1	39.8 45.7	38.5 43.8	3.46 17.01	2.40 4.18	1.85 2.58	1.45 1.90	-1.93	-3.21	-5.83
TN	4.0	0.4	0.1	39,500	34,700	34,800	2.3	2.8	3.8	G. 21.6 V. 34.3	16.9 28.7	22.4 38.3	2.50 4.83	1.93 3.20	1.60 2.28	1.20 1.48	-2.50	-4.33	-6.43
TK	4.0	0.2	0.05	37,800	33,000	33,000	2.6	3.3	3.3	G. 22.3 V. 35.2	19.7 38.3	21.8 39.3	2.28 4.76	1.75 2.55	1.40 2.33	1.05 1.35	-2.33	-4.17	-5.30
TL	4.0	-	0.1	37,600	32,100	31,900	2.1	4.0	3.8	G. 10.9 V. 29.8	8.4 15.0	9.5 30.8	1.93 3.06	1.53 2.55	1.38 2.20	1.08 1.35	-2.13	-3.70	-5.40

RT - Room Temp Aged ST - Steam Aged HT - High Temp Aged
G - Gate End V - Vent End

TABLE 3

Mechanical Testing Results: Manganese Series

Cast No.	Nominal Composition - % -			Ultimate Tensile Strength - psi -			Elongation % in 2 in.			Impact Strength - ft-lb -					Dimensional Stability - in./in. x 10^{-4} -		
	Al	Cu	Mn	RT	ST	HT	RT	ST	HT		RT	ST	HT	-20°	RT	ST	HT
MA	4.0	-	-	38,700	32,500	31,500	3.0	4.8	8.5	G.	30.7	22.5	33.5	1.70	-1.80	-2.93	-4.90
										V.	42.7	33.8	41.6	2.83			
MH	4.0	-	-	39,000	32,600	32,800	4.1	5.9	8.2	G.	32.1	32.3	35.9	1.75	-3.50	-4.07	-6.50
										V.	39.5	37.2	42.2	2.35			
MG	4.0	0.4	-	41,000	35,300	35,600	4.0	5.3	5.8	G.	38.4	36.8	40.0	1.98	-2.13	-3.07	-6.53
										V.	42.8	37.0	43.5	2.80			
MJ	4.0	0.4	-	40,300	35,300	35,500	3.9	5.2	5.7	G.	35.2	40.6	39.3	1.80	-2.27	-4.03	-6.60
										V.	42.7	45.5	44.0	2.90			
MB	4.0	0.4	0.06	40,700	36,200	34,800	2.8	3.8	5.0	G.	31.6	35.8	36.2	1.83	-2.10	-3.10	-5.43
										V.	40.6	41.1	43.0	2.85			
MF	4.0	0.4	0.06	39,200	35,100	34,900	3.0	4.1	4.5	G.	25.4	25.7	24.4	1.65	-2.30	-1.60	-5.90
										V.	36.7	40.0	41.0	2.43			
MC	4.0	0.2	0.03	40,000	35,100	35,200	3.9	4.7	7.4	G.	28.8	37.7	37.6	1.83	-1.47	-2.33	-4.93
										V.	40.7	44.1	44.1	2.73			
ME	4.0	0.2	0.03	39,500	34,700	34,700	4.1	5.2	8.8	G.	28.7	36.6	31.4	1.70	-2.43	-0.30	-6.40
										V.	40.3	42.8	42.0	2.65			
MD	4.0	-	0.06	38,000	32,800	32,900	4.3	6.4	8.0	G.	21.4	24.0	23.7	1.75	-2.27	-2.70	-5.23
										V.	35.9	39.3	38.7	2.38			
MI	4.0	-	0.06	38,300	33,200	33,400	3.7	5.7	6.1	G.	20.9	18.9	18.3	1.48	-3.37	-4.03	-6.30
										V.	38.0	32.4	38.1	2.08			

RT - Room Temp Aged ST - Steam Aged HT - High Temp Aged G - Gate End V - Vent End

TABLE 4

Mechanical Testing Results: Nickel Series

Cast No.	Nominal Composition - % -			Ultimate Tensile Strength - psi -			Elongation % in 2 in.			Impact Strength - ft lb -				Dimensional Stability - in./in. x 10^{-4} -		
	Al	Cu	Ni	RT	ST	HT	RT	ST	HT	RT	ST	HT	-20°	RT	ST	HT
NC	4.0	0.4	0.06	40,900	35,000	34,900	3.3	6.4	6.2	G. 35.2 V. 43.3	30.7 42.2	33.2 41.5	1.92 3.95	-2.13	-2.54	-6.17
NE	4.0	0.4	0.06	40,200	34,300	34,700	4.0	5.5	5.9	G. 33.8 V. 44.1	32.1 36.6	33.9 41.2	1.93 3.18	-2.74	-3.40	-6.93
NB	4.0	0.2	0.03	39,400	33,700	33,600	3.7	6.4	5.8	G. 26.8 V. 40.3	28.7 29.0	29.3 43.2	1.60 2.35	-3.80	-3.67	-7.67
NF	4.0	0.2	0.03	39,800	34,200	34,400	4.1	5.4	6.4	G. 28.4 V. 43.1	26.1 30.2	27.1 41.7	1.58 2.43	-2.87	-3.17	-6.43
NA	4.0	-	0.06	37,900	32,400	32,100	3.3	6.0	5.2	G. 20.2 V. 40.1	20.3 31.3	22.8 40.1	1.45 1.98	-3.60	-2.59	-7.30
ND	4.0	-	0.06	38,300	32,100	31,900	4.2	6.6	8.3	G. 18.0 V. 40.1	11.8 15.5	18.9 41.2	1.48 1.90	-2.23	-3.07	-5.83

RT - Room Temp Aged   ST - Steam Aged   HT - High Temp Aged   G - Gate End   V - Vent End

