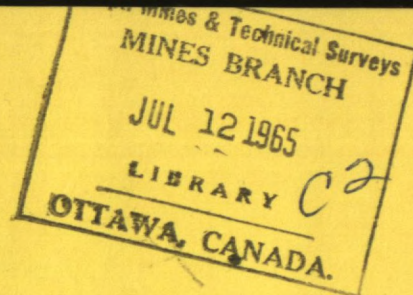




CANADA



INVESTIGATIONS ON SAND-CAST ALUMINUM ALLOY TEST BARS

W.A. POLLARD & J.W. MEIER

DEPARTMENT OF MINES AND
TECHNICAL SURVEYS, OTTAWA

MINES BRANCH

RESEARCH REPORT

R 150

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PHYSICAL METALLURGY DIVISION

JANUARY 1965

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FOREWORD

In connection with work on international standardization, undertaken by the International Organization for Standardization (ISO/TC79) on aluminum casting alloys, and with perennial discussions about the role of a separately-cast test bar in quality control and industrial inspection procedures, some investigations on these subjects were carried out at the Physical Metallurgy Division, Mines Branch.

Some papers on this work were presented at the Symposium on Sand-Cast Aluminum Alloy Test Bars, held at the 29th International Foundry Congress, Detroit, Mich., U.S.A., 8 May 1962, and two additional papers, dealing with the use of fluorescent screen radiography for the study of the metal flow in test bar sand moulds, were presented at the AFS Casting Congresses in St. Louis, Mo. (1963) and Atlantic City, N. J. (1964).

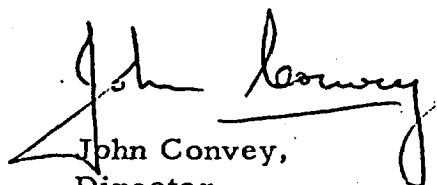
The present report includes the following:

- Part I. "Introductory Remarks" - by J. W. Meier, who organized the Symposium on Sand-Cast Aluminum Alloy Test Bars and acted as its convener.
- Part II. "Comparison of Some Test Bar Pattern Designs Used in Various Countries for Aluminum" - by W. A. Pollard and J. W. Meier.
- Part III. "Study of Metal Flow in Aluminum Test Bar Moulds by Fluorescent Screen Radiography" - by W. A. Pollard.
- Part IV. "Comparison Between the Flow of Water Solution and Molten Aluminum in Moulds by Fluorescent Screen Radiography" - by W. A. Pollard.

The full text of the "Symposium on Sand-Cast Aluminum Alloy Test Bars" has been published in a separate brochure by the American Foundrymen's Society, Des Plaines, Ill. (1963) and may be ordered from this Society. It contains the following papers:

1. "Introductory Remarks" - J. W. Meier
2. "Sand-Cast Test Bar Practice for Aluminum Alloys in Great Britain" - by F. H. Smith
3. "Separately-Cast Tensile Test Bars Used in France for Aluminum Alloys" - by C. Mascré
4. "Sand-Cast Aluminum Alloy Test Bar Practice in Germany"
5. "American Aluminum Sand-Cast Test Bar Practice" - by D. L. LaVelle
6. "Comparison of Some Test Bar Pattern Designs Used in Various Countries in Aluminum Alloys" - by W. A. Pollard and J. W. Meier
7. "Discussions and Closing Remarks"

The issue of this report, although it is already available in publications, is made because of the still unsettled discussions at ISO/TC79/WG5 on Characteristics of Aluminum and Magnesium Castings, and to include the work in the series of Mines Branch Research Reports.


John Convey,
Director,
Mines Branch

Ottawa, 28, January, 1965

AVANT-PROPOS

Relativement aux travaux de normalisation à l'échelle internationale entrepris par l'Organisation internationale pour la normalisation (ISO/TC 79) à propos des pièces moulées d'aluminium allié, et en raison des discussions intarissables sur le rôle d'une éprouvette coulée séparément, servant aux essais de qualité et au contrôle industriel, la Division de la métallurgie physique, Direction des mines, a mené à bien quelques recherches sur ces sujets.

Des études sur ce travail ont été présentées au Colloque sur les éprouvettes d'aluminium allié moulé au sable, au 29^e congrès international de la Fonderie tenu à Détroit (Mich., É.-U.), le 8 mai 1962; deux autres rapports, traitant de l'emploi de la radiographie sur écran fluorescent pour l'étude du mouvement du métal dans les moules au sable pour éprouvettes, ont été présentés aux Congrès de l'AFS sur les moulages, tenus à Saint-Louis (Mo.) en 1963 et à Atlantic City (N. J.) en 1964.

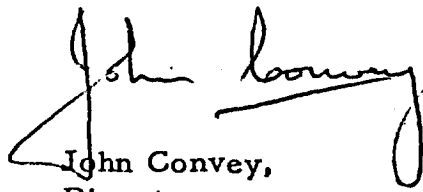
Le présent rapport comprend ce qui suit:

- 1^e partie - "Remarques préliminaires" par J. W. Meier, qui a organisé le Colloque sur les éprouvettes en aluminium allié et moulé au sable, et s'est occupé de réunir ses collègues.
- 2^e partie - "Comparaison entre quelques modèles d'éprouvettes en aluminium utilisés dans divers pays" par W.A. Pollard et J. W. Meier.
- 3^e partie - "Etude radiographique du mouvement du métal sur écran fluorescent des moulages d'éprouvettes en aluminium" par W.A. Pollard.
- 4^e partie - "Comparaison entre le mouvement d'une solution aqueuse et celui de l'aluminium fondu dans les moules, par radiographie sur écran fluorescent" par W.A. Pollard.

Le texte complet du "Colloque sur les éprouvettes en aluminium moulé au sable" a été publié séparément par l'"American Foundrymen's Society", Des Plaines (Ill.) en 1963; on peut se procurer la brochure en s'y adressant. Elle contient les études suivantes:

1. "Remarques préliminaires" par J. W. Meier.
2. "Méthodes d'utilisation en Grande-Bretagne des éprouvettes en aluminium allié" par F. H. Smith.
3. "Les éprouvettes moulées séparément utilisées en France pour les essais de traction" par C. Mascré.
4. "Méthodes d'utilisation en Allemagne des éprouvettes en aluminium allié moulé au sable".
5. "Méthodes d'utilisation aux États-Unis des éprouvettes en aluminium moulé au sable" par D. L. LaVelle.
6. "Comparaison entre quelques modèles utilisés dans divers pays, d'éprouvettes en aluminium allié", par W. A. Pollard et J. W. Meier.
7. "Discussions et remarques finales".

La parution du présent rapport, bien qu'il soit déjà disponible dans certaines publications, a été décidée parce qu'il y a des questions encore pendantes à l'ISO/TC79/WG5 sur les caractéristiques des moulages d'aluminium et de magnésium et pour que ces travaux fassent partie de la série des rapports de la Direction des mines.


John Convey,
Directeur,
Direction des mines

Ottawa, le 28 janvier, 1965

Mines Branch Research Report R 150

INVESTIGATIONS ON SAND-CAST ALUMINUM ALLOY TEST BARS

by

W. A. Pollard* and J. W. Meier**

ABSTRACT

To aid the standardization work of ISO/TC79 on Light Metals and Alloys, a Symposium on Sand-Cast Aluminum Alloy Test Bars was held at the International Foundry Congress in Detroit in 1962. The Canadian contribution to this symposium was a comparison of the characteristics of six test bar pattern designs, used in various countries. This report presents the results of this study, along with the discussions held at the Symposium.

The last two parts of the report deal with a novel method of studying the flow of molten metal in test bar sand moulds by means of fluorescent screen radiography.

* Senior Scientific Officer, and ** Principal Metallurgist (Non-Ferrous Metals), Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

Direction des mines

Rapport de recherches R 150

RECHERCHES SUR LES EPROUVETTES EN ALLIAGE
D'ALUMINIUM COULEES EN SABLE

par

W. A. Pollard* et J. W. Meier**

RÉSUMÉ

Un Colloque sur les éprouvettes en alliage d'aluminium coulées en sable s'est déroulé au Congrès international de la fonderie, en 1962, à Détroit, en vue d'aider au travail de normalisation d'ISO/TC79 sur les métaux légers et les alliages. L'apport canadien à ce Colloque a consisté en une comparaison des caractéristiques de six modèles d'éprouvettes employés en divers pays. Le présent rapport rend compte des résultats des études ainsi que des questions débattues au Colloque.

Les deux dernières parties du rapport traitent d'une nouvelle méthode pour étudier le mouvement du métal fondu dans les moules en sable pour éprouvettes, au moyen de la radiographie sur écran fluorescent.

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PART I

INTRODUCTORY REMARKS

by

J. W. Meier*

(At Symposium on Sand-Cast Aluminum Alloy Test Bars
sponsored by the Light Metals Division, American
Foundrymen's Society, Detroit, Michigan, 8 May, 1962)

To avoid any misunderstanding, it should be stated right at the beginning that the subject of this Symposium is limited to aluminum alloy test bars cast separately into sand moulds. It should be also emphasized that separately-cast test bars are not intended to represent the properties of production castings of various shapes and sizes; they are used throughout the foundry industry to check melt quality and heat treatment, as well as for research or development work on alloy compositions or heat treating techniques and the effect of extreme service conditions on the properties of cast alloys.

It is quite obvious that the full value of melt quality evaluation can be achieved only if the test bars are cast under "standardized and strictly controlled" conditions. As reported earlier^{(1) (2)}, there are about fifty variables affecting the results of mechanical tests on cast test bars.

* Principal Metallurgist (Non-Ferrous Metals), Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

- (1) J. W. Meier - "The Effect of Various Factors on the Mechanical Properties of Magnesium Alloy Castings" - Proc. 25th International Foundry Congress, Liège, Belgium (Sept. 1958), pp. 223-240.
- (2) J. W. Meier and A. Couture - "Effect of Casting Temperature on Aluminum Alloy Test Bar Properties" - Mines Branch Research Report R 54 (1959); Trans. AFS 68, 636-647 (1960).

They are related to the alloy composition, melting conditions, casting design, heat treatment, test bar preparation, and some testing variables.

Recent efforts to establish international standards for aluminum casting alloys, undertaken by the International Organization for Standardization (ISO/TC79), showed that alloy properties cannot be specified without a basic agreement on at least some of the more important factors affecting test bar results.

The standardization of alloys and their properties, as well as of testing methods, should be left to the ISO or various national standardization bodies, but the subject of casting and preparation of test bars is definitely the concern of the foundryman.

The present International Foundry Congress presented an opportunity to arrange for a discussion on test bar techniques used in various countries and to prepare material for an international agreement in this field.

The papers presented at this Symposium contain descriptions of test bar casting designs and techniques used in various countries, and a report on a laboratory-scale comparison of results obtained from these test bar designs.

In evaluating different test bar casting arrangements (pattern designs), the following characteristics should be considered:

- (a) consistency of results obtained from bars cast in the same mould (within-mould variation) and bars from different moulds from the same melt (between-moulds or within-melt variation),
- (b) reproducibility of results obtained from bars cast in different melts under identical conditions (between-melts variation),
- (c) sensitivity of test bar results to significant changes in melt quality or alloy composition, and
- (d) cost per test bar (mould preparation, multiple bar design vs. single bar, cost of machining, cores, etc.).

It is obvious that reliability or reproducibility of results from any test bar design should be based on a large number of industrial melts, preferably from various production foundries throughout the country. A laboratory-scale investigation can give only very limited data and could

even be somewhat misleading. This is why the French and Germans did not standardize their test bar designs before checking them in industrial conditions, and a similar procedure would have to be followed if the AFS approves a test bar design.

On the other hand, a laboratory-scale investigation can be very useful in establishing those characteristics where strict control of all foundry variables is essential, i.e., the sensitivity of test bar results to changes in melt quality, alloy composition or purity, and variation in heat treatment.

Sensitivity of test bar results to significant changes in melt quality or alloy composition is, of course, an essential characteristic of a melt quality control tool. This is especially important when the mechanical properties are affected by very small differences in the amount of an alloying element, which is easily lost during the melting operation. An example of this is illustrated in Figure 1, showing the effect of magnesium content on the tensile properties of sand-cast aluminum alloy SG70-T6.

In recent years we learned, as well, not to underestimate the effect of small amounts of impurities on the mechanical properties of some alloys. Table 1 shows two such examples.

TABLE 1
Effect of Melt Purity.

| Alloy* | Ultimate Tensile Strength, kpsi | 0.2% Yield Strength, kpsi | Elongation, % in 4D |
|-----------|------------------------------------|------------------------------|------------------------|
| C4 - T6 | 40 | 28 | 4 |
| C4X - T6 | 48 | 32 | 8 |
| G10 - T6 | 46 | 25 | 16 |
| G10X - T6 | 54 | 27 | 32 |

* C4 and G10 - commercial purity alloys

C4X and G10X - high-purity alloys (based on 99.8% Al)

So far as the cost of test bars is concerned, the most important factor is machining of the gauge length. There is no doubt that test results depend on the accuracy of dimensional measurements of the cross-section in the gauge length, and that the test results may be affected by the uniformity of cross section as well as the degree of surface smoothness. The question arises whether the slight differences in tensile results are significant enough to justify costly and time-consuming machining, especially in larger foundries where the number of test bars is considerable. Figures 2 and 3 show results of an investigation⁽³⁾ on six commercial sand-casting alloys. No significant differences in properties were found in any of the alloys and it seems, therefore, that the cost of machining is not warranted. Here in North America, almost nobody uses machined bars (it was always unpopular here, as may be seen in a paper published by Gillet⁽⁴⁾ in 1912), but most European specifications still insist on a machined surface.

One further aspect of international standardization is the gauge length specified for the determination of the elongation value. The great majority of countries throughout the world uses a gauge length equal to 5 or 10 diameters of the bar. We here in North America are using 4D. The only other "outsiders" are Great Britain (3.5D) and France (7.25D), but both of these countries are at present considering changing to the international 5D. Sooner or later we shall have to consider the same move. Comparisons of elongation values based on various gauge length-to-diameter ratios were recently published⁽³⁾ (5).

Another difficulty is still encountered when comparing yield strength values. The 0.2% YS is used in all countries except the United Kingdom; British Standard BS 18:1956 specifies an 0.1% YS (called "0.1% Proof Stress"). A recent comparison of 0.1% and 0.2% YS for six commercial sand-casting alloys showed⁽³⁾ a straight line relationship between these two values, but significantly different for each alloy.

(3) A. Couture and J. W. Meier - "The Effect of Some Test Bar Variables on Mechanical Properties of Aluminum Casting Alloys" - Mines Branch Research Report R 102, Department of Mines and Technical Surveys, Ottawa (1962).

(4) H. W. Gillet - "The Influence of Pouring Temperature on Aluminum Alloys" - Proc. 8th Internat. Congress Applied Chemistry, Washington and New York, Section II, pp. 105-112 (1912).

(5) C. Mascré - "The Measurement of Elongation on Cast Aluminum Alloys" - Fonderie 184, 185-187 (May 1961).

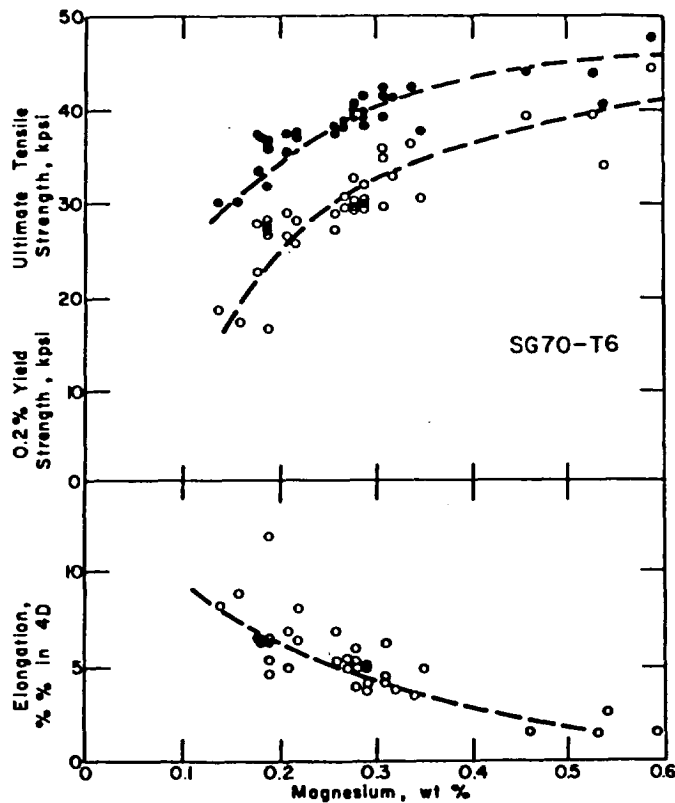


Figure 1. Effect of Magnesium-Content on Tensile Properties of Aluminum Sand-Casting Alloy SG70-T6.

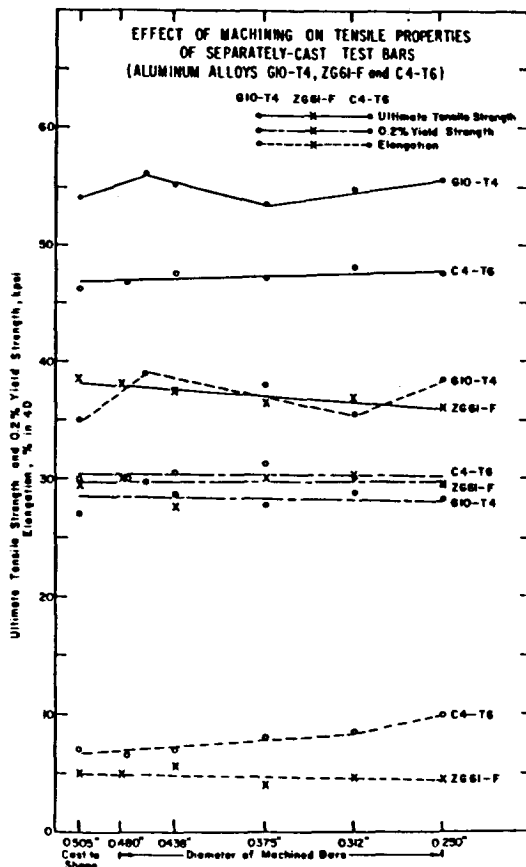


Figure 2.

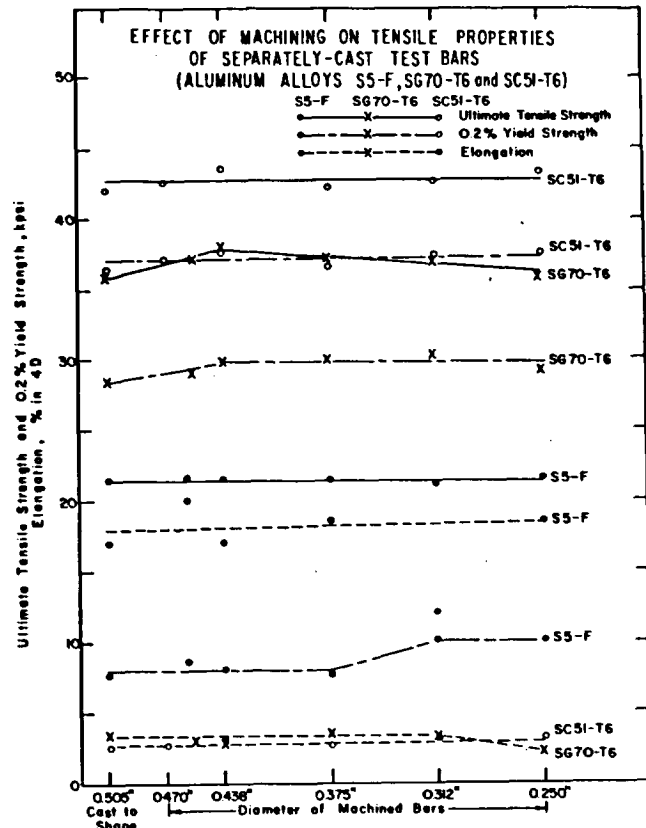


Figure 3.

PART II

COMPARISON OF SOME TEST BAR PATTERN DESIGNS USED IN VARIOUS COUNTRIES FOR ALUMINUM ALLOYS

by

W. A. Pollard* and J. W. Meier**

INTRODUCTION

One of the obstacles encountered in the international standardization of aluminum casting alloys, undertaken by ISO/TC79, is the difficulty in comparing test bar results obtained in different countries. As shown earlier⁽¹⁾⁽²⁾, there are almost fifty variables affecting the results of mechanical tests on cast test bars. Most of these variables are connected with alloy composition, melting conditions, casting procedures or heat treatment, and can be readily standardized and strictly controlled. Other variables are related to test bar preparation (as-cast vs. machined) or testing conditions (gauge length 0.1% vs. 0.2% yield strength, etc.) and in most countries these are included in official standards and specifications. Unfortunately, no conformity exists between the various national requirements, and considerable effort to obtain an international agreement on these issues is still necessary.

As a contribution to the solution of this problem and following some earlier work in this field⁽²⁾⁽³⁾, a study was undertaken to compare test bar pattern designs used in various countries. Due to limitations of a laboratory-scale program only six designs could be included in the present work; some of the other test bar pattern designs are described in Appendix A.

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The object of this study was to compare the characteristics of six test bar pattern designs for aluminum-base casting alloys. Five of these designs are either already standard or are near-standard in four countries and the sixth is a recent design proposed for consideration by the American Foundrymen's Society.

The criteria used in comparing the various test bars were as follows:

- (a) ease of mould preparation,
- (b) ease of casting,
- (c) sensitivity to significant changes in melt quality or composition,
- (d) consistency of results within melts,
- (e) cost per test bar.

A further factor of importance is the reproducibility of results between melts of the same quality and composition, but in the present investigation only a limited appraisal of this could be made. Ideally a large number of identical melts would have to be made under commercial conditions and the results analysed statistically.

Four aluminum-base casting alloys were used in the present work: G10 (Al-10% Mg), C4 (Al-4.5% Cu), SG70 (Al-7% Si-0.3% Mg), and SC51 (Al-5% Si-1% Cu-0.5% Mg).*

TEST BAR DESIGNS

The test bar designs chosen for the present work (Figure 1) may be divided into three groups. First, those in which the bars are cast-to-shape and are filled from one end only (Dow and French). Second, those in which the bars are filled from both ends (AFS, CSA, German and British E-type). The E-type bar differs from the others in this group (which are cast-to-shape) in that the bars are cast oversize and machined before testing. Third, the British DTD bar which is cast vertically and is machined before testing.

More detailed drawings of the seven test bars used in this investigation are given in Appendix A (Figures A 1 - A 7).

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

Group 1.

The Dow test bar (4) was designed for magnesium-base casting alloys. At the Mines Branch Laboratories, however, it has been used for a number of years also for aluminum-base alloys and has proved reasonably satisfactory for development work on new alloys and heat treatments. For use in magnesium-base alloys a perforated metal screen is usually placed below the sprue; it is omitted when casting aluminum-base alloys. Since the screen tends to act as a choke, its removal makes it rather difficult to keep the sprue full during pouring.

The French test bar is an alternate design allowed in alloys. It differs slightly from that described by C. Mascré⁽⁷⁾, principally in the design of the runners adjacent to the sprue-base. No particular difficulties were encountered in moulding or casting the French test bar.

Group 2.

The German test bar design was developed by the German Foundrymen's Association (8) (9). It differs from the other two designs in this group in that the sprue is not symmetrical with respect to the gating system and asymmetric flow of metal in the bars is, therefore, to be expected. The preparation of this mould was somewhat complicated by the use of a sprue that has to be made in core sand.

The design proposed for consideration by the Test Bar Committee of the Light Alloys Division, American Foundrymen's Society, and designated AFS in the present work, has already been described by D. L. LaVelle (10). It has four bars which are filled from both ends and is gated and risered in accordance with the recommendations of the Battelle Memorial Institute from work done under AFS sponsorship. In an attempt to prevent the metal streams meeting in the reduced sections of the bars with the resulting risk of a flaw or weak spot in this region, the bars are set at an angle so that the metal enters one end before the other. In practice, however, it was found that the metal streams met at various positions along the reduced section of the bar in an apparently haphazard manner (see Appendix B).

The Canadian standard bar (11), designated CSA, is similar to the bar used in the U.S.A. (U.S. Federal Test Method Standard No. 151a). It is a two-bar pattern, and the metal enters from both ends. One difficulty with this design is the position of the sprue in the centre of the mould. This makes tranquil pouring impossible unless a small ladle is used, since the lip of the crucible cannot be brought close to the top of the sprue. This difficulty was pointed out by Colton and LaVelle (12), who suggested a modification in which the sprue was moved to one side of the mould.

The British E-type test bar was designed (13) and is specified (14) as an alternate test bar for the Al-10% Mg alloy. The bars are cast slightly oversize and machined to final dimensions (diameter of reduced section as-cast: 0.625 in., after machining: 0.564 in.). The design suffers from the same defect as the CSA type mentioned above, in that the sprue is situated in the centre of the mould.

Group 3.

The DTD test bar is specified (14) (15) in Great Britain for all cast aluminum alloys. The 1 in. diameter cast piece is machined to final dimensions (0.564 in. diameter reduced section).

EXPERIMENTAL PROCEDURE

Moulding Conditions

All of the moulds in the present work were prepared in green sand. For the Al-10% Mg alloy a synthetic sand was used, made up of No. 70 AFS washed silica sand with 3% water, 4% bentonite and 2% boric acid. For the other alloys McConnellsville sand (AFS No. 135) with 3% water was employed. All moulds, with the exception of the DTD bars which were hand-rammed in 4 in. diameter steel tubes, were made on a simple jolt-squeeze moulding machine.

All moulds were made with a cope height of 4 in., because it was not convenient to use different boxes for the various patterns. No separately moulded pouring basins were used, although the core sand sprue used for the German mould had a pouring basin formed in it. For the other types of moulds the top of the sprue was cut to form a conical funnel approximately 2 in. in diameter.

In the case of the French test bar design, the specified cope height is about 60 mm (2.4 in.) and a pouring basin is normally used (7). In order to obtain some idea of the effect of these variations in moulding practice, two additional melts were made in C4 alloy and these are described in Appendix C.

Melt Materials and Preparation

Melts described as "ingot melts" were made using commercial pre-alloyed ingots. Some melts in the Al-10% Mg alloys were prepared using 99.99% Al, 99.75% Al or 99.5% Al, pure magnesium, Al-5% Be master alloy, and Al-5% Ti master alloy. Some melts in the other alloys were made up using 99.75% Al as base and appropriate master alloys.

Melting Conditions

All melting was done in a gas-fired crucible furnace. Normally at the Mines Branch Laboratories aluminum alloys are melted in carbon-bonded silicon carbide crucibles, but, in a few cases in the present work, limitations of melting capacity necessitated the use of a steel crucible which, although coated with a china-clay wash, resulted in a pick-up of iron in those melts which were raised to an unusually high temperature. The implications of this are further discussed below.

Melt Treatment

Normal melting procedures were used for all alloys. The melts were degassed by flushing with either nitrogen or chlorine, or both, and the effectiveness of the treatment checked by means of a simple reduced-pressure gas test. In all cases where a "gassy" melt was required, the flushing treatment was omitted and the gas test was used to confirm the presence of gas.

In general the melt temperature was kept below 700°C (1290°F), or 720°C (1330°F) for C4 alloy, but in two cases G10 alloy melts were deliberately raised to 800°C (1470°F) and held for thirty minutes in order to obtain poor quality material. It should be understood that, for practical reasons, standard pouring temperatures had to be used in this work for all test bar castings, although it was realized that some of the test bar castings were designed for use at higher temperature, e.g., the German bar should be poured at 750°C (1380°F).

