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EFFECT OF CASTING TEMPERATURE ON ALUMINIUM ALLOY TEST BAR PROPERTIES

by

J. W. MEIER AND A. COUTURE

PHYSICAL METALLURGY DIVISION

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J. W. Meier* and A. Couture**

ABSTRACT

After a recapitulation of the role of separately-cast test bars in checking the melt quality and the response to heat treatment, a general review is presented of the effects of pouring temperature, maximum melt temperature and prolonged holding time on the properties of aluminium sand casting alloys.

Separately-cast test bars can be used successfully for melt quality evaluation only if they are cast under standardised and strictly controlled conditions. To accomplish this, they should be cast at the most suitable temperature, independently of the pouring temperature of the production castings.

The aim of the present investigation was to evaluate the effect of various pouring temperatures on the mechanical properties, the grain size and the porosity (density) of separately-cast test bars in six commonly used commercial alloys. Additionally, consideration was given to the effects of overheating of the melt and of prolonged holding times at three temperature levels.

The results showed that higher pouring temperatures affect markedly (although in varying degree) the properties of alloys C4, G10, S5 and SC51, but have little or no effect on alloys SG70 and ZG61. Overheating or prolonged holding times have no lasting effect on the properties of alloys S5, SC51, SG70 and ZG61, provided a proper pouring temperature is used. Properties of bars from overheated alloy C4 melts could not be completely restored, and no recovery whatever could be obtained for alloy G10 melts.

It is concluded that the maximum melt temperature and the pouring temperature for separately-cast test bars in alloys C4 and G10 should not exceed 720°C (1330°F), if consistent and comparable results are to be expected. For the other alloys, the use of a standardised pouring temperature (or temperature range) is essential to ensure effective melt quality control.

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Direction des mines

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EFFETS DE LA TEMPÉRATURE DE COULÉE SUR LES PROPRIÉTÉS DE BARREAUX D'ESSAI FAITS D'ALUMINIUM ALLIÉ

par

J.W. Meier* et A. Couture**

RÉSUMÉ

Après avoir indiqué brièvement le rôle des barreaux d'essai moulés séparément dans le contrôle de la qualité et de la réaction du bain au traitement thermique, le présent rapport donne un aperçu général des effets de la température de coulée, de la température maximum du bain et du maintien prolongé de diverses températures sur les propriétés des alliages d'aluminium moulés dans le sable.

Des barreaux d'essai moulés séparément peuvent être utilisés avec succès pour évaluer la qualité du bain, mais pourvu qu'ils soient coulés dans des conditions normalisées et rigoureusement contrôlées. Il faut, par exemple, qu'ils soient coulés à la température optimum, qui est indépendante de la température de coulée des moulages produits.

La présente étude avait pour but d'évaluer les effets des diverses températures de coulée sur les propriétés mécaniques, sur la finesse du grain et sur la porosité (densité) de barreaux d'essai moulés séparément et faits de six alliages commerciaux d'usage courant. En plus, on devait aussi étudier les effets de la surchauffe du métal fondu et des temps prolongés de maintien à trois niveaux de température.

Les résultats ont permis d'établir que les températures de coulée les plus élevées ont des effets marqués (quoique variables) sur les propriétés des alliages C4, G10, S5 et SC51, tandis que ces effets sont faibles ou nuls dans le cas des alliages SG70 et ZG61. La surchauffe ou les périodes prolongées de maintien à diverses températures n'ont pas d'effets permanents sur les propriétés des alliages S5, SC51, SG70 et ZG61, pourvu qu'on ait recours à la bonne température de coulée. Les propriétés des barreaux faits de l'alliage C4 soumis à la surchauffe n'ont pu être restaurées parfaitement, tandis qu'aucune des propriétés n'a été restaurée dans le cas de l'alliage G10 fondu et soumis à la surchauffe.

On en conclut que, dans le cas de barreaux d'essai faits d'alliages C4 et G10 moulés séparément, la température maximum du bain et la température de coulée ne doivent pas dépasser 720° C (1,330° F) si l'on veut obtenir des résultats constants et comparables. Pour ce qui est des autres alliages, il est essentiel d'avoir recours à une température normalisée de coulée (ou gamme de températures) si l'on veut contrôler efficacement la qualité du bain.

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CONTENTS

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TABLES

FIGURES

INTRODUCTION

The perennial dispute over the usefulness of separately-cast test bars for the evaluation of the quality of castings was discussed in an earlier paper.(1) It was emphasised that separately-cast test bars are not intended to represent the properties of production castings and should be used only to check the melt quality, or the response to heat treatment, of the material of which the castings were made.

Table 1(1) illustrates the significance of test results obtained on the different kinds of test bars, as related to the properties of production castings. The table shows that there is no compromise: either the test bars must be cast separately under strictly controlled casting procedure (a) and the melt quality be assessed, or production castings must be cut into test bars (f) to check the actual properties of these castings. All other ways (b-e) are useless and, in most cases, misleading. Indeed, they are often detrimental to the quality of the production casting, because cast-on additions may change the solidification pattern and cause defective castings.

The designers and users of castings are, of course, interested only in the actual properties of the castings. Metallurgists and foundrymen generally agree that the only way to guarantee high quality and consistent properties of production castings is by strict control of all melting, casting and heat treating operations, and by checking the melt quality on test bars cast separately from the same melt as the production castings.

This is also the basis of international standardisation of casting alloys, recently adopted by ISO/TC 79(2) at the June 1958 meeting at Harrogate, England. A free translation of part of Resolution 33 may be of interest:

> The mechanical properties of a casting are determined by the casting procedure used. For this reason it is practically impossible to use standard test bars (a) to reproduce the mechanical properties of the casting or (b) to represent general casting conditions applicable to all the different casting methods.
>
> That is why it is customary to establish the melt quality of the metal used to make the castings by determining the mechanical properties of separately-cast test bars produced under strictly controlled conditions.
>
> In general, it is not expected that the mechanical properties obtained from such test bars will be reproduced in all parts of the castings that the test bars represent, because of complexity of shape, variation in wall thickness, location of risers or chills, etc. However, by special foundry techniques, it is often possible to obtain, in specified parts of the casting, mechanical properties approaching or even exceeding those of the separately-cast test bar.
>
> The form and dimensions of test bars must be standardised and the test bars must be cast under standard conditions, including gating design.

It should be particularly stressed that the full value of melt quality evaluation can be achieved only if the test bars are cast under "standardised and strictly controlled" conditions. As shown earlier,(1) there are almost fifty variables affecting the results of mechanical tests on cast test bars. They are related to the alloy composition, melting conditions, casting procedure, casting design, heat treatment, test bar preparation, and some testing variables.

The main purpose of this report is to discuss one of the most important factors affecting the melt quality, namely, the pouring temperature. The full significance of this variable can be assessed only if the "thermal history" of the melt, especially the maximum melt temperature and the holding time, is known. These three variables are interdependent and have a cumulative effect on the properties of the castings. A considerable number of papers on this subject have been published in the past fifty years and a selected list of references is given at the end of this report.(3-22)

GENERAL CONSIDERATIONS

Pouring Temperature

Most foundrymen are well aware of the importance of the proper choice and strict control of the pouring temperature. It is accepted that the best one for most aluminium alloys is the lowest temperature at which a sound casting can be produced and that, usually, the mechanical properties decrease with the increasing pouring temperature. There are some exceptions: for example, alloy ZG61* (known in the trade as Frontier 40E) shows — as do most magnesium-base alloys — optimum tensile properties when poured at a temperature somewhat higher than the lowest possible;(12,21) Hurren(4) reports similar behaviour for alloy CN42 ("Y" alloy).

There are numerous references on the effect of pouring temperature on the mechanical properties of aluminium casting alloys.(3-22) In most cases, the decrease of mechanical properties with rising pouring temperature has been attributed to the increase in grain size. A close correlation of mechanical properties with grain size has been reported for various alloys.(13,17,23)

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* Designations of alloys and tempers used throughout the report are according to Canadian Standards Association codes H.1.1.-1958 (alloy designations) and H.1.2-1958 (temper designations).

Colton and LaVelle(20) do not believe that lower mechanical properties of castings are due to large grain size and state that the decrease in strength and ductility is due to increased shrinkage and gas porosity caused by higher temperature; the large grain size, they say, is also caused by high temperature, but this is merely a concurrent phenomenon, not the cause of poor properties. They found that test bars of equal soundness have equal properties, regardless of the grain size within a 10-15 fold range.

Ruddle and Cibula(22) state that in cast alloys of cubic structure the influence of grain size "per se" is negligible; nevertheless, the mechanical properties are very much affected by the grain size, because of its influence on the shape and magnitude of the shrinkage voids, inevitably present to some extent in castings of long-freezing-range alloys. The effect of grain coarsening upon tensile properties may, therefore, be attributed to variation in the size, and particularly in the shape, of the voids, the increase in the total volume of voids being a minor factor.(17)

To overcome the effects of grain coarsening at higher temperatures, the use of more effective grain refiners has been recommended.(15-17,19)

Melt Temperature

The maximum melt temperature, i.e. the highest temperature reached by the molten alloy during the melting or refining operations, is considered as another important factor affecting the melt quality. In general, it has been found that overheating of the melt is very deleterious to the mechanical properties and grain size of aluminium casting alloys.(4-7,9,10,16,17,21,22) In the case of some alloys, cooling the melt down to a low pouring temperature may partly or completely restore the melt quality, but in more sensitive alloys (e.g. C4, and especially G10) a complete recovery can be achieved only by solidification (ingotting) and remelting.(5,9,10,12,16)

Quadt(14) reported that he never experienced deleterious effects of overheating on the properties of commonly used commercial casting alloys, if a low pouring temperature was used. In the present investigation, this observation was confirmed for alloys S5, SC51, SG70, and ZG61; however, the recovery of alloy C4 melts was found to be incomplete (see Figure 2), and no recovery after overheating could be obtained for alloy G10 (see Figure 3).