TABLE 5

Mechanical Testing Results: Zirconium Series

Cast No.	Nominal Composition - % -			Ultimate Tensile Strength - psi -			Elongation % in 2 in.			Impact Strength - ft-lb -								Dimensional Stability - in./in. x 10^{-4} -		
	Al	Cu	Zr	RT	ST	HT	RT	ST	HT		RT	ST	HT	0°	-10°	-20°	-40°	RT	ST	HT
ZA	4.0	-	-	38,800	32,400	32,400	3.5	4.9	8.1	G.	26.1	21.3	29.1	2.78	1.98	1.80	1.38	-2.46	-2.04	-5.50
										V.	41.1	41.5	41.4	4.43	3.23	2.00	1.45			
ZD	4.0	-	-	38,600	32,500	32,500	4.4	5.7	9.8	G.	39.0	40.2	38.9	3.53	2.55	2.23	1.68	-2.96	-4.08	-5.54
										V.	44.1	42.5	42.6	5.20	3.33	3.05	1.90			
ZK	4.0	-	-	38,600	32,300	32,200	3.4	4.0	6.6	G.	34.8	27.4	35.3	2.58	1.90	1.58	1.35	-2.29	-3.84	-5.17
										V.	45.0	32.1	42.2	6.06	3.25	2.60	1.70			
ZB	4.0	0.4	-	40,600	35,300	35,000	3.2	4.7	5.3	G.	32.0	36.7	37.3	3.15	2.05	1.95	1.43	-1.97	-4.83	-5.84
										V.	45.4	45.5	44.3	8.04	2.90	2.63	1.75			
ZF	4.0	0.4	-	40,500	34,900	35,000	3.3	4.3	5.2	G.	40.0	43.8	41.5	3.99	2.75	2.13	1.75	-1.80	-4.47	-5.80
										V.	46.3	46.7	43.6	17.1	4.55	3.28	1.95			
ZC	4.0	0.4	0.1	39,400	34,400	34,200	2.3	4.0	4.0	G.	18.3	21.4	18.9	2.86	2.28	1.33	1.35	-1.83	-2.63	-6.30
										V.	36.0	36.8	38.1	5.56	3.08	2.13	1.35			
ZI	4.0	0.4	0.1	40,200	34,600	34,400	2.5	4.6	4.5	G.	22.4	25.2	25.1	3.45	2.15	1.90	1.38	-2.47	-3.47	-6.53
										V.	37.6	33.5	39.3	6.48	3.38	2.25	1.70			
ZH	4.0	0.2	0.05	38,400	33,000	32,900	2.4	4.0	4.5	G.	22.6	20.6	24.7	2.81	2.25	1.85	1.43	-2.90	-3.80	-6.20
										V.	38.5	38.8	40.6	5.31	2.93	2.50	1.75			
ZJ	4.0	0.2	0.05	38,700	33,200	32,700	2.8	4.2	4.6	G.	24.8	26.5	25.9	2.58	2.35	1.53	1.32	-2.27	-4.07	-5.73
										V.	41.1	39.2	42.0	4.73	3.25	2.20	1.60			
ZE	4.0	-	0.1	37,900	31,900	31,600	3.2	5.1	5.0	G.	20.8	21.0	25.3	3.00	2.20	2.05	1.23	-1.60	-1.16	-4.37
										V.	36.9	33.0	41.1	4.31	2.55	2.15	1.68			
ZG	4.0	-	0.1	37,800	31,600	31,400	3.1	4.6	5.9	G.	23.7	20.8	20.8	2.73	2.13	1.93	1.55	-2.63	-2.53	-5.40
										V.	34.8	36.5	40.9	3.84	3.20	2.50	2.00			

RT - Room Temp Aged   ST - Steam Aged   HT - High Temp. Aged   G - Gate End   V - Vent End

TABLE 6(a)

Mechanical Testing Results: Beryllium Series

Cast No.	Nominal Composition - % -			Ultimate Tensile Strength - psi -			Elongation % in 2 in.			Impact Strength - ft-lb -					Dimensional Stability - in./in. x 10^{-4} -		
	Al	Cu	Be	RT	ST	HT	RT	ST	HT		RT	ST	HT	-20°	RT	ST	HT
BB	4.0	–	0.005	36,000	32,200	31,700	2.1	3.6	3.4	G.	13.3	6.7	14.9	1.35	-2.00	-2.83	-5.17
										V.	23.3	17.0	23.0	1.55			
BC	4.0	–	0.001	39,400	32,700	32,300	3.6	7.1	8.8	G.	41.7	38.1	41.9	2.25	-2.87	-5.17	-6.20
										V.	45.2	35.3	41.9	2.85			
*DD	4.0	–	–	42,700	35,200	35,600	20.7	24.1	29.4	G.	42.5	38.8	40.9	3.5	-2.72	-5.44	-6.88
										M.	47.7	46.5	43.8	4.5			
										V.	46.2	47.9	44.8	3.6			
*DE	4.0	–	0.001	42,500	35,200	35,200	19.9	24.9	27.0	G.	38.9	36.4	39.3	2.1	-2.89	-5.00	-6.66
										M.	47.5	46.8	42.9	3.1			
										V.	47.9	44.0	43.8	3.8			
*DF	4.0	–	0.0005	42,100	35,000	35,300	18.2	23.7	26.0	G.	39.2	38.7	39.9	1.4	-2.72	-4.50	-6.22
										M.	47.7	41.6	43.2	1.9			
										V.	47.7	46.5	44.0	2.3			

RT – Room Temp Aged ST – Steam Aged HT – High Temp Aged G – Gate End M – Middle Section V – Vent End

*Cast on Cleveland "200" Die Casting Machine.

TABLE 6(b)

Yield Strength Results: Beryllium Series

Cast No.	Nominal Composition - % -			Yield Strength - psi -					
				0.2% offset			0.1% offset		
	Al	Cu	Be	RT	ST	HT	RT	ST	HT
DD	4.0	-	-	29,800	24,500	24,400	26,100	20,100	21,100
DE	4.0	-	0.001	29,700	23,300	23,800	26,600	20,100	20,500
DF	4.0	-	0.0005	28,700	23,800	24,000	25,100	20,600	20,400