Pouring

Most moulds were poured directly from the melting crucible. As mentioned earlier, the CSA and E-type moulds were difficult to pour in a tranquil manner owing to their sprues being in the centres of the moulds. Some attempts were made early in the work to use a hand ladle to pour these moulds, but this led to temperature control difficulties and was abandoned. The DTD moulds were tilted to about 30 deg from vertical before pouring and rotated to the vertical position as the bar filled with metal.

Heat Treatment

All heat treatment was carried out according to the recommendations of the Canadian Standard CSA.HA.9-1958. The DTD and E-type bars were heat treated before machining and in the case of some of the G10 alloy bars this led to a considerable change in properties due to room temperature ageing.

CHEMICAL ANALYSIS AND SEGREGATION SURVEY

Following the normal practice at the Mines Branch laboratories, chemical analysis samples were taken by transverse drilling into the grip ends of broken test bars. Samples obtained in this way, from one of each type of test bar (except the British), were mixed to form each melt sample. The results obtained are shown in Table 1.

In all cases where C4 and G10 alloy melts were made up, the chemical analysis results (obtained as described above) gave higher values for the principal alloying element than were expected from the composition of the charge. In some melts of C4 alloy this could have been caused by segregation in master alloys, but in the majority of cases segregation in the test bar appeared to be the only explanation.

In order to obtain further information on this point a survey of some of the C4 and G10 melts was made as follows. From each melt, one of each type of test bar was sampled in two positions: one from the centre of the gauge length (about 1/2 in. was removed by turning in the lathe), and the other from the face of the extreme end of the grip farthest from the centre of the bar.

The results of this survey are shown in Tables 2 and 3. It will be seen that in all cases, in both alloys, the solute element is segregated towards the centre of the gauge length. The "grip" values shown are, with a few exceptions, lower than those given in Table 1, which in general represent metal closer to the centre of the gauge length. This suggests that the variation in solute content is continuous from the extreme end of the grip to the centre of the gauge length.

In the G10 alloy melts the AFS bars show higher segregation than the other test bar types. In the C4 alloy there is no significant difference between the test bar types except in the vertically poured DTD bars which show considerable segregation from one end to the other, in agreement with published data on this design (13)(15)(16). The lowest solute content occurs at the top of the bar immediately below the riser. The "gauge"-analysis is slightly lower than that of the lower end of the bar.

The results from the G10 and C4 alloys show that in all test bar designs the composition of the bar, which is actually tested (gauge length), may differ considerably from that of the melt from which it is poured.

Similar surveys were carried out on one melt of SG70 (analyses for silicon and magnesium) and one melt of SC51 (analyses for silicon, magnesium and copper). The results show that all elements analysed segregated towards the centres of the bars, but that the amount of the segregation was small compared with magnesium in G10 and copper in C4. Thus in both aluminum-silicon alloys the difference between the end of the grip and the gauge length was of the order of 0.2% Si; about 0.02% Mg; and (in SC51) about 0.05% Cu. Since these differences are close to the experimental errors to be expected in the chemical analysis of these elements, an exact quantitative estimate of the segregation is difficult, but qualitatively the trend appears well-established.

The chemical analysis results for the supplementary SG70 and SC51 alloy melts are shown in Table 4 and were obtained on samples taken from the gauge lengths of broken Dow test bars.

DENSITY MEASUREMENTS

Density measurements were made on one bar from each of the cast-to-shape test bar moulds, including E-type, and on the DTD bars after machining. In all cases the density of the whole bar was determined. The results are summarized in Tables 5 to 8, which give mean values for each test bar type and mean values for the melts.

In general, the density results show trends which are consistent with changes in melt quality and composition. Thus, in the C4 alloy, the difference in quality (gas content) between melts 515 and 537 is shown by all test bar types. A similar trend is shown by SC51 melts 521 and 522.

In the C4 and G10 alloys variation in copper and magnesium contents has resulted in the expected variation in density (increase with the copper content in C4 and decrease with rising magnesium in G10).

The very low density of melt 511 may be noted. This melt was deliberately not degassed and showed a high level of porosity, but in spite of this there was no marked decrease in tensile properties (Figure 2).

In the G10 alloy melts there was a consistent tendency for the density to decrease with increasing as-cast bar diameter. Thus the German test bars (reduced section 12 mm diameter) tended to give the highest density results while the E-type test bars (15.8 mm as-cast diameter) tended to give the lowest density values.

A similar but much less marked or consistent trend was shown in the C4 alloys.

Presumably this tendency is due to reduced soundness in the larger bars, possibly owing to lower riser/bar volume ratios resulting in lower temperature gradients and less efficient feeding.

This trend is not reflected in the tensile test results and this may be because the influence of the grip sections of the specimens (which were included in the density measurements) has confused any effects which occurred in the reduced sections of the test bars. (Experience shows that the porosity distribution is often different between the grip sections and the gauge length.)

The density results from the supplementary tests are shown in Tables 9 and 10. In almost every case the quality differences within pairs of melts are shown clearly. There is a trend for the CSA and DTD bars to have lower densities than the other test bar types.

TENSILE TEST RESULTS

Since the gauge length on which the percentage elongation is measured is not yet internationally standardized, some effort was made to obtain elongation values based on 3.5 D (British), 4 D (North American) and 5 D (decimal). However, owing to many breaks occurring between gauge marks and various other difficulties (e.g., the British standard bar is too short to use as a 5 D gauge length), this was abandoned and elongations are reported for 4 D only. Yield strength values are reported for 0.2% offset. Some work on the relationships between the various elongation values and between the 0.1% (British) and 0.2% yield strengths has been reported separately (3).

The tensile test results are summarized in Figures 2 to 9. In almost all cases the average values, from which these charts were made, were calculated using all of the experimental results. The results of only a very few bars (less than 1%) were rejected because they were very much higher or lower than the mean values owing either to extremely severe flaws or to errors in testing. In general, however, the results from bars

containing flaws were included, even though some reduction in properties apparently resulted from the imperfections.

At the left hand end of Figures 2-9 the unweighted means of the means are plotted. (These are calculated by simply adding the means of each test bar type and dividing by the number of test bar types.) It was thought that, in the absence of any other independent measure of the tensile properties of melts, the use of the "melt means" would provide some indication of melt tendency.

Al-10% Mg (G10) Alloy Results

Although the Al-10% Mg alloy is not as widely used as some other aluminum-base alloys, its inclusion in the present work was felt to be justified, as it is quite sensitive to melt variables and represents a class of high-quality alloys in which the control of melt quality by means of test bars is particularly important.

Using G10 alloy the various test bar designs were compared on the basis of their sensitivity to variations in the quality or composition of the melts.

Reduction in melt quality was obtained either by raising the temperature of the melt to 800°C (1470°F) (melts 520 and 534), or by not degassing (melt 511). Figure 2 illustrates the effect of melt quality in high purity melts as shown by the different bars. High melt temperature has been shown to result in a decrease in quality ⁽²⁾ although the effect is more marked in lower purity alloys. The lower quality is not entirely due to gas pick-up (as shown by density - see Table 5), nor to grain coarsening, loss of magnesium, increased iron content, or a combination of these. However, whatever the cause, in the present case there seems to be little doubt that the quality of melt 520 was lower than that of melt 510. The only test bar type which did not respond to this difference in quality was the French. (The yield strength results are not thought to be very closely related to melt quality in these melts.)

Density measurements (see Table 5) showed that the bars cast from melt 511 (which was not degassed) were quite porous, but this did not result in a very marked decrease in tensile properties. Only the German test bar results (elongation) failed to show some decrease compared with those of melt 510. The difference in quality between melts 520 and 511, as shown by tensile properties, is probably not significant since there is no consistent trend shown by the various bars.

Figure 3 shows the effect of a marked decrease in quality on commercial purity (pre-alloyed ingot) melts caused by raising the temperature to 800°C (1470°F). In this case all the test bars have shown the

difference in quality satisfactorily. The test may have given more useful results if the quality difference had been less.

Figure 4 illustrates the effect of varying purity as shown by the tensile properties of the various test bars. All the test bars show the same trend, with the exception of the yield strength of the German and the CSA bars in melts 507 and 541. The French and German bars were slightly less sensitive to the difference between melts 510 and 507.

The yield strength of the Al-10% Mg alloy increases with magnesium content⁽¹⁷⁾. The series of melts (545, 508, 543, 510 and 509) shown in Figure 5 illustrates this and all test bar types show the same trend. In the case of the British bars the yield strengths of the high magnesium melts are somewhat higher than those of the other test bar types, owing to natural ageing which occurred between heat treatment and tensile testing (about forty days in each case).

In general the ultimate tensile strength results follow the same trend as the yield strengths; slight deviations from this trend occur in the German and AFS bars. However, in the CSA bar the deviation is quite marked in melts 508 and 543, and this cannot be accounted for from the operational data available.

There is a fairly consistent trend for the elongation of the highest magnesium content melt (509) to be lower than the general level. The French, CSA and German bars did not reflect this tendency, which is in agreement with published data on these alloys⁽¹⁷⁾.

Al-4% Cu (C4) Alloy Results

The effect of varying the copper content of the C4 alloy as reflected in the tensile properties of the various test bar types is shown in Figure 6. These melts were made up using 99.75% Al and Al-Si, Al-Cu and Al-Ti master alloys. The yield strength shows a steady increase up to 5.4% Cu which is in approximate agreement with published data⁽¹⁸⁾, although the level of melt 517 is higher than is indicated by the chemical analysis. The ultimate tensile strength results increase with copper content at a slower rate than the yield strength results and reach a maximum at between 4.7 and 5.4% Cu, above which there is a decrease; this is presumably caused by increased brittleness at the higher copper levels. The elongation results decrease with increasing copper.

The AFS, CSA and British bars are somewhat less consistent in showing these trends than the other designs. For example, the AFS and CSA bars gave higher elongation results for melt 544 than for melt 518.

The general levels of results from the Dow and French bars were lower than those for other designs. Although these bars show the trends described quite consistently, the properties are in some cases below "typical" values given for the alloy in North American practice.

Figure 7 illustrates the effect of gas content on pre-alloyed ingot melts. Reduced-pressure gas test samples and density measurements (see Table 6) indicated that there was a real difference in quality between the two melts (melt 515 was degassed, melt 537 was not) and this difference is shown in varying degrees by the ultimate tensile strength and elongation results. The AFS, CSA, German and British designs all show marked sensitivity to the difference in melt quality. Only the French, and, to some extent, the Dow bars failed to show this difference in quality. The "Student's t" test for significance of differences between means was applied to the pairs of results and these differences were found to be significant at the 0.005 level or lower, for these four designs. The difference in the case of the Dow bar ultimate tensile results was significant at about the 0.05 level, but for the French bar the difference was not significant. Thus on the basis of the limited data available, the French design, and to some extent the Dow bar, seem to be insensitive to the melt quality change studied (i.e., gassiness).

It is of interest that the difference in mean density between the melts within each pair is of the same order for all test bar designs (see Table 6). It therefore appears that the higher gas content of the poor melt affected the soundness of all the bars, but that in the case of the French bars this did not lower the properties to a significant extent. Presumably some other factor in the design of these bars masked the effect of gas content.

Again the general level of properties in the French and Dow designs is lower than that in the other bars.

Al-7% Si-0.3% Mg (SG70) Alloy Results

Figure 8 shows the effect of changes in magnesium content on the properties of SG70 alloy, prepared from 99.75% aluminum, Al-Si and Al-Ti master alloys, and pure magnesium. All the bars reflected these changes with similar sensitivity. The levels of the properties of the British, and to some extent the French and Dow bars, were below the North American "typical" values for the alloy.

Al-5% Si-1% Cu-0.5% Mg (SC51) Alloy Results

Figure 9 shows the effect of variation in melt quality (gas content - melts 521 and 522) and chemical composition (silicon, copper and magnesium contents - melts 521, 523 and 525) on the tensile properties of the various test bars.

The Dow, French, AFS and CSA bars appear to reflect the melt quality variation between melts 521 and 522 in the ultimate tensile results. The German design does not show the difference between the two melts in the ultimate tensile strength values, and the British bars show no differences in any of the tensile properties.

The chemical composition variations between melts 521, 523 and 525 (see Table 1) are reflected fairly consistently by the tensile properties of the various bars. The anomalous ultimate tensile strength results of the German and British bars, and those of yield strength for the CSA and British, may be noted. The elongation of this alloy is low and it is only in the German and, to some extent, the CSA and AFS bars that useful conclusions could be drawn from variations in this property.

Variability of Tensile Results

As mentioned earlier, it is essential that a test bar design should give reproducible results on melts of the same quality, composition, etc. This includes reproducibility of results both "within-melts" and "between-melts". In both cases, but especially in the latter, a satisfactory estimate of these characteristics is possible only by statistical analysis of the results from a large number of melts; this is rather difficult to obtain in a laboratory-scale investigation.

However, some attempt was made to estimate the within-melt variability of the tensile results of each test bar design. The test bar types in each melt were ranked in order of increasing variability (using the coefficient of variation). The rank numbers of each test bar design were then summed for all the melts in each alloy. Correlation tests showed that the resulting combined rankings were only significant in the cases of the ultimate tensile strength and elongation results for G10 alloy. These rankings are given in Table 11, which shows that in this case the French bars had the lowest and the German bars the highest within-melt variability. It will be seen that both the ultimate tensile strength and the elongation rankings are almost the same and, as each was significant at the 0.01 level, it appears that the order of within-melt variability given is of some significance.

SUPPLEMENTARY MELTS OF SG70 AND SC51 ALLOYS

When the results of the original program of work were assessed, it became obvious that only a limited estimate of the relative variabilities of the various test bar designs could be made. Two further series of melts were therefore made and, since the bulk of the original program of work had been done on G10 and C4 alloys (both of which have a rather limited use in the foundry industry), the more widely used alloys SG70 and SC51 were selected.

Experimental Procedure

The metal used was commercial pre-alloyed ingot. One batch of ingot of each composition was used, in order to provide a constant source of material and thus minimize variations in the composition of the melts.

For each alloy the experimental design employed was as follows: Ten 90-lb melts were made, each melt containing enough metal to pour two of each of the four-bar moulds, three of each of the two-bar moulds, and four DTD bars. The ten melts were divided into five pairs; in each pair one melt (called "good" melt) was degassed (nitrogen and chlorine flushing) and poured at 700°C (1290°F), while the other (called "poor" melt) was not degassed and was poured at 800°C (1470°F). Each pair of melts was completed in one working day, the order of processing "good" and "poor" melts being alternated from day to day. The object of these precautions was to minimize the effect of uncontrolled variables on the difference between "good" and "poor" melts within each pair.

The order of pouring the test bar moulds within each melt was designed with the following points in mind:

- (a) the moulds of each type were distributed as uniformly as possible through the melt and, in particular, no two moulds of the same type were poured consecutively,
- (b) the order of pouring was the same for the two melts within a pair and,
- (c) the order of pouring was varied from day to day so that, for example, the same type of mould was not the first to be poured in each melt. (This could have been a weakness of the earlier experiments.)

All the bars from each pair of melts were heat-treated together in order to minimize the effect of possible heat-treatment variations.

Results

As mentioned earlier, segregation of silicon, magnesium and copper in these alloys is not very great and does not vary significantly between the various test bar types investigated. For the present program, therefore, analysis of samples from the gauge lengths of Dow bars were taken as representative of the melt analyses and are given in Table 4.

The mean tensile results are shown in Tables 12 and 13. It will be seen that in neither alloy were uniform results obtained between replicates. It is not clear what caused these variations, because every effort was made to standardize the source of material, melting conditions, heat treatment, etc.; whatever the cause*, it made it impossible to estimate the "between-melt" variabilities of the various test bar types.

The average "within-melt" and "within-mould" variabilities were calculated for the "good" and "poor" melts of each alloy. The results are shown in Tables 14 and 15 in terms of the coefficient of variation (i.e., standard deviation expressed as a percentage of the mean). It should be emphasized that these averages were calculated from melt variances which themselves had a high variability. More reliable results could be expected if a larger number of melts had been available. No marked trends are shown. In the SG70 results (Table 14) there is some tendency for the variabilities of the bars from "poor" melts to be higher than those from "good" melts and for the "within-melt" variability to be higher than the "within-mould" variability, but there are several exceptions to these trends. Multiple ranking (similar to that shown in Table 11 for alloy G10) failed to show any significant correlation between melts in either of the two alloys.

Tables 16 and 17 summarize the tensile results (ultimate tensile strength and elongation) to illustrate the relative sensitivities of the various test bar types to variation in melt quality. The "mean totals" were obtained by summing the mean results (Tables 12 and 13) for "good" and "poor" melts respectively. Analysis of variance of the results showed that the differences between the "mean totals" for "good" and "poor" melts varied significantly with test bar type (test bar type x quality interaction)

*Some of the variation in properties between nominally identical melts may have been due to varying time intervals (at room temperature) between solution treatment and artificial ageing. This factor was not controlled during the processing of the bars although some investigators (19) (20) indicated that it can have a pronounced effect on tensile properties of these alloys.

for both ultimate tensile strength and elongation in the SC51 alloy (0.01 level of significance), and for the ultimate tensile strength in the SG70 (0.05 level of significance). Although the elongation results for SG70 alloy do not show a significant interaction between test bar type and quality, they are included in Table 16 because of their good correlation with the ultimate tensile strength results.

In both alloys, the French test bar was comparatively insensitive to melt quality changes. This confirms the earlier results obtained on C4 alloy. The lack of sensitivity to quality changes in SC51 alloy, shown by the DTD bar is very marked and this also confirms earlier results. In both alloys the German test bar was the most sensitive to melt quality changes; this is somewhat contrary to the earlier findings on the SC51 alloy. The AFS test bar was quite sensitive in SC51 alloy, but rather insensitive in the SG70 alloy.

DISCUSSION

The various test bar designs investigated will now be discussed individually with respect to their behavior in the tests described above and to the factors mentioned in the Introduction.

Dow Test Bars

The Dow test bar is easy to mould and cast although the sprue is difficult to keep full during pouring when, as in the present work, it is used without a screen at the sprue base. However, this does not appear to have an adverse effect on the properties of the test bars. The weight of one casting (four bars with sprue, gates and risers) is approximately 5.6 lb in SG 70 alloy. Thus, from the point of view of weight of metal cast per test bar (see Table 18), the Dow and the French bar designs are the most efficient.

The Dow bar, in the present work, was generally sensitive to significant changes in melt quality and composition. However, one possible disadvantage was the somewhat low level of tensile results obtained with the C4 alloy. In some cases the values generally accepted as typical for this alloy were not attained and in some of the melts the elongation results were below specification minimum, although other test bar designs gave satisfactory results. It should be mentioned that the Dow bar casting was designed for magnesium alloys and may, therefore, need some changes in sprue or gating to be entirely satisfactory for aluminum alloys.

French Test Bars

No difficulty was experienced in moulding the French test bar mould and pouring was rather easier than with the Dow mould. As shown in Table 18 the casting efficiency in terms of the weight of metal required for each test bar produced was as good as that of the Dow bar. (This weight was obtained on a casting having risers with dimensions shown in the specification and not those obtained when a 4 in. cope height was used.)

In responding to melt quality and composition variables the French bar gave rather inconsistent and misleading results in several tests. In particular, it failed to show the difference in melt quality between gassy and degassed C4 alloy melts (see Figure 7) and was comparatively insensitive to the melt quality changes in the supplementary SG70 and SC51 alloy melts (Figures 10 and 11).

In general, the level of results obtained was lower than in the other test bars investigated and, although this in itself is not important, in some cases the properties were below minimum levels for the alloys concerned.

German Test Bars

The German test bar mould was somewhat complicated by the use of a baked core-sand sprue, but otherwise no difficulty was experienced. The mould was easy to cast, the sprue being severely choked so that it was easy to fill and keep full.

In casting efficiency the German bar was lower than that of the Dow and the French bars (see Table 18).

This test bar gave somewhat inconsistent results in some of the G10 tests, but in the SG70 and SC51 supplementary series it proved the most sensitive to melt quality changes.

AFS Test Bars

The AFS test bar gave no difficulties in moulding or pouring. Its casting efficiency was similar to that of the German bar (see Table 18). It should be mentioned that several misruns occurred during attempts to cast C4 alloy bars in these moulds, but this difficulty was subsequently avoided by raising the pouring temperature. However, in several melts of C4 alloy very low properties in some test bars suggested that incipient misruns may have been present.

The AFS bar showed a few anomalous effects in the G10 and the C4 alloy tests, but in general was satisfactory in responding to melt quality changes.

In the supplementary tests this bar was very sensitive to quality changes in the SC51 alloy but comparatively insensitive in the SG70 alloy tests.

CSA Test Bars

The CSA test bar design was easy to mould but the position of the sprue made it rather difficult to pour in a tranquil manner. As each mould contained only two bars, more moulds had to be made to obtain the necessary number of bars. Also, the casting efficiency was somewhat lower than for the four-bar cast-to-shape moulds.

This design gave some inconsistent results (see Figures 5, 6 and 9), but in general was reasonably sensitive to significant melt quality changes.

British E-type Test Bars

The E-type test bar castings were easy to mould, but somewhat difficult to pour because of the sprue position. The casting efficiency (see Table 18) was rather low, owing in part to the machining allowance on the test bars.

In all tests the bar gave quite consistent results although, as mentioned earlier, the level of results was affected by room temperature ageing between heat treatment and testing.

British DTD Test Bars

The DTD bar was simplest of all to mould and required very little sand and special equipment. In the present work no particular care was taken in pouring the DTD bars, although the moulds were tilted to an angle of about 30 deg from the vertical before pouring and raised to vertical as the bar was filled. Pouring took only a few seconds. British practice suggests that better results can be obtained when the metal is poured very slowly; it is also known that specially skilled operators are used to produce bars with consistently high properties.

The casting efficiency of the design (see Table 18) is reasonably good.

The DTD bar gave generally consistent results in the C4 and SG70 alloys, although in supplementary tests it was rather insensitive to quality changes in SG70 (see Table 12). However, it was in all cases comparatively insensitive to melt quality changes in the SC51 alloy (see Table 13).

CONCLUSIONS

Within the somewhat limited scope of the present investigation it has been shown that, although most of the test bar types examined were reasonably sensitive to the quality and composition changes studied, some of the designs (e.g., the French) were less satisfactory than others, particularly for certain alloys. Thus, the French and Dow bars were less suitable than others for C4 alloy, and the DTD bar was insensitive to melt changes in the CS51 alloy.

It would be very difficult, however, to rank the test bar types in order of suitability. No one design performed completely satisfactorily in all tests, but the German and AFS designs probably showed the least number of serious deficiencies. It is possible that design changes in the AFS pattern might improve its performance, for example making the metal distribution more uniform, and thus produce a very satisfactory test bar casting.

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TABLE 1

Chemical Analysis Results

| Alloy | Melt No. | Cu % | Mg % | Si % | Fe % | Ti % |
|-------|----------|------|------|------|------|------|
| C4 | 515 * | 4.3 | - | 0.83 | 0.32 | 0.12 |
| | 517 | 5.4 | - | 0.64 | 0.18 | 0.09 |
| | 518 | 3.8 | - | 0.63 | 0.16 | 0.09 |
| | 537 * | 4.3 | - | 0.82 | 0.36 | 0.11 |
| | 538 | 4.7 | - | 0.61 | 0.21 | 0.09 |
| | 539 | 5.6 | - | 0.65 | 0.24 | 0.09 |
| | 544 | 4.1 | - | 0.64 | 0.21 | 0.09 |
| G10 | 507 * | - | 10.8 | 0.10 | 0.09 | - |
| | 508 | - | 9.5 | 0.01 | 0.01 | 0.07 |
| | 509 | - | 11.7 | 0.02 | 0.02 | 0.07 |
| | 510 | - | 10.6 | 0.01 | 0.02 | 0.07 |
| | 511 | - | 10.5 | 0.02 | 0.03 | 0.07 |
| | 520 | - | 10.5 | 0.01 | 0.15 | 0.06 |
| | 534 * | - | 10.5 | 0.10 | 0.49 | - |
| | 541 | - | 10.5 | 0.08 | 0.27 | 0.05 |
| | 543 | - | 9.9 | 0.02 | 0.02 | 0.07 |
| | 545 | - | 8.7 | 0.02 | 0.01 | 0.08 |
| SG70 | 512 | - | 0.28 | 6.8 | 0.20 | 0.09 |
| | 513 | - | 0.28 | 6.6 | 0.20 | 0.09 |
| | 514 | - | 0.43 | 6.9 | 0.19 | 0.10 |
| | 542 | - | 0.22 | 6.6 | 0.18 | 0.10 |
| SC51 | 521 * | 1.4 | 0.54 | 5.1 | 0.59 | 0.09 |
| | 522 * | 1.3 | 0.51 | 5.1 | 0.56 | 0.11 |
| | 523 | 1.3 | 0.36 | 4.7 | 0.39 | 0.05 |
| | 525 | 1.1 | 0.56 | 5.8 | 0.39 | 0.01 |

*Made from commercial alloy ingot.