Holding Time

It is always desirable that the holding time, i.e. the time the alloy is kept in the molten state before pouring, be as short as possible. In commercial foundry practice this cannot be consistently obtained, because of unforeseen delays in mould preparation, or similar operational shortcomings. It is essential, therefore, to know how such prolonged holding times, at various melt temperature levels, affect the properties of the castings.

Hurren(4) found that the effect of prolonged heating on tensile properties was only slight, but reported a greater influence on the resistance to repeated impact. Bossert(5) investigated holding times up to 24 hours and found that soaking at 715°C (1320°F) did not affect the melt quality, but that soaking at 790°C (1455°F) resulted in considerable grain coarsening. Cibula(16) found that prolonged holding of a C4 melt at 760°C (1400°F) caused a marked grain coarsening, and reports that to restore the original grain size the melt had to be superheated to 975°C (1785°F), solidified, and remelted.

Gas Content

The deleterious effect of gas content on the mechanical properties of aluminium alloy castings is well known(24-27) and the necessity of a thorough melt degassing operation in the production of quality castings is today generally recognized. Chlorine, nitrogen, and various proprietary compounds are used for degassing aluminium alloy melts at temperatures below 720°C (1330°F). Degassing should be continued until a gas content test, e.g. the commonly used reduced pressure solidification test, shows that the melt is substantially gas-free.

An interesting additional aid in testing the gas content, by quick determination of the density of a constant volume sample, has recently been proposed by Sulinski and Lipson.(28)

POURING TEMPERATURE FOR TEST BARS

In considering the pouring temperature for separately-cast test bars, it should be borne in mind that the only reason for using these test bars is to check the quality of the melt under standardised conditions. To accomplish this, test bars should be cast at the most suitable temperature, independently of the pouring temperature of the production castings. The proper temperature to provide the most effective solidification conditions for the test bars has to be established and standardised for each alloy composition.

Unfortunately, the choice of the casting temperature is sometimes limited by specification clauses; e.g., the U.S. Federal

Specification QQ-A-601b (1957) requires that "the temperature of the metal while pouring test bars shall not be lower than 20 F (11 C) degrees below the temperature at which the casting is poured". There is, however, an alternative requirement, that, if the pouring temperature of the castings is above 760°C (1400°F), specific approval must be obtained from the procuring agency.

Colton and LaVelle,(20) commenting on the above clause, remark that if all the properties in the specification are based on results from bars cast at a temperature of 675°C (1250°F), it will be difficult to obtain the same properties with metal poured at 760°C (1400°F). They propose, therefore, that if the castings are of such a shape or complexity that it is necessary to pour at 760°C (1400°F) or higher, the portion of metal that is left for test bars should be allowed to cool down to at least 705°C (1300°F) before the test bars are poured.

The purpose of the present investigation was to evaluate the effect of various pouring temperatures on the mechanical properties, the grain size and the porosity (density) of separately-cast test bars in six commonly used commercial aluminium alloys. Additionally, consideration was given to the effects of overheating the melt and of holding times at three temperature levels.

EXPERIMENTAL PROCEDURES AND RESULTS

Materials and Procedures

Most of the melts prepared in the course of this investigation were made from commercial-quality alloy ingots, supplied to Canadian Standards Association (CSA) Specification HA.3-1958 (see Table 2). Exceptions to this were several alloy C4 melts which were prepared from higher purity aluminium ingots (99.85%) with additions of commercial alloy hardeners; these melts were made for comparison purposes and used in the study of holding times (see Table 5).

The alloy ingots were melted down in an oil-fired furnace, using silicon carbide crucibles, and the melt sizes varied from 40 to 80 pounds. No flux or grain refining additions were used. All melts were degassed by chlorine or nitrogen flushing (or a combination of both), at a temperature of 680°C (1255°F), until results of the reduced-pressure solidification test indicated gas-free metal. After degassing, a 10-minute settling time was allowed at the same temperature.

Test bars were 'cast to shape'(Figure 1) in green sand and tested without machining. This test bar design(29) is widely used in the magnesium industry, and is being employed in the Mines Branch experimental foundry for investigations on all aluminium and magnesium casting alloys (as well as on some copper-base alloys). Previous work(30) showed that this test bar design gives reliable and consistent results, and is more sensitive to melt-quality variations than are any of the other test bar designs used in Great Britain or the U.S.A. The grain size gradient reported by Quadt for a similar four-bar design(13) has never been observed in any of the many alloys used in our laboratories during the past fifteen years.

Solution heat treatments (Table 3) were carried out in a circulating-air furnace heated electrically and controlled to ± 2° C; boiling water was used as quenching medium. Ageing treatments (Table 3) were carried out in an electric oven with air circulation and close temperature control (to ±1°C). ZG61 alloy bars were not heat treated and were tested after 21 days of room temperature ageing.

Chemical Composition

To evaluate the effect of variations of pouring temperatures and holding times on the chemical composition of the alloys, two samples for chemical analysis were taken from each melt: one from test bars cast in the first mould, and the other from test bars cast in the last mould.

The ranges of analytical results obtained from castings representing all melts are listed in Table 4. The results show that the first six alloy compositions were well within the specification limits. Alloy ZG61 had a slightly higher magnesium content and a somewhat low chromium content, but this did not affect the level of mechanical properties obtained in this investigation.

A close review of all results showed that the variations in pouring temperatures up to 820°C (1510°F), and in holding times up to two hours in this temperature range, had no significant effect on the chemical composition of any of the alloys investigated.

Pouring Temperature

Figures 2 to 7 illustrate the effect of variations of pouring temperature on the properties of separately-cast test bars for six commercial aluminium casting alloys. The first series of results, as shown by the graphs presented on the left side, was obtained from melts with increasing pouring temperatures; the second series, as shown by the graphs on the right side, was obtained on melts with decreasing pouring temperatures.

The procedure followed in the first series was to melt down the ingots, heat the melt rapidly to 680°C (1255°F), and degas at that temperature. After a 10-minute settling time the crucible was removed from the furnace, and after the melt had cooled down to the lowest pouring temperature (640°C or 660°C) the first four test bars (Figure 1) were cast. The remainder of the melt was then returned to the furnace and heated to the next pouring temperature, and another set of test bars was cast. This procedure was repeated until the top temperature of 820°C (1510°F) was reached.

In the second series the melt was degassed at 680°C (1255°F), and after a 10-minute settling time at this temperature, the first bars were cast at the "normal" pouring temperature: for the first five alloys, 670°C (1240°F); for alloy ZG61,730°C (1345°F). The melt was returned to the furnace, heated to 820°C (1510°F), and removed from the furnace. The second set of test bars was cast immediately, and the next castings were made when the metal cooled down to the lower pouring temperatures (see Figures 2 to 7).

Holding Time

Tables 5 to 10 present the results on the effect of holding time, at three levels of temperature, on the properties of separately-cast test bars for six commercial aluminium casting alloys. The melting procedure was similar to that used in the investigation on pouring temperatures. In the first series the alloy ingots were melted down, heated rapidly to 680°C (1255°F), degassed, and kept for 10 minutes to settle. The first test bars were cast at that temperature, and the melt was returned to the furnace and kept for 30 minutes at 680°C before casting the next test bars. This was repeated until a total holding time of two hours was reached.

In the second and third series, the same procedure was used for the first set of test bars. The metal was then heated to the higher temperature (740°C or 800°C) and the second set of test bars was cast immediately, following which the metal was kept at that temperature for the various holding times. After reaching the two-hour holding time and casting the sixth test bar set, the melt was cooled down to the original pouring temperature of 680°C (1255°F). One test bar set was cast immediately, and another one after additional settling for 30 minutes. These last two castings were made to determine whether the original test bar properties (which in most cases decreased appreciably at the higher temperatures) could be restored by using a low pouring temperature.

It should be mentioned here that the 10-minute settling time — used in all melts after the degassing operation — was not included in the holding times listed in Tables 5 to 10.

Melt Temperature

The effect of overheating the melts to 820°C (1510°F) on the properties of separately-cast bars is illustrated in the graphs on the right side of Figures 2 to 7.

The combined effect of overheating and prolonged holding time on the properties of separately-cast bars is shown in Tables 5 to 10.

Cast Plates

To check results obtained on separately-cast test bars, four melts of alloys C4X, G10, SG70 and ZG61, respectively, were sand-cast into 4½ x 6 x ½ and 4½ x 6 x 1½ inch plates. In each case the melt was held for 10 minutes at the "normal" pouring temperature of the alloy before pouring the first series of castings. The melt was returned to the furnace, heated to 800°C (1470°F), and held at this temperature for 15 minutes. After pouring a second series of castings at 800°C (1470°F), the melt was cooled down to the "normal" pouring temperature and held at this temperature for 30 minutes before pouring the third series of castings.

Tables 11-14 present the results obtained on separately-cast test bars and on test bars machined from the plates. Some of the tensile property results from cast plates, especially in alloys G10 and SG70, were below average values obtainable for such castings. A repetition of these melts was considered unnecessary, because the variations of the properties, due to changes of the melt temperature, confirmed the trends noted in the evaluation of separately-cast test bars.

DISCUSSION OF RESULTS

Al-4% Cu Alloys (C4 and C4X)

The marked effect of increasing pouring temperatures on the properties of alloy C4-T6 test bars is shown in Figure 2. Increasing pouring temperatures are responsible for a steady decrease of ultimate tensile strength, elongation, and density, as well as for grain coarsening. The right-hand graphs clearly demonstrate that considerable deterioration of tensile properties is caused by overheating the melt to 820°C (1510°F), and that only a partial recovery of the melt quality can be achieved by cooling down to a low pouring temperature. It should be noted that the right-hand graphs indicate only a partial recovery of the mechanical properties and the density, in spite of the complete recovery of the grain size.