TABLE 7

Mechanical Testing Results: Lithium Series

Cast No.	Nominal Composition - % -			Ultimate Tensile Strength - psi -			Elongation % in 2 in.			Impact Strength - ft-lb -				Dimensional Stability - in./in. x 10^{-4} -		
	Al	Cu	Li	RT	ST	HT	RT	ST	HT	RT	ST	HT	-20°	RT	ST	HT
LA	4.0	-	*	39,300	33,300	33,700	5.3	6.7	8.1	G. 33.5 V. 40.5	37.9 40.5	40.9 42.7	1.80 2.28	-2.20	-3.33	-5.70
LD	4.0	-	**	39,200	33,400	33,300	3.0	6.7	5.7	G. 37.1 V. 42.8	35.5 40.0	38.1 42.8	1.75 2.40	-2.67	-4.93	-6.33
LB	4.0	0.4	*	39,500	35,600	35,800	3.5	5.0	5.0	G. 38.4 V. 43.5	41.0 46.2	43.2 42.4	1.93 2.78	-1.80	-3.73	-6.07
LC	4.0	0.4	**	40,000	35,200	35,900	3.4	4.5	4.6	G. 35.7 V. 43.0	40.8 44.2	37.2 43.5	1.88 2.75	-2.84	-5.73	-6.47

RT - Room Temp Aged ST - Steam Aged HT - High Temp Aged G - Gate End V - Vent End

*Treated with 0.15% Li
**Treated with 0.10% Li

TABLE 8

Mechanical Testing Results: Zamak 5 Series

Cast No.	Nominal Composition - % -			Ultimate Tensile Strength - psi -			Elongation % in 2 in.			Impact Strength - ft-lb -				Dimensional Stability - in./in. x 10^{-4} -		
	Al	Cu		RT	ST	HT	RT	ST	HT	RT	ST	HT	-20°	RT	ST	HT
CA	4.0	1.0		41,000	36,700	36,300	2.3	4.1	3.3	G. 36.0 V. 38.1	29.3 32.4	28.3 39.0	2.00 2.85	-1.93	-5.63	-7.07
CT	4.0	1.0	Ti-0.30	39,100	35,400	35,500	2.2	2.7	2.7	G. 9.7 V. 15.1	5.0 7.9	7.3 10.1	1.28 1.80	-1.97	-3.54	-7.10
CM	4.0	1.0	Mn-0.35	36,000	32,800	33,000	1.3	1.4	1.5	G. 8.8 V. 13.5	4.1 7.1	5.6 10.4	1.05 1.53	-1.83	-4.73	-7.23
CN	4.0	1.0	Ni-0.30	38,600	35,400	35,200	2.5	2.6	3.1	G. 16.0 V. 23.8	6.3 6.6	7.2 14.4	1.28 1.93	-2.57	-3.70	-7.36
CZ	4.0	1.0	Zr-0.10	40,600	35,700	36,000	2.3	2.8	3.1	G. 19.5 V. 30.4	16.8 23.7	16.3 28.1	1.88 2.73	-1.93	-4.63	-6.60

RT - Room Temp Aged   ST - Steam Aged   HT - High Temp Aged   G - Gate End   V - Vent End

TABLE 9

Statistical Analysis Results: Titanium Series*

Mechanical Property and Specimen Treatment	Ti Series I (Ten Casts – two per composition)						Ti Series II (Five Casts – one per composition)						Ti Series I and II Combined (three casts per composition)					
	b_o	b_1	b_2	S_s	S_r	N	b_o	b_1	b_2	S_s	S_r	N	b_o	b_1	b_2	S_s	S_r	N
Ultimate Tensile Strength – psi																		
Heat treated	33,000	927	NS	1050	650	20	33,480	1476	NS	310	440	19	33,160	1110	NS	900	650	
SE b's	207	231					198	221					168	188				
Room temp	38,210	NS	NS	1460	1040	20	38,870	NS	NS	810	1200	17	38,430	NS	NS	1310	1100	
SE b's	330						530						284					
Steam treated	33,030	818	NS	1640	990	15	33,580	1308	NS	336	528	15	33,210	980	NS	1350	890	
SE b's	313	350					236	264					229	256				
Elongation – % in 2 in.																		
Heat treated	3.92	NS	NS	1.43	1.35	20	4.87	NS	NS	1.40	1.87	18	4.24	NS	-0.80	1.42	1.40	
SE b's	0.43						0.84						0.36		0.40			
Room temp	2.30	-0.33	NS	0.69	0.35	20	2.68	NS	NS	0.54	0.52	16	2.43	-0.25	NS	0.65	0.43	
SE b's	0.11	0.12					0.23						0.11	0.12				
Steam treated	3.32	-0.42	NS	0.88	0.55	15	4.05	NS	NS	0.80	1.25	14	3.56	-0.55	NS	0.85	0.78	
SE b's	0.17	0.19					0.56						0.20	0.22				
Dimensional Stability – in./in. x 10^{-4}																		
Heat treated	-6.98	NS	NS	0.44	0.92	5	-5.66	NS	NS	0.51	0.48	5	-6.54	NS	NS	0.46	1.01	
SE b's	0.29						0.22						0.26					
Room temp	-3.52	NS	NS	0.34	1.08	5	-2.22	NS	NS	0.27	0.21	5	-3.09	NS	NS	0.32	1.08	
SE b's	0.34						0.10						0.28					
Steam treated	-3.82	NS	NS	1.33	1.46	5	-3.82	NS	NS	0.71	0.44	5	-3.82	-0.58	-0.62	1.06	0.98	
SE b's	0.46						0.20						0.25	0.28	0.28			
Impact Strength – ft-lb																		
Heat treated – Gate	17.00	NS	-9.17	7.06	4.18	20	26.38	NS	-11.57	4.78	6.07	17	20.12	NS	-9.97	6.54	6.56	
SE b's	1.32		1.48				2.71		3.03				1.69		1.89			
– Vent	28.27	NS	-6.76	11.00	4.26	20	39.13	NS	NS	4.23	5.26	19	31.89	NS	-6.01	9.54	6.68	
SE b's	1.35		1.50				2.35						1.73		1.93			
Room temp – Gate	17.49	NS	-8.10	6.05	3.82	20	25.15	NS	-9.60	5.37	4.86	19	20.05	NS	-8.60	5.86	5.46	
SE b's	1.21		1.35				2.17		2.43				1.41		1.58			
– Vent	25.85	NS	-6.60	5.37	3.08	20	38.02	NS	-6.66	3.73	2.58	20	29.91	NS	-6.62	4.94	6.73	
SE b's	0.97		1.09				1.16		1.29				1.73		1.94			
Steam treated – Gate	13.64	NS	-7.19	6.38	4.87	15	22.98	4.54	-11.13	6.74	2.62	14	16.76	NS	-8.51	6.49	6.88	
SE b's	1.54		1.72				1.17	1.31	1.31				1.78		1.99			
– Vent	24.77	4.30	-8.29	10.66	4.39	15	32.53	NS	NS	8.01	11.55	13	27.36	4.90	-8.60	9.95	5.70	
SE b's	1.39	1.55	1.55				5.17						1.47	1.64	1.64			
Low temp 0°C – Gate	2.53	NS	-0.36	0.29	0.24	20	2.60	NS	NS	0.36	0.59	20	2.55	0.20	-0.39	0.32	0.22	
SE b's	0.07		0.08				0.26						0.06	0.06	0.06			
– Vent	3.64	0.54	-0.69	1.01	0.48	20	7.09	NS	NS	5.16	5.63	20	4.79	NS	NS	3.14	3.53	
SE b's	0.15	0.17	0.17				2.52						0.91					
-10°C – Gate	2.03	NS	-0.16	0.19	0.12	15	1.92	NS	NS	0.21	0.33	10	1.99	NS	-0.19	0.19	0.17	
SE b's	0.04		0.04				0.15						0.05		0.05			
– Vent	2.56	0.16	-0.23	0.44	0.18	15	3.24	NS	NS	0.61	0.72	10	2.79	NS	-0.33	0.49	0.49	
SE b's	0.06	0.06	0.06				0.32						0.13		0.14			
-20°C – Gate	1.71	NS	-0.13	0.16	0.12	15	1.60	NS	NS	0.22	0.21	10	1.67	NS	-0.14	0.18	0.15	
SE b's	0.04		0.04				0.09						0.04		0.05			
– Vent	1.96	NS	-0.10	0.30	0.12	15	2.38	NS	-0.16	0.41	0.06	10	2.10	NS	NS	0.33	0.25	
SE b's	0.04		0.04				0.03		0.03				0.05					
-40°C – Gate	1.35	NS	NS	0.14	0.07	15	1.22	0.07	-0.19	0.12	0.04	10	1.30	NS	NS	0.14	0.12	
SE b's	0.02						0.02	0.02	0.02				0.03					
– Vent	1.52	NS	NS	0.22	0.08	15	1.61	NS	NS	0.26	0.03	10	1.55	NS	NS	0.23	0.18	
SE b's	0.03						0.13						0.05					