TABLE 2

Segregation of Mg in G10 Alloy Test Bars

| MELT NO. | | 545 | | 508 | | 543 | | 510 | | 509 | |
|---------------------------------|------------|--------------|-------|--------------|-------|---------------|-------|----------------|-------|----------------|-------|
| BAR | SAMPLE | % Mg | Diff. | % Mg | Diff. | % Mg | Diff. | % Mg | Diff. | % Mg | Diff. |
| D | Gauge Grip | 9.13 8.47 | 0.66 | 9.78 9.36 | 0.42 | 10.17 9.41 | 0.76 | 10.92 10.21 | 0.71 | 11.68 11.28 | 0.40 |
| F | Gauge Grip | 9.09 8.42 | 0.67 | 9.80 9.02 | 0.78 | 10.25 9.07 | 1.18 | 10.86 10.49 | 0.37 | 11.72 11.10 | 0.60 |
| G | Gauge Grip | 8.97 8.26 | 0.71 | 9.58 8.88 | 0.70 | 10.22 9.92 | 0.30 | 10.91 10.50 | 0.41 | 11.53 10.93 | 0.60 |
| A | Gauge Grip | 9.06 8.14 | 0.92 | 9.97 8.83 | 1.14 | 10.37 9.00 | 1.37 | 10.93 10.02 | 0.91 | 11.76 10.59 | 1.17 |
| C | Gauge Grip | 9.03 8.14 | 0.89 | 9.87 9.50 | 0.37 | 10.12 9.42 | 0.70 | 10.83 10.43 | 0.40 | 11.80 11.34 | 0.46 |
| B (E) | Gauge Grip | 9.10 8.52 | 0.58 | 9.90 9.25 | 0.65 | 10.36 9.67 | 0.69 | 11.17 10.38 | 0.79 | 11.85 11.18 | 0.67 |
| "MELT" Values (From Table 1) | | 8.7 | | 9.5 | | 9.9 | | 10.6 | | 11.7 | |

TABLE 3

Segregation of Cu in C4 Alloy Test Bars

| MELT NO. | | 518 | | 544 | | 538 | | 517 | | 539 | |
|---------------------------------|---------------------------|----------------------|---------------|----------------------|---------------|----------------------|---------------|----------------------|---------------|----------------------|---------------|
| BAR | SAMPLE | % Cu | Diff. | % Cu | Diff. | % Cu | Diff. | % Cu | Diff. | % Cu | Diff. |
| D | Gauge Grip | 3.93 3.56 | 0.37 | 4.43 4.08 | 0.35 | 4.85 4.30 | 0.55 | 5.58 5.18 | 0.40 | 5.77 5.35 | 0.42 |
| F | Gauge Grip | 3.88 3.83 | 0.05 | 4.32 3.90 | 0.42 | 4.85 4.33 | 0.50 | 5.57 5.14 | 0.43 | 5.73 5.46 | 0.27 |
| G | Gauge Grip | 3.85 3.48 | 0.37 | 4.51 3.94 | 0.57 | 4.94 4.34 | 0.60 | 5.62 5.14 | 0.48 | 5.70 5.32 | 0.38 |
| A | Gauge Grip | 3.89 3.34 | 0.55 | 4.45 3.92 | 0.53 | 4.87 3.90 | 0.97 | 5.53 5.10 | 0.43 | 5.68 5.04 | 0.64 |
| C | Gauge Grip | 3.90 3.60 | 0.30 | 4.43 4.12 | 0.31 | 4.90 4.22 | 0.68 | 5.53 5.26 | 0.27 | 5.80 5.31 | 0.49 |
| B (DTD) | Gauge Grip 1 Grip 2 | 3.76 3.00 3.89 | 0.76 -0.13 | 4.20 3.35 4.35 | 0.85 -0.15 | 4.52 3.88 4.67 | 0.64 -0.15 | 5.26 5.39 4.43 | -0.13 0.83 | 5.48 5.52 4.53 | -0.04 0.85 |
| "MELT" Values (From Table 1) | | 3.8 | | 4.1 | | 4.7 | | 5.4 | | 5.6 | |

TABLE 4

Chemical Analysis Results for Supplementary
SG70 and SC51 Alloy Melts

| Alloy | Melt No. | Cu % | Mg % | Si % | Fe %* | Ti %* |
|-------|----------|------|------|------|-------|-------|
| SG70 | 547 | - | 0.36 | 7.29 | 0.09 | 0.12 |
| | 548 | - | 0.35 | 7.30 | 0.08 | 0.18 |
| | 549 | - | 0.31 | 7.28 | 0.12 | 0.17 |
| | 550 | - | 0.33 | 7.39 | 0.11 | 0.17 |
| | 551 | - | 0.33 | 7.34 | 0.10 | 0.19 |
| | 552 | - | 0.33 | 7.15 | 0.10 | 0.20 |
| | 553 | - | 0.29 | 7.29 | 0.10 | 0.19 |
| | 554 | - | 0.36 | 7.29 | 0.09 | 0.18 |
| | 555 | - | 0.35 | 7.18 | 0.09 | 0.17 |
| | 556 | - | 0.35 | 7.32 | 0.08 | 0.16 |
| SC51 | 557 | 1.26 | 0.50 | 5.37 | 0.11 | 0.16 |
| | 558 | 1.29 | 0.51 | 5.40 | 0.14 | 0.15 |
| | 559 | 1.26 | 0.53 | 5.32 | 0.12 | 0.14 |
| | 560 | 1.27 | 0.52 | 5.27 | 0.13 | 0.15 |
| | 561 | 1.23 | 0.51 | 5.32 | 0.14 | 0.11 |
| | 562 | 1.30 | 0.51 | 5.24 | 0.12 | 0.16 |
| | 563 | 1.30 | 0.52 | 5.31 | 0.11 | 0.13 |
| | 564 | 1.30 | 0.54 | 5.36 | 0.11 | 0.13 |
| | 565 | 1.30 | 0.54 | 5.38 | 0.12 | 0.12 |
| | 566 | 1.29 | 0.52 | 5.31 | 0.12 | 0.15 |

*These results obtained by Spectrographic Analysis.

TABLE 5

Density Results for G10 Alloy Test Bars

| Melt No. | Dow | French | German | AFS | CSA | British (E-type) | Melt Average |
|----------|-------|--------|--------|-------|-------|------------------|--------------|
| 507 | 2.565 | 2.558 | 2.567 | 2.565 | 2.567 | 2.561 | 2.564 |
| 534 | 2.560 | 2.554 | 2.562 | 2.560 | 2.560 | 2.555 | 2.559 |
| 545 | 2.586 | 2.579 | 2.588 | 2.586 | 2.584 | 2.580 | 2.584 |
| 508 | 2.576 | 2.567 | 2.576 | 2.576 | 2.575 | 2.568 | 2.573 |
| 543 | 2.576 | 2.566 | 2.576 | 2.577 | 2.573 | 2.570 | 2.573 |
| 510 | 2.565 | 2.557 | 2.566 | 2.566 | 2.566 | 2.560 | 2.563 |
| 509 | 2.558 | 2.551 | 2.559 | 2.558 | 2.559 | 2.547 | 2.555 |
| 511 | 2.522 | 2.513 | 2.531 | 2.524 | 2.523 | 2.508 | 2.520 |
| 520 | 2.570 | 2.561 | 2.569 | 2.569 | 2.569 | 2.561 | 2.567 |
| 541 | 2.571 | 2.562 | 2.571 | 2.569 | 2.570 | 2.566 | 2.568 |

TABLE 6

Density Results for C4 Alloy Test Bars

| Melt No. | Dow | French | German | AFS | CSA | British (DTD) | Melt Average |
|----------|-------|--------|--------|-------|-------|---------------|--------------|
| 515 | 2.781 | 2.775 | 2.790 | 2.784 | 2.784 | 2.777 | 2.782 |
| 537 | 2.759 | 2.757 | 2.768 | 2.761 | 2.757 | 2.751 | 2.759 |
| 518 | 2.759 | 2.754 | 2.760 | 2.758 | 2.754 | 2.751 | 2.756 |
| 544 | 2.781 | 2.778 | 2.782 | 2.784 | 2.780 | 2.776 | 2.780 |
| 538 | 2.790 | 2.784 | 2.789 | 2.789 | 2.786 | 2.781 | 2.787 |
| 517 | 2.809 | 2.807 | 2.807 | 2.807 | 2.804 | 2.798 | 2.805 |
| 539 | 2.815 | 2.813 | 2.812 | 2.812 | 2.808 | 2.806 | 2.811 |

TABLE 7

Density Results for SG70 Alloy Test Bars

| Melt No. | Dow | French | German | AFS | CSA | British (DTD) | Melt Average |
|----------|-------|--------|--------|-------|-------|---------------|--------------|
| 512 | 2.678 | 2.678 | 2.676 | 2.676 | 2.674 | - | 2.676 |
| 513 | 2.677 | 2.678 | 2.675 | 2.677 | 2.674 | 2.674 | 2.676 |
| 514 | 2.677 | 2.676 | 2.676 | 2.676 | 2.674 | 2.674 | 2.676 |
| 542 | 2.683 | 2.681 | 2.680 | 2.680 | 2.676 | 2.679 | 2.680 |

TABLE 8

Density Results for SC51 Alloy Test Bars

| Melt No. | Dow | French | German | AFS | CSA | British (DTD) | Melt Average |
|----------|-------|--------|--------|-------|-------|---------------|--------------|
| 521 | 2.695 | 2.690 | 2.695 | 2.695 | 2.691 | 2.688 | 2.692 |
| 522 | 2.688 | 2.685 | 2.688 | 2.683 | 2.680 | 2.684 | 2.685 |
| 523 | 2.696 | 2.695 | 2.700 | 2.696 | 2.693 | 2.691 | 2.695 |
| 525 | 2.693 | 2.686 | 2.694 | 2.692 | 2.685 | 2.689 | 2.690 |

TABLE 9

Density Results for Supplementary Melts of SG70 Alloy

| Melt No. | Dow | French | German | AFS | CSA | British (DTD) | Melt Average |
|----------|-------|--------|--------|-------|-------|---------------|--------------|
| 547 | 2.674 | 2.673 | 2.673 | 2.673 | 2.669 | 2.662 | 2.671 |
| 548 | 2.660 | 2.663 | 2.665 | 2.664 | 2.653 | 2.650 | 2.659 |
| 550 | 2.676 | 2.674 | 2.674 | 2.674 | 2.669 | 2.672 | 2.673 |
| 549 | 2.664 | 2.663 | 2.665 | 2.665 | 2.650 | 2.661 | 2.661 |
| 551 | 2.676 | 2.674 | 2.674 | 2.675 | 2.669 | 2.670 | 2.673 |
| 552 | 2.657 | 2.657 | 2.663 | 2.657 | 2.647 | 2.652 | 2.656 |
| 554 | 2.674 | 2.674 | 2.674 | 2.674 | 2.668 | 2.672 | 2.673 |
| 553 | 2.655 | 2.660 | 2.661 | 2.660 | 2.647 | 2.657 | 2.657 |
| 555 | 2.674 | 2.672 | 2.672 | 2.673 | 2.670 | 2.671 | 2.672 |
| 556 | 2.661 | 2.667 | 2.657 | 2.663 | 2.658 | 2.658 | 2.661 |

Figures are means of two determinations except -

CSA - means of three determinations

DTD - one determination only.

Note: Melts No. 547 550, 551, 554 and 555 were degassed and poured at a low temperature.

Melts No. 548, 549, 552, 553 and 556 were not degassed and poured at a higher temperature.

TABLE 10

Density Results for Supplementary Melts of SC51 Alloy

| Melt No. | Dow | French | German | AFS | CSA | British (DTD) | Melt Average |
|----------|-------|--------|--------|-------|-------|---------------|--------------|
| 557 | 2.702 | 2.703 | 2.700 | 2.703 | 2.691 | 2.698 | 2.700 |
| 558 | 2.681 | 2.688 | 2.684 | 2.682 | 2.672 | 2.678 | 2.681 |
| 560 | 2.703 | 2.704 | 2.703 | 2.704 | 2.695 | 2.699 | 2.701 |
| 559 | 2.685 | 2.685 | 2.682 | 2.684 | 2.673 | 2.680 | 2.682 |
| 561 | 2.703 | 2.702 | 2.702 | 2.702 | 2.696 | 2.694 | 2.700 |
| 562 | 2.682 | 2.679 | 2.682 | 2.680 | 2.670 | 2.700 | 2.682 |
| 564 | 2.701 | 2.704 | 2.703 | 2.704 | 2.695 | 2.698 | 2.701 |
| 563 | 2.684 | 2.685 | 2.684 | 2.684 | 2.673 | 2.679 | 2.682 |
| 565 | 2.704 | 2.700 | 2.702 | 2.701 | 2.695 | 2.696 | 2.700 |
| 566 | 2.681 | 2.682 | 2.676 | 2.681 | 2.672 | 2.675 | 2.678 |

Figures are means of two determinations except -

CSA - means of three determinations

DTD - one determination only.

Note: Melts No. 557, 560, 561, 564 and 565 were degassed and poured at a low temperature.

Melts No. 558, 559, 562, 563 and 566 were not degassed and poured at a higher temperature.

TABLE 11

Rank Totals for 10 Melts of G10 Alloy to Show the Relative
"Within-Melt" Variability of the Various Test Bar Designs

(Original Rankings Based on Coefficients of Variation)

| Test Bar Type | Rank Totals (10 melts) | |
|------------------|------------------------------|------------|
| | Ultimate Tensile Strength | Elongation |
| French | 25 | 23 |
| British E-type | 29 | 33 |
| AFS | 31 | 29 |
| CSA | 32 | 31 |
| Dow | 40 | 44 |
| German | 53 | 50 |

TABLE 12

Mean Tensile Test Results for SG70 Alloy

| | Degassed 547 | Gassy 548 | Degassed 550 | Gassy 549 | Degassed 551 | Gassy 552 | Degassed 554 | Gassy 553 | Degassed 555 | Gassy 556 |
|---------|-----------------|--------------|-----------------|--------------|-----------------|--------------|-----------------|--------------|-----------------|--------------|
| Dow | 34.5 | 33.4 | 36.8 | 34.8 | 36.2 | 32.2 | 37.2 | 36.2 | 34.9 | 35.0 |
| French | 32.1 | 32.6 | 35.6 | 34.4 | 34.8 | 33.1 | 35.8 | 35.6 | 33.7 | 33.2 |
| German | 33.3 | 32.8 | 37.1 | 33.5 | 36.0 | 32.0 | 38.9 | 36.0 | 34.5 | 30.7 |
| AFS | 34.3 | 33.4 | 37.0 | 34.8 | 34.6 | 33.7 | 37.9 | 36.3 | 34.1 | 34.3 |
| CSA | 33.0 | 32.2 | 36.5 | 32.4 | 36.1 | 31.8 | 37.9 | 34.9 | 34.1 | 33.1 |
| British | 33.0 | 32.4 | 33.7 | 30.5 | 31.7 | 28.9 | 34.9 | 33.0 | 32.0 | 32.6 |
| Dow | 23.5 | 23.8 | 26.8 | 25.4 | 25.6 | 23.5 | 30.0 | 29.6 | 25.0 | 26.0 |
| French | 23.6 | 23.8 | 26.7 | 25.4 | 24.1 | 23.7 | 29.6 | 29.8 | 25.1 | 25.0 |
| German | 24.1 | 23.7 | 27.0 | 24.9 | 24.5 | 23.1 | 29.6 | 28.8 | 24.1 | 24.7 |
| AFS | 24.4 | 23.7 | 26.4 | 26.1 | 23.6 | 23.6 | 30.2 | 29.3 | 25.2 | 25.7 |
| CSA | 23.6 | 22.8 | 26.2 | 24.9 | 24.5 | 23.4 | 30.0 | 28.5 | 25.1 | 25.7 |
| British | 25.0 | 25.0 | 26.6 | 26.2 | 24.2 | 24.0 | 30.6 | 29.2 | 25.6 | 26.9 |
| Dow | 5.0 | 4.0 | 4.5 | 4.0 | 4.5 | 3.0 | 3.5 | 2.0 | 4.5 | 4.0 |
| French | 4.0 | 3.0 | 3.5 | 3.0 | 5.0 | 4.0 | 2.0 | 3.0 | 4.0 | 3.0 |
| German | 4.0 | 3.5 | 4.0 | 3.0 | 6.0 | 4.0 | 4.5 | 2.5 | 3.5 | 2.5 |
| AFS | 4.0 | 4.0 | 5.5 | 3.5 | 5.0 | 4.5 | 3.5 | 3.0 | 3.5 | 3.5 |
| CSA | 4.0 | 3.5 | 4.0 | 2.5 | 5.0 | 4.0 | 3.5 | 2.5 | 3.5 | 3.0 |
| British | 3.0 | 2.5 | 2.0 | 1.5 | 2.5 | 2.0 | 1.5 | 1.5 | 2.0 | 2.0 |

TABLE 13

Mean Tensile Test Results for SC51 Alloy

| | Degassed 557 | Gassy 558 | Degassed 560 | Gassy 559 | Degassed 561 | Gassy 562 | Degassed 564 | Gassy 563 | Degassed 565 | Gassy 566 |
|---------|-----------------|--------------|-----------------|--------------|-----------------|--------------|-----------------|--------------|-----------------|--------------|
| Dow | 39.2 | 36.2 | 39.3 | 35.0 | 39.0 | 35.8 | 37.8 | 34.8 | 38.9 | 36.5 |
| French | 37.1 | 34.1 | 38.3 | 34.3 | 36.9 | 35.8 | 37.2 | 34.7 | 38.3 | 35.7 |
| German | 41.4 | 35.3 | 40.0 | 33.8 | 38.7 | 36.1 | 38.2 | 36.0 | 41.1 | 35.1 |
| AFS | 39.8 | 36.9 | 41.0 | 35.5 | 41.5 | 37.1 | 40.7 | 35.7 | 41.6 | 36.6 |
| CSA | 38.3 | 35.4 | 39.1 | 34.0 | 38.7 | 36.1 | 37.4 | 32.3 | 39.7 | 34.3 |
| British | 34.4 | 34.0 | 35.1 | 33.1 | 35.2 | 33.3 | 34.8 | 33.8 | 36.7 | 33.9 |
| Dow | 27.8 | 28.2 | 28.9 | 27.1 | 31.4 | 29.6 | 28.1 | 27.6 | 30.5 | 29.7 |
| French | 27.9 | 27.8 | 28.3 | 26.8 | 29.8 | 29.5 | 28.0 | 28.5 | 30.4 | 29.7 |
| German | 28.4 | 28.5 | 29.3 | 26.9 | 30.2 | 29.4 | 28.7 | 27.8 | 30.0 | 28.8 |
| AFS | 27.9 | 28.5 | 29.1 | 27.1 | 31.5 | 30.2 | 29.6 | 27.4 | 30.6 | 29.6 |
| CSA | 28.2 | 27.8 | 29.4 | 26.7 | 30.3 | 28.7 | 29.2 | 26.9 | 31.0 | 28.3 |
| British | 28.3 | 28.0 | 28.9 | 27.4 | 29.7 | 27.8 | 27.8 | 28.0 | 30.4 | 28.7 |
| Dow | 4.0 | 3.0 | 4.0 | 2.5 | 2.5 | 2.0 | 3.0 | 3.0 | 2.5 | 2.5 |
| French | 2.0 | 2.0 | 3.5 | 2.0 | 3.0 | 2.0 | 2.5 | 2.5 | 3.0 | 2.5 |
| German | 4.5 | 2.5 | 3.5 | 2.5 | 2.5 | 2.5 | 2.5 | 3.5 | 3.5 | 2.5 |
| AFS | 4.0 | 2.5 | 5.0 | 3.0 | 4.5 | 2.0 | 3.5 | 2.5 | 4.5 | 2.0 |
| CSA | 3.0 | 2.5 | 3.5 | 2.5 | 3.0 | 2.0 | 3.0 | 2.0 | 3.5 | 2.0 |
| British | 2.0 | 2.5 | 2.5 | 2.5 | 1.5 | 2.0 | 3.0 | 2.5 | 2.5 | 2.5 |

TABLE 14

Within-Melt and Within-Mould Variabilities for SG70 Melts

| | | Dow Within- Melt Mould | | French Within- Melt Mould | | German Within- Melt Mould | | AFS Within- Melt Mould | | CSA Within- Melt Mould | | DTD Within- Melt Mould | |
|-----------------------------|----------|------------------------------|-----|---------------------------------|-----|---------------------------------|-----|------------------------------|-----|------------------------------|-----|------------------------------|---|
| Coeff. of Variation % | Degassed | 2.8 | 2.6 | 4.9 | 4.4 | 3.6 | 4.0 | 3.8 | 3.0 | 3.4 | 2.3 | 2.7 | - |
| | Gassy | 4.2 | 3.3 | 3.6 | 3.6 | 5.5 | 6.0 | 4.5 | 3.0 | 6.4 | 2.4 | 2.4 | - |

TABLE 15

Within-Melt and Within-Mould Variabilities for SC51 Melts

| | | Dow Within- Melt Mould | | French Within- Melt Mould | | German Within- Melt Mould | | AFS Within- Melt Mould | | CSA Within- Melt Mould | | DTD Within- Melt Mould | |
|-----------------------------|----------|------------------------------|-----|---------------------------------|-----|---------------------------------|-----|------------------------------|-----|------------------------------|-----|------------------------------|---|
| Coeff. of Variation % | Degassed | 3.9 | 3.9 | 3.9 | 3.2 | 5.1 | 4.8 | 2.6 | 2.7 | 4.8 | 4.7 | 4.1 | - |
| | Gassy | 4.1 | 3.6 | 4.0 | 4.0 | 3.5 | 3.2 | 2.6 | 2.7 | 4.9 | 4.7 | 3.0 | - |

TABLE 16

Sensitivity of Various Test Bar Types to
Melt Quality Variation in SG70 Alloy

| | Dow | | French | | German | | AFS | | CSA | | DTD | |
|------------------------|-------|------|--------|------|--------|------|-------|------|-------|------|-------|------|
| | UTS | E | UTS | E | UTS | E | UTS | E | UTS | E | UTS | E |
| Mean Totals { Degassed | 179.6 | 22.0 | 172.0 | 18.5 | 179.8 | 22.0 | 177.9 | 21.5 | 177.6 | 20.0 | 165.3 | 11.0 |
| (5 Melts Each) { Gassy | 171.6 | 17.0 | 168.9 | 16.0 | 165.0 | 15.5 | 172.5 | 18.5 | 164.4 | 15.5 | 157.4 | 9.5 |
| Differences | 8.0 | 5.0 | 3.1 | 2.5 | 14.8 | 6.5 | 5.4 | 3.0 | 13.2 | 4.5 | 7.9 | 1.5 |
| Order* | 3 | 2 | 6 | 5 | 1 | 1 | 5 | 4 | 2 | 3 | 4 | 6 |
| | Dow | | French | | German | | AFS | | CSA | | DTD | |

*1 most sensitive, 6 least sensitive.

TABLE 17

Sensitivity of Various Test Bar Types to
Melt Quality Variation in SC51 Alloy

| | Dow | | French | | German | | AFS | | CSA | | DTD | |
|------------------------|-------|------|--------|------|--------|------|-------|------|-------|------|-------|------|
| | UTS | E | UTS | E | UTS | E | UTS | E | UTS | E | UTS | E |
| Mean Totals { Degassed | 194.2 | 16.0 | 187.8 | 14.0 | 199.4 | 16.5 | 204.6 | 21.5 | 193.2 | 16.0 | 176.2 | 11.5 |
| (5 Melts Each) { Gassy | 178.3 | 13.0 | 174.6 | 11.0 | 176.3 | 13.5 | 181.8 | 12.0 | 172.1 | 11.0 | 168.1 | 12.0 |
| Differences | 15.9 | 3.0 | 13.2 | 3.0 | 23.1 | 3.0 | 22.8 | 9.5 | 21.1 | 5.0 | 8.1 | -0.5 |
| Order* | 4 | 4 | 5 | 4 | 1 | 4 | 2 | 1 | 3 | 2 | 6 | 6 |
| | Dow | | French | | German | | AFS | | CSA | | DTD | |

*1 most sensitive, 6 least sensitive.

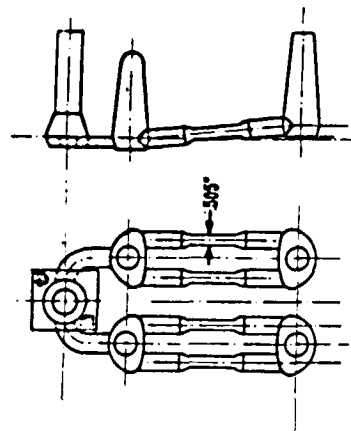
TABLE 18

Casting Efficiency of Test Bars

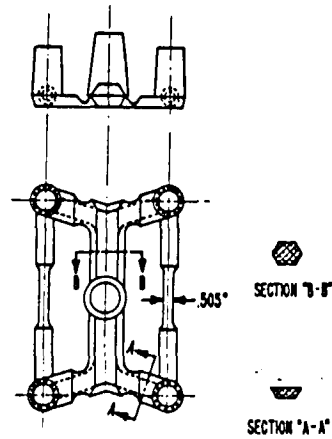
| Test Bar Design | Approx. Weight* of Untrimmed Casting, lb | Approx. Weight* per Test Bar, lb |
|-----------------|--|--|
| Dow | 5.6 | 1.4 |
| French | 5.5 | 1.4 |
| German | 7.8 | 2.0 |
| AFS | 8.0 | 2.0 |
| CSA | 4.4 | 2.2 |
| British E-type | 10.4 | 2.6 |
| British DTD | 1.9 | 1.9 |

* In SG70 alloy - density about 2.68 g/cc.

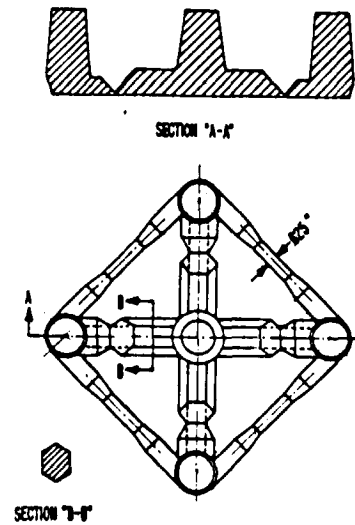
TEST BAR DESIGNS FOR SAND-CAST ALUMINUM ALLOYS



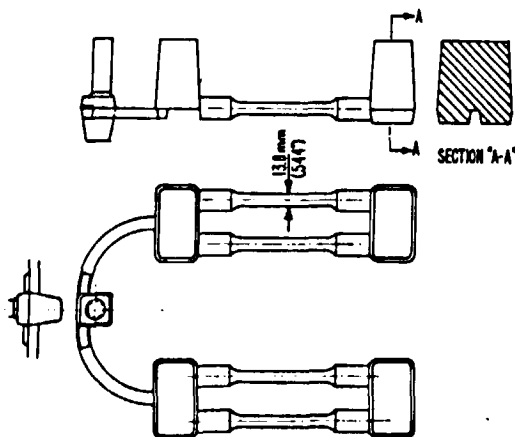
U.S. FEDERAL SPECIFICATION QQ-M-56, FIG. 1A



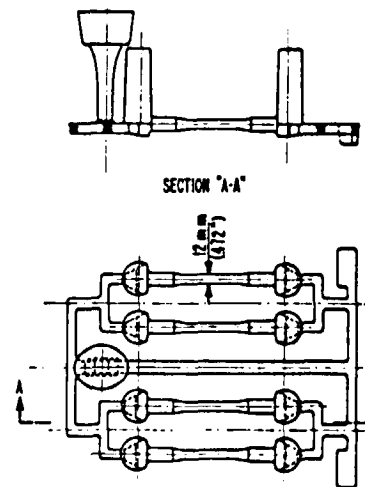
(CANADIAN) CSA SPECIFICATION NA.1.3-1958



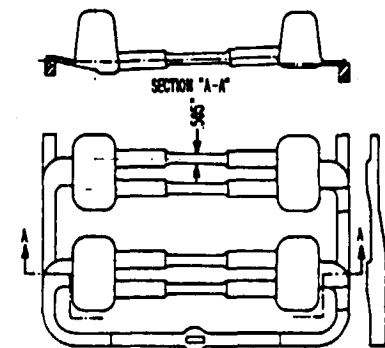
BRITISH STANDARD 1490:1955



FRENCH TEST BAR
(FONDERIE - 145, FEB 1958)



GERMAN TEST BAR
(GIESSERI - 47, MAY 1960)



AFS PROPOSAL (JULY 1967)

Figure 1.

GIO—Effect of Melt Quality on Super Pure-Base Melts

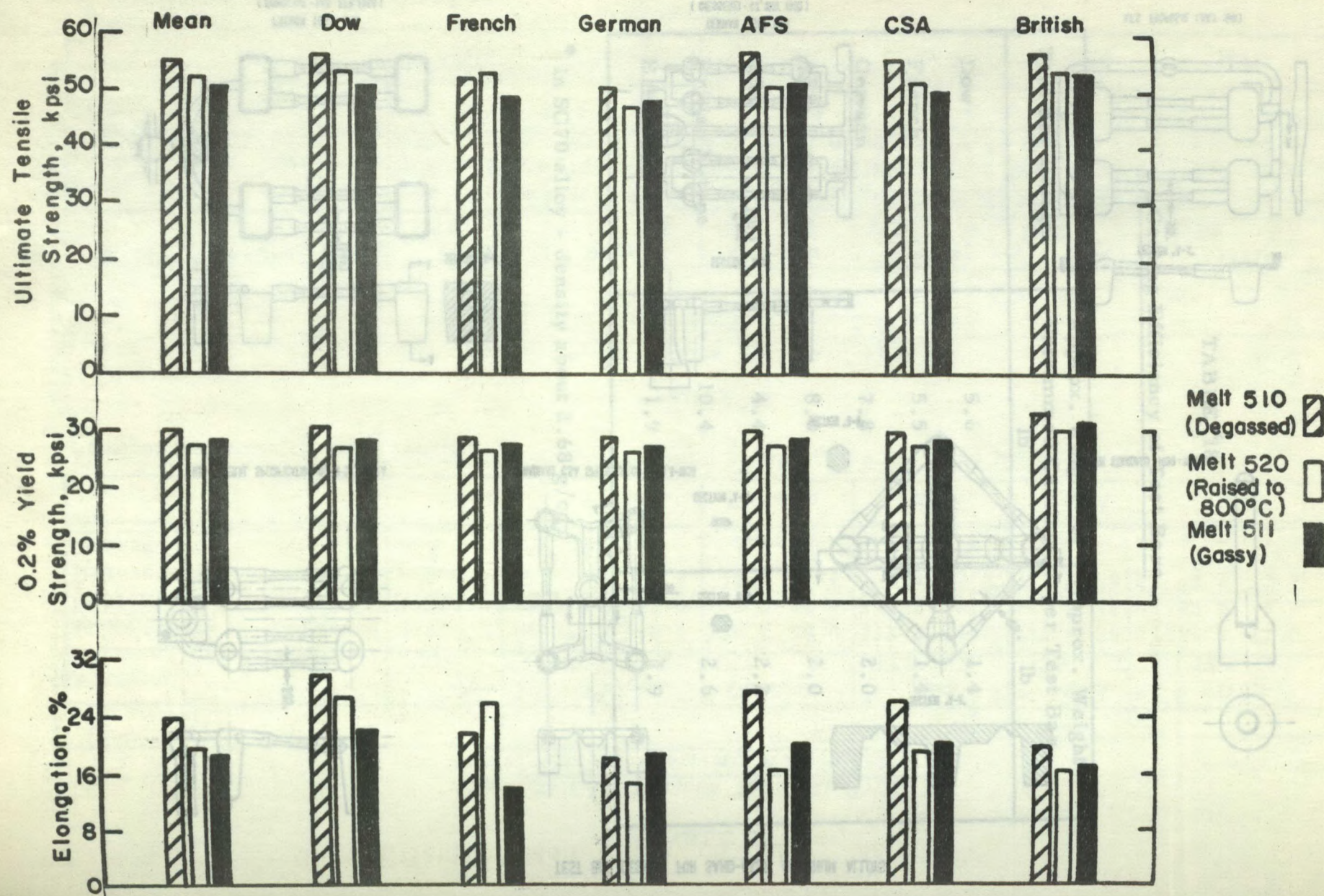


Figure 2.