Table 5 shows the effect of holding time at three temperature levels on the properties of C4X-T6 (higher-purity alloy) test bars. Holding up to two hours at 680°C (1255°F) has no effect on the properties. Holding the melt at 740°C (1365°F) slightly affects the test bar properties; a full recovery can be achieved by lowering the melt temperature and holding the melt for some time at this temperature before pouring. Holding at 800°C (1470°F) causes a serious decrease in test bar properties, similar to that shown in Figure 2. Lowering the melt temperature and holding the melt at a low temperature restored the melt quality only partly, although the density returned to its original value.

Table 11 lists the results obtained on cast plates. Although the recovery of the original properties is almost complete, it should be noted that in this experiment the exposure of the melt to the high temperature was much shorter than in the earlier experiments (Figure 2 and Table 5) and higher purity metal was used.

It should be added here that during the present investigation it was found that C4 alloy melts prepared from high-purity metals were much less sensitive to higher temperatures than were those made from commercial ingots. A similar observation was also made on G10 alloy melts, but the difference was less pronounced and full recovery of melt quality after overheating was never obtained.

Al-10% Mg Alloy (G10)

The left-side graphs in Figure 3 show that the properties of aluminium casting alloy G10-T4 are not affected by pouring temperatures below 720°C (1330°F). Above this temperature, and especially above 740°C (1365°F), the ultimate tensile strength, elongation and density values decrease rapidly, accompanied by a marked grain coarsening.

The right-side graphs illustrate the effect of overheating the melt to a high temperature (820°C, 1510°F) and pouring at successively lower temperatures. Although the density and, to a greater degree, the grain size show improvement at lower pouring temperatures, the tensile properties remain unchanged at the low level caused by overheating.

The same pattern of behaviour is shown in Tables 6 and 12. Holding the melt at higher temperatures causes a marked decrease in ultimate tensile strength and elongation. The melt quality cannot be restored by cooling down to a low pouring temperature, and no significant improvement could be obtained by prolonged holding at low temperature (680°C, 1255°F). It should be noted (Table 6) that in the melt held at 740°C (1365°F) the grain size showed some improvement and the density was fully restored, and in the melt held at 800°C (1470°F) the density was appreciably improved; in both cases, however, this had very little effect on the tensile properties.

Al-Si Alloys (S5, SC51, SG70)

As may be seen from Figure 4 and Table 7, the properties of alloy S5-F test bars are significantly affected by variations in the pouring temperature and by holding at 800°C (1470°F), but complete recovery from the ill effects of overheating can be achieved by cooling down the melt to a low pouring temperature.

Figure 5 and Table 8 demonstrate a similar behaviour for alloy SC51-T6, although the decrease in properties at higher pouring temperatures is much less pronounced.

Figure 6 shows no significant effect of melt or pouring temperature variations up to 820°C (1510°F) on the tensile properties of alloy SG70-T6 test bars, in spite of marked changes in density and especially in grain size. Table 9 shows a slight decrease in tensile properties after holding the melt at 800°C (1470°F), but they are completely restored at low pouring temperature. Table 13 shows a similar trend in results obtained on cast plates.

In the case of alloys S5 and SC51, a decrease in mechanical properties is usually accompanied by an increase in grain size and a decrease in density, although a deterioration of the grain size and density is not always followed by a similar decrease of the tensile properties.

Al-Zn-Mg Alloy (ZG61)

The results presented in Figure 7, and Tables 10 and 14, demonstrate that the tensile properties of alloy ZG61-F are not affected by variations of melt or pouring temperatures between 720°C (1330°F) and 820°C (1510°F), in spite of small changes in density and grain size. Tensile properties of test bars cast below 720°C (1330°F) seem to be somewhat lower, which is in agreement with published data.(11)

Grand(18) reports that this alloy is susceptible, at low melt temperatures, to partial loss of chromium and titanium and recommends, therefore, the use of a pouring temperature above 710-720°C (1310-1330°F).

This would account for the somewhat low chromium content obtained for some melts (see Table 4).

Mechanical Properties vs Grain Size and Density

Figures 8 and 9 present the correlation of mechanical properties of alloys C4 and G10 with grain size and density (porosity). In the case of alloy C4, separate curves show also the effect of purity of the metal, although the trend of the curves is the same for both purities. In comparing these graphs, it should be noted that different scales were used because of the greater range of results obtained for alloy G10.

These two graphs indicate that the ultimate tensile strength and the elongation decrease appreciably with increasing grain size and decreasing density. The curves for alloy G10 show that its properties decrease more rapidly than those of alloy C4 and attain a critical point beyond which practically no further decrease of tensile properties can be observed.

The relation of mechanical properties with grain size was illustrated graphically in earlier publications, both for alloy C4(17) and for alloy G10.(23) The graphs shown in these publications are very similar to those presented here (Figures 8 and 9), although the results obtained differ considerably, mainly because of the difference in the range of properties encountered.

Similar relationships were found for alloy S5. Alloy SC51 showed a correlation between mechanical properties and density, but none with grain size.

There appeared to be no correlation of mechanical properties with grain size or density for the alloys insensitive to melt overheating (SG70, ZG61).

A close examination of all results obtained in this investigation (Tables 5-14 and Figures 2-9) shows that a decrease in mechanical properties is usually accompanied by an increase of the grain size and a decrease of the density. On the other hand, as was already noted in the discussions of the individual alloys, in many cases a change in the grain size or the density is not necessarily followed by a similar change of the mechanical properties.

It seems, therefore, that even in the alloys which are highly sensitive to the effects of melt overheating (C4 and G10), the mechanical properties of castings produced from overheated melts are affected by factors other than density (shrinkage and gas porosity) and grain size. This may involve the reaction of trace elements, residual impurities, gases, etc, at higher temperatures to produce or eliminate compounds or effects not present in melts prepared at lower temperatures.

CONCLUSIONS

The results of the present investigation may be summarized in the following conclusions:

1. Higher pouring temperatures affect markedly, although in varying degree, the properties of aluminium casting alloys C4, G10, S5 and SC51, and have little or no effect on alloys SG70 and ZG61.

2. Overheating or prolonged holding times have no lasting effect on the properties of aluminium casting alloys S5, SC51, SG70 and ZG61, provided a proper pouring temperature is used. Cooling down the overheated melts and using a low pouring temperature did not

completely restore the properties of aluminium casting alloy C4, and no recovery whatever could be obtained for alloy G10.

3. Maximum melt temperatures and the pouring temperature for separately-cast test bars in alloys C4 and G10 should not exceed 720°C (1330°F), if consistent and comparable results are to be expected. It therefore seems evident that, at least in the case of these two alloys, the proposal(20) to cast test bars at the end of the casting operation, after cooling down the remaining part of the melt (overheated because of complexity or shape of castings) to a lower pouring temperature, would not be effective. For the other alloys, especially for S5 and SC51, the use of a standardized pouring temperature (or temperature range) is essential to ensure effective melt quality control.

4. A general correlation of mechanical properties with grain size and density has been shown graphically for alloys C4 and G10, which are highly sensitive to the effects of melt overheating, although it was noted, in some cases, that improvement in grain size or density is not necessarily accompanied by similar increase of mechanical properties of the casting.

5. No correlation of mechanical properties with grain size or density could be established for alloys that are relatively insensitive to the effects of melt overheating.

6. It seems that even in the alloys which are highly sensitive to the effects of melt overheating (C4 and G10), the mechanical properties are affected by factors other than density (porosity) and grain size.

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JWM:AC:(PES)VB

TABLE 1

Correlation of Test Bar and Casting Properties

Type of Test Bar	Are Test Bar Properties Correlated With:	
	Melt Quality?	Properties of Casting?
a) Separately-cast under controlled (standardised) casting conditions	Yes	No
b) Separately-cast without control of casting variables	Unlikely	No
c) Joined to same sprue as casting	No	No
d) Cast on the casting	No	No
e) Machined from coupon cast on the casting	No	No
f) Cut out from the cast casting	No	Depends on casting design (thermal gradient)- in most cases, correlation is limited to section from which test bar was taken.

-

TABLE 2

Chemical Composition of Alloy Ingots* (%)

Alloy Designation**	Cu	Fe	Mg	Mn	Si	Ti	Zn	Cr
C4	4.0-5.0	0.80	0.03	0.30	1.2	0.20	0.10	-
G10	0.10	0.20	9.5-10.6	0.10	0.20	0.20	0.10	-
S5	0.10	0.60	-	0.10	4.5-6.0	0.20	0.10	-
SC51	1.0-1.5	0.50	0.40-0.60	0.30	4.5-5.5	0.20	0.10	-
SG70	0.20	0.40	0.20-0.40	0.10	6.5-7.5	0.20	0.10	-
ZG61	0.30	0.75	0.55-0.70	0.30	0.25	0.15-0.30	5.0-6.0	0.40-0.60

Unless range is shown, single values are the maximum amounts permitted.

* According to CSA Specification HA.3-1958.

** According to CSA Code H.1.1-1958.

TABLE 3

Heat Treatments and Properties for Separately-Cast Test Bars*

Alloy Designation**	Heat Treatment		Ageing		Ultimate Tensile Strength, psi	0.2% Yield Strength, psi	Elongation, % in 2 in.
	Temp, °C	Time, hr	Temp, °C	Time, hr	Minimum		
C4-T6	515	16	160	4	32,000	20,000	3
G10-T4	435	20	-	-	42,000	22,000	12
S5-F	-	-	-	-	17,000	-	3
SC51-T6	525	16	160	4	32,000	20,000	2
SG70-T6	535	16	160	4	30,000	20,000	3
ZG61-F***	-	-	-	-	32,000	22,000	3

* According to CSA Specification HA.9-1958.