*b_o, b_1, b_2 – regression coefficients.
S_s – standard deviation of variation within casts.
S_r – standard deviation of variation about regression.
S_c – standard deviation of variation between duplicate casts.
N – average number of specimens per cast.
SE_b – standard error.
NS – not significant.

TABLE 10

Statistical Analysis Results: Manganese, Nickel and Zirconium Series*

Mechanical Property and Specimen Treatment	Mn Series (Ten Casts - two per composition)							Ni Series (Ten Casts - two per composition)							Zr Series (Ten Casts - two per composition)					
	b_o	b_1	b_2	b_{12}	S_s	S_r	N	b_o	b_1	b_2	b_{12}	S_s	S_r	N	b_o	b_1	b_2	S_s	S_c	N
Ultimate Tensile Strength - psi																				
Heat treated	34,130	1260	NS	NS	345	710	16	33,700	1540	NS	NS	120	500	19	33,190	1370	-386	287	236	21
SE b's	225	252						160	180						77	86	86			
Room temp	39,480	910	NS	NS	760	570	16	39,550	1100	NS	NS	840	340	17	39,070	960	-376	578	354	19
SE b's	182	204						110	120						120	134	134			
Steam treated	34,290	1340	NS	NS	362	510	13	33,700	1300	NS	NS	450	290	14	33,370	1350	-316	317	224	14
SE b's	162	181						95	105						76	85	85			
Elongation - % in 2 in.																				
Heat treated	6.79	-1.23	NS	NS	2.04	1.09	17	6.60	-0.82	NS	NS	2.05	1.00	19	5.53	-1.02	-0.94	1.47	1.12	21
SE b's	0.35	0.39						0.32	0.35						0.37	0.41	0.41			
Room temp	3.66	NS	NS	-0.38	0.68	0.45	16	3.77	NS	NS	NS	0.78	0.43	17	3.06	-0.35	-0.40	0.60	0.34	19
SE b's	0.15			0.16				0.13							0.12	0.13	0.13			
Steam treated	5.10	-0.53	NS	-0.51	1.04	0.43	13	5.79	NS	0.46	NS	1.38	0.49	14	4.53	NS	NS	0.76	0.52	14
SE b's	0.14	0.15		0.15				0.15		0.17					0.18					
Dimensional Stability - in./in. x 10^{-4}																				
Heat treated	-5.87	NS	NS	NS	0.34	0.69	5	-6.49	NS	NS	NS	0.40	0.77	5	-5.69	-0.50	NS	0.39	0.37	5
SE b's	0.22							0.28							0.13	0.14				
Room temp	-2.36	NS	NS	NS	0.37	0.63	5	-2.71	NS	NS	NS	0.36	0.71	5	-2.27	NS	NS	0.27	0.46	5
SE b's	0.20							0.27							0.15					
Steam treated	-2.82	NS	NS	NS	1.17	1.19	5	-3.25	NS	NS	NS	0.99	0.54	5	-3.49	-0.47	-0.93	0.75	0.42	5
SE b's	0.38							0.23							0.17	0.19	0.19			
Impact Strength - ft-lb																				
Heat treated - Gate	32.03	3.56	-5.76	NS	6.87	4.33	18	31.39	4.41	-4.99	NS	7.72	3.13	18	29.35	NS	-7.88	5.62	3.15	21
SE b's	1.37	1.53	1.53					0.99	1.10	1.10					1.07		1.20			
- Vent	41.81	1.36	-1.31	NS	3.75	1.22	19	42.00	0.63	-0.92	NS	3.13	0.67	19	41.47	NS	-1.66	3.00	0.97	21
SE b's	0.38	0.43	0.43					0.21	0.24	0.24					0.37		0.41			
Room temp - Gate	29.31	3.18	-4.62	NS	6.36	2.01	20	29.86	5.19	-3.63	2.51	6.16	2.00	20	27.83	NS	-7.57	5.34	3.38	22
SE b's	0.63	0.71	0.71					0.63	0.71	0.71	0.71				1.13		1.26			
- Vent	39.99	NS	-2.06	NS	4.62	1.63	19	41.86	1.32	NS	NS	4.59	1.19	20	40.55	NS	-4.45	3.82	0.92	21
SE b's	0.52		0.58					0.38	0.42						0.39		0.44			
Steam treated - Gate	31.03	5.15	NS	NS	8.91	6.17	13	28.19	6.66	-4.65	NS	9.10	3.88	14	28.36	NS	-7.46	6.66	5.12	13
SE b's	1.95	2.18						1.23	1.37	1.37					1.72		1.92			
- Vent	39.32	NS	NS	NS	6.87	4.28	13	33.84	NS	NS	NS	9.19	8.25	13	38.47	NS	-3.36	6.38	3.90	14
SE b's	1.35							2.60							1.35		1.51			
Low temp 0°C - Gate															3.07	NS	NS	0.46	0.45	20
SE b's															0.15					
- Vent															6.66	NS	NS	3.67	3.77	20
SE b's															1.22					
-10°C - Gate															2.26	NS	NS	0.29	0.23	10
SE b's															0.08					
- Vent															3.24	NS	NS	0.77	0.46	10
SE b's															0.17					
-20°C - Gate	1.74	NS	NS	NS	0.20	0.13	10	1.72	0.16	NS	NS	0.28	0.13	10	1.85	NS	NS	0.21	0.28	10
SE b's	0.04							0.04	0.04						0.09					
- Vent	2.60	NS	NS	NS	0.38	0.27	10	2.67	0.47	NS	0.34	0.52	0.30	10	2.53	NS	-0.32	0.40	0.20	10
SE b's	0.08							0.09	0.10		0.10				0.08		0.08			
-40°C - Gate															1.44	NS	NS	0.21	0.15	10
SE b's															0.53					
- Vent															1.74	NS	NS	0.32	0.16	10
SE b's															0.06					