GIO— Effect of Melt Quality on "Ingot" Metal

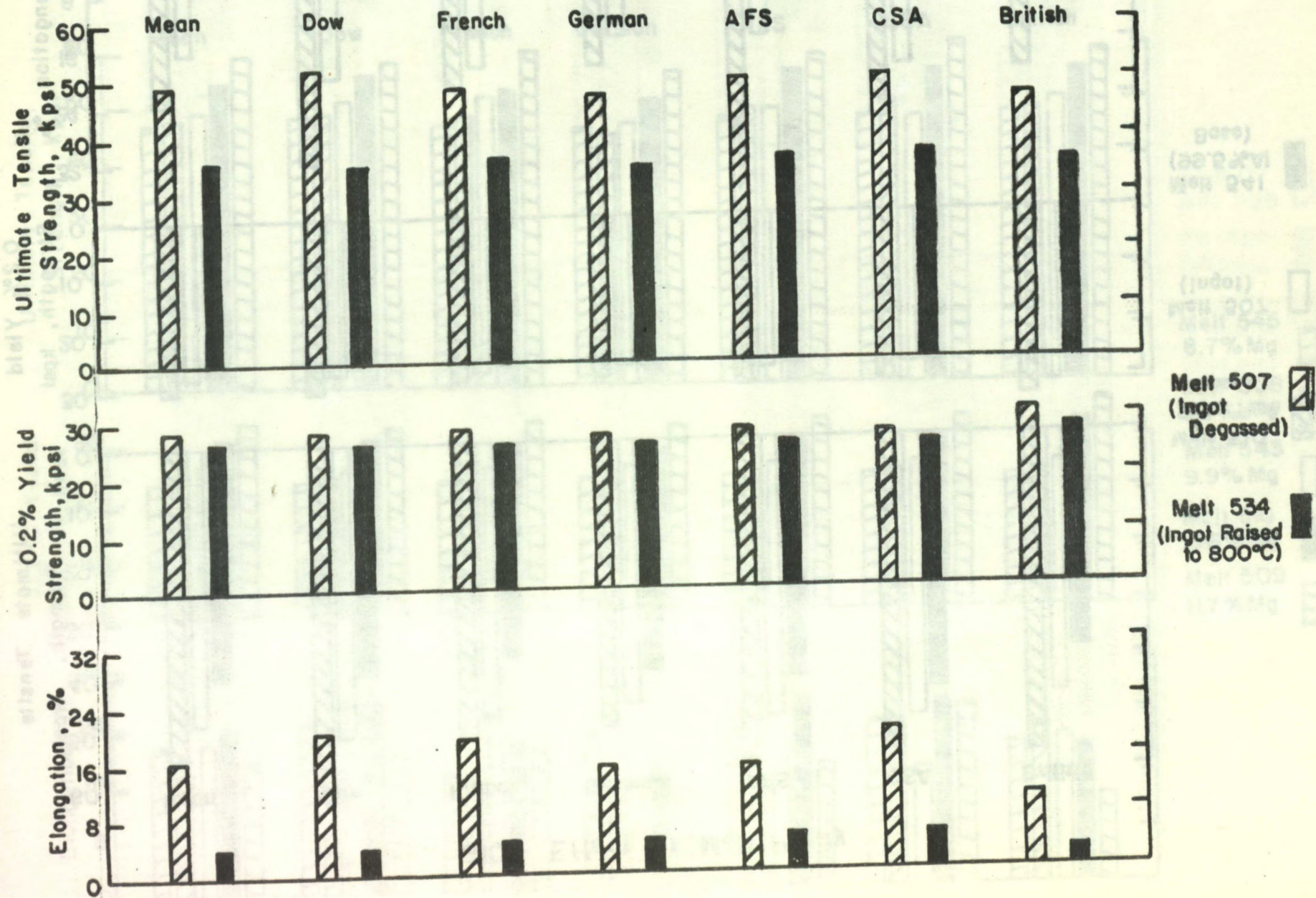


Figure 5.

GIO — Effect of Melt Purity

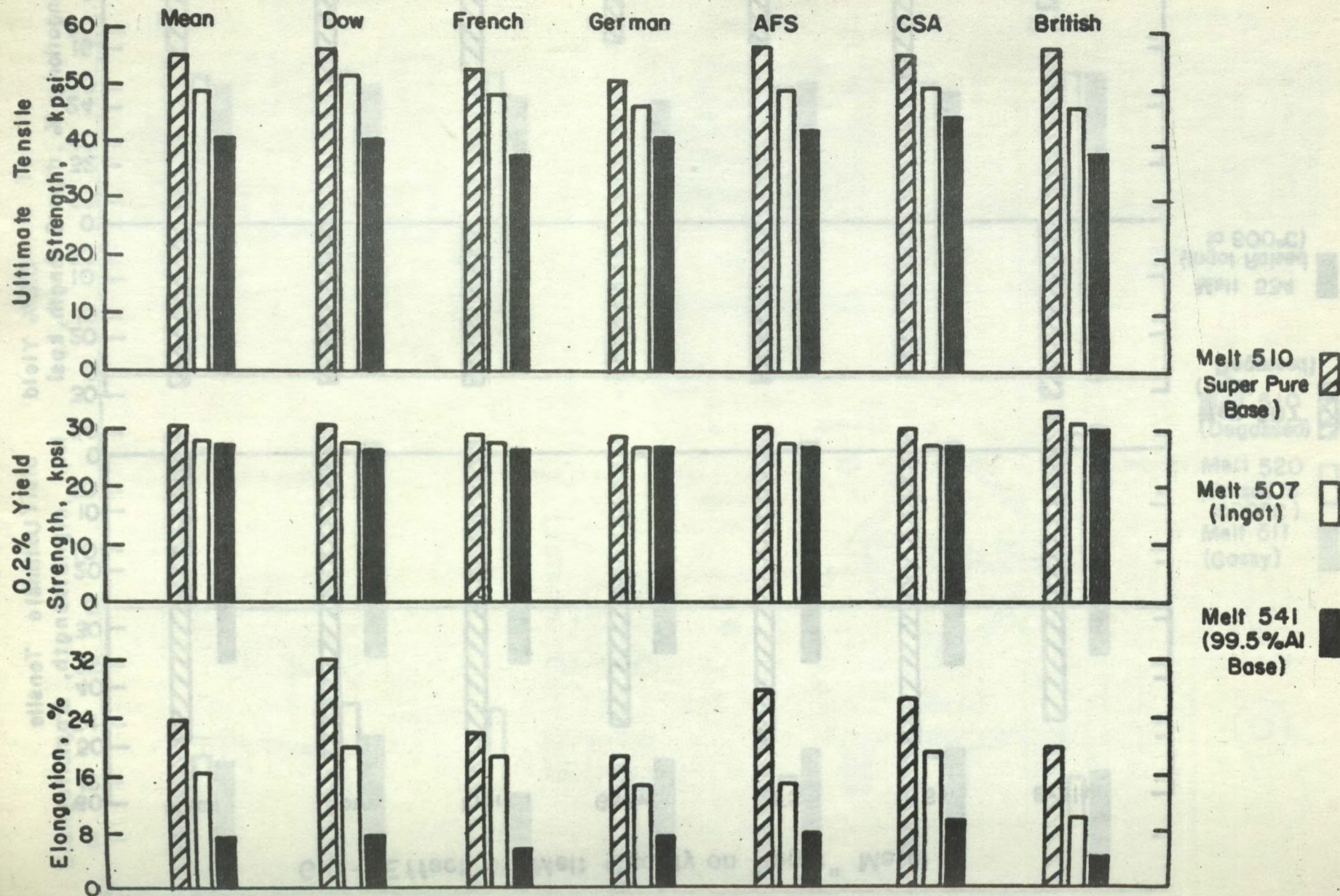


Figure 4.

GIO — Effect of Magnesium Content

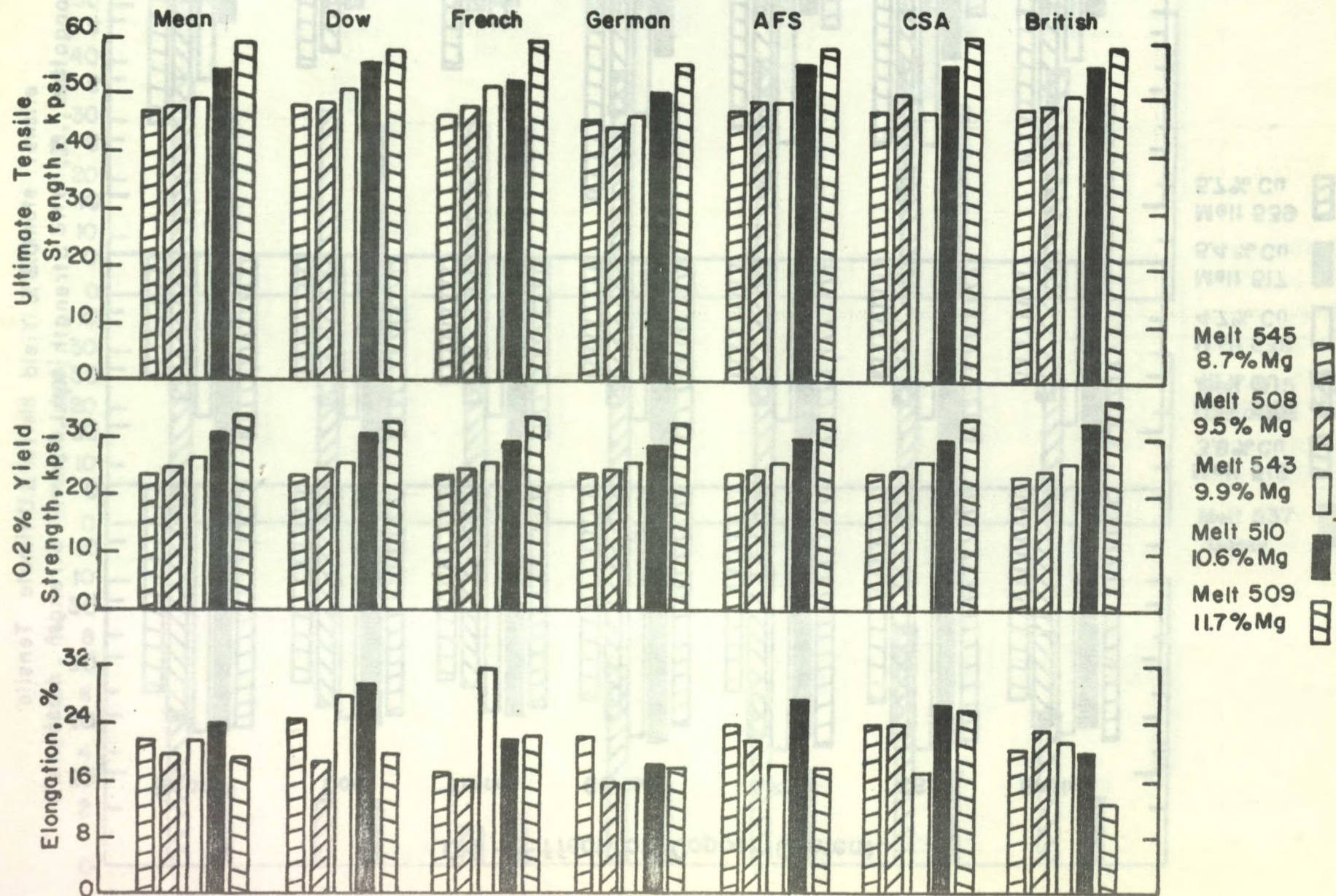


Figure 5.

C4 - Effect of Copper Content

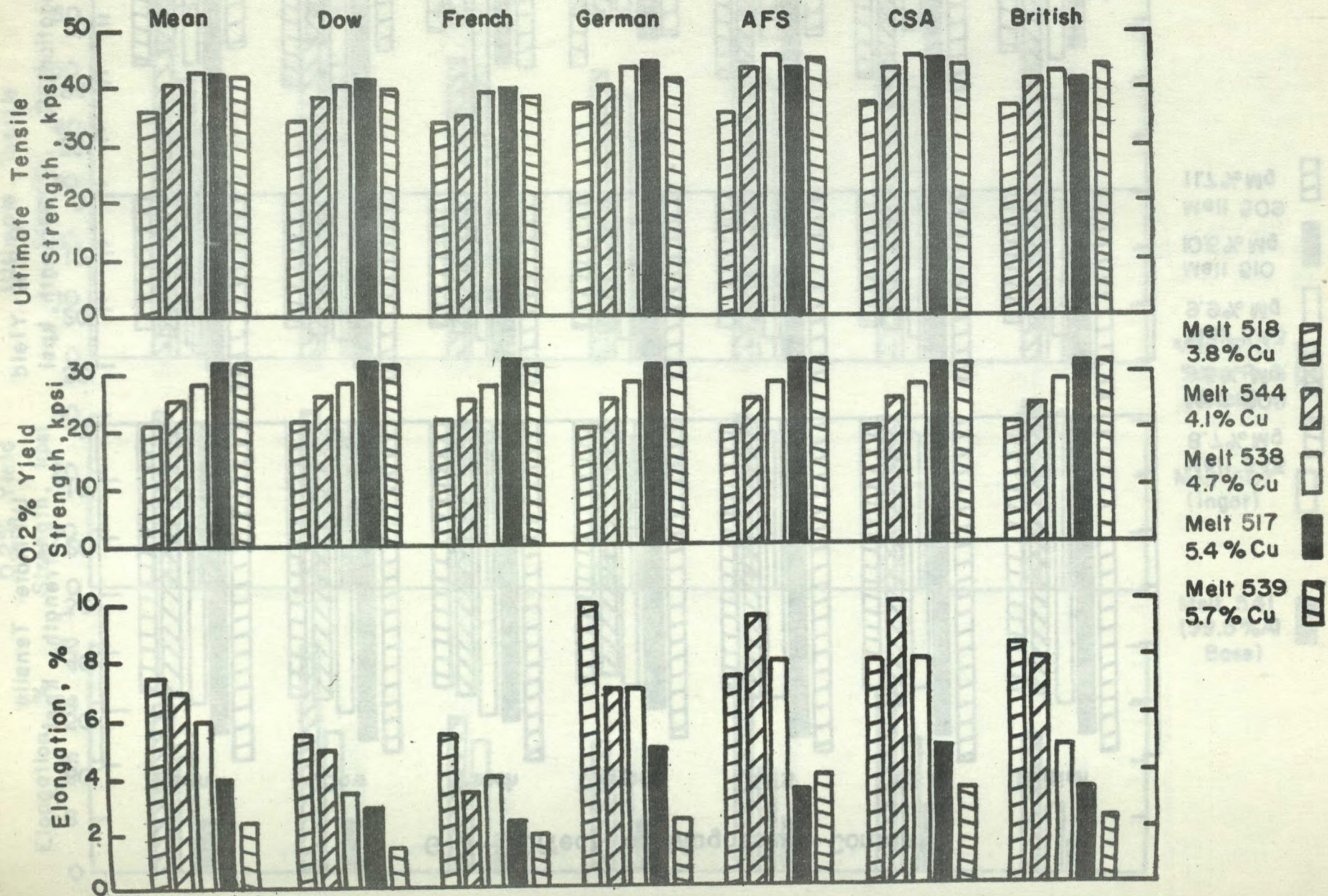


Figure 6.

C 4 — Effect of Melt Quality (Gas Content)

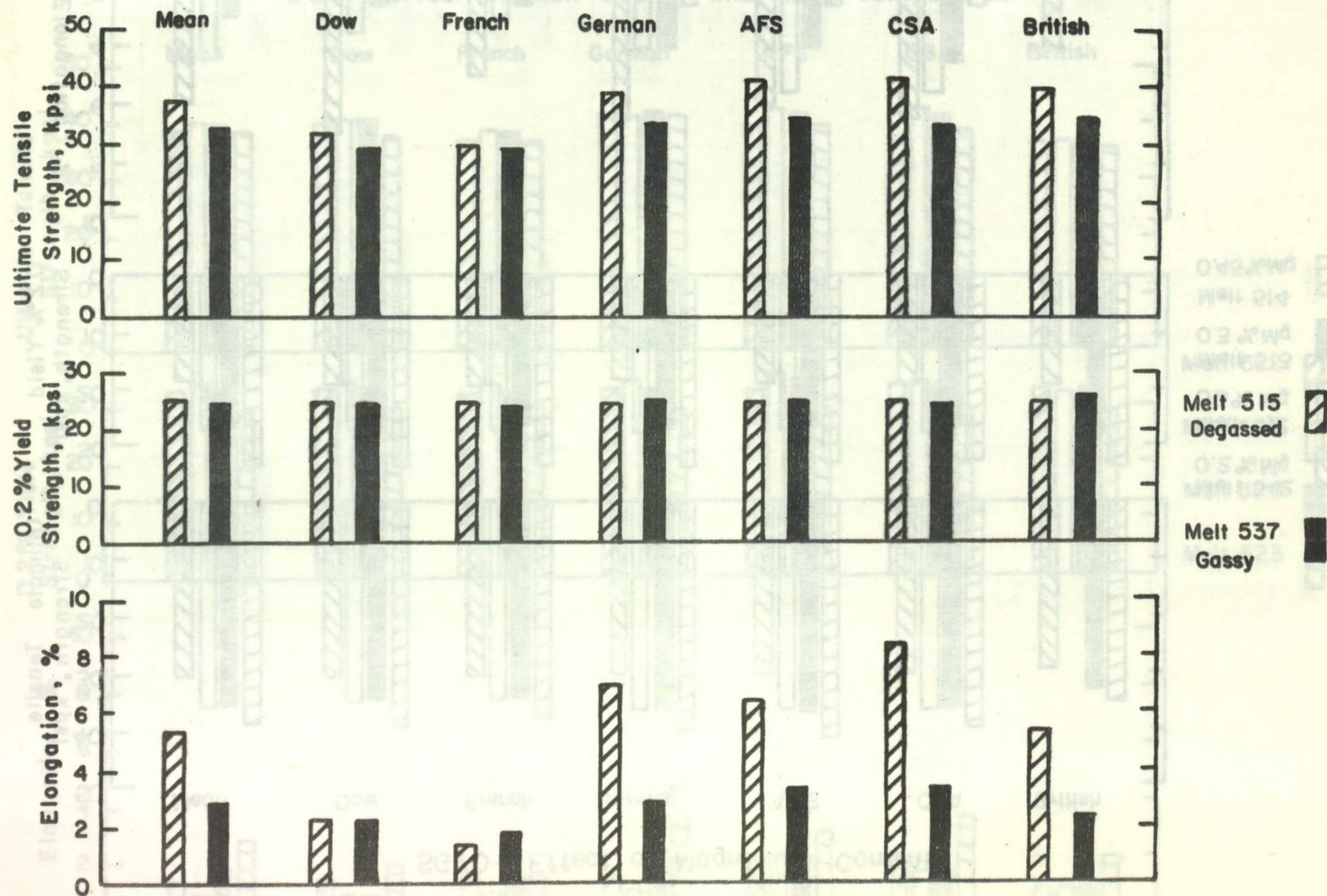


Figure 7.

SG 70 - Effect of Magnesium Content

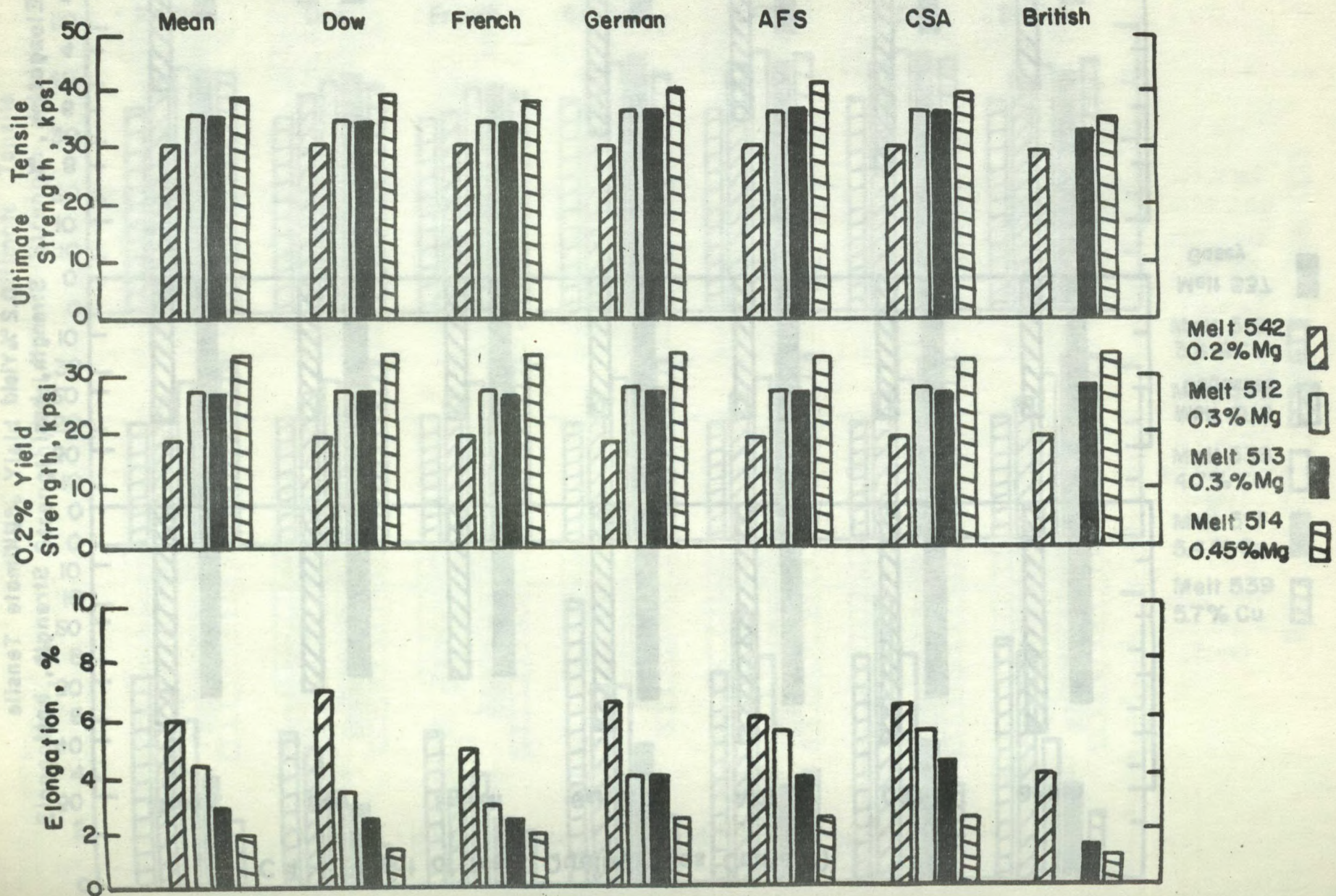


Figure 8.

SC51—Effect of Melt Quality and Alloy Composition

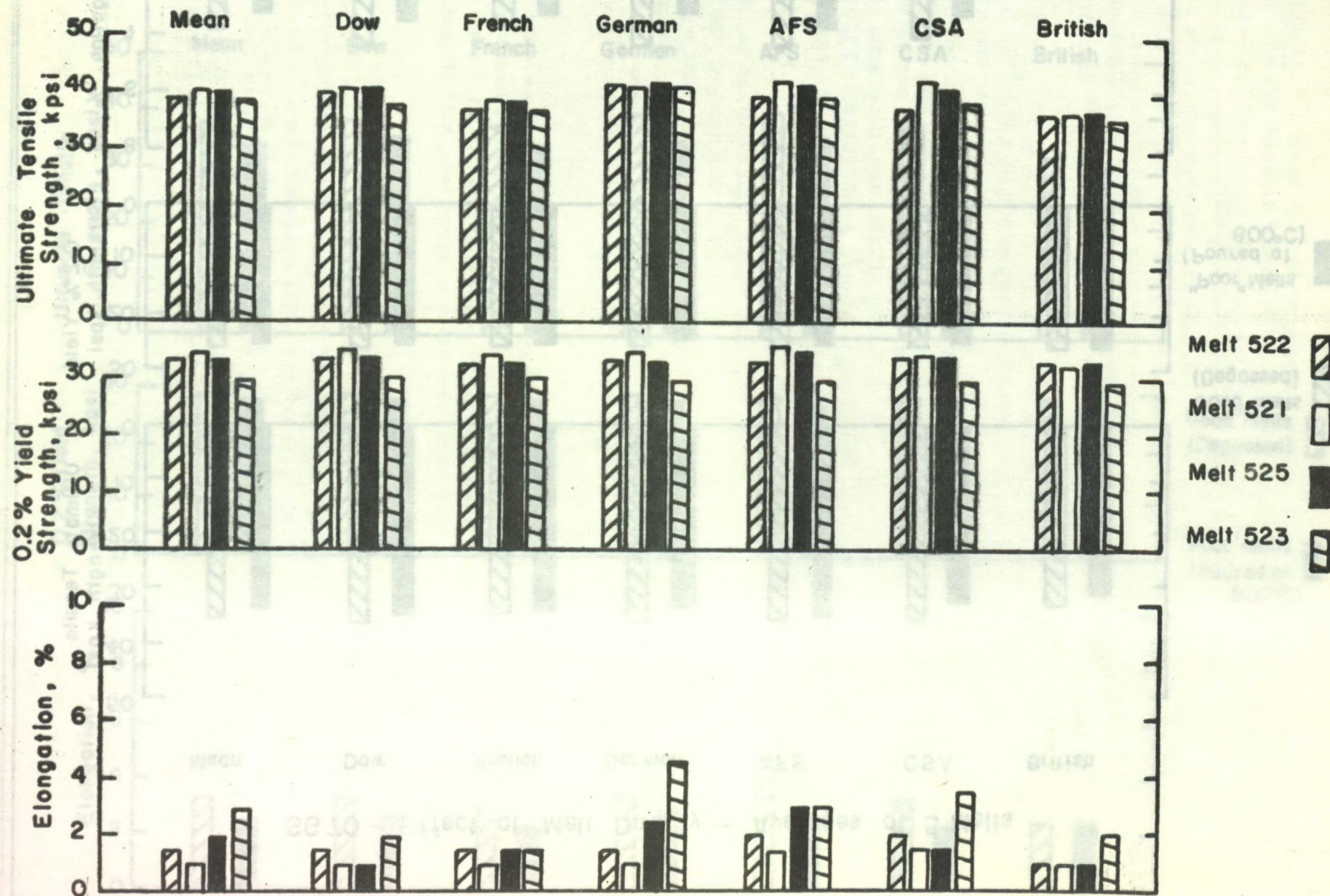


Figure 9.