** According to CSA Codes H.1.1-1958 and H.1.2-1958.

*** Room temperature aged for 21 days.

TABLE 4

Ranges of Analytical Results (%)

Alloy Designation★	Cu	Fe	Mg	Si	Ti	
C4★★	4.69-4.76	0.37-0.38	-	0.75-0.78	0.11-0.12	-
C4X★★	4.62-4.82	0.15-0.18	-	0.46-0.53	0.10-0.12	-
G10	-	0.12-0.17	10.09-10.58	0.06-0.10	0.01-0.01	-
S5	-	0.25-0.27	-	4.88-5.00	0.08-0.09	-
SC51	1.23-1.32	0.32-0.35	0.45-0.52	4.98-5.15	0.11-0.13	-
SG70	-	0.25-0.30	0.30-0.35	6.78-7.55	0.13-0.17	-
				Zn		Cr
ZG61	0.15-0.19	0.44-0.47	0.65-0.75	5.22-5.68	0.12-0.16	0.27-0.46

★ According to CSA Code H.1.1-1958.

★★ C4 Commercial alloy ingots.

C4X Alloy prepared from higher purity aluminium and commercial alloy hardeners.

TABLE 5

Effect of Holding Time (C4X-T6)

Pouring Temperature °C	°F	Holding Time, min	UTS★	YS★	E★	GS★	D★
680	1255	0	48.4	30.7	6.0	10	2.801
		30	46.4	31.3	5.0	10	2.802
		60	48.4	32.3	5.5	10	2.802
		90	46.7	32.1	5.0	10	2.802
		120	47.9	32.3	4.0	10	2.802
680	1255	0	47.7	30.9	8.0	8	2.800
740	1365	0	44.0	29.7	6.0	10	2.794
		30	45.0	30.4	6.5	15	2.790
		60	43.0	31.3	5.5	15	2.791
		90	42.7	31.4	5.5	15	2.792
		120	42.7	31.1	5.0	15	2.792
680	1255	0	43.4	30.9	6.0	12	2.797
		30	47.5	31.1	8.0	10	2.800
680	1255	0	46.6	31.0	6.0	10	2.798
800	1470	0	41.3	30.2	4.5	15	2.780
		30	38.4	30.4	3.0	18	2.776
		60	38.0	29.8	2.0	20	2.775
		90	39.8	29.5	3.5	20	2.774
		120	40.4	31.2	4.5	15	2.775
680	1255	0	40.0	32.0	3.5	12	2.790
		30	43.5	32.7	5.0	12	2.797

★ UTS - Ultimate Tensile Strength, in 1000 psi
YS - 0.2% Yield Strength, in 1000 psi
E - Elongation in 2", %
GS - Average Grain Diameter, in 0.001 inch
D - Density, in g/cm^3

TABLE 6

Effect of Holding Time (G10-T4)

Pouring Temperature °C	Pouring Temperature °F	Holding Time, min	UTS*	YS*	E*	GS*	D*
680	1255	0	54.0	27.6	28.6	15	2.567
		30	54.6	27.9	30.4	15	2.567
		60	55.9	27.4	31.6	15	2.568
		120	55.2	27.0	32.2	15	2.568
680	1255	0	50.3	27.4	18.5	12	2.564
740	1365	0	49.4	26.8	15.0	15	2.560
		30	43.3	27.6	9.0	20	2.559
		60	42.2	26.2	7.5	20	2.560
		90	41.6	25.9	8.0	20	2.562
		120	41.5	26.3	9.0	20	2.563
680	1255	0	43.4	26.2	9.0	15	2.565
		30	42.5	26.0	7.5	15	2.565
680	1255	0	52.1	28.0	25.0	15	2.565
800	1470	0	36.5	25.8	8.5	50	2.534
		30	34.3	25.4	7.0	60	2.522
		60	33.2	25.3	7.0	60	2.528
		90	33.4	25.6	7.5	70	2.527
		120	34.2	25.9	6.0	80	2.534
680	1255	0	38.0	27.1	9.0	70	2.548
		30	38.5	25.9	8.0	50	2.556

* UTS - Ultimate Tensile Strength, in 1000 psi
YS - 0.2% Yield Strength, in 1000 psi
E - Elongation in 2", %
GS - Average Grain Diameter, in 0.001 inch
D - Density, in g/cm^3

TABLE 7

Effect of Holding Time (S5-F)

Pouring Temperature °C	°F	Holding Time, min	UTS*	YS*	E*	GS*	D*
680	1255	0	20.6	7.5	13.0	35	2.689
		30	20.8	7.7	14.0	35	2.691
		60	20.3	7.6	12.5	25	2.690
		90	20.5	7.6	13.0	30	2.691
		120	20.5	7.8	13.5	30	2.691
680	1255	0	20.6	7.4	14.0	25	2.692
740	1365	0	20.2	8.0	13.5	40	2.682
		30	20.2	7.4	14.0	30	2.682
		60	20.3	7.6	14.5	30	2.686
		90	20.2	7.1	13.0	30	2.687
		120	19.6	7.8	10.0	35	2.679
680	1255	0	20.2	8.0	12.0	30	2.681
		30	20.8	7.8	14.5	30	2.691
680	1255	0	20.5	6.7	15.0	35	2.691
800	1470	0	17.8	6.9	9.0	30	2.644
		30	17.3	7.1	8.5	60	2.645
		60	17.0	6.7	6.5	70	2.648
		90	17.6	7.4	7.0	80	2.662
		120	18.2	7.3	9.0	100	2.661
680	1255	0	20.0	7.4	13.0	70	2.690
		30	20.0	7.3	12.0	50	2.690

* UTS - Ultimate Tensile Strength, in 1000 psi
YS - 0.2% Yield Strength, in 1000 psi
E - Elongation in 2", %
GS - Average Grain Diameter, in 0.001 inch
D - Density, in g/cm^3

TABLE 8

Effect of Holding Time (SC51-T6)

Pouring Temperature		Holding Time, min	UTS★	YS★	E★	GS★	D★
°C	°F						
680	1255	0	41.2	33.3	3.0	20	2.707
		30	40.7	33.8	3.0	20	2.705
		60	40.7	34.4	3.0	20	2.705
		90	41.2	34.6	2.5	30	2.708
		120	41.8	34.9	3.0	20	2.707
680	1255	0	41.4	33.2	2.5	20	2.708
740	1365	0	40.0	33.2	3.0	30	2.704
		30	40.8	34.2	2.0	30	2.700
		60	40.2	32.8	2.5	30	2.701
		90	39.9	33.0	2.5	30	2.700
		120	39.2	33.5	3.0	30	2.697
680	1255	0	39.1	33.2	3.0	20	2.700
		30	38.0	34.0	2.0	20	2.700
680	1255	0	41.8	34.1	2.5	30	2.706
800	1470	0	38.2	32.8	2.0	50	2.690
		30	34.2	29.8	2.0	80	2.670
		60	34.8	30.1	2.0	100	2.678
		90	34.3	30.3	2.0	120	2.677
		120	33.4	30.4	1.0	120	2.681
680	1255	0	39.0	32.5	3.0	30	2.693
		30	40.3	32.0	3.0	30	2.709

★ UTS - Ultimate Tensile Strength, in 1000 psi
YS - 0.2% Yield Strength, in 1000 psi
E - Elongation in 2", %
GS - Average Grain Diameter, in 0.001 inch
D - Density, in g/cm^3

TABLE 9

Effect of Holding Time (SG70-T6)

Pouring Temperature °C	°F	Holding Time, min	UTS★	YS★	E★	GS★	D★
680	1255	0	38.4	30.5	3.0	30	2.680
		30	38.0	32.2	3.0	20	2.680
		60	38.0	32.3	3.0	20	2.679
		90	37.7	33.5	4.0	20	2.680
		120	38.0	32.9	3.0	20	2.679
680	1255	0	37.5	30.0	3.5	30	2.681
740	1365	0	37.1	30.4	3.5	40	2.680
		30	36.4	28.9	3.5	50	2.674
		60	35.8	28.8	3.5	60	2.668
		90	36.6	27.6	4.5	70	2.671
		120	36.2	28.6	4.5	80	2.669
680	1255	0	35.8	30.3	4.0	20	2.669
		30	36.2	31.3	3.5	30	2.677
680	1255	0	36.2	30.1	3.0	30	2.680
800	1470	0	36.4	29.3	3.0	50	2.674
		30	34.8	27.6	3.0	60	2.658
		60	34.6	26.4	3.0	60	2.656
		90	33.8	27.3	3.0	60	2.645
		120	34.5	28.5	3.0	60	2.655
680	1255	0	35.5	28.6	3.0	20	2.667
		30	36.1	29.7	4.0	30	2.680

★ UTS - Ultimate Tensile Strength, in 1000 psi
YS - 0.2% Yield Strength, in 1000 psi
E - Elongation in 2", %
GS - Average Grain Diameter, in 0.001 inch
D - Density, in g/cm^3

TABLE 10

Effect of Holding Time (ZG61-F)

Pouring Temperature °C	Pouring Temperature °F	Holding Time, min	UTS*	YS*	E*	GS*	D*
680	1255	0	36.4	25.4	4.0	15	2.803
		30	36.9	25.3	5.0	15	2.802
		60	36.2	25.6	5.0	15	2.805
		90	36.8	25.4	4.0	15	2.805
		120	36.4	25.6	4.0	15	2.803
680	1255	0	35.8	26.3	4.0	15	2.803
740	1365	0	36.6	26.5	5.0	15	2.804
		30	36.4	26.2	4.5	30	2.804
		60	36.2	27.4	5.0	30	2.802
		90	35.7	27.8	4.5	30	2.805
		120	37.0	27.5	5.0	30	2.804
680	1255	0	36.5	27.9	4.5	20	2.805
		30	34.4	27.6	4.0	15	2.802
680	1255	0	35.8	26.3	3.5	15	2.803
800	1470	0	37.8	25.4	5.0	20	2.798
		30	36.3	25.4	6.0	30	2.797
		60	36.4	27.6	5.0	30	2.793
		90	35.6	28.4	5.0	30	2.794
		120	37.0	27.4	5.5	20	2.790
680	1255	0	35.6	26.3	4.0	15	2.800
		30	35.0	27.4	4.0	15	2.799