*b_o, b_1, b_2, b_{12} - regression coefficients.
S_s - standard deviation of variation within casts.
S_r - standard deviation of variation about regression.
S_c - standard deviation of variation between duplicate casts.
N - average number of specimens per cast.
SE_b - standard error.
NS - not significant.

TABLE 11

Composition of Titanium Series Alloys

Sample No.	Chemical Analyses - %				Spectrographic Analyses - %			
	Al	Cu	Ti	Fe	Mg	Pb	Cd	Cu
145	3.96	0.41		0.015	0.040	0.0013	0.0002	
TA	3.95	0.41			0.042	0.0010		
147	4.03		0.09	0.017	0.040	0.0010	0.0001	0.0015
TB	3.94		0.09		0.038	0.0016		
146	3.99	0.20	0.05	0.015	0.040	0.0010	0.0002	
TC	3.98	0.20	0.05		0.040	0.0015		
138	3.95	0.40		0.009	0.041	0.0013	0.0003	
TD	4.02	0.40			0.037	0.0014		
141	3.97			0.011	0.044	0.0009	0.0002	0.003
TE	3.95		sample	misplaced				
144	4.01	0.21	0.05	0.015	0.036	0.0012	0.0002	
TF	3.99	0.20	0.05		0.039	0.0016		
136	4.07			0.009	0.042	0.0010	0.0003	0.0035
TG	4.07		sample	misplaced				
148	4.03	0.41	0.10	0.016	0.040	0.0011	0.0001	
TH	4.01	0.41	0.10		0.038	0.0009		
143	3.98	0.42	0.10	0.018	0.036	0.0012	0.0003	
TI	4.03	0.40	0.09		0.039	0.0013		
142	3.97		0.09	0.016	0.040	0.0013	0.0004	0.0010
TJ	3.95		0.09		0.043	0.0016		
169	3.98	0.20	0.05		0.041	0.0012	0.0002	
TK	3.99	0.20	0.05	0.008	0.040	0.0013	0.0002	
168	4.10		0.09		0.044	0.0013	0.0002	0.007
TL	4.05		0.09	0.010	0.042	0.0012	0.0002	0.008
170	4.01	0.41			0.042	0.0013	0.0003	
TM	3.95	0.38		0.009	0.041	0.0013	0.0003	
167	4.07	0.40	0.09		0.038	0.0013	0.0002	
TN	3.98	0.39	0.09	0.006	0.040	0.0014	0.0002	
165	4.00				0.043	0.0013	0.0004	0.001
TO	3.98			0.009	0.043	0.0013	0.0004	0.005

TABLE 12

Composition of Manganese Series Alloys

Sample No.	Chemical Analyses - %				Spectrographic Analyses - %			
	Al	Cu	Mn	Fe	Mg	Pb	Cd	Cu
176	4.03				0.040	0.0018	0.0005	0.001
MA	4.02			0.010	0.041	0.0017	0.0005	0.003
175	4.03	0.40	0.05		0.041	0.0021	0.0003	
MB	4.00	0.40	0.05	0.008	0.040	0.0021	0.0003	
177	4.01	0.20	0.03		0.045	0.0014	0.0004	
MC	3.95	0.21	0.02	0.006	0.040	0.0016	0.0004	
174	4.04		0.06		0.042	0.0018	0.0004	0.001
MD	3.92		0.04	0.008	0.046	0.0017	0.0005	0.004
180	3.98	0.19	0.03		0.043	0.0013	0.0003	
ME	3.99	0.18	0.03	0.006	0.040	0.0013	0.0003	
179	3.90	0.38	0.06		0.039	0.0013	0.0002	
MF	3.91	0.39	0.05	0.009	0.039	0.0013	0.0003	
173	3.98	0.41			0.039	0.0012	0.0002	
MG	3.97	0.40		0.009	0.039	0.0013	0.0003	
172	3.98				0.044	0.0013	0.0003	0.002
MH	3.98			0.008	0.045	0.0013	0.0004	0.003
178	4.04		0.06		0.041	0.0012	0.0005	0.001
MI	3.96		0.05	0.011	0.047	0.0012	0.0004	0.001
171	4.03	0.42			0.040	0.0014	0.0002	
MJ	3.99	0.41		0.009	0.039	0.0013	0.0003	