SG 70— Effect of Melt Quality — Averages of 5 Melts

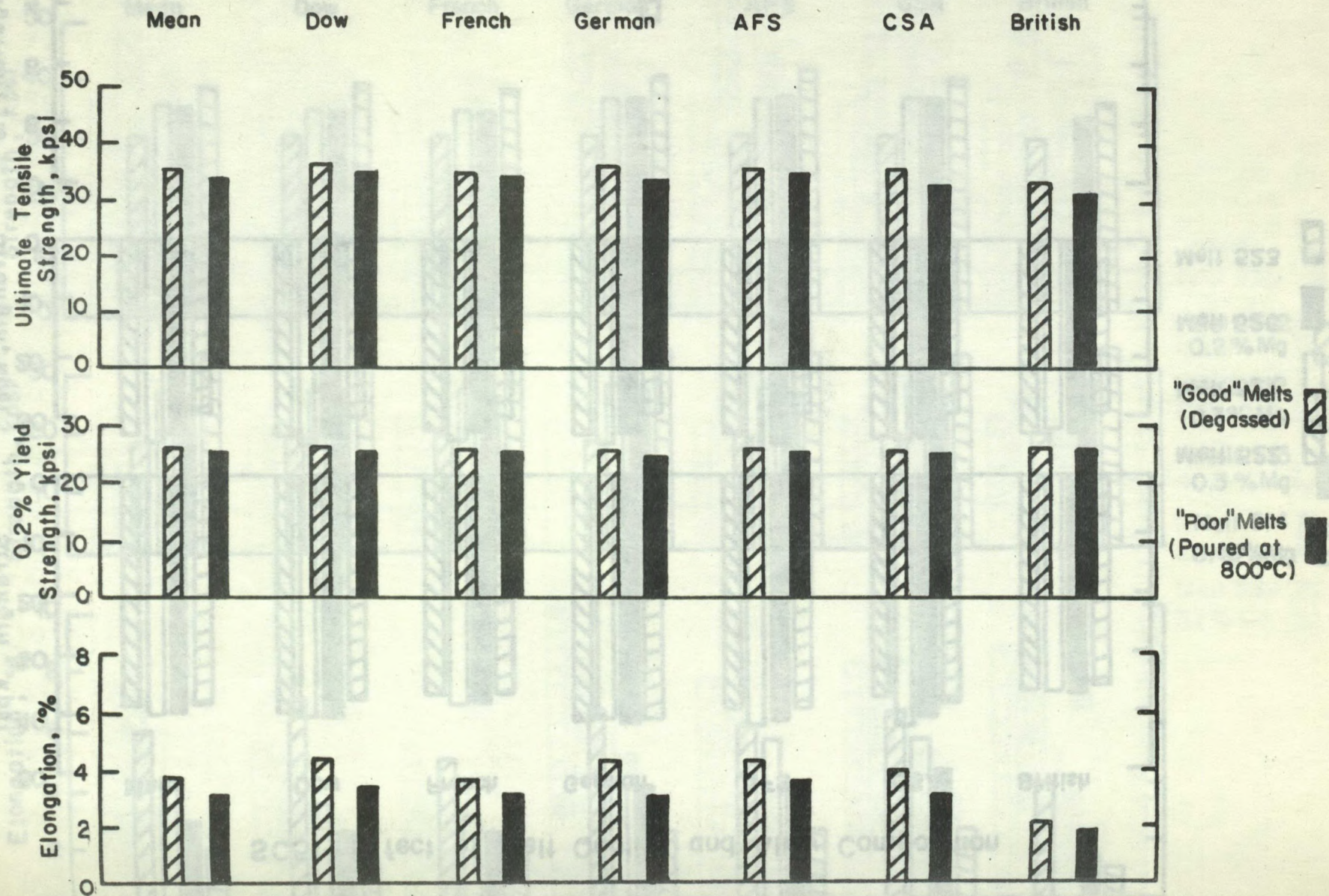


Figure 10.

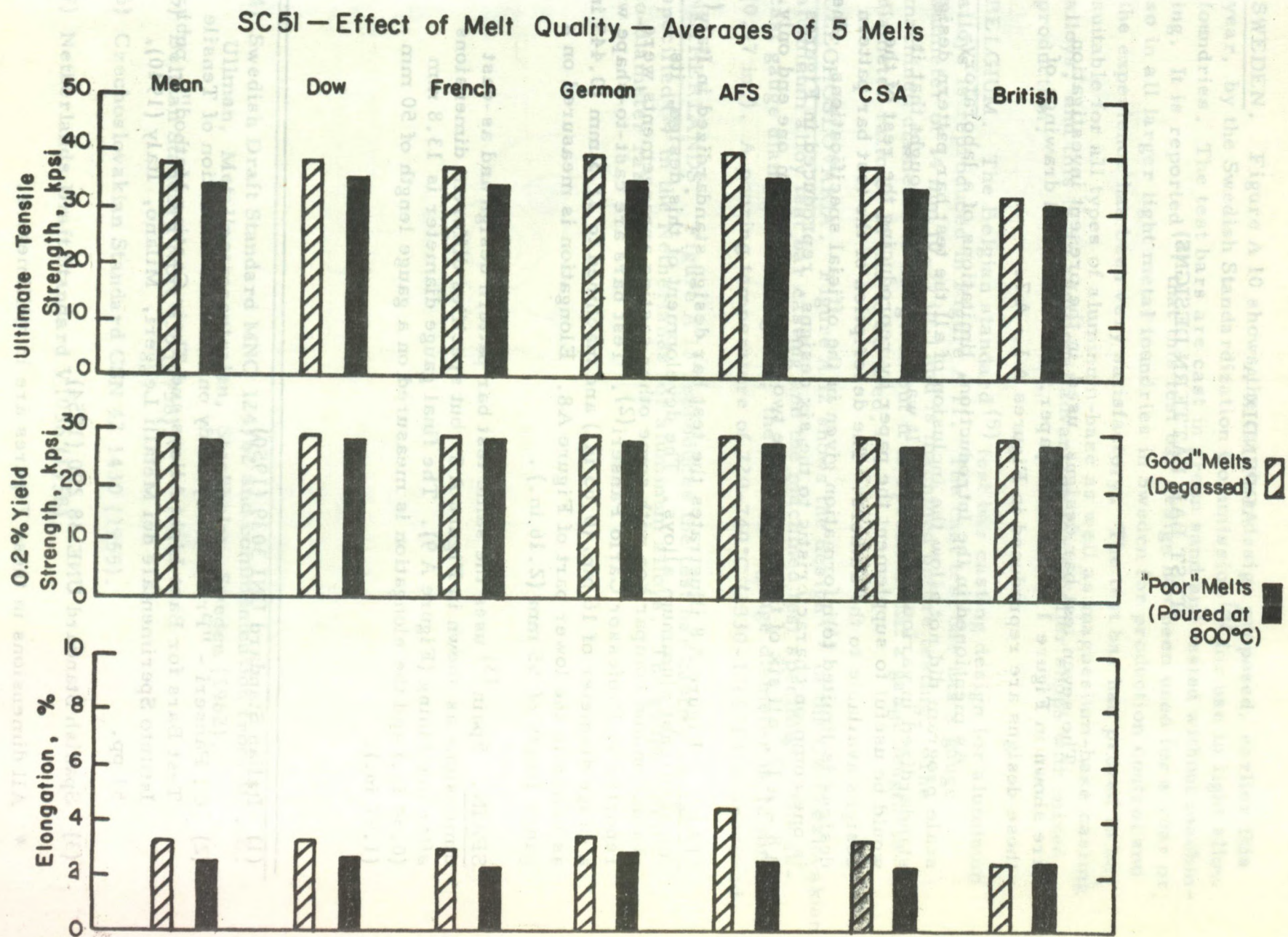


Figure 11.

APPENDIX A

TEST BAR PATTERN DESIGNS

The seven test bar designs used in the present investigation are shown in Figure 1 of the main paper. More detailed drawings of these designs are reproduced in Figures A 1 - A 7.

As mentioned in the Introduction, limitations of a laboratory-scale program did not allow the inclusion of all the test bar pattern designs standardized in various countries. It was, therefore, thought that it would be useful to supplement the paper by reproducing the rest of the designs available to the authors. The description of the test bar pattern designs is limited to information given in the official specifications. There is one common characteristic to the six designs, reproduced in Figures A 8 - A 13,* all six of them are of the two-bar type fed from one end only.

ITALY. Figure A 8 illustrates the test bar design standardized in Italy⁽¹⁾ for sand-cast aluminum alloys. The development of this design, its evaluation, and comparison with some other casting arrangements, were reported by Professor Carlo Panseri⁽²⁾. Test bars are cast-to-shape with a gauge diameter of 16 mm (0.63 in.) and machined to 11.3 mm (0.445 in.), as shown in the lower part of Figure A 8. Elongation is measured on a gauge length of 55 mm (2.16 in.).

SPAIN. Spain⁽³⁾ uses the same test bar pattern design and as-cast dimensions as shown in Figure A 8, but specifies different dimensions after machining (Figure A 9). The final gauge diameter is 13.8 mm (0.54 in.) and the elongation is measured on a gauge length of 50 mm (1.97 in.).

(1) Italian Standard UNI 3039 (1950).

(2) C. Panseri - "Preliminary Study on the Standardization of Tensile Test Bars for Bast Light Alloys and Their Casting Method" - publ. Istituto Sperimentale dei Metalli Leggeri, Milano, Italy (1940), 51 pp.

(3) Spanish Standard UNE 38 200 (1954).

* All dimensions in these Figures are in millimeters.

SWEDEN. Figure A 10 shows the test bar design proposed, earlier this year, by the Swedish Standardization Commission⁽⁴⁾ for use in light alloy foundries. The test bars are cast in green sand and tested without machining. It is reported⁽⁴⁾ that this test bar design has been used for a year or so in all larger light metal foundries in Sweden for production control and the experience has been very satisfactory. The test bar has proved to be suitable for all types of aluminum-base as well as magnesium-base casting alloys, and this is an additional advantage for smaller shops with mixed production.

BELGIUM. The Belgian standard⁽⁵⁾ test bar casting design for aluminum alloys is reproduced in Figure A 11. The cast test bar has a gauge diameter of 14 mm (0.55 in.) and is machined before testing. The machined diameter is not given but it is specified that a gauge length-to-diameter ratio of 10 has to be used.

CZECHOSLOVAKIA. Figure A 12 shows the design⁽⁶⁾ of the Czechoslovakian aluminum alloy test bar casting and the machined test specimen. The as-cast gauge diameter is not given; the machined gauge diameter is 12 mm (0.47 in.). A pouring temperature of 720-740°C (1330-1365°F) is specified.

NETHERLANDS. Figure A 13 reproduces the test bar casting design specified⁽⁷⁾ in the Netherlands for aluminum alloys. The gauge length-to-diameter ratio of 5 is used.

(4) Swedish Draft Standard MNC 124/62 and communication from Mr. E. Ullman, Metallnormcentralen, Stockholm, Sweden (1962).

(5) Belgian Standard NBN 436 (1958).

(6) Czechoslovakian Standard CSN 42 1430 (1955).

(7) Netherlands Draft Standard V1036 (1958).

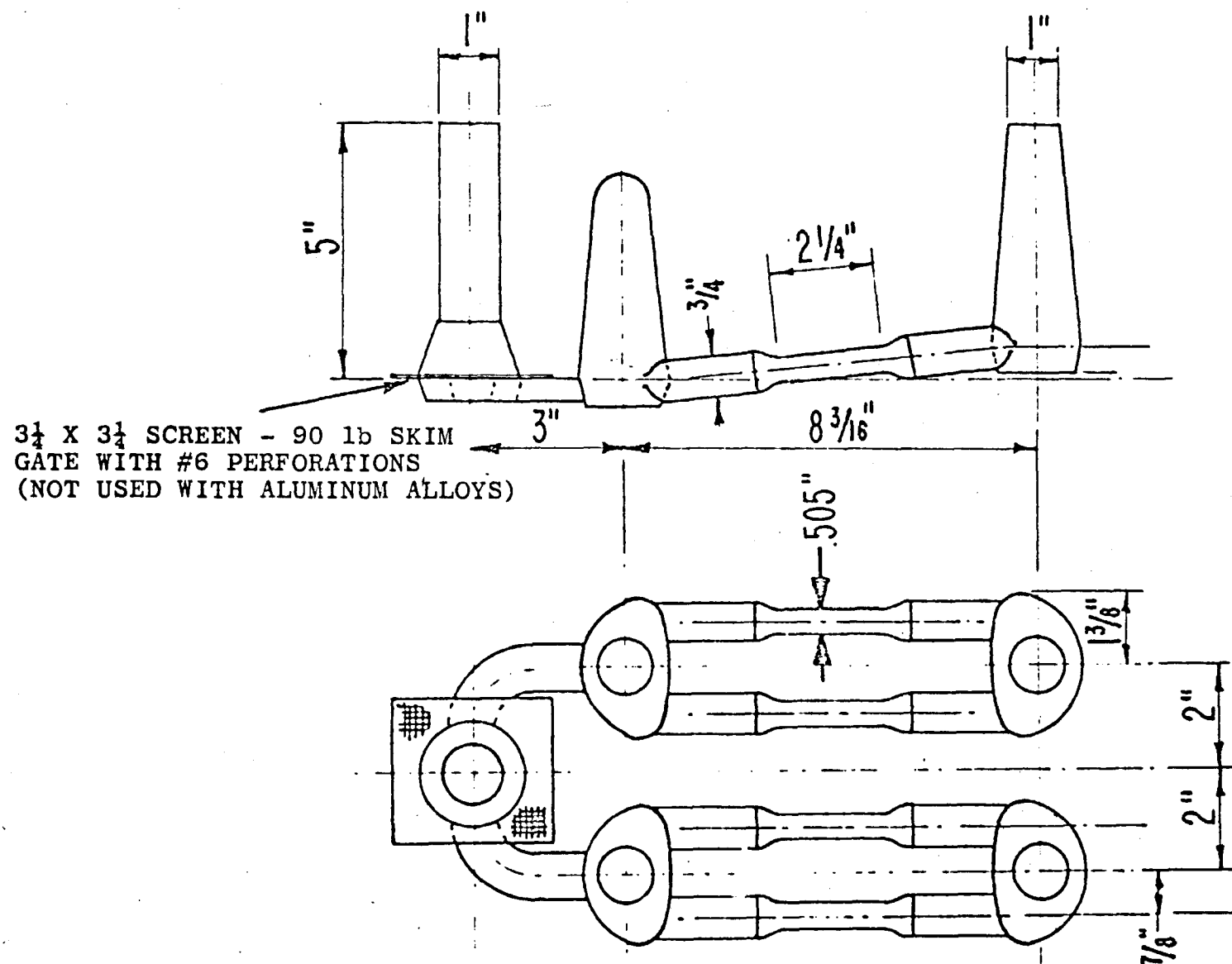


Figure A 1. "Dow" test bar (U.S. Federal Specification QQ-M-56).

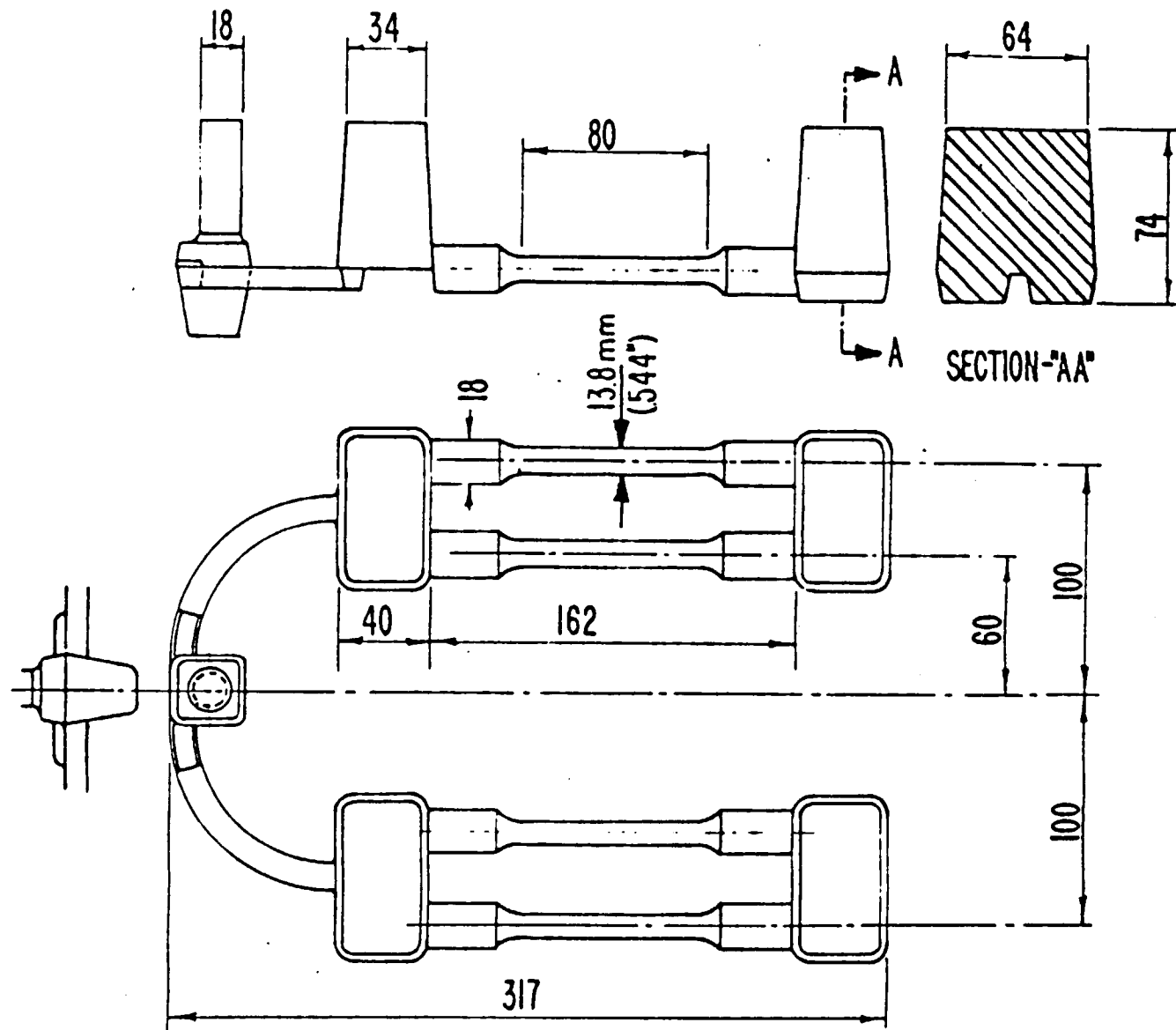


Figure A2. French Test Bar (NF A 57-702, type B). Dimensions in mm.

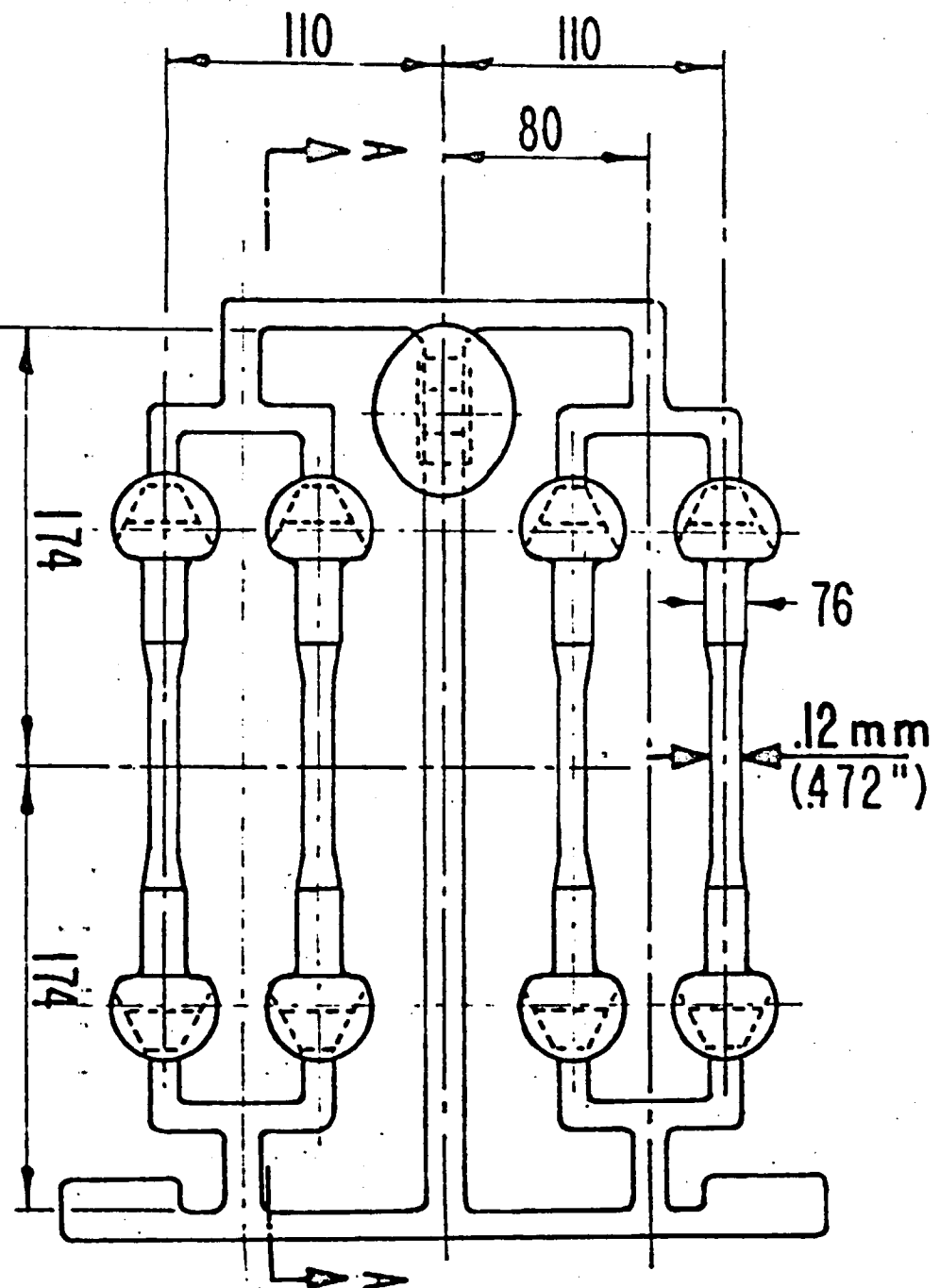
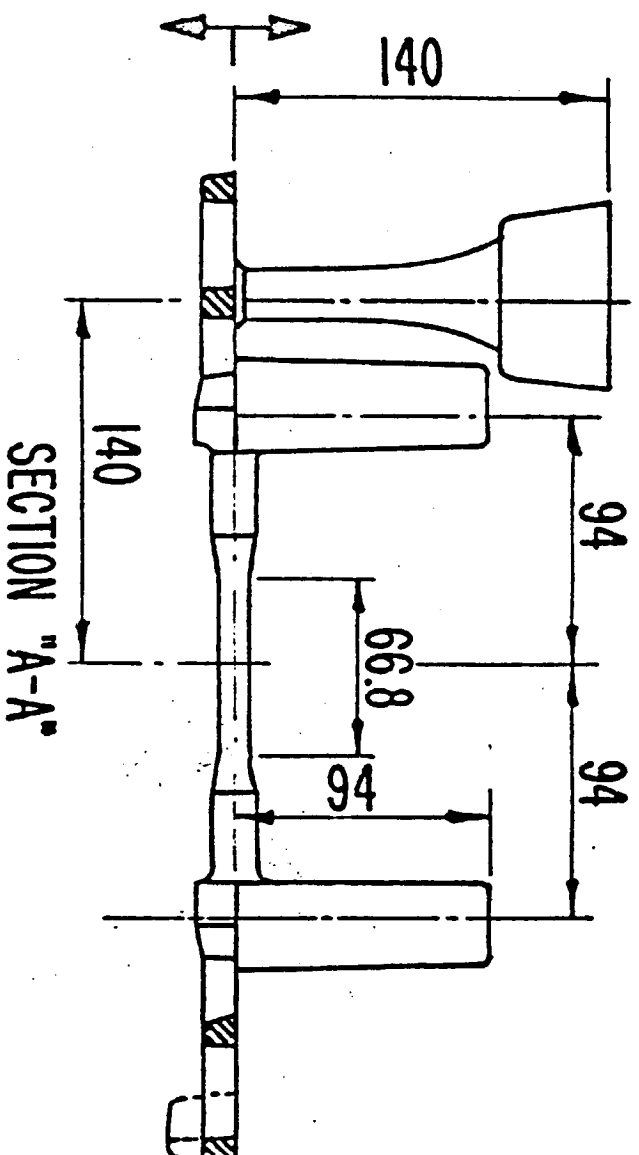


Figure A 3. German Test Bar Design (VDG Recommendation proposed in Sept. 1959). Dimensions in mm.