* UTS - Ultimate Tensile Strength, in 1000 psi
YS - 0.2% Yield Strength, in 1000 psi
E - Elongation in 2", %
GS - Average Grain Diameter, in 0.001 inch
D - Density, in g/cm^3

TABLE 11

Effect of Melt Temperature (C4X-T6)

Type of Casting	Pouring Temperature		UTS*	YS*	E*	GS*	D*
	°C	°F					
Separately-cast test bars	680	1255	48.8	31.0	7.0	8	2.796
	800	1470	43.9	31.8	6.5	15	2.777
	680	1255	46.8	33.5	7.0	10	2.794
½-inch thick plate	680	1255	44.6	31.4	7.5	8	2.786
	800	1470	36.6	28.4	3.0	12	2.762
	680	1255	43.5	30.0	7.5	8	2.783
1½-inch thick plate	680	1255	35.4	27.5	3.0	8	2.785
	800	1470	26.1	23.1	2.5	15	2.751
	680	1255	35.0	26.9	2.5	10	2.778

* UTS - Ultimate Tensile Strength, in 1000 psi
YS - 0.2% Yield Strength, in 1000 psi
E - Elongation in 2", %
GS - Average Grain Diameter, in 0.001 inch
D - Density, in g/cm^3

TABLE 12

Effect of Melt Temperature (G10-T4)

Type of Casting	Pouring Temperature		UTS*	YS*	E*	GS*	D*
	°C	°F					
Separately-cast test bars	680	1255	52.9	27.5	27.5	15	2.562
	800	1470	40.1	28.0	8.0	40	2.556
	680	1255	41.6	29.1	8.0	40	2.560
½-inch thick plate	680	1255	35.7	27.4	7.0	15	2.562
	800	1470	28.3	24.4	3.5	40	2.553
	680	1255	32.0	26.3	5.5	30	2.558
1½-inch thick plate	680	1255	33.7	24.5	7.0	20	2.547
	800	1470	28.9	21.9	7.0	40	2.513
	680	1255	30.1	23.1	6.0	40	2.521

* UTS - Ultimate Tensile Strength, in 1000 psi
YS - 0.2% Yield Strength, in 1000 psi
E - Elongation in 2", %
GS - Average Grain Diameter, in 0.001 inch
D - Density, in g/cm^3

TABLE 13

Effect of Melt Temperature (SG70-T6)

Type of Casting	Pouring Temperature °C	Pouring Temperature °F	UTS*	YS*	E*	GS*	D*
Separately-cast test bars	680	1255	36.2	28.5	3.5	15	2.681
	800	1470	37.4	28.6	5.0	50	2.680
	680	1255	37.4	28.5	5.0	15	2.681
½-inch thick plates	680	1255	33.2	29.4	2.0	15	2.678
	800	1470	33.2	29.2	2.5	60	2.676
	680	1255	34.1	28.6	3.5	15	2.678
1½-inch thick plates	680	1255	31.2	28.2	1.5	30	2.674
	800	1470	27.2	27.0	1.0	60	2.664
	680	1255	30.1	26.8	2.0	20	2.679

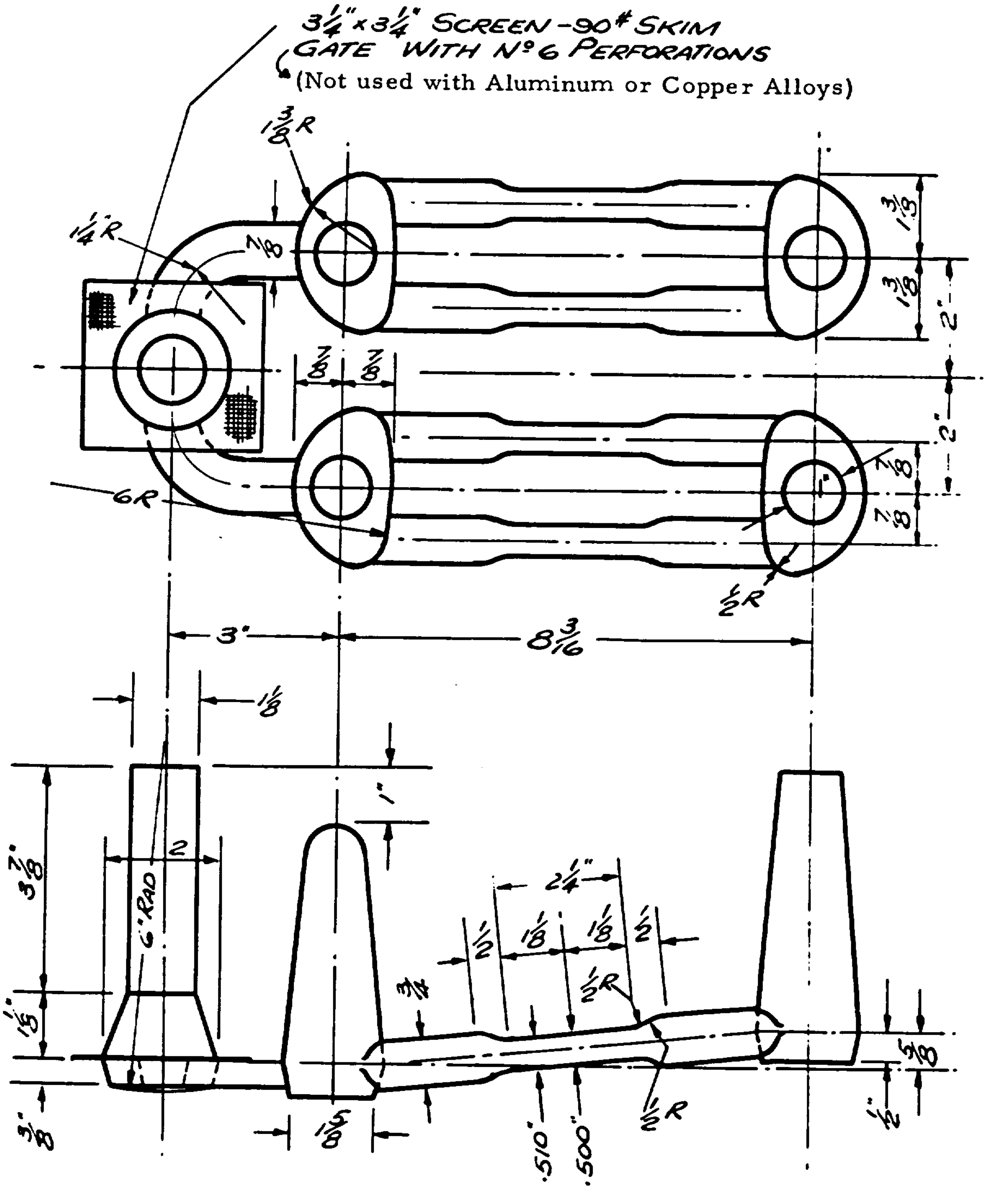
* UTS - Ultimate Tensile Strength, in 1000 psi
YS - 0.2% Yield Strength, in 1000 psi
E - Elongation in 2", %
GS - Average Grain Diameter, in 0.001 inch
D - Density, in g/cm^3

TABLE 14

Effect of Melt Temperature (ZG61-F)

Type of Casting	Pouring Temperature °C	°F	UTS★	YS★	E★	GS★	D★
Separately-cast test bars	730	1345	36.8	26.4	5.0	20	2.809
	800	1470	38.5	26.2	5.5	20	2.808
	730	1345	38.4	26.4	5.5	20	2.808
½-inch thick plates	730	1345	32.9	26.4	4.5	15	2.801
	800	1470	33.7	26.7	4.5	15	2.795
	730	1345	31.9	24.8	4.0	15	2.790
1½-inch thick plates	730	1345	29.9	25.1	2.5	20	2.790
	800	1470	29.7	24.7	3.0	20	2.778
	730	1345	29.9	25.1	3.0	20	2.791

★ UTS - Ultimate Tensile Strength, in 1000 psi
YS - 0.2% Yield Strength, in 1000 psi
E - Elongation in 2", %
GS - Average Grain Diameter, in 0.001 inch
D - Density, in g/cm^3



(Not used with Aluminum or Copper Alloys)