TABLE 13

Composition of Nickel Series Alloys

Sample No.	Chemical Analyses - %				Spectrographic Analyses - %			
	Al	Cu	Ni	Fe	Mg	Pb	Cd	Cu
185	4.07		0.05		0.050	0.0002	0.0002	0.001
NA	4.03		0.045	0.006	0.047	0.0002	0.0002	0.002
183	3.96	0.20	0.03		0.039	0.0005	0.0001	
NB	4.00	0.19	0.025	0.008	0.040	0.0005	0.0001	
186	4.04	0.39	0.05		0.039	0.0005	0.0001	
NC	4.03	0.38	0.04	0.009	0.039	0.0005	0.0001	
181	4.00		0.05		0.047	0.0002	0.0002	0.001
ND	3.98		0.035	0.006	0.045	0.0002	0.0002	0.005
182	3.99	0.36	0.05		0.038	0.0006	0.0001	
NE	4.04	0.35	0.045	0.008	0.039	0.0006	0.0001	
188	4.02	0.19	0.025		0.039	0.0004	0.0001	
NF	4.04	0.20	0.02	0.008	0.040	0.0004	0.0001	

TABLE 14

Composition of Zirconium Series Alloys

Sample No.	Chemical Analyses - %				Spectrographic Analyses - %			
	Al	Cu	Zr	Fe	Mg	Pb	Cd	Cu
151	4.17				0.038			
ZA	4.06			0.010	0.040	0.0011	0.0001	0.004
156	4.00	0.39			0.044	0.0013	0.0002	
ZB	4.02	0.39		0.008	0.042	0.0013	0.0002	
162	4.01	0.40	0.09		0.043	0.0007	0.0001	
ZC	4.03	0.40	0.09	0.009	0.044	0.0007	0.0001	
154	3.99				0.033	0.0011	0.0001	0.001
ZD	4.02			0.008	0.034	0.0012	0.0001	0.003
155	4.00		0.09		0.043	0.0011	0.0003	0.001
ZE	4.04		0.09	0.009	0.042	0.0011	0.0003	0.001
161	4.03	0.41			0.041	0.0004	0.0001	
ZF	3.99	0.40		0.008	0.043	0.0004	0.0001	
163	4.13		0.09		0.044	0.0004	0.0001	0.002
ZG	4.03		0.09	0.009	0.043	0.0005	0.0001	0.006
159	4.02	0.21	0.05		0.043	0.0004	0.0001	
ZH	4.02	0.20	0.05	0.010	0.041	0.0004	0.0001	
160	4.03	0.39	0.08		0.043	0.0004	0.0001	
ZI	4.01	0.39	0.08	0.009	0.042	0.0004	0.0001	
157	3.98	0.20	0.05		0.046	0.0011	0.0002	
ZJ	3.98	0.21	0.04	0.010	0.042	0.0012	0.0002	
158	3.93				0.044	0.0013	0.0002	0.001
ZK	4.00			0.009	0.042	0.0013	0.0002	0.003

TABLE 15

Composition of Beryllium Series Alloys

Sample No.	Chemical Analyses - %			Spectrographic Analyses - %			
	Al	Be	Fe	Mg	Pb	Cd	Cu
198	3.94	0.007	0.004	0.043	0.0005	0.0005	0.0032
BB	3.93	0.007	0.005	0.044	0.0014	0.0006	0.015
200	3.95	0.002	0.008	0.045	0.0005	0.0003	0.007
BC	3.97	0.002	0.008	0.045	0.0005	0.0003	0.0085
DE	3.95	0.0004	0.003	0.042	0.0008	0.0001	0.011
DF	3.90	0.0004	0.002	0.039	0.0009	0.0002	0.015

TABLE 16

Composition of Lithium Series Alloys

Sample No.	Chemical Analyses - %				Spectrographic Analyses - %			
	Al	Cu	Li	Fe	Mg	Pb	Cd	Cu
187	4.08			0.005	0.044	0.0007	0.0002	0.002
LA	4.00		0.0002	0.0049	0.046	0.0007	0.0002	0.0034
192		sample misplaced						
LB	3.98	0.40	0.0005	0.006	0.044	0.0011	0.0003	
189	4.04	0.38		0.0056	0.039	0.0010	0.0001	
LC	3.90	0.39	0.0009	0.008	0.043	0.0009	0.0002	
190	4.08			0.0045	0.047	0.0004	0.0002	0.002
LD	4.10		0.0004	0.005	0.046	0.0003	0.0002	0.0046

TABLE 17

Composition of Zamak 5 Series Alloys

Sample No.	Chemical Analyses - %				Spectrographic Analyses %		
	Al	Cu	Additive	Fe	Mg	Pb	Cd
140	4.03	1.03		0.006	0.041	0.0027	0.0003
CA	4.05	1.04		0.004	0.042	0.0028	0.0004
196	3.98	0.96	Ti-0.38	0.009	0.036	0.0021	0.0005
CT	4.01	0.93	Ti-0.38	0.006	0.035	0.0020	0.0005
195	3.90	0.94	Mn-0.30	0.008	0.037	0.0024	0.0007
CM	3.95	0.92	Mn-0.29	0.009	0.037	0.0023	0.0007
194-1	4.31	0.99	Ni-0.53				
-2	3.90	0.85	Ni-0.13				
CN	4.10	0.93	Ni-0.34	0.006	0.036	0.0018	0.0008
197	3.99	0.96	Zr-0.10	0.009	0.043	0.0018	0.0007
CZ	4.02	0.93	Zr-0.09	0.005	0.041	0.0019	0.0007

TABLE 18

Mechanical Testing Results: Rockwell "E" Hardness
(100 kg load, 1/8 in. dia. ball)