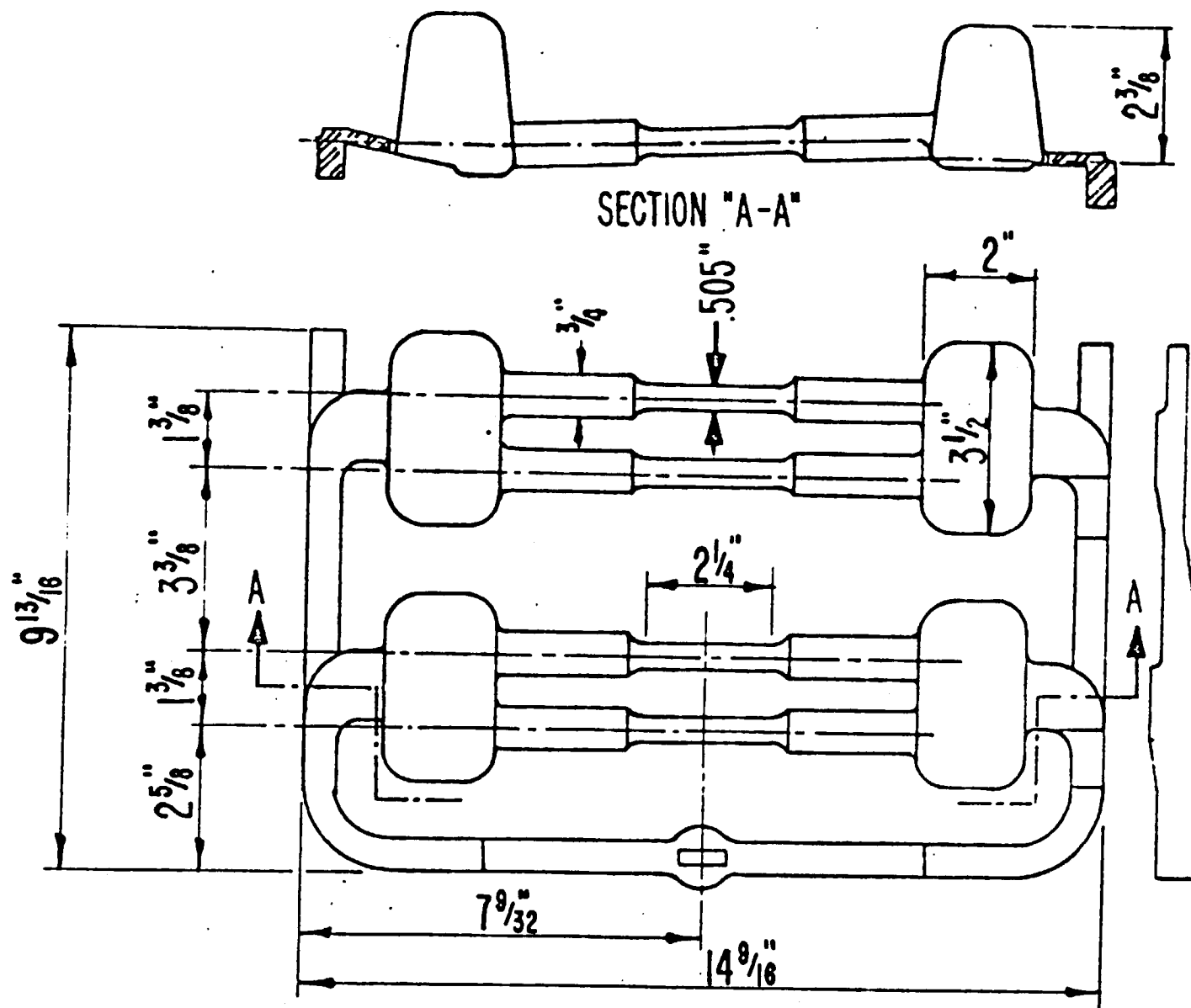
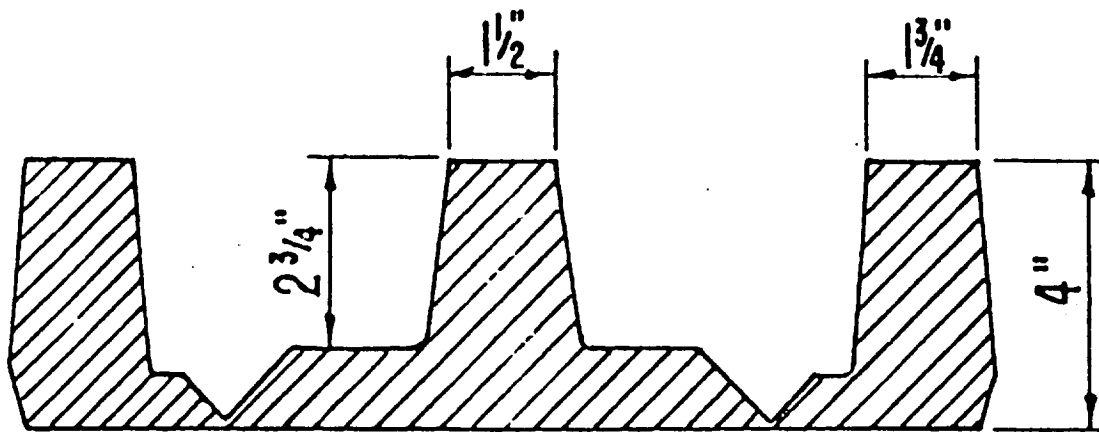


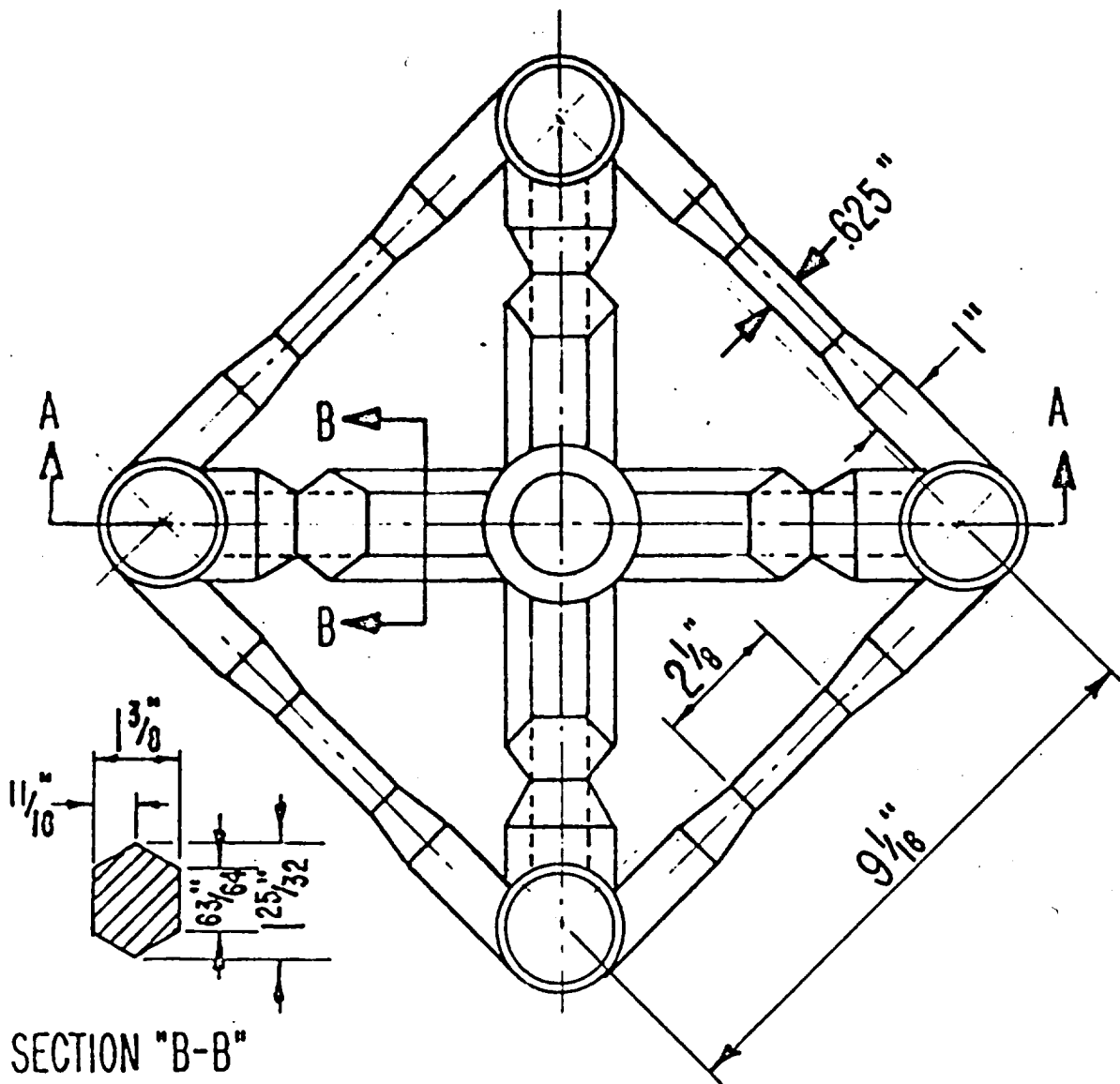
Figure A 4. AFS Test Bar Design (proposed in July 1961).



**Figure A 5. Test Bar Design specified in Canadian Standard
CSA.HA.1.3-1958.**



SECTION "A-A"



SECTION "B-B"

Figure A 6. British E-type Test Bar Design specified for the Al-10% Mg alloy (BS 1499:1955).

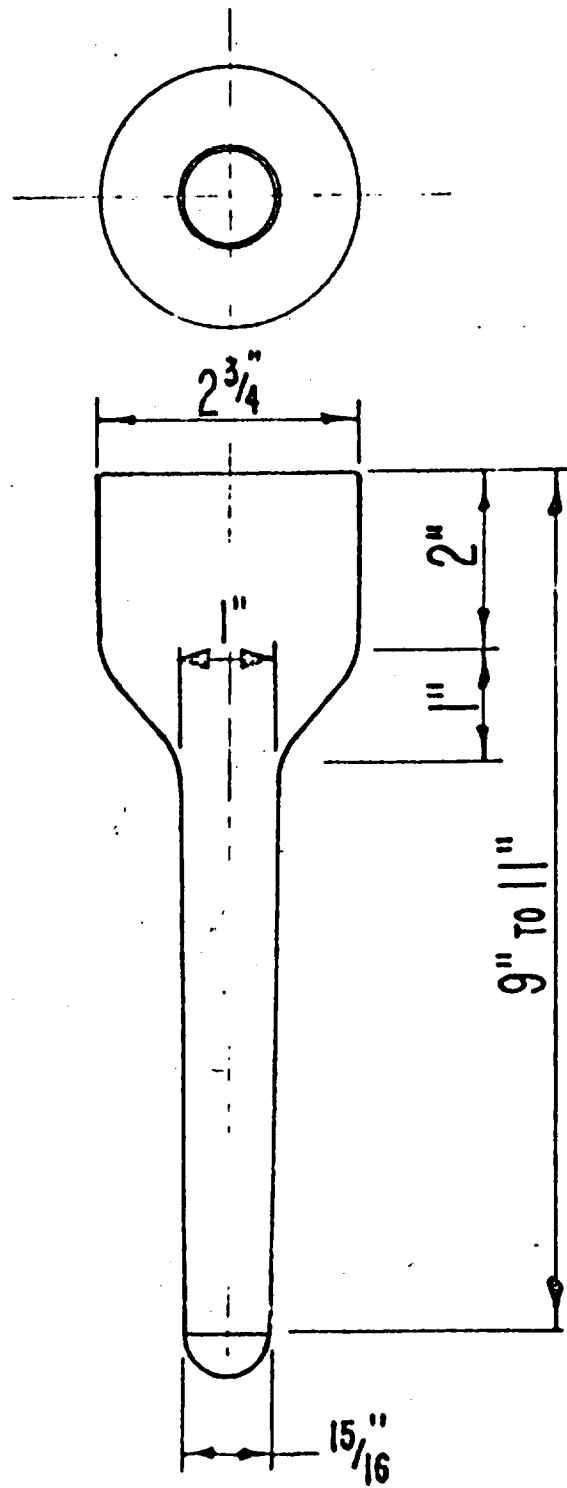


Figure A 7. British DTD Test Bar Design (BS 1490:1955).

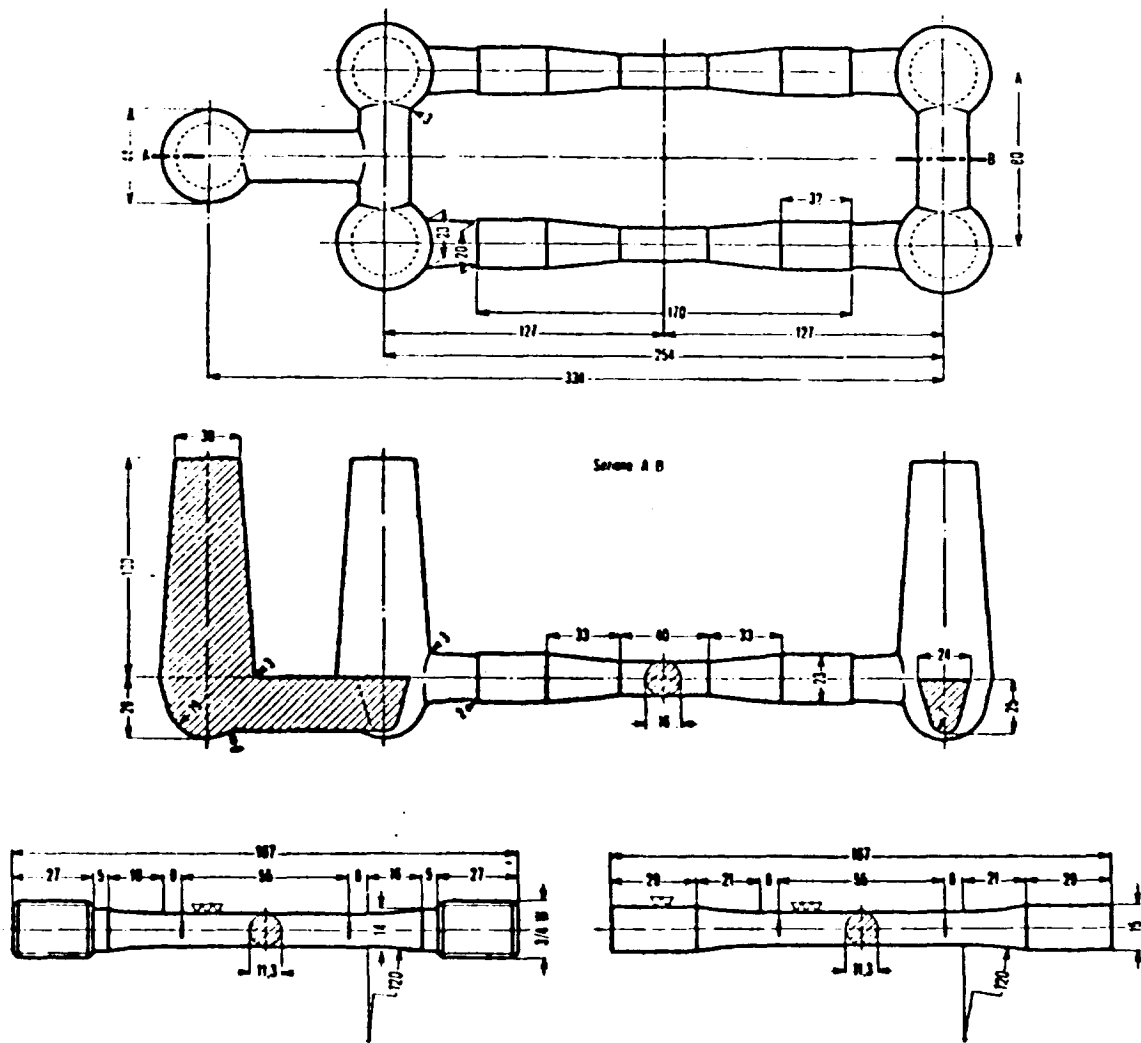


Figure A 8. Italian Test Bar Design.

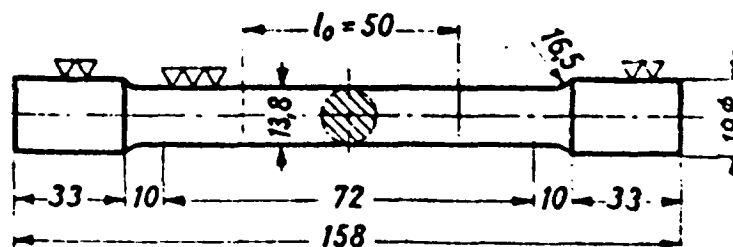


Figure A 9. Spanish Test Bar after machining.

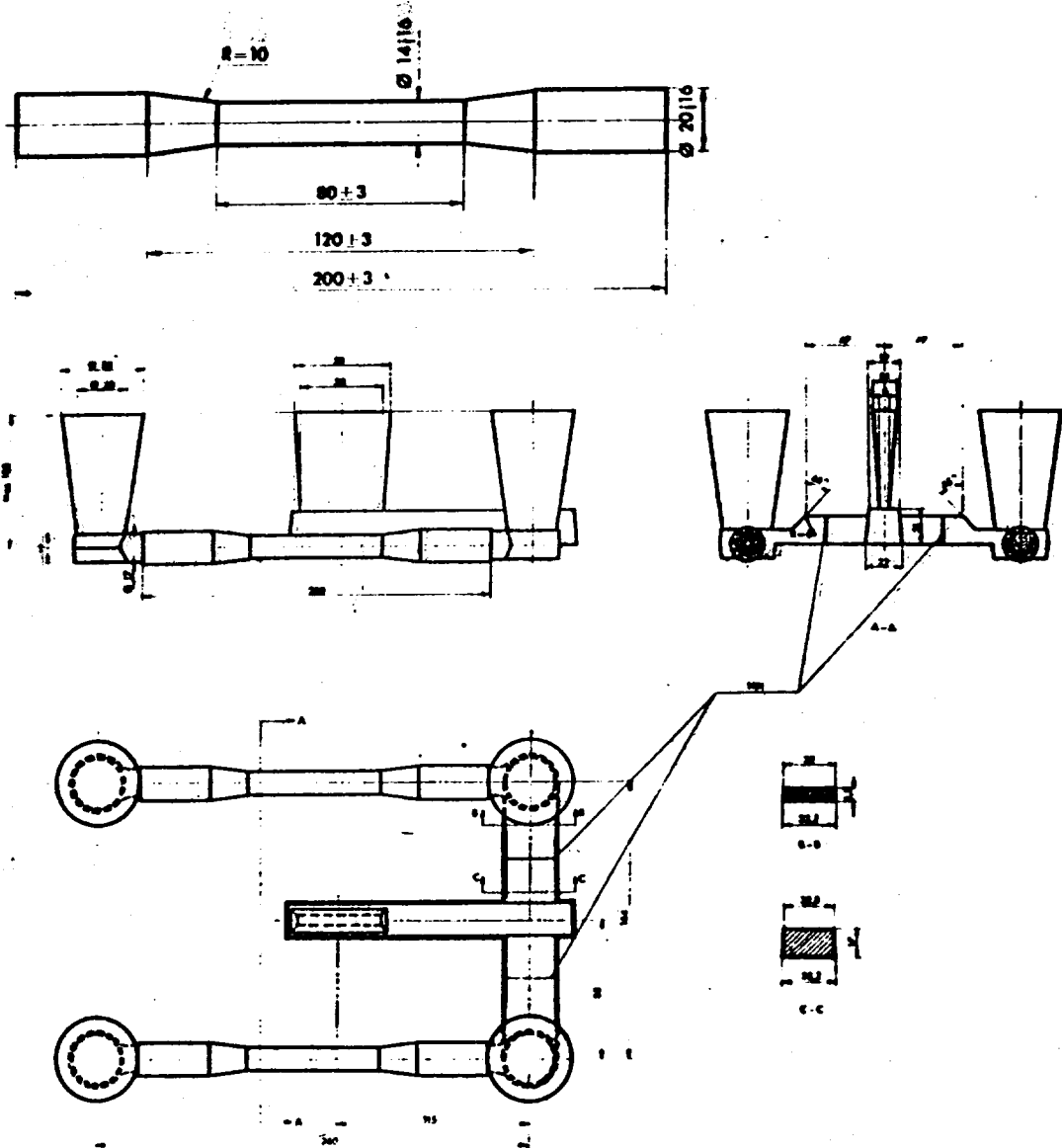


Figure A 10. Swedish Test Bar Design.

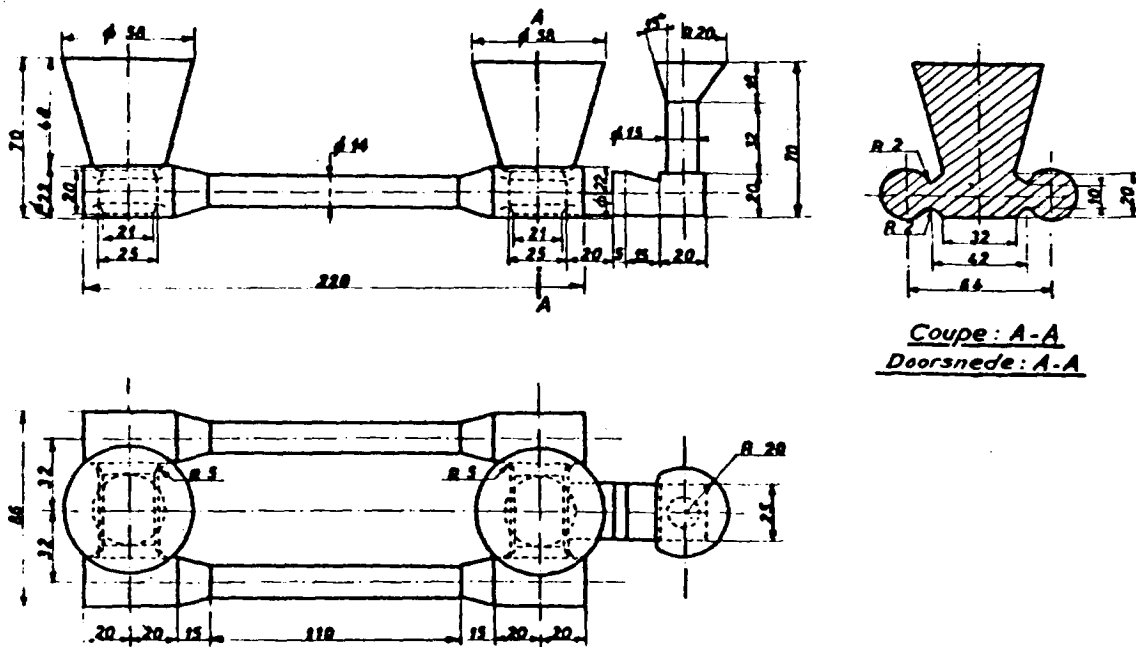


Figure A 11. Belgian Test Bar Design.

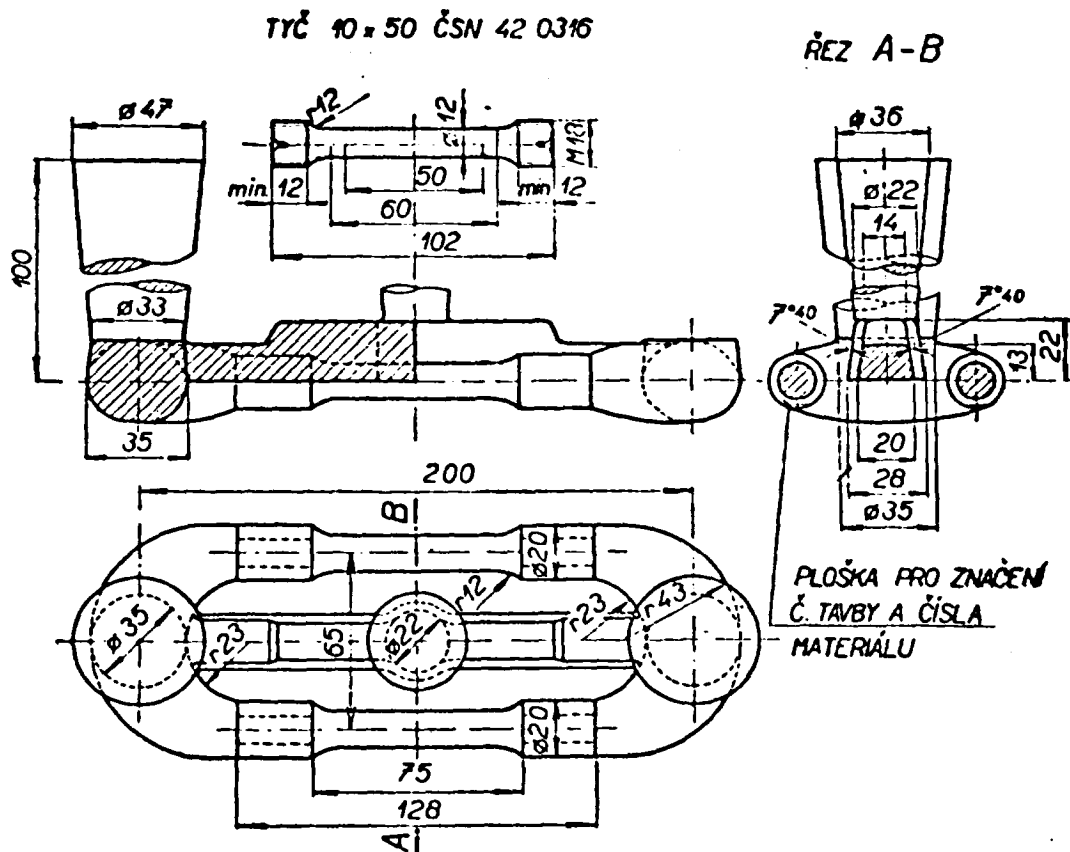


Figure A 12. Czechoslovakian Test Bar Design.

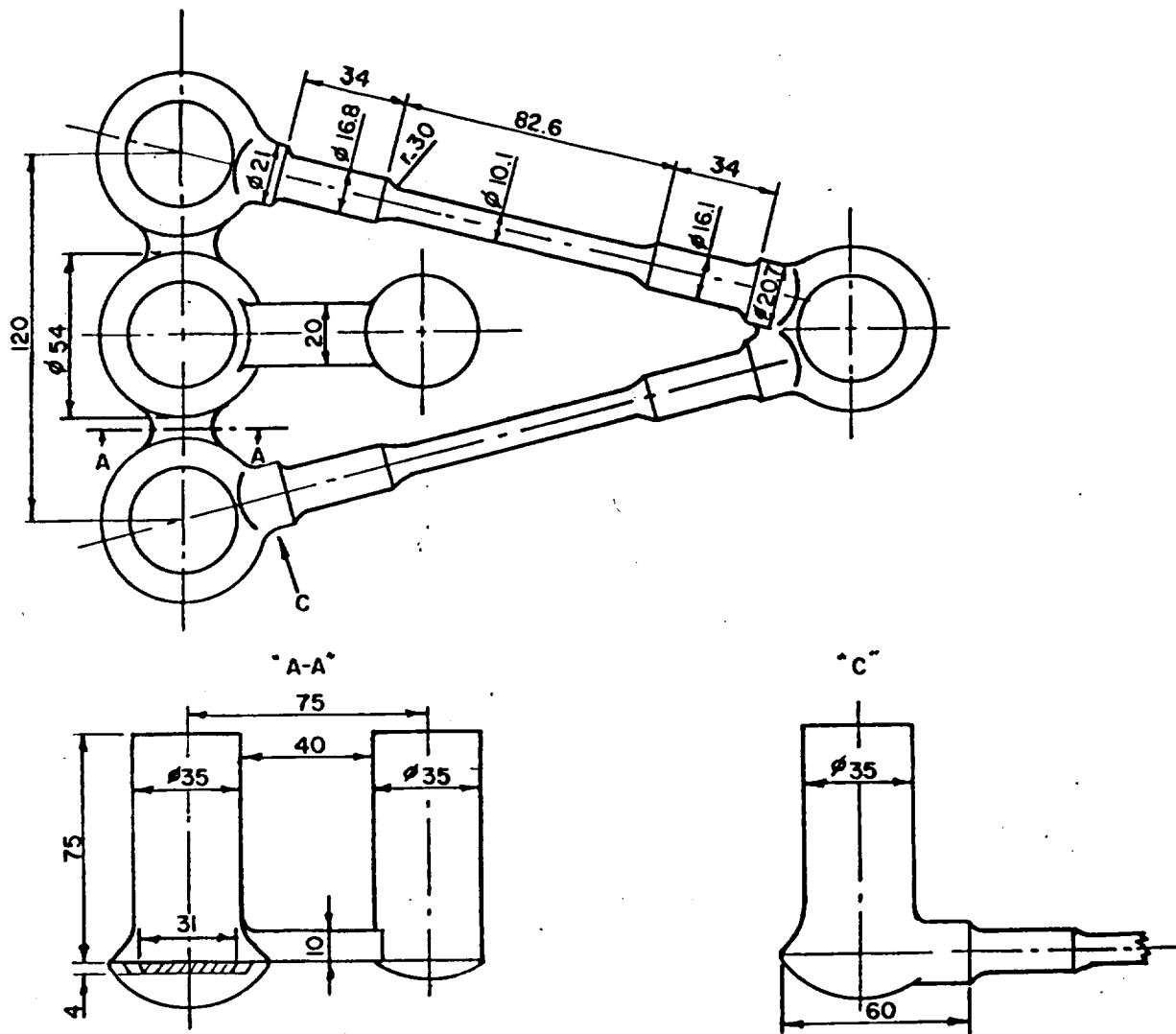


Figure A 13. Netherlands Test Bar Design.