Figure 1. - Test bar design according to U.S. Federal Specification QQ-M-56

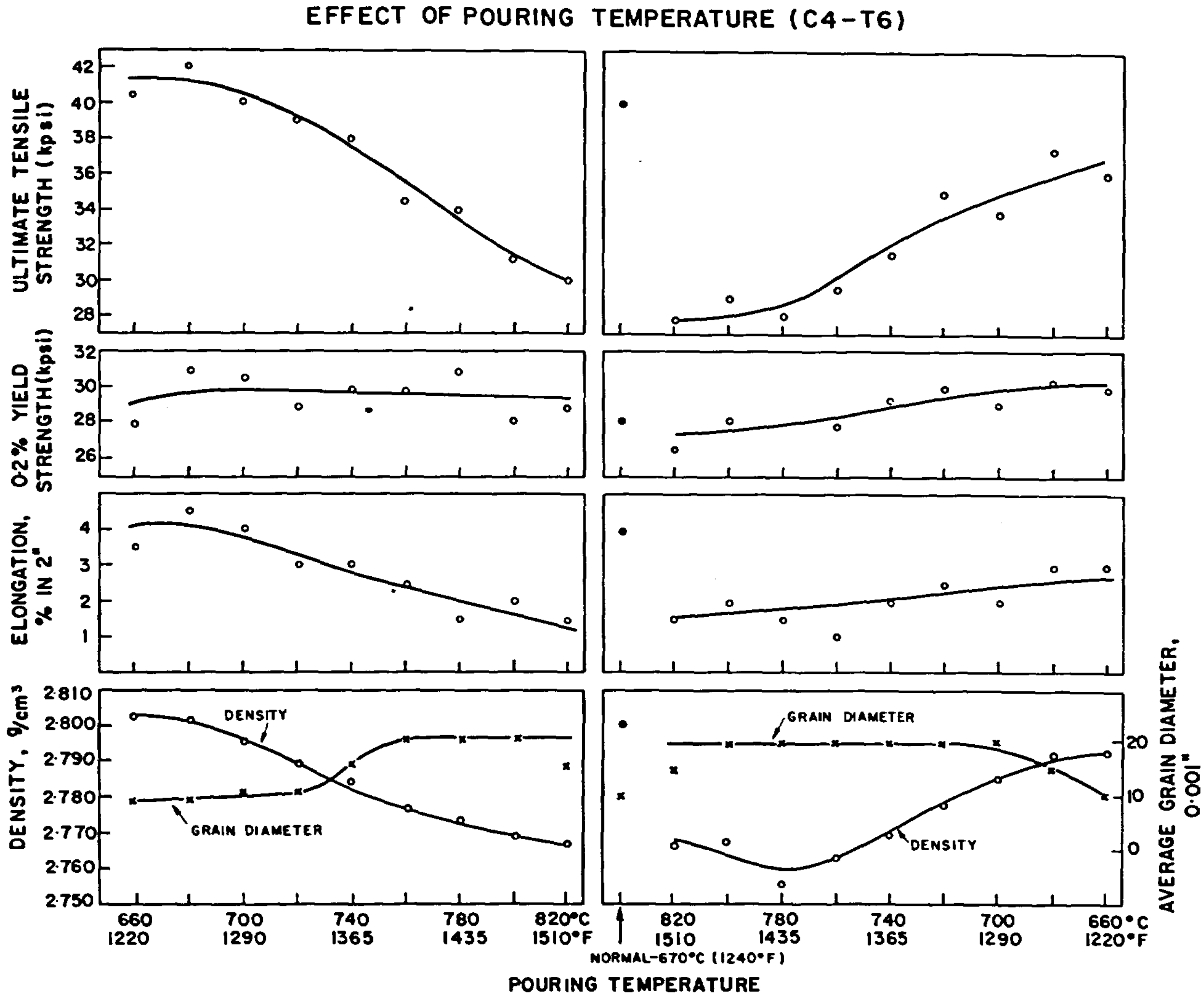


Figure 2. - Effect of pouring temperature (C4-T6).

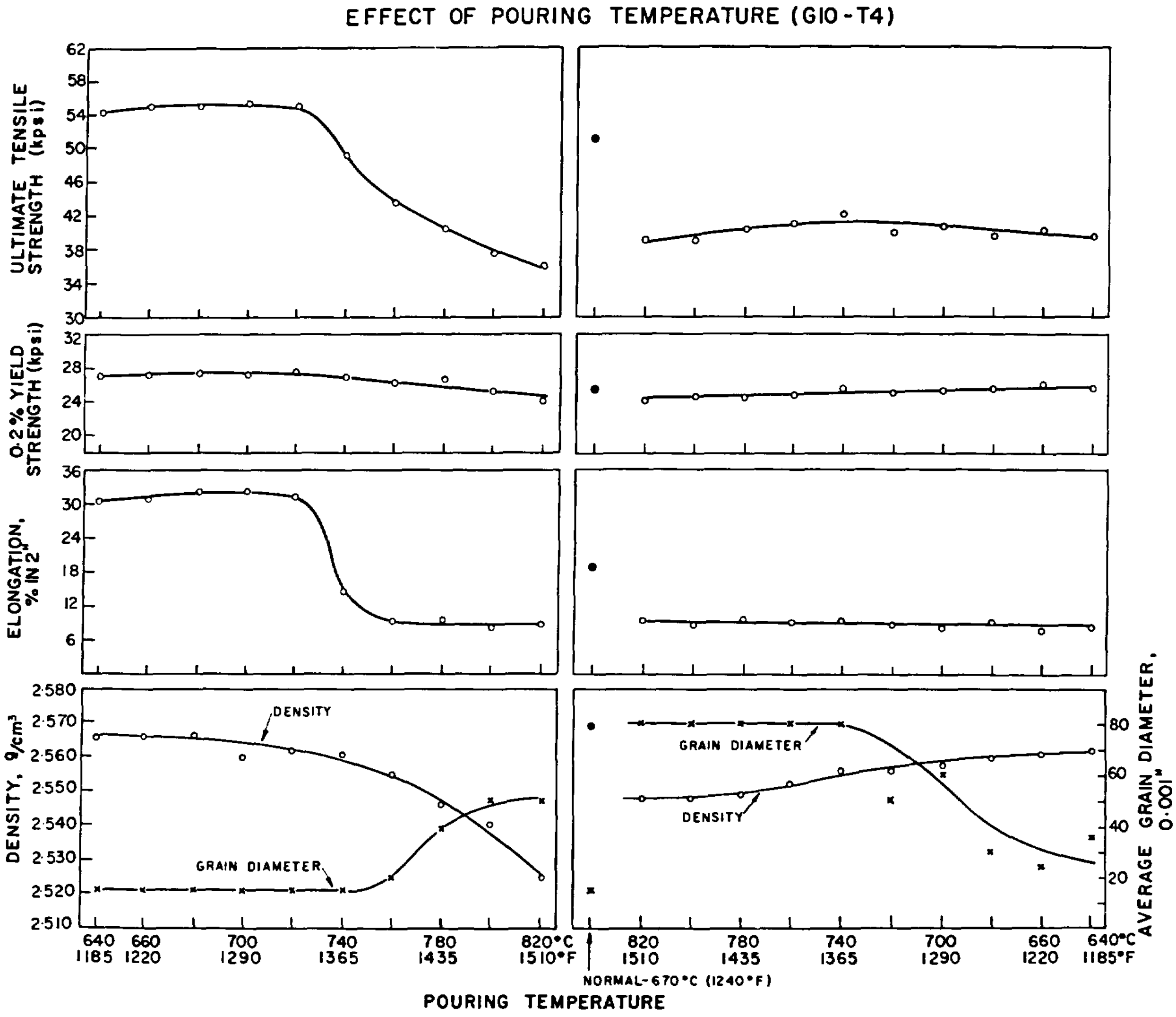


Figure 3. - Effect of pouring temperature (G10-T4).

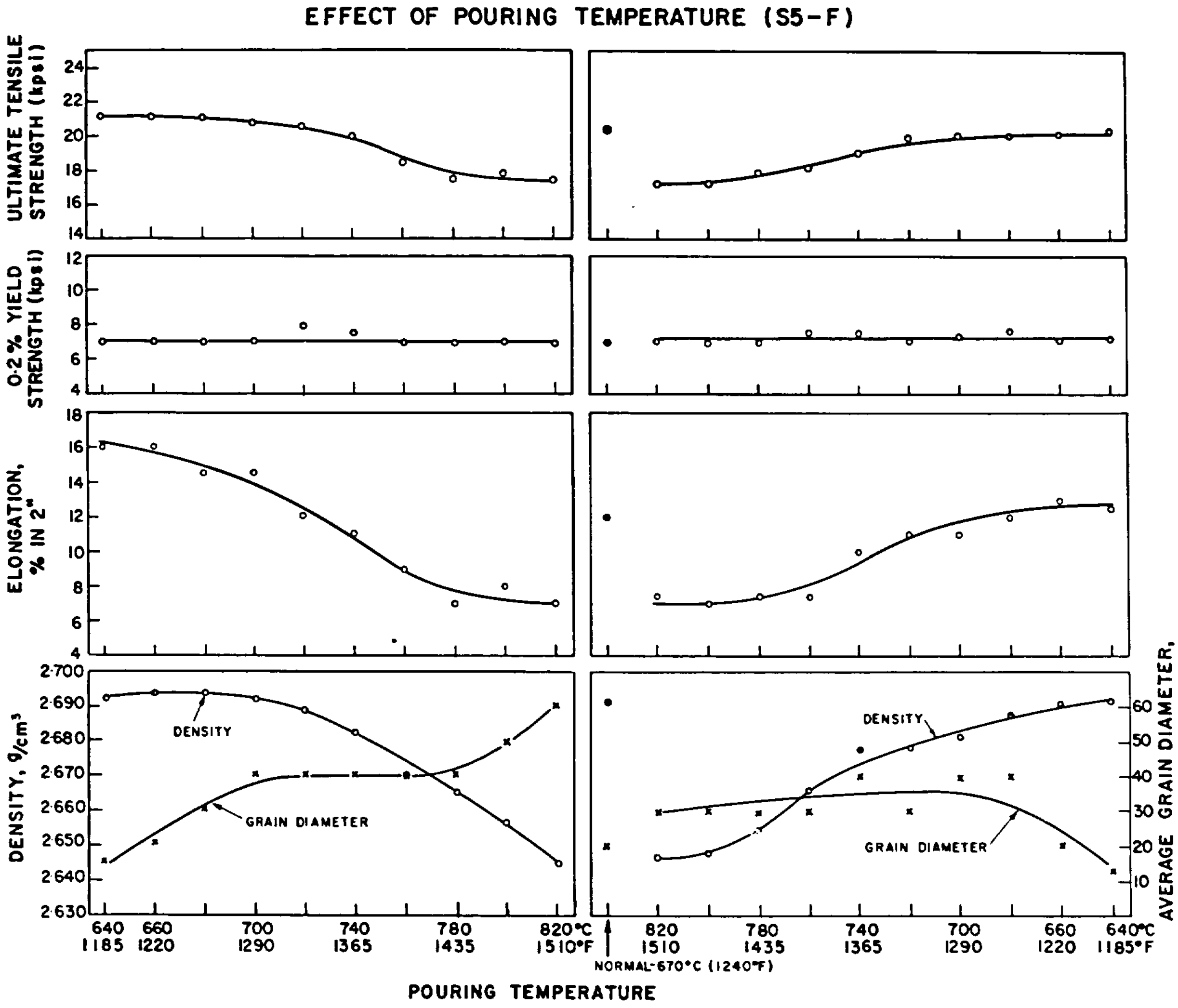


Figure 4. - Effect of pouring temperature (S5-F).