Cast	Nominal Composition - % -								Hardness Readings			
									Individual			Group Average
	Au	Cu	Ti	Mn	Ni	Zr	Li	Be	1	2	3	
TO	4.0								80.0	79.0	79.5	
ZA	4.0								80.5	80.0	78.5	
ZD	4.0								77.5	79.0	77.0	
ZK	4.0								77.0	78.0	77.0	
MA	4.0								78.5	77.0	77.0	
NH	4.0								78.5	77.5	78.0	78.5
TM	4.0	0.40							82.0	83.5	84.5	
ZB	4.0	0.40							82.0	83.0	79.5	
ZF	4.0	0.40							81.0	82.5	81.0	
MG	4.0	0.40							84.5	81.5	84.0	
MJ	4.0	0.40							81.5	83.5	83.0	82.5
TL	4.0		0.10						77.5	76.5	79.5	78.0
TN	4.0	0.40	0.10						84.0	83.5	84.5	84.0
TK	4.0	0.20	0.05						80.5	81.5	79.5	80.5
MD	4.0			0.06					76.0	78.0	77.0	
MI	4.0			0.06					78.5	79.5	78.0	78.0
MB	4.0	0.40		0.06					82.0	80.0	81.0	
MF	4.0	0.40		0.06					81.5	78.5	79.5	80.5
MC	4.0	0.20		0.03					82.0	80.0	83.0	
ME	4.0	0.20		0.03					82.5	82.0	81.0	82.0
NA	4.0				0.06				77.5	79.0	79.0	
ND	4.0				0.06				79.5	81.5	80.5	79.5
NC	4.0	0.40			0.06				85.0	81.5	83.5	
NE	4.0	0.40			0.06				84.0	85.0	81.5	83.5
NB	4.0	0.20			0.03				82.5	83.0	80.0	
NF	4.0	0.20			0.03				85.0	84.0	81.5	82.5
ZE	4.0					0.10			77.5	79.5	78.0	
ZG	4.0					0.10			76.0	77.0	80.0	78.0
ZC	4.0	0.40				0.10			81.0	83.0	83.0	
ZI	4.0	0.40				0.10			82.0	80.0	82.5	82.0
ZH	4.0	0.20				0.05			80.5	79.5	80.5	
ZJ	4.0	0.20				0.05			79.5	80.5	78.5	80.0
LA	4.0						*		79.0	79.5	80.5	
LD	4.0						*		79.5	79.0	81.0	80.0
LB	4.0	0.40					*		84.0	83.0	83.5	
LC	4.0	0.40					*		84.0	83.0	82.0	83.5
BB	4.0							0.005	83.5	82.0	82.0	
									83.0	82.0	83.0	82.5
CA	4.0	1.0							87.5	88.0	86.0	
									87.0	88.0	88.0	87.5
CT	4.0	1.0	0.30						87.0	86.5	88.0	
									85.0	87.5	88.0	87.0
CM	4.0	1.0		0.35					83.5	85.0	86.0	
									84.0	87.0	87.0	85.5
CN	4.0	1.0			0.30				86.0	86.5	84.5	
									85.0	83.0	83.0	85.0
CZ	4.0	1.0				0.10			84.5	88.0	87.0	
									85.5	89.0	87.0	87.0

*Alloy treated with approximately 0.15% Li. Retention < 0.001% Li.

Date: November 19, 1957

Pressure Die Casting Log

Alloying Melt No. 171

Alloy Composition %	Al	Mg	Cu	Fe	Pb	Sn	Cd
Nominal	4.0	.04	0.40				
Actual	4.03	.039	0.41	.009	.0014		.0002

Cast No.	MJ	Die Closure	6 sec
Starting Time	10:25 a.m.	Dwell	3 sec
Finishing Time	12:30 p.m.	Remarks	
Time Elapsed	125 min		
Average Rate	77 shots/hr		

Shot No.	Die Temp - °C		Pot Temp - °C	Remelt Fce Temp - °C	Remarks
	Ejector Half	Cover Half			
0	200	255	410		
10	205	260	410		
20	205	255	410		
30	200	255	410		
40	200	250	410		sample
50	200	250	405		
60	200	250	415		
70	200	255	410		
80	205	255	415		sample
90	200	255	415		
100	200	255	410		
110	200	255	410		
120	200	255	405		sample
130	205	255	410		
140	200	255	415		
150	200	250	410		
160	200	250	410		sample

Date: November 29, 1957

Mechanical Testing Section
Tensile Test Results

Cast No. MJ Date Cast Nov. 19 Remarks

Alloy Composition Zamak 3 + 0.4% Cu

Condition Room temp aged

Sample No.	Sample Size-in.	Area sq in.	Break lb	U.T.S. psi	Elong. % in 2 in.	Remarks
34	0.251	0.0495	2030	41,000	5.0	
71			~~1800~~	~~36,400~~	~~3.0~~	~~00~~
151			2010	40,600	4.0	
10			1950	39,400	3.0	
76			2015	40,700	5.0	
140			1950	39,400	3.5	
99			1990	40,200	3.5	
116			2025	40,900	4.0	
53			1950	39,400	3.5	
82			1945	39,300	3.5	
23			2005	40,500	4.5	
40			1990	40,200	4.0	
137			2015	40,700	3.5	
131			2015	40,700	3.5	
4			~~1865~~	~~37,700~~	~~2.5~~	~~00~~
159			2040	41,200	4.5	
46			2040	41,200	4.0	
33			1950	39,400	4.0	
62			2030	41,000	4.0	
91			1965	39,700	3.5	
Average				725,500 (18)	70.5 (18)	
				40,300	3.9	

Note: 0 - Broke outside middle third of gauge length.
00 - Flaw in structure.

Date: November 29, 1957

Mechanical Testing Section
Tensile Test Results

Cast No. MJ Date Cast Nov. 19 Remarks

Alloy Composition Zamak 3 + 0.4% Cu

Condition Humidity cabinet aged

Sample No.	Sample size-in.	Area sq in.	Break lb	U.T.S. psi	Elong. % in 2 in.	Remarks
25	0.251	0.0495	1730	35,000	4.5	
98			1750	35,400	5.5	
61			1735	35,100	4.5	
14			1760	35,600	6.5	
122			~~1750~~	~~35,400~~	~~5.5~~	~~00~~
45			1750	35,400	5.0	
81			1675	33,800	3.0	
60			1755	35,500	4.5	
59			1750	35,400	5.0	
130			1750	35,400	6.0	
5			~~1700~~	~~34,400~~	~~2.5~~	~~00~~
110			1760	35,600	7.0	
115			1755	35,500	5.5	
133			1750	35,400	4.5	
66			1775	35,900	6.5	
Average				459,000 (13)	68.0 (13)	
				35,300	5.2	

Note: 0 - Broke outside middle third of gauge length.
00 - Flaw in structure.