APPENDIX B

METAL FLOW IN AFS TEST BAR MOULD

In order to study the flow of metal in the AFS test bar mould, fluorescent screen radiography was used and the image recorded on 16-mm movie film. To obtain sufficient sensitivity, the cope section of the parts of the mould to be viewed was reduced to a thickness of about 3/4 in. by replacing the normal backing sand with a thin layer of CO₂-hardened sand. The whole drag section of the mould was similarly reduced.

It was not possible to view the whole mould in any one cast because of the limited size of the irradiated area (fairly short target-to-object distance had to be used in order to obtain sufficient intensity). However, by observing a number of casts, a good "composite" picture of the filling of the whole mould could be obtained.

Figures B 1 to B 4 show diagrams obtained by tracing (on a photographic enlarger) from "stills" made, at constant frame intervals, from the movie film. The flow of metal in the in-gates could not be observed owing to insufficient sensitivity, so that these parts of the mould were shown filled when metal was first seen to enter the risers.

All of the figures shown were obtained on castings made in C4 alloy. Three were cast at 720°C (1330°F), and the fourth at 680°C (1255°F) to show a misrun.

The metal entering the mould tends to flow first to the side of the riser farthest from the sprue. This results in the metal entering and in some cases filling the bars (in each pair) farthest from the sprue before the other two bars.

In the case of the risers at the low end of the mould, the peculiar flow pattern, in which the outer ends of the risers are empty for a comparatively long period after the bars have begun to fill, is due to the steeply sloped bases of these risers (see Figure 1 in main report).

In all cases observed, the metal streams met either at the shoulder or in the reduced section of the bar, and there seemed to be no tendency for the meeting place to be influenced by the slope of the bars, as intended by the designers of the pattern.

One interesting feature of the metal flow was its hesitant nature. This was particularly noticeable in the original movies. In many cases the advancing metal stream appeared to be arrested either momentarily or, in some instances, until met by the stream from the other end of the bar. Presumably these arrests were due to air entrapment or friction effects; if premature freezing were the cause one would not expect the stream to begin to move again. The relationship of these arrests with possible defects in the bars would be an interesting subject for further investigation.

It is hoped to continue work on this technique in the future as it is felt that it enables metal flow in moulds to be observed under conditions that are very close to those existing in the foundry.

ACKNOWLEDGEMENT

The authors wish to acknowledge the help of Mr. W.E. Havercroft, Head, and other members of the Nondestructive Testing Section, Physical Metallurgy Division in doing the work described above.

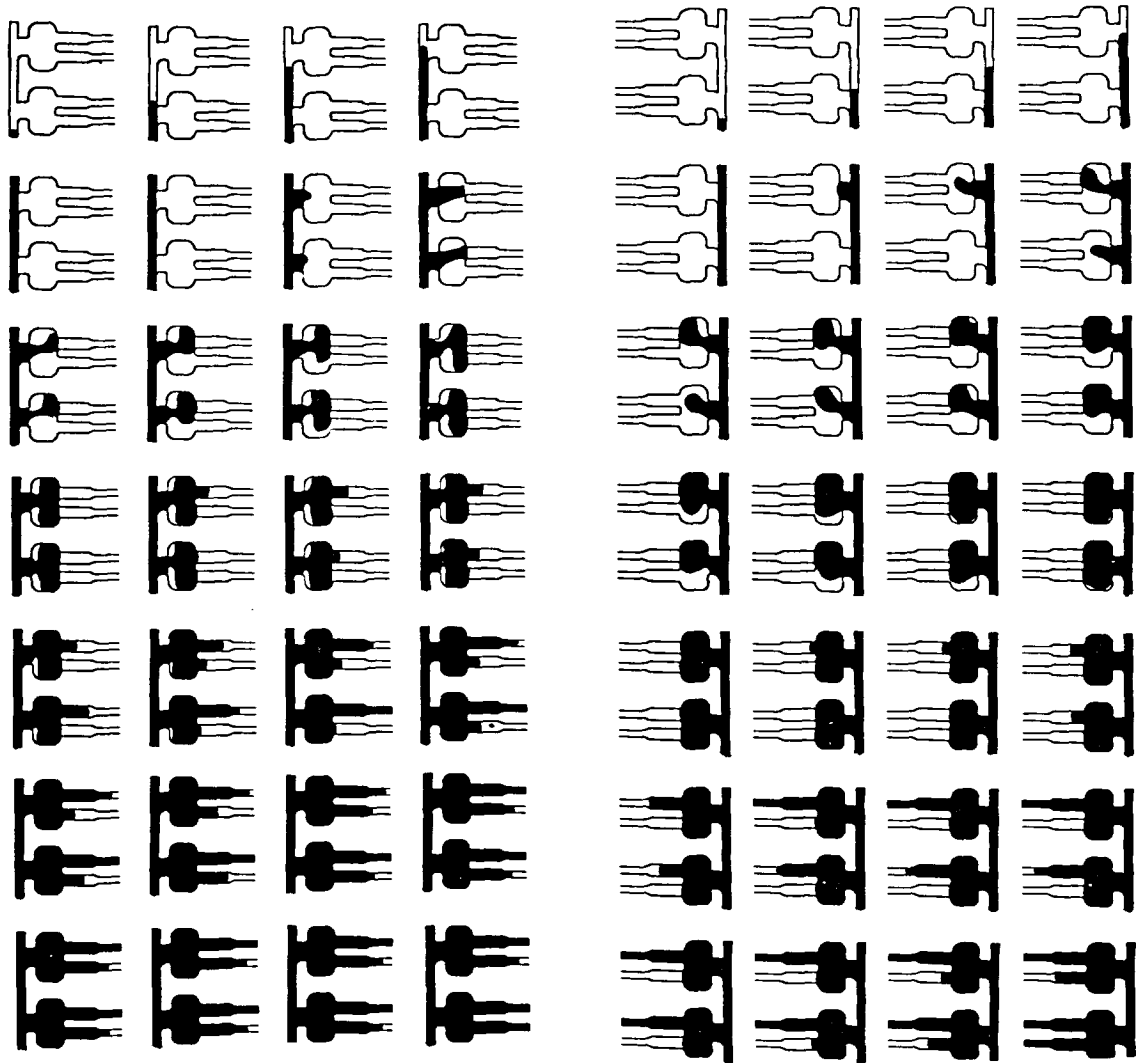


Figure B1

Figure B2

Figures B1, B2 - Diagrams to the flow of metal in runners, risers and bars of AFS test bar moulds. They were obtained by tracing from single frames from a movie film of fluorescent screen X-ray displays. Every fourth frame was reproduced so that the time interval between each diagram was approximately $1/4$ second. (Speed of film: 16 frames per second). Thus the total time elapsed in each of the series above was about 7 seconds. Figure B1 shows the "low" side of the mould and Figure B2 the "high" side.

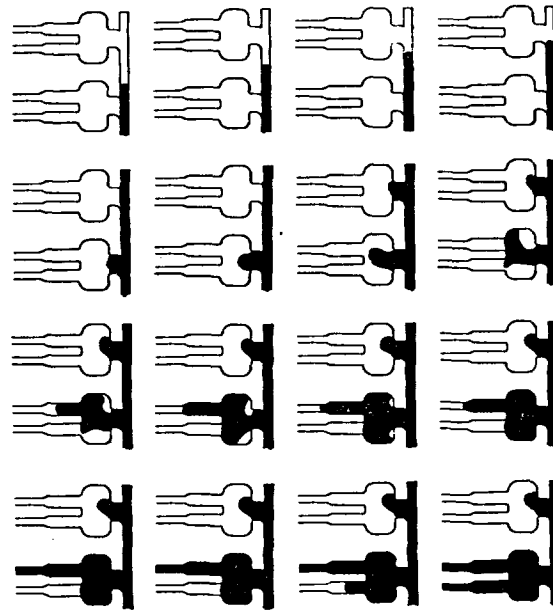


Figure B3 - Diagrams to show the flow of metal in the "high" side of AFS test bar mould when one pair of bars misran. Conditions similar to those in Figures B1, B2.

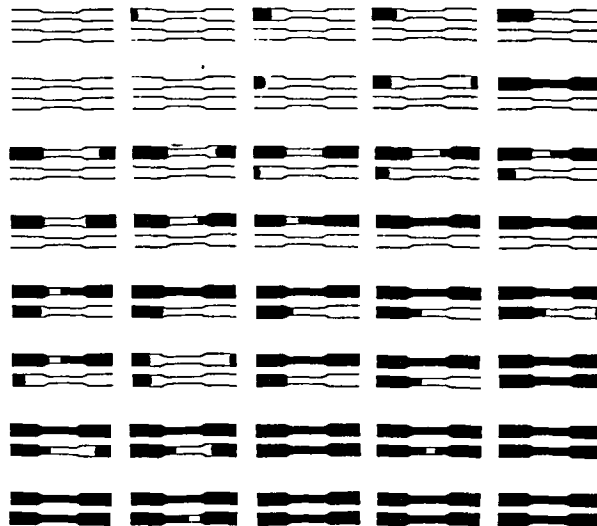


Figure B4 - Flow in bars of AFS test bar mould. Relationship of runner to bars was similar to that in Figures B1 to B3. Every third frame was reproduced so that time interval between diagrams is very approximately 1/5 second.

APPENDIX C

EFFECT OF CHANGES IN MOULDING AND POURING
THE FRENCH TEST BAR

The mould and pouring practice employed for the French test bar in the work described in the main report differed in two respects from normal practice in France. First, Mascré (7) states that a pouring basin is used and second, the height of the cope used in the present work was 4 in. instead of approximately 60 mm (about 2.4 in.) as specified. In order to obtain some information on the effects of these variations, two melts of C4 alloy were made and in each three French test bar castings were poured with the high cope and no pouring basin and three with the lower cope and a baked core sand pouring basin. In addition, two AFS test bar moulds were cast as controls.

The results of chemical analysis of samples taken from the centres of the gauge lengths of bars from each melt are given below.

TABLE C 1

Chemical Analysis Results

| Melt No. | Element, Per Cent | | | | |
|----------|-------------------|------|------|------|------|
| | Cu | Fe | Si | Ti | Mg |
| 568 | 4.45 | 0.37 | 0.81 | 0.13 | 0.03 |
| 569 | 4.36 | 0.36 | 0.81 | 0.15 | 0.03 |

The tensile results obtained (T6 condition) are shown in the Table below; they are mean values obtained from twelve (French) or eight (AFS) bars.

TABLE C 2

Tensile Test Results for Two C4 Alloy Melts

| Melt No. | Type Mould | Ultimate Tensile Strength | | 0.2% Yield Strength, kpsi | Elongation, % on 4 D |
|----------|------------|---------------------------|-----------------------------|---------------------------|----------------------|
| | | Mean, kpsi | Coefficient of Variation, % | | |
| 568 | French A* | 34.6 | 9.0 | 25.8 | 3.6 |
| | French B* | 36.5 | 8.2 | 26.0 | 4.4 |
| | AFS | 41.5 | 3.3 | 26.2 | 8.5 |
| 569 | French A* | 34.7 | 9.2 | 25.9 | 4.0 |
| | French B* | 37.0 | 5.7 | 26.1 | 4.5 |
| | AFS | 43.1 | 3.5 | 27.1 | 8.0 |

* French A - high cope, no pouring basin.
French B - low cope, pouring basin.

It will be seen that the ultimate tensile strength and elongation of the bars poured with a pouring basin and lower cope were higher than those of the other French bars, although still considerably lower than those of the AFS bars. There was also a slight reduction in the variability of the ultimate tensile strength results, although in these melts the variabilities of both types of French bar were high when compared with those of the AFS bars.

It is not possible to predict the effects of these changes in the French bar on its sensitivity to melt quality changes, although the moderate improvement shown in the above results suggests that its behaviour would not be very different from that of the version used in the bulk of the work reported earlier.

PART III

STUDY OF METAL FLOW IN ALUMINUM TEST BAR MOULDS

BY FLUORESCENT SCREEN RADIOGRAPHY

by

W. A. Pollard*

INTRODUCTION

As part of an investigation of aluminum alloy test bar patterns used in various countries⁽¹⁾, molten metal flow in some of the test bar moulds was studied using fluorescent screen radiography. Some early results obtained on the proposed AFS design were reported in an appendix to the paper⁽¹⁾ but a more complete description of the work, which was subsequently extended to cover several other test bar types, is given here.

A previous use of this technique of observing metal flow in moulds was reported by Fry⁽²⁾ who studied the vertical gating of moulds in elevation, that is, the moulds were irradiated horizontally. In the present work the test bars were all poured horizontally so that vertical irradiation had to be used.

Although the radiographic method is somewhat more complex experimentally than alternative methods such as the observation of water flow in plastic moulds, it was thought that the advantage of making direct observations under conditions which duplicated those in the foundry, justified the additional complexity of the method.

* Senior Scientific Officer, Non-Ferrous Metals Section, Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

Paper presented at the 67th Castings Congress, American Foundrymen's Society, held in St. Louis, Mo., May 1963; published in Trans. AFS 71, 296-304 (1963).

EXPERIMENTAL PROCEDURE

Moulding

In order to obtain adequate sensitivity, it was necessary to reduce the thickness of the sand in the moulds to the minimum consistent with the mechanical strength required to withstand handling and the pressure of the molten metal. This was done by replacing the normal green backing sand with approximately 1 in. of sodium silicate-bonded, carbon dioxide-hardened sand, retaining about 3/8 in. thickness of facing sand. The presence of the unusual backing sand did not appear to affect the moisture content and other properties of the facing sand and it is considered that these were very similar to those of a normal mould.

Typical moulds are shown in Figures 1 and 2. As will be seen, a shallow drag section was used. The main reason for this was that the mould cavity should be as near the fluorescent screen as possible in order to minimize loss of definition in the image due to the penumbra effect.

Drawings of the moulds studied are shown in Figures 3 to 7. For the sake of brevity they are referred to as AFS, CSA, German, Dow and French, respectively. The position of the sprue in the CSA mould (Figure 4) made it necessary to add an external trough or runner (see Figure 2), so that the pouring ladle could be held outside the irradiated field.

Apparatus

A diagrammatic sketch of the experimental arrangement is shown in Figure 8. The X-ray machine used was operated at 200 kV and 10 mA and the target-to-screen distance was 28 in. In order to give adequate radiation shielding, 1/8 in. lead sheets were hung round the apparatus in single, double or triple thicknesses, as required. As shown in Figure 8, the image on the fluorescent screen was viewed horizontally by means of an inclined plane mirror. The observations were recorded on 16 mm motion picture film.

Photographic Details

The light intensity of the image on the fluorescent screen was comparatively low, even when the X-ray tube was operated at maximum rating, and it was necessary to use the most sensitive film available (Kodak Royal-X Pan Recording). This material gave a coarse-grained image but was otherwise satisfactory.

The intensity of the image on the fluorescent screen fluctuated with the 60 cycle power supplied to the "self rectifying" X-ray tube used. At most cine frame speeds this resulted in a distracting pulsating effect on the motion picture owing to "beating" between the image intensity fluctuation and the film frame frequency. By adjusting the speed of the camera to give an exposure of $1/30$ sec, two complete X-ray pulses were included in each exposure and the beating was almost entirely eliminated. With the particular camera used, the film frame frequency corresponding to an exposure of $1/30$ sec was 13 frames per second.

RESULTS

General Observations

The sensitivity of the method was too low to observe small variations in thickness of the test bars. However, in general, when the metal stream entered the test bar mould cavity it filled the whole cross-section of the bar, and this was confirmed in bars which were deliberately misrun. Exceptions to this behaviour were noted: (a) in the AFS bar, when the first metal to enter the low end of the bar did so in a relatively shallow stream (see Figure 9), and (b) late in the running of the Dow and French bars, when the grip sections farthest from the sprue were completely filled only after metal had entered the end risers. In each of these cases a noticeable increase in image density could be observed as the section of the bar was filled.

One interesting feature of the metal flow was its hesitant nature. This was particularly noticeable in the motion pictures, especially in the AFS moulds. In many instances the advancing metal stream was stopped momentarily or, in some cases, until met by the stream from the other end of the bar. Presumably, these arrests were due to air entrapment or friction effects. If premature freezing were the cause, one would not expect the metal streams to begin to move again.

The effects of pouring temperature and alloy composition on speed and mode of metal flow were not very marked except when the temperature was so low that the mould was in danger of misrunning. Thus with C4* alloy cast into AFS, CSA and German moulds at 680°C (1255°F), misruns or near misruns (German) were observed. However, even when a "fluid" alloy such as SG70 was cast at a high temperature some hesitancy in the metal flow, as mentioned above, was observed.

AFS Mould

The AFS design (see Figure 3) was tested using three alloys (C4, G10 and SG70) each being poured at several different temperatures. Figure 9 shows a series of "stills" taken from a typical motion picture film (C4 alloy poured at 700°C (1290°F)). (Other series of diagrams showing flow in the AFS mould were given in the Appendix to the earlier report on this subject⁽¹⁾.) In all cases, in this mould, the metal which entered each riser tended to flow first to the side farthest from the sprue. This resulted in the metal entering and, in some instances, filling the bar in each pair farthest from the sprue before the other two bars. This flow pattern was presumably caused by the inertia of the flowing metal and by the asymmetric gate/riser configuration. This was also observed by LaVelle⁽³⁾. The peculiar flow pattern observed in the risers at the lower end of the bars (see Figure 3), in which the outer ends of the risers were empty for a comparatively long period after the bars began to fill, was presumably due to the steeply sloped bases of these risers. This, as mentioned above, was one of the few instances when the test bar cross-section was not completely full.

The metal streams usually met either at the shoulder or in the reduced section of the bar and there was only a slight tendency for the meeting place to be influenced by the slope of the bars as intended by the pattern designer. Thus, in a few casts the junction of the metal streams was in the grip section of the bar at the higher end and, when the streams met in the gauge length, it was more often nearer the higher end and, when the streams met in the gauge length, it was more often nearer the higher end than the lower end of the bar.

The rate of filling of the bars in the AFS mould was the lowest of all the designs studied. This is thought to be a result of resistance to flow in the gates which in this mould are very thin.

* The alloy designations used in this report are according to Canadian Standards Association Code H.1.1-1958.

CSA Mould

A series of stills showing flow in a CSA-type mould (see Figure 4) is given in Figure 10. A pouring trough had to be added to this mould and this unfortunately resulted in asymmetrical pouring and running, so that in most cases the metal streams met closer to the end of the gauge length nearest the pouring position. Reference to Figure 10 also shows that the metal entered the sprue in a thin stream. The symmetry and speed of pouring (allowing the sprue to be kept full) could probably have been improved by plugging the sprue until the pouring trough was full. This was not attempted in the present work. These moulds filled very much more rapidly than the AFS moulds.

German

The German test bar design is shown in Figure 5. Stills from a typical motion picture showing flow in this bar (C4 alloy poured at the recommended (1) temperature for this mould, 750°C (1382°F)) are given in Figure 11. It will be seen that the position of the sprue resulted in the metal streams meeting outside the gauge length in all cases and often very close to the risers at the end farthest from the sprue. The rate of filling of these bars was somewhat slower than that of the CSA mould, but considerably faster than that of the AFS mould.

Dow and French

The Dow and French bars (Figures 5 and 6) are each gated from one end so that the question of the meeting point of the metal streams does not arise. In both moulds the rate of flow was high.

DISCUSSION AND CONCLUSIONS

The results reported above have shown that in the AFS design, the metal streams do not consistently meet at one end of the test bars, as intended. Considering the comparatively slow pouring rate of this mould and the asymmetric flow in the risers, it is suggested that the cross-sectional area of the ingates is too small and that the gates should be increased in thickness.

The desired displacement of the meeting place of the metal streams might be further promoted by modifying the design of the ingate system at the lower ends of the bars. In the present design the metal enters the risers at each end of the bars approximately at the same time because the runners and gates are at the same height. If the gates and runner at the low end of the bars were lowered, the flow into the risers and bars should be significantly advanced on that side of the mould.

The value of the observations of flow in the CSA bar was reduced owing to the asymmetric pouring method. However, the high rate of filling was notable and the pronounced affect of the directional pouring on the meeting place of the metal streams was a little surprising.

The metal flow in the German mould was shown to give pronounced displacement of the metal stream junction towards one end of the bar. This is interesting in view of the generally satisfactory behaviour of this design in the tensile test program previously reported⁽¹⁾. It would suggest that such an asymmetric flow pattern is, in fact, an object worth aiming for.

Finally, it is considered that the fluorescent screen radiographic method of observing metal flow in moulds directly offers advantages when limitations such as mould size, shape, etc., are not exceeded.

ACKNOWLEDGEMENT

The author would like to thank Mr. W. E. Havercroft, Head of the Nondestructive Testing Section, Physical Metallurgy Division, and his assistants for their help in doing the work described.

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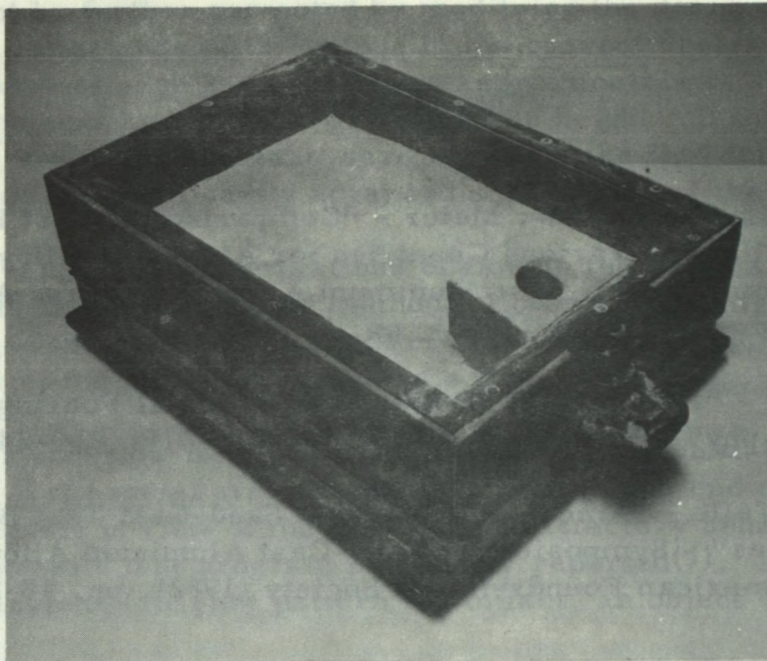


Figure 1. Dow mould showing reduced height of cope and drag.

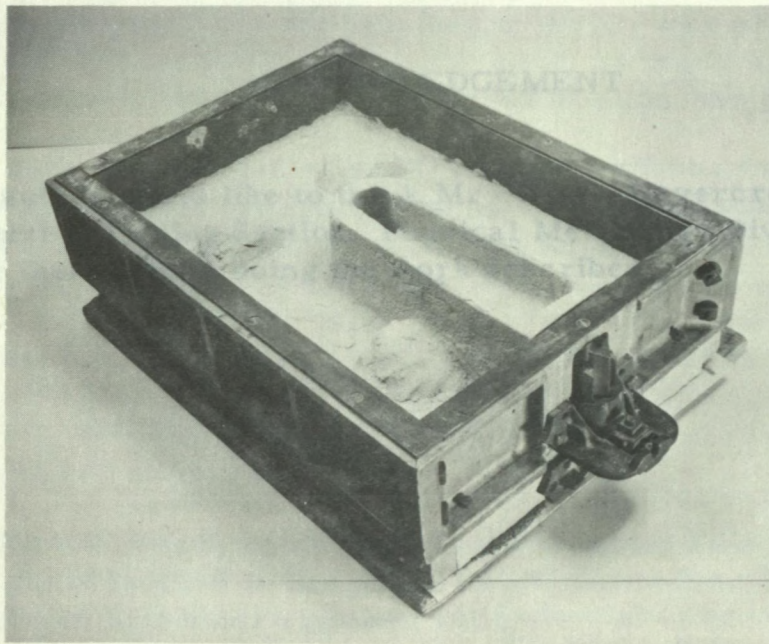


Figure 2. CSA mould showing trough to allow the mould to be poured from one end.

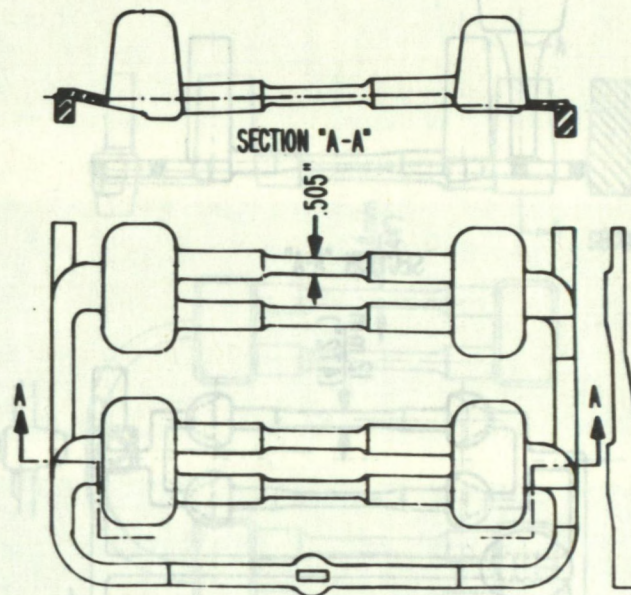


Figure 3. AFS Test Bar Design (proposed in July 1961).

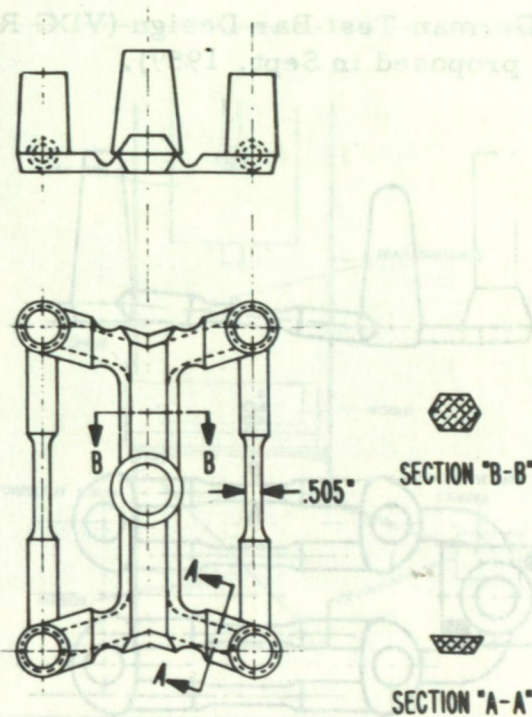


Figure 4. Test Bar Design specified in Canadian Standard CSA.HA.1.3.-1958.

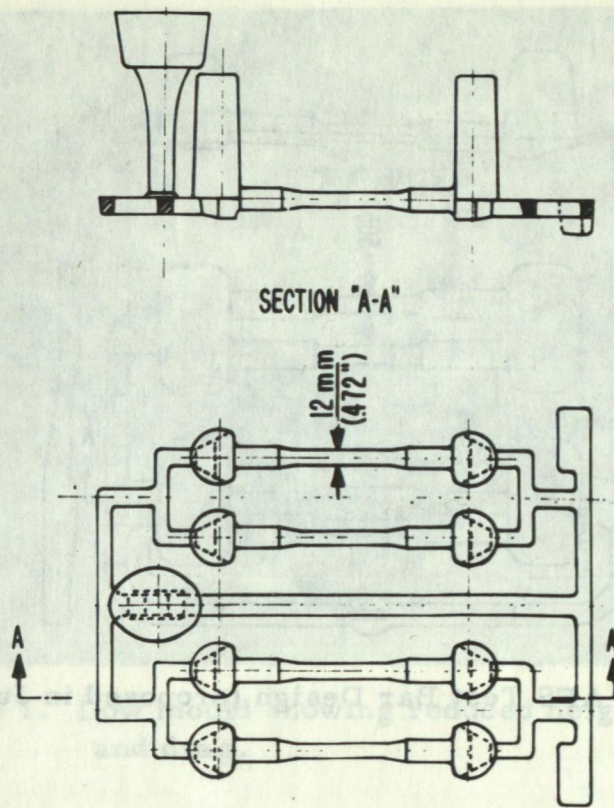


Figure 5. German Test Bar Design (VDG Recommendation proposed in Sept. 1959).