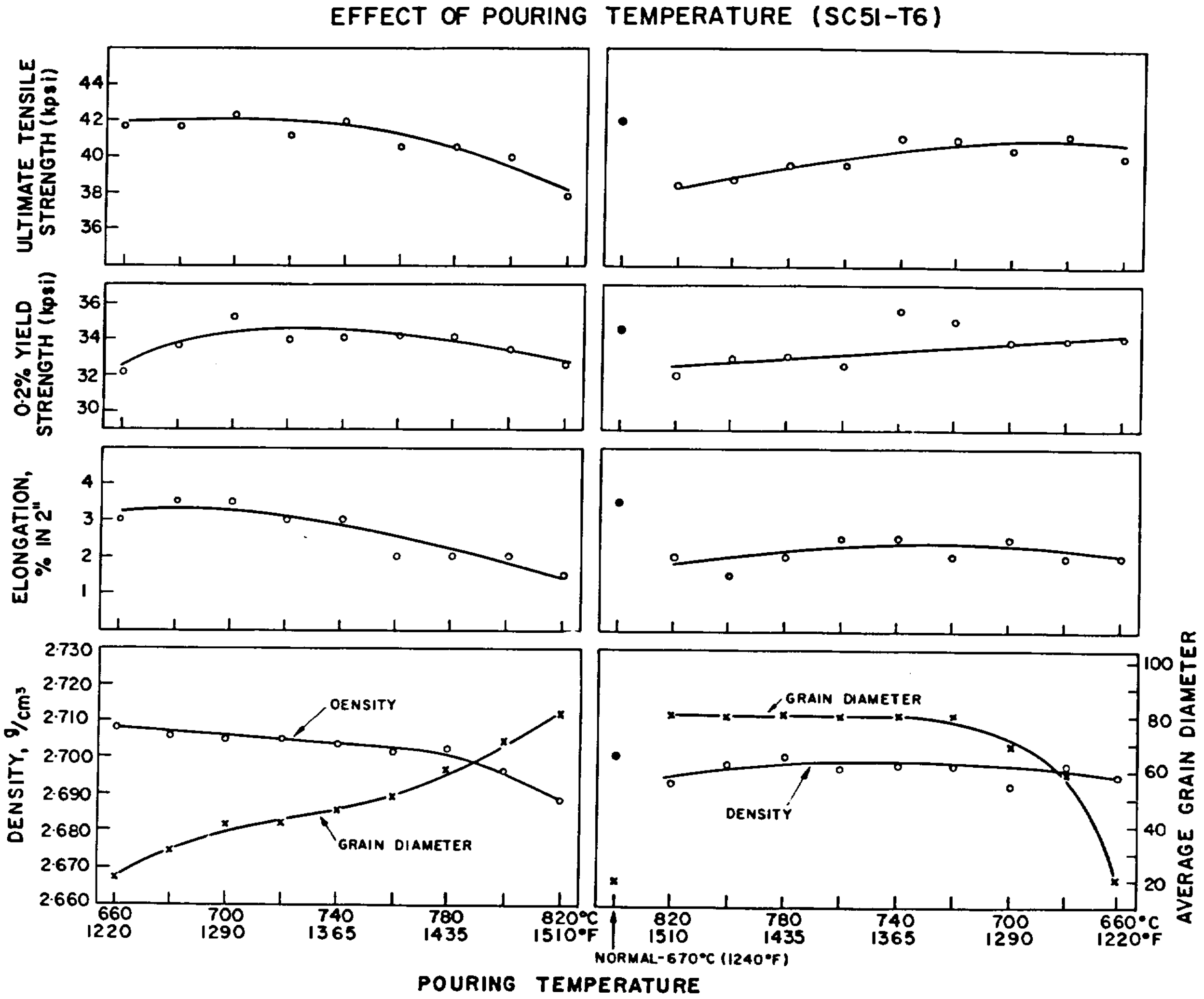


Figure 5. - Effect of pouring temperature (SC51-T6).

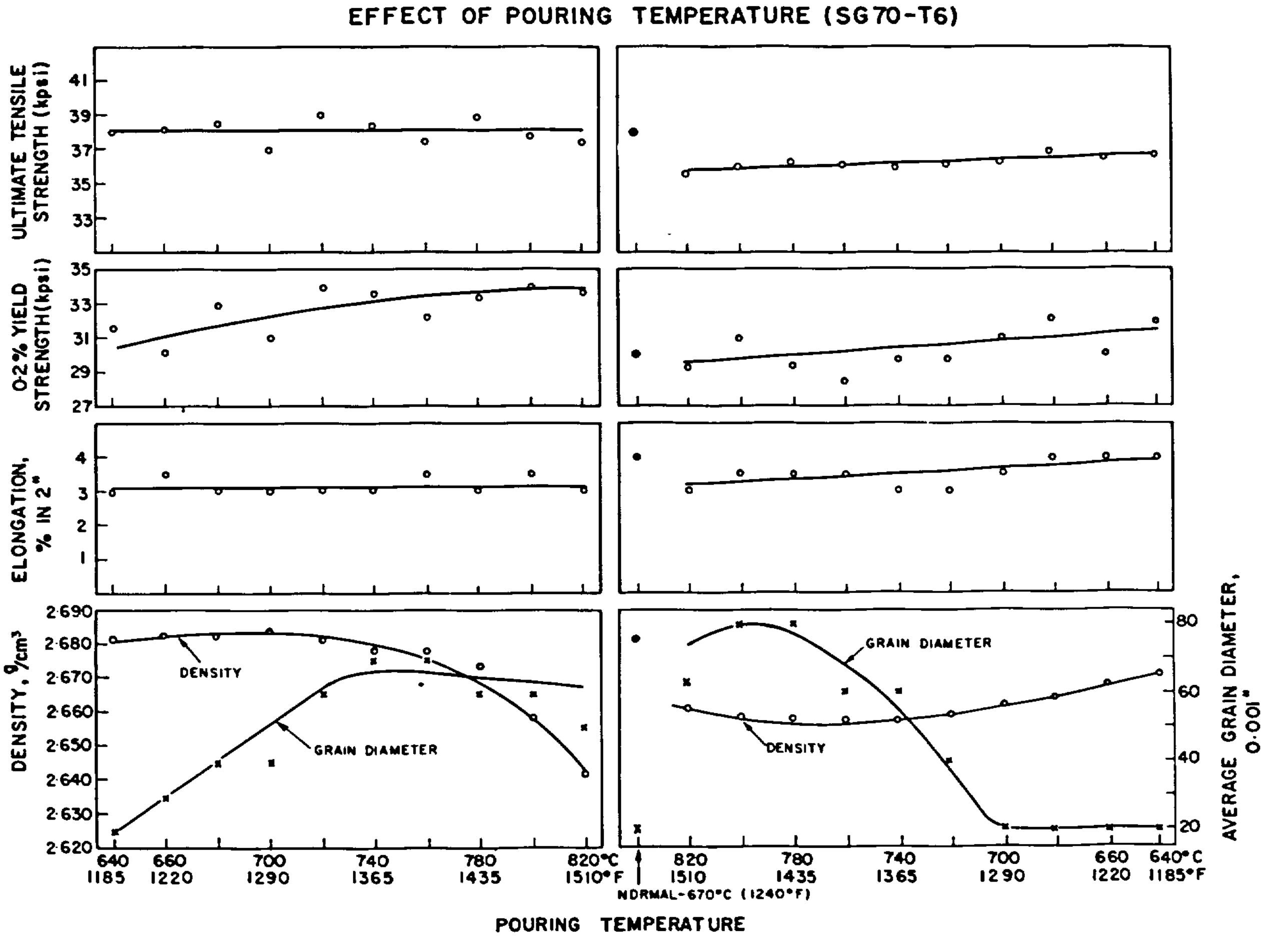


Figure 6. - Effect of pouring temperature (SG70-T6).