Date: November 29, 1957

Mechanical Testing Section
Tensile Test Results

Cast No. MJ Date Cast Nov. 19 Remarks
Alloy Composition Zamak 3 + 0.4% Cu
Condition High temperature aged

Sample No.	Sample size-in.	Area sq in.	Break lb	U.T.S. psi	Elong. % in 2 in.	Remarks
142	0.251	0.0495	1775	35,900	5.0	
20			1760	35,600	4.0	
57			1760	35,600	7.0	
117			1765	35,700	5.5	
160			1755	35,500	7.0	
148			1765	35,700	6.0	
74			1750	35,400	7.0	
17			~~1680~~	~~34,000~~	~~3.5~~	~~00~~
39			1755	35,500	4.5	
114			1750	35,400	5.0	
9			~~1680~~	~~34,000~~	~~4.5~~	~~00~~
138			1750	35,400	6.0	
102			1745	35,300	4.0	
31			~~1675~~	~~33,800~~	~~3.5~~	~~00~~
118			1765	35,700	7.5	
56			1765	35,700	7.5	
107			1745	35,200	5.0	
44			1740	35,200	4.5	
146			1750	35,400	6.0	
16			~~1715~~	~~34,700~~	~~4.5~~	~~00~~
Average				568,300 (16)	91.5 (16)	
				35,500	5.7	

Note: 0 - Broke outside middle third of gauge length.
00 - Flaw in structure.

Date: November 29, 1957

Mechanical Testing Section
Impact Test Results

Cast No. MJ Date Cast	Nov. 19	Remarks
Alloy Composition	Zamak 3 + 0.4% Cu	Unless otherwise indicated, bars broke on testing
Room Temperature	23°C	

Sample No.	Type of Treat.	Impact - ft-lb				Remarks
		Gate		Vent		
25	S.T.	47	nf	47	nf	
98		47	nf	39	½c	
61		47.5	nf	47	nf	
14		31.5	c	44.5	sc	
122		39	½c	42	sc	
45		39.5	½c	48.5	nf	
81		43	sc	~~26.5~~		
60		48	nf	49	nf	
59		47	nf	48.5	nf	
130		38	c	38	c	
5		43	sc	49	nf	
110		36	c	44.5	sc	
115		19.5		48	nf	
133		48	nf	43	½c	
66		35.5	<	49	nf	
Average		609.5 (15)		637.0 (14)		
		40.6		45.5		
34	R.T.	42.5	½c	37	c	
71		40.5	½c	47	nf	
151		36	c	37	c	
10		37.5	c	46.5	nf	
76		30.5	c	45	sc	
140		35.5	c	47	nf	
99		43.5	½c	38.5	½c	
116		42	½c	45.5	sc	
53		20		45.5	sc	
82		23		39	½c	
23		36	c	44	sc	
40		37	½c	48.5	nf	
137		34	c	46.5	nf	
131		36	c	32.5	c	
4		36	c	36.5	c	
159		42	½c	47	nf	
46		41	½c	41	½c	
33		26		43.5	sc	
62		28.5		45	½c	
91		35.5	c	41.5	½c	
Average		703.0 (20)		854.0 (20)		
		35.1		42.7		
142	H.T.	42	sc	44.5	nf	
20		42.5	sc	45	nf	
57		41.5	sc	45	nf	
117		43	sc	46	nf	
160		40.5	sc	46	nf	
148		42	sc	40	½c	
74		45	nf	45.5	nf	
17		31	c	39	½c	
39		37	½c	44.5	nf	
114		43	sc	45.5	nf	
9		32.5	c	42.5	nf	
138		44	nf	44	nf	
102		32	c	45	nf	
31		43.5	sc	40	½c	
118		29.5	c	45	nf	
56		23.5	c	45	nf	
107		46	nf	45	nf	
44		45	nf	44	sc	
146		41	½c	45	nf	
16		41.5	sc	43	sc	
Average		786.0 (20)		879.5 (20)		
		39.3		44.0		

b - broke, c - cracked, nf - no fracture, sc - slight crack
R.T. - Room temp, H.T. - Heat treatment, S.T. - Steam treatment

Date: November 29, 1957

Mechanical Testing Section
Impact Test Results
Low Temperature

Cast No.	MJ	Date Cast	Nov. 19	Remarks
Alloy Composition	Zamak 3 + 0.4% Cu			All bars broke on testing.
Room Temperature	23°C (73°F)			

0°C			-10°C			-20°C			-40°C		
Sample	Gate	Vent	Sample	Gate	Vent	Sample	Gate	Vent	Sample	Gate	Vent
						52	1.75	3			
						42	2	3			
						121	2	3			
						73	1.75	2.75			
						69	1.75	2.75			
						92	1.75	2.75			
						153	1.75	3			
						1	1.75	2.5			
						88	2	3.25			
						13	1.5	3			
Average							18.00 (10)	29.00 (10)			
							1.80	2.90			

b - broke, c - cracked, nf - no fracture.

Final Date (1) November 29, 1957
(2)

Dimensional Stability Test Results

Cast No. (1) MJ Date Cast (1) Nov. 19 Remarks
(2) (2)

Alloy Composition (1) Zamak 3 + 0.4% Cu
(2)

Room Temp 23°C (73°F)

	Sample No.	Type of Treat.	Initial Length in.	Final Length in.	Diff. in in.	Diff. in./in. x 10^{-4}	Average
(1)	78	S.T.	5.9986	5.9958	-.0028	-4.67	
	68		5.9974	5.9946	-.0028	-4.67	
	135		5.9990	5.9969	-.0021	-3.50	
	95		5.9964	5.9943	-.0021	-3.50	
	22		5.9971	5.9948	-.0023	-3.83	-20.17 - 4.03
	156	R.T.	5.9982	5.9970	-.0012	-2.00	
	72		5.9973	5.9961	-.0012	-2.00	
	30		5.9967	5.9954	-.0013	-2.17	
	113		5.9965	5.9950	-.0015	-2.50	
	75		5.9977	5.9961	-.0016	-2.67	-11.34 - 2.27
	83	H.T.	6.0014	5.9976	-.0038	-6.33	
	97		5.9995	5.9954	-.0041	-6.83	
	63		5.9979	5.9937	-.0042	-7.00	
	12		5.9967	5.9928	-.0039	-6.50	
	128		5.9971	5.9933	-.0038	-6.33	-32.99 - 6.50
(2)							

R.T. - Room temperature, H.T. - Heat treatment,
S.T. - Steam treatment.