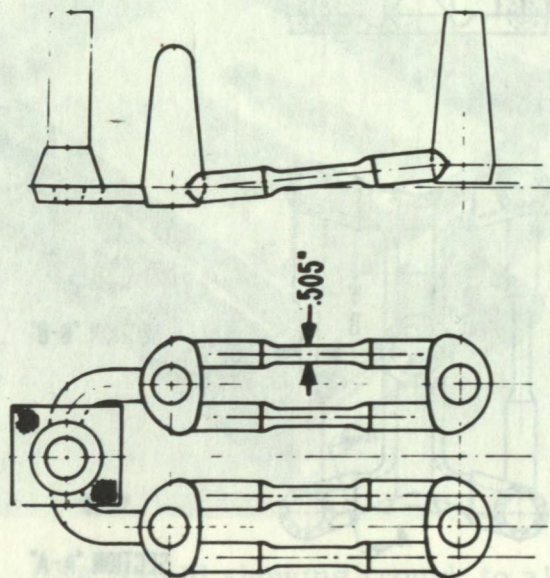


Figure 6. "Dow" test bar (U. S. Federal Specification QQ-M-56).

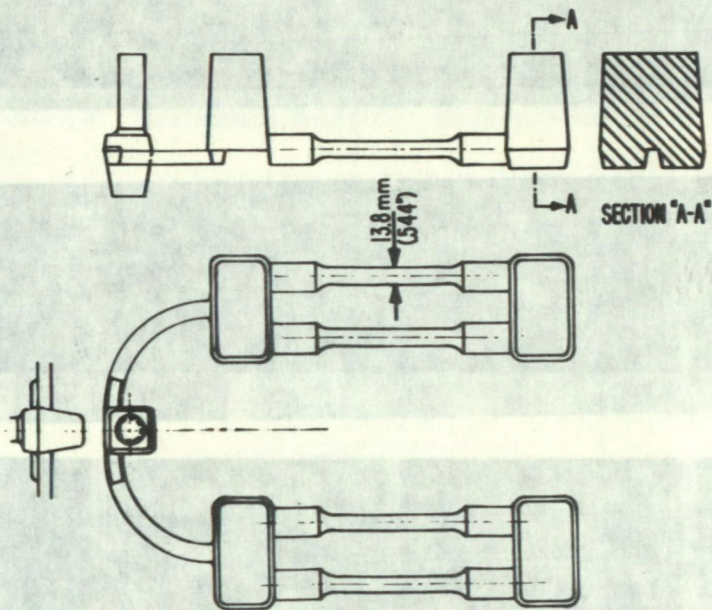


Figure 7. French Test Bar (NF A 57-702, type B).

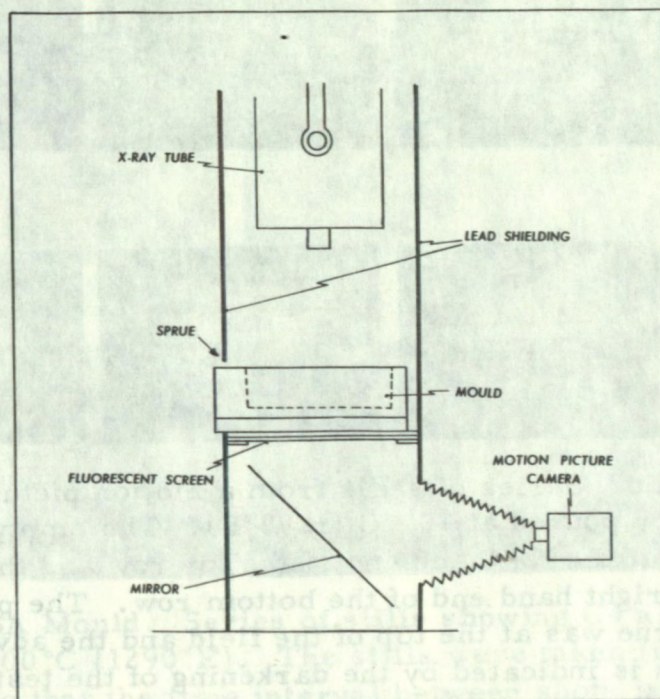


Figure 8. Sketch to show the arrangement of apparatus for fluorescent screen radiography of test bar moulds .

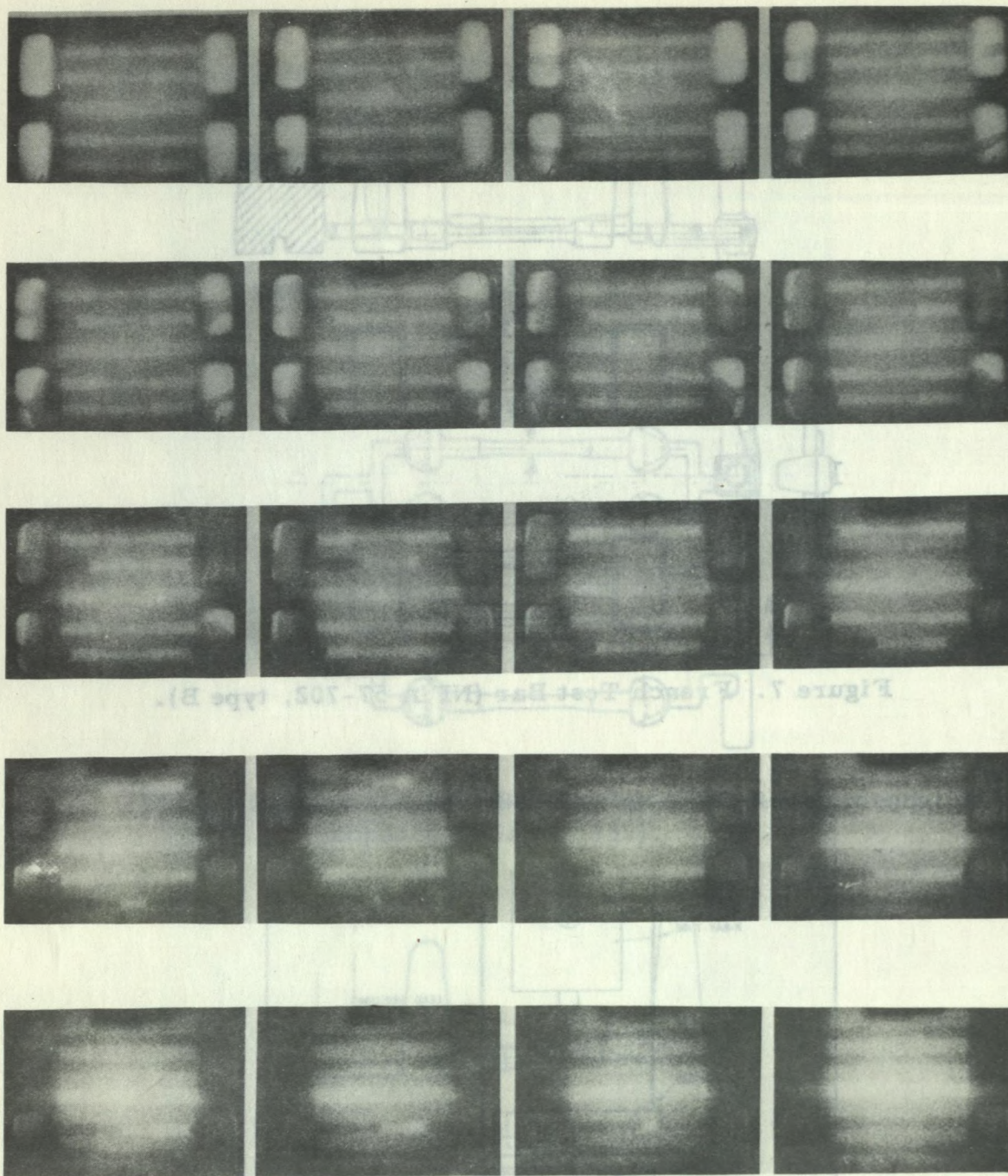


Figure 9. AFS Mould. Series of stills from a motion picture showing C4 alloy poured at 700 °C (1290 °F). The empty mould is shown at the left hand end of the top row and the full mould at the right hand end of the bottom row. The position of the sprue was at the top of the field and the advancing metal stream is indicated by the darkening of the test bar image. The stills were taken from every third frame of the motion picture so that the time interval between shots is approximately 3/13 second.

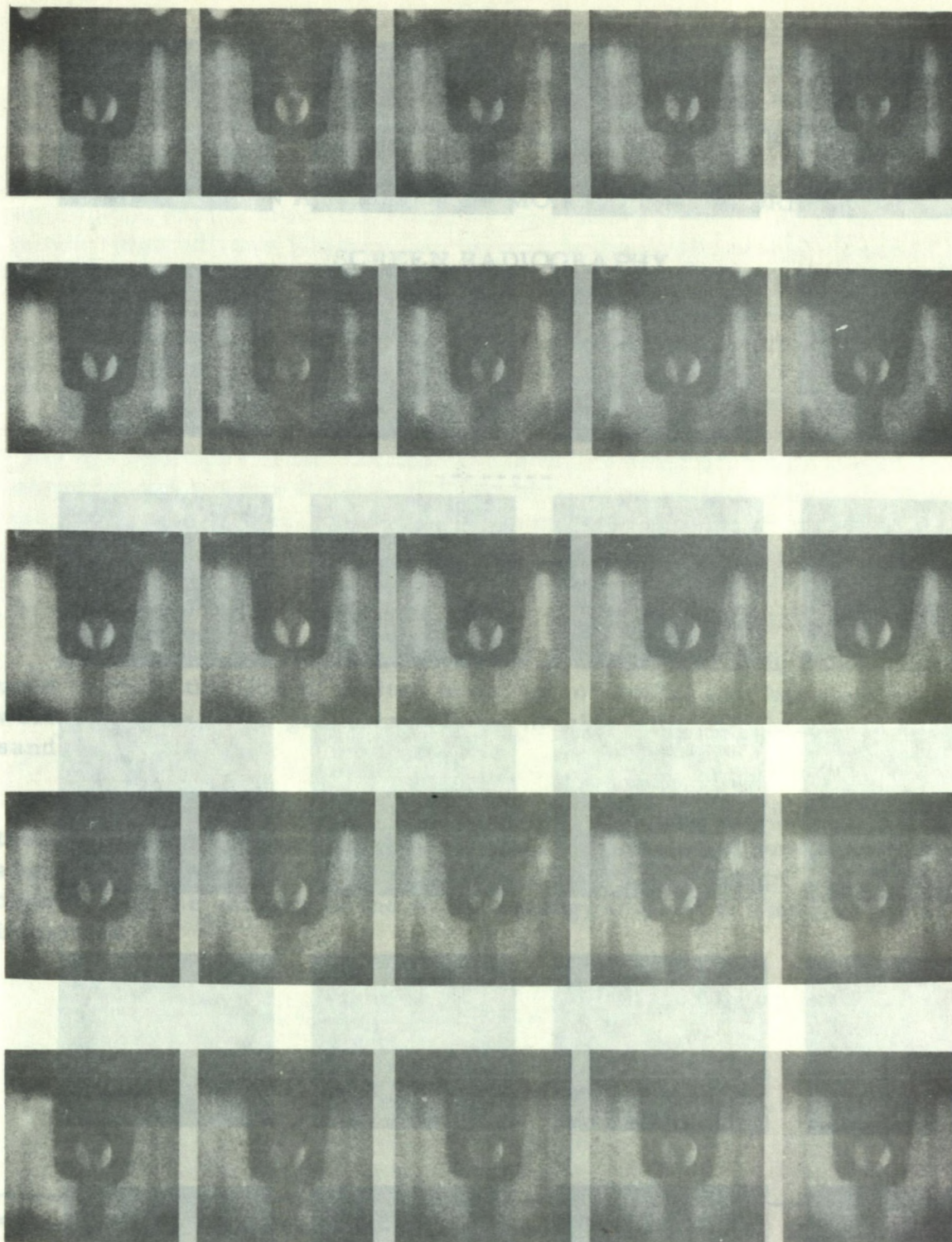


Figure 10. CSA Mould. Series of stills showing C4 alloy poured at 700°C (1290°F). The stills were taken from every frame so that the time interval between shots is approximately $1/13$ second. The metal entered the pouring trough at the top of the field.

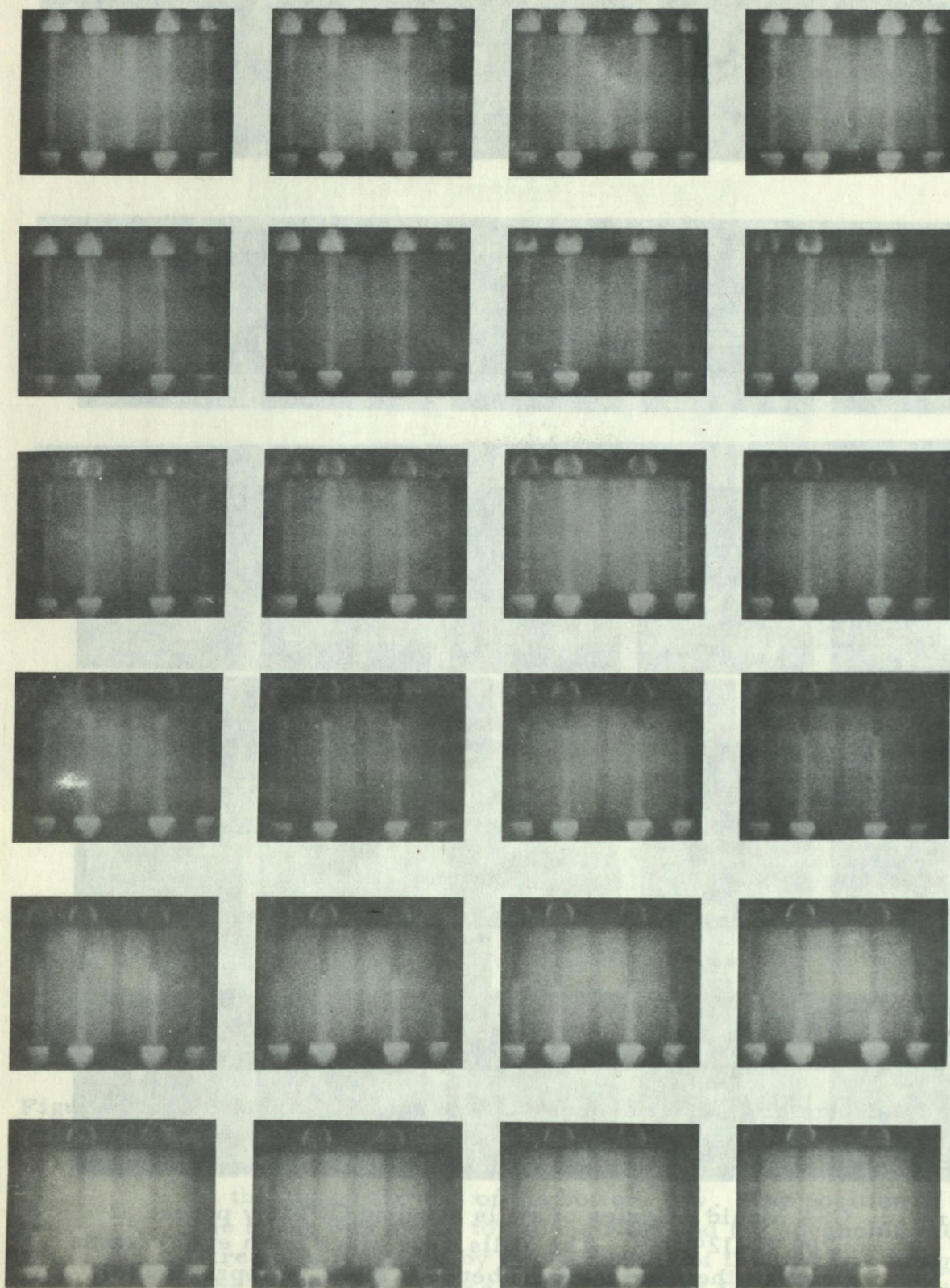


Figure 11. German Mould. Series of stills showing C4 alloy poured at 750°C (1380°F). Stills were taken from every second frame of the motion picture so that the time interval between pictures is about $2/13$ second. The sprue was at the top of the field.

PART IV

COMPARISON BETWEEN THE FLOW OF WATER SOLUTION AND MOLTEN ALUMINUM IN MOULDS BY FLUORESCENT SCREEN RADIOGRAPHY

by

W. A. Pollard*

INTRODUCTION

Recently⁽¹⁾, a fluorescent screen radiographic technique has been used to study the flow of molten metal in horizontal test bar moulds. This work was done using green sand faced moulds with CO₂-hardened backing sand.

A few experiments were also carried out using shell moulds and, in these, a direct comparison could be made between the flow of molten aluminum and that of a water solution. The results are of interest in considering the validity of the water analogy method of studying metal flow in moulds.

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Paper presented at the 68th Castings Congress, American Foundrymen's Society, held in Atlantic City, N. J., May 1964; published in Trans. AFS 72, 887-889 (1964).

EXPERIMENTAL METHOD

The technique of fluorescent screen radiography was the same as that described earlier⁽¹⁾. Briefly, the mould is placed above a fluorescent screen and the system is irradiated vertically from above by X-rays. The image on the screen is recorded on 16 mm cine film as the mould is poured.

The shell moulds were made from pre-coated silica sand (140 AFS) and the halves joined by bolting. It was found that water solutions did not wet the shell mould so that one mould could be used for many experiments by simply tipping the solution out after each pour. The "Dow" mould* design was used in this work.

The aluminum alloy used was C4 (Al-4% Cu) and was poured at 700 °C (1290 °F). In order to obtain adequate X-ray sensitivity, a saturated lead nitrate solution was used instead of water for the comparison tests. The kinematic viscosity of this solution is similar to that of water (i.e., approximately 0.01 stokes) and aluminum. The surface tension is not known, but probably does not exceed that of water by more than about 50%, so that it is still an order of magnitude less than that of molten aluminum. It is therefore considered that the substitution of lead nitrate solution for water does not significantly affect the validity of the comparison with molten metal.

RESULTS AND DISCUSSION

Stills from two representative pours are shown in Figures 1 and 2. As found previously⁽¹⁾, the molten aluminum generally filled the whole cross-section as it entered the test bar cavities. In contrast, the water solution entered the bar cavities in a shallow stream.

* U. S. Federal Specification QQ-M-56 (1950), p. 6, Figure 1A (called here the "Dow" bar because it was introduced by the Dow Chemical Company).

The difference in flow characteristics is probably attributable to the difference between effective surface tensions of the two liquids. It is apparent from the figures that the flow behaviour of the metal could not be predicted, even qualitatively, from that of the water solution.

However it should be emphasized that the present work refers only to the early, transient stage of flow in moulds and is, of course, purely qualitative. There would be less influence of surface tension on flow when the mould channels are running full, so that comparisons between water and molten metal flow would then be more justified. The effects of turbulence and aspiration at corners and abrupt changes in section, which have been shown⁽²⁾ in water analogy experiments, would also be expected to be related to the effective surface tension.

The type of flow shown by the aluminum in the present tests would be expected to be less turbulent and damaging to metal quality than the type of flow shown by the water solution. This would suggest that some of the results obtained by water analogy experiments might have given an exaggerated picture of the deleterious effects of various mould characteristics on metal quality.

REFERENCES

1. W. A. Pollard - "Study of Metal Flow in Aluminum Test Bar Moulds by Fluorescent Screen Radiography" - Trans AFS 71, 296-304 (1963).
2. R. E. Swift, J. H. Jackson and L. W. Eastwood - "A Study of the Principles of Gating" - Trans. AFS 57, 76-88 (1949).

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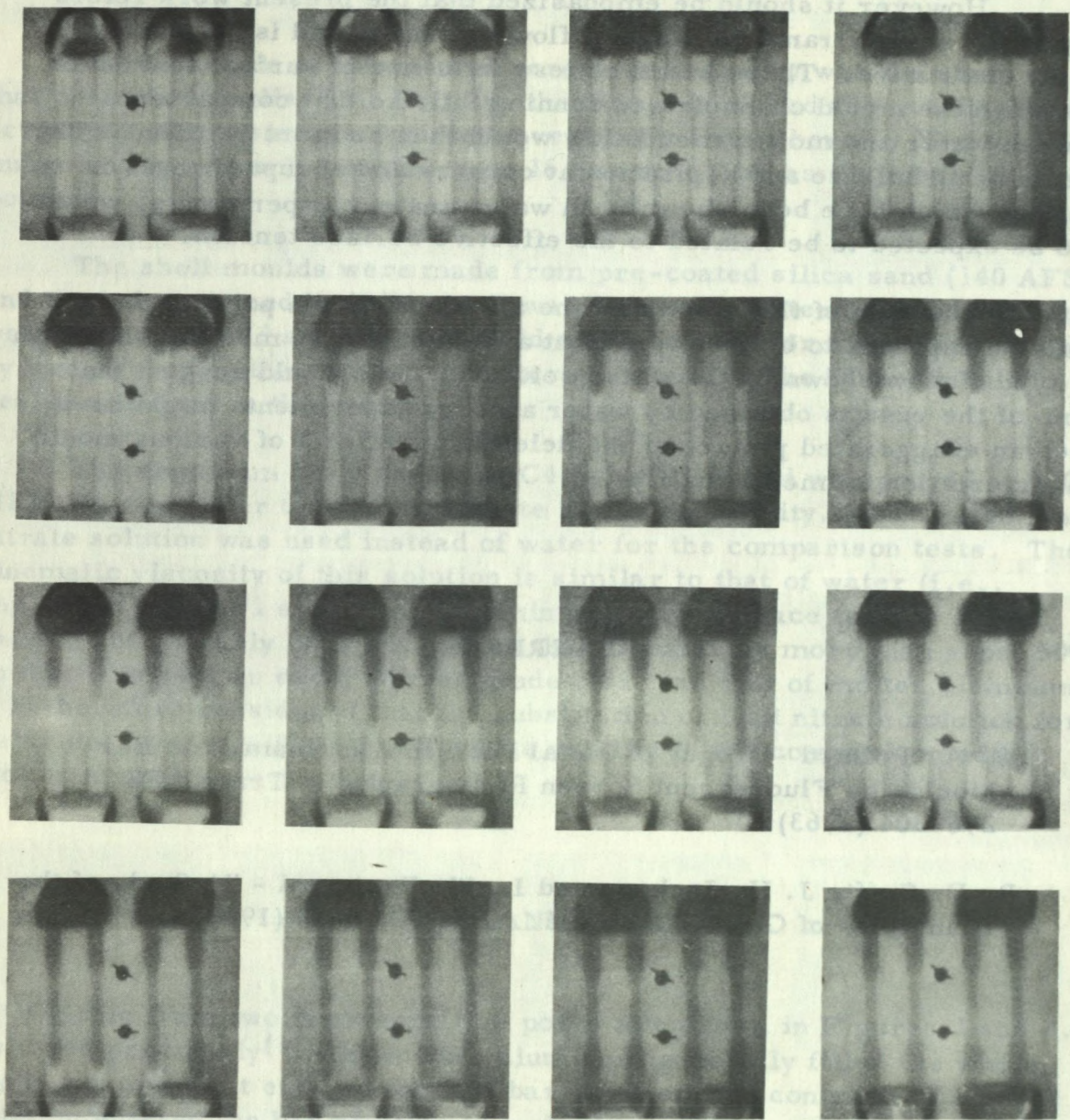


Figure 1. Stills from a cine film showing molten C4 alloy flowing in a Dow test bar shell mould. The interval between successive stills is approximately 3/13 second.

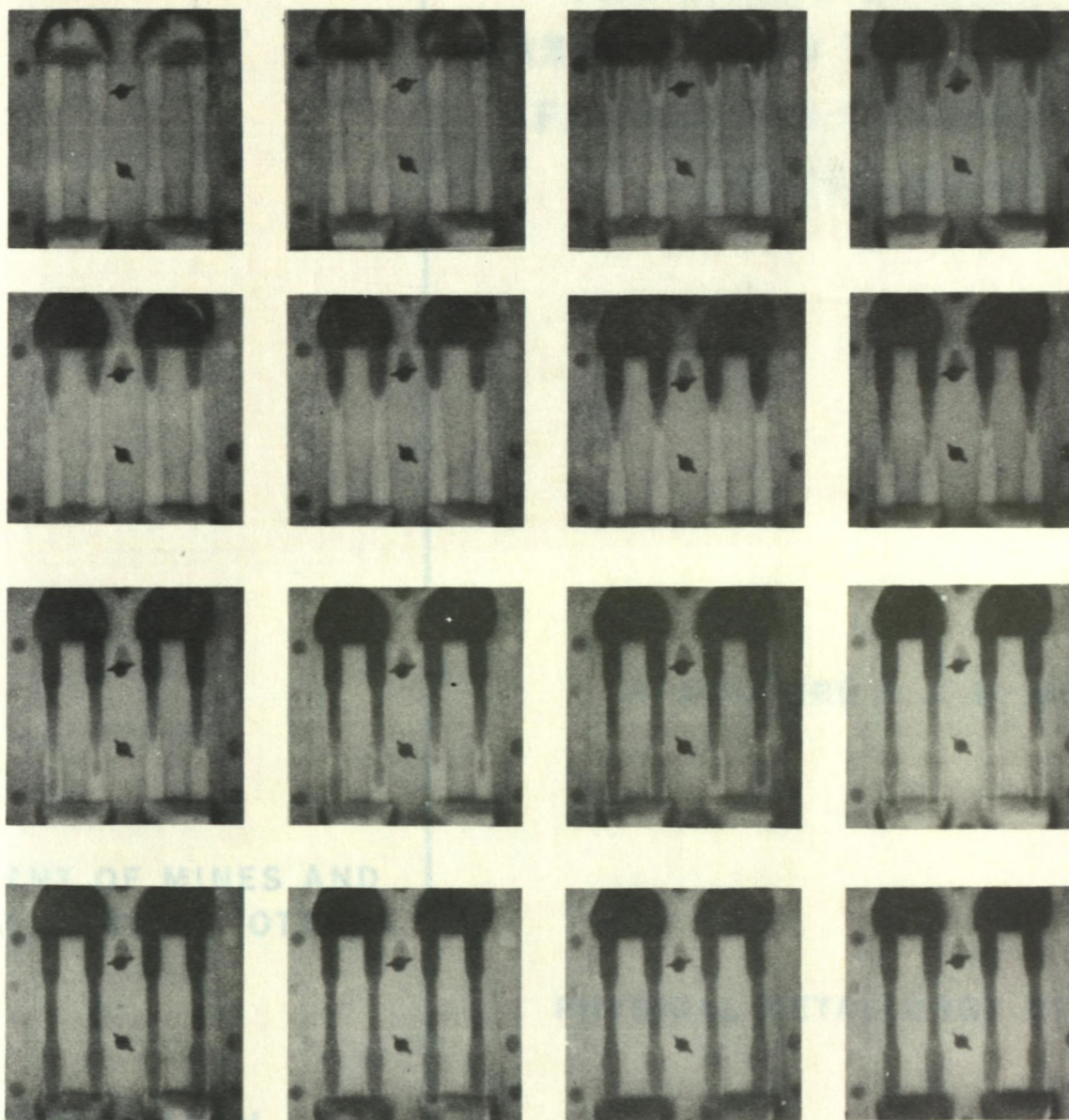


Figure 2. Stills from a cine film showing saturated lead nitrate solution flowing in a Dow test bar shell mould. The interval between successive stills is approximately $3/13$ second.