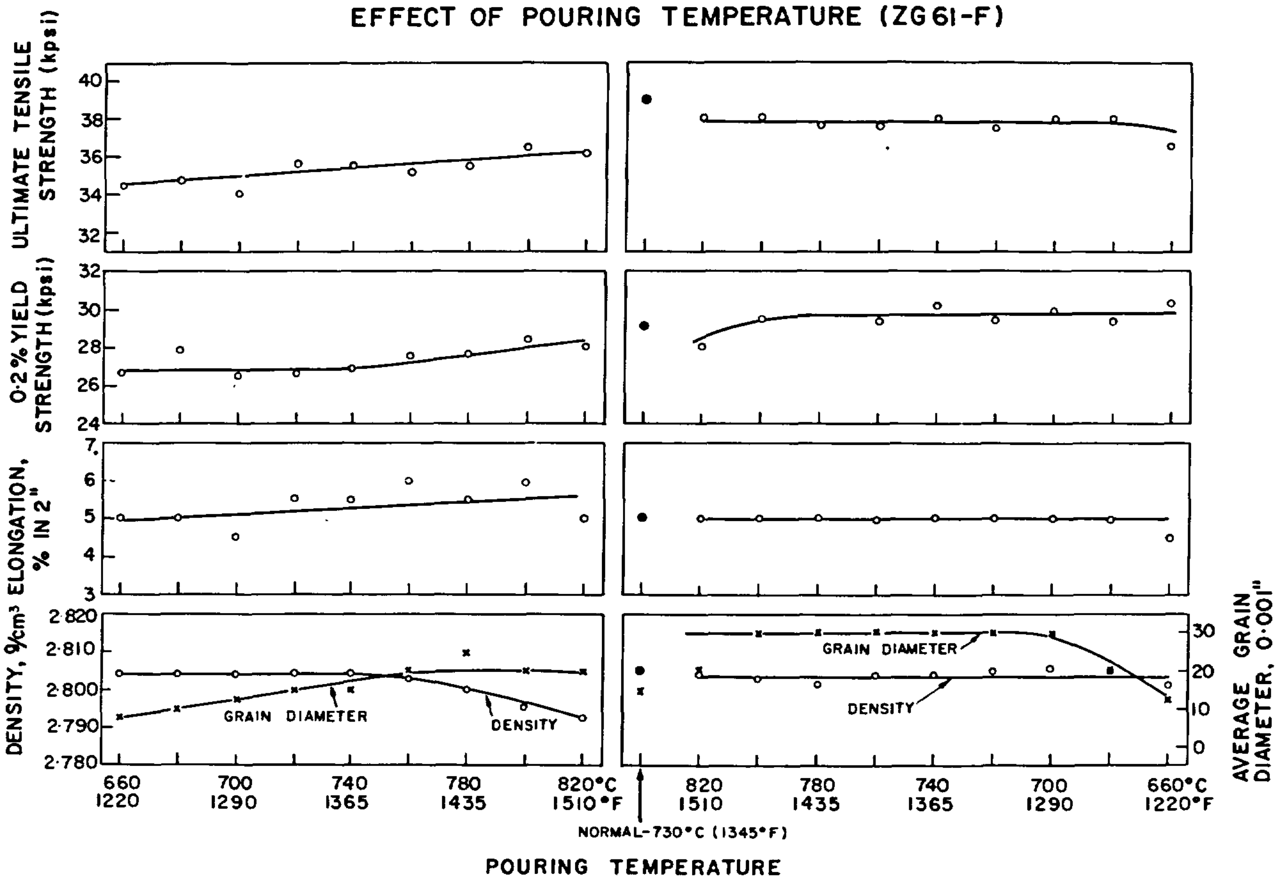


Figure 7. - Effect of pouring temperature (ZG61-F).

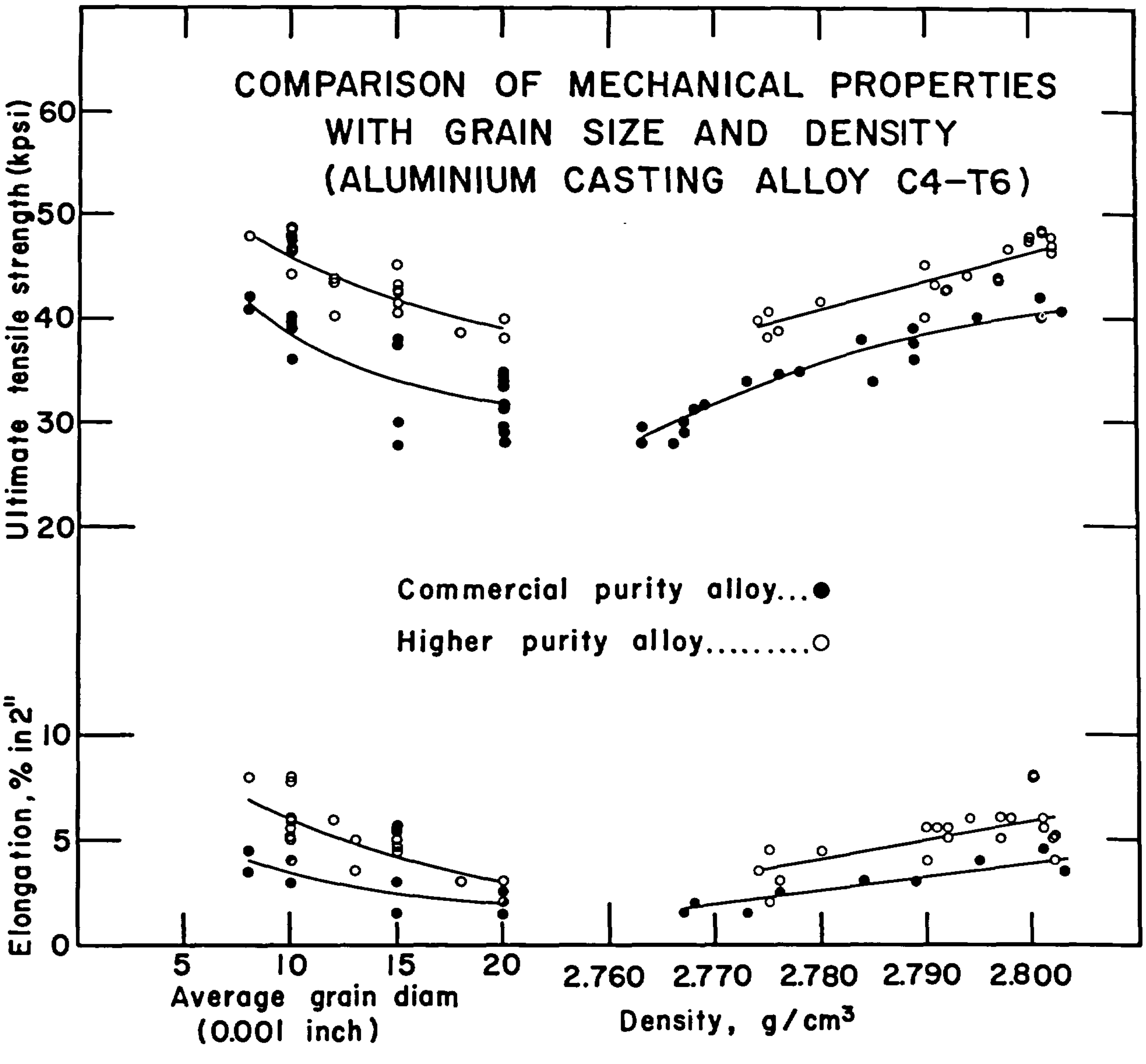


Figure 8. - Comparison of mechanical properties with grain size and density (C4-T6).

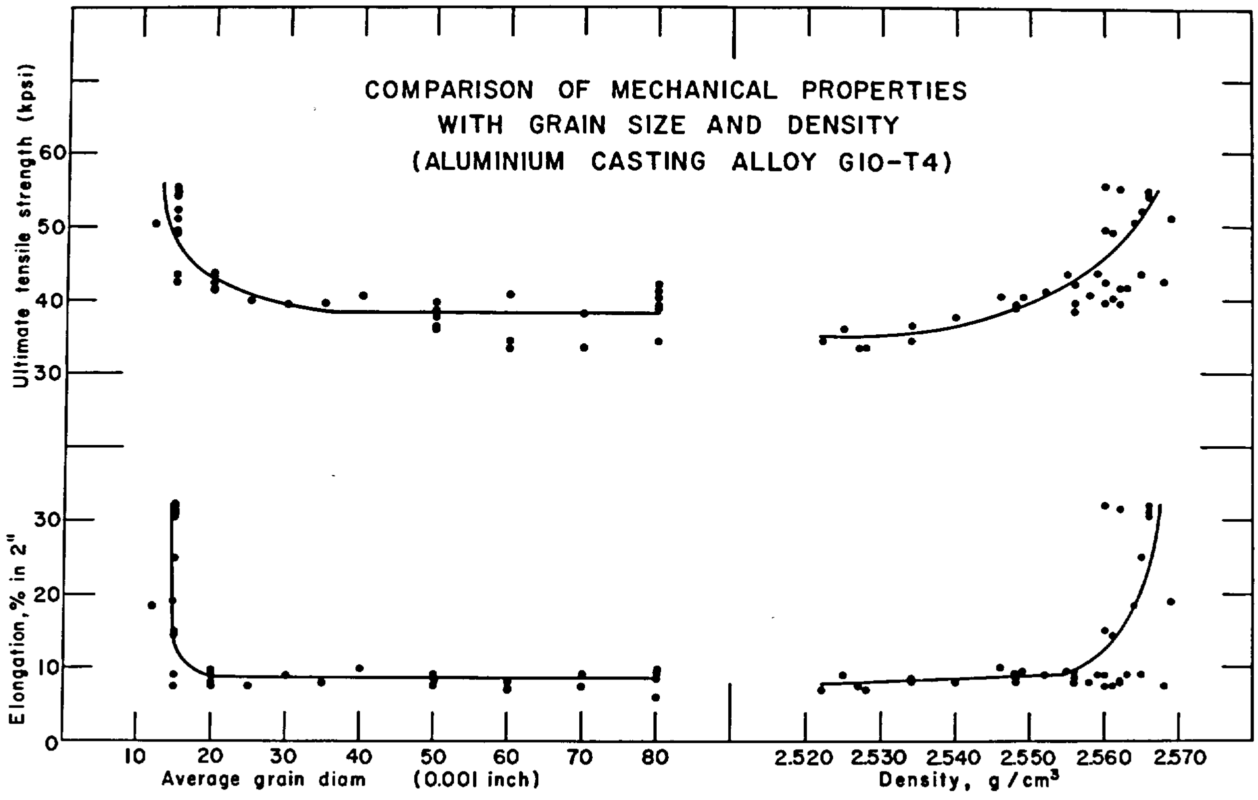


Figure 9. - Comparison of mechanical properties with grain size and density (G10-T4).

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