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INVESTIGATION OF "DOW" TEST BAR DESIGN FOR SAND-CAST MAGNESIUM ALLOYS

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY

An investigation was carried out on some design alterations to the "Dow" test bar for sand-cast magnesium alloys to make it adaptable for use as ISO reference test bar and/or as an AFS Recommended Practice test bar for magnesium foundries in North America.

The design changes included the use of a smaller sprue and lengthening of the test bar, both in the reduced gauge length (for international use with elongation based on gauge lengths equal to 5 times the gauge diameter) and at the grip ends (to ensure better gripping during the tension test and to avoid failure at the grip ends).

A statistically designed and analysed test series showed that differences in the tensile test results obtained on standard "Dow" bars and on redesigned test bars are of no practical significance.

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INTRODUCTION

The investigation of the "Dow" test bar design* for sand-cast magnesium alloys was undertaken at the request of both the

(1) ISO/TC79/WG5** on Mechanical Characteristics of Aluminum and Magnesium Castings, and the
(2) Magnesium Committee, Light Metals Division, American Foundrymen's Society.

ad 1) At the meetings of ISO/TC79/WG5, held in June 1958 in Harrogate and on 21 November 1962 in Paris, it was agreed that any discussions of mechanical properties of light alloy castings must be preceded by the establishment of an ISO reference test bar design and of specified and strictly controlled casting conditions. After considerable discussion it was agreed that the choice of the reference test bar should be based on the following:

(a) cast-to-shape test bar to be used without machining,
(b) gauge diameter (D) of 12-14 mm (0.47 to 0.55 in.),
(c) gauge length equal 5D (60-70 mm, 2.36 to 2.75 in.),
(d) mould design for four test bars,
(e) casting under specified and strictly controlled conditions.

So far as magnesium alloy sand castings are concerned, Mr. P. A. Fisher (representing the United Kingdom) proposed the adoption of the "Dow" test bar, used for many years in most magnesium foundries throughout North America. This proposal was tentatively approved, after the author of this report (representing both Canada and the U.S.A.) agreed to undertake a study of the necessary modifications of the "Dow" test bar design and submit the corrected design for final approval of ISO/TC79/WG5.

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* Test bar according to Canadian Standard CSA.HG.1-1963 and U. S. Federal Specification QQ-M-56b, Figure 1A. The test bar design is referred to as "Dow" test bar because it was introduced, years ago, by the Dow Chemical Company.

** International Organization for Standardization, Technical Committee 79 on Light Metals and their Alloys, Working Group 5.

ad 2) The Executive Committee of the Light Metals Division, American Foundrymen's Society, discussed at its meetings of 20 September 1962 and 18 September 1963 the possibility of establishing an AFS Recommendation for a test bar design for sand-cast magnesium alloys. Mr. K. E. Nelson, Chairman of the Magnesium Committee of the above AFS Division, carried out a survey of test bar practices in various U. S. magnesium foundries. He found that the main complaint was that the "Dow" test bar grips were too short causing, in some cases, failure of test bars (shearing off in the grip section) before the ultimate tensile strength was reached.

Additionally, a difficulty with the original test bar design was encountered and resolved, some years ago, at the foundry of the Mines Branch, Ottawa. The standard "Dow" test bar pattern (see Figure 1) has a 1-1/8-inch diameter sprue. Since no pouring basins were used, it was practically impossible to keep the sprue filled all the time during pouring. The turbulence in the mould was quite extensive and with more difficult alloys - such as ZK61, HK31, EZ33 and ZH62 - difficulties were encountered with test bars having oxide inclusions in the gauge length. The design was, therefore, modified to use a tapered sprue (0.5-inch bottom diameter). The rate of pouring is slow and there is no difficulty in keeping the sprue full, and soundness of test bars is greatly improved. Both the original and the modified "Dow" test bar patterns were used in the present investigation.

In connection with both the ISO/TC79/WG5 and AFS discussions, a short investigation was carried out at these laboratories to check how changes in (a) the gating and risering of the "Dow" bar, and (b) the length of the test bar, would affect the tensile property values of the test bars.

Materials and Experimental Procedures

Alloys and heat treating schedules used in this investigation are listed in Tables 1 and 2.

Materials used for the production of test bars were:

(a) for Zr-containing alloys: Domal 99.98% Mg and Tadanac 99.99% Zn ingots, mischmetal (for alloy EZ33) and Mg-14% Th master alloy (for alloy HK31). Zirconium was introduced in all cases as a fused salt mixture containing 50% $ZrCl_4$ and 25% each KCl and NaCl.

(b) for alloy AZ92: Commercial Domal and Dow alloy ingots.

Standard melting techniques were used; AZ92 alloy melts were grain refined by lampblack additions and degassed by chlorine treatment. Pouring temperatures used were: 760°C (1400°F) for alloys ZK61 and EZ33, 750°C (1380°F) for alloy AZ92, and 740°C (1365°F) for alloy HK31.

Solution heat treatments were carried out in an electrically heated circulating air furnace with an automatically controlled protective atmosphere containing 1% SO_2, the temperature being controlled to $\pm$ 2 °C. Ageing was carried out in an electric oven with air circulation and close temperature control (to $\pm$ 1 °C).

Designations of alloys and tempers used throughout the report are according to Canadian Standard Association's Codes CSA.H.1.1-1958 (alloy designations) and CSA.H.1.2-1958 (temper designations).

Results of ultimate tensile and 0.2% yield strengths are reported in kpsi (1000 psi) and elongations in per cent of gauge lengths equal to 4D or 5D (gauge diameter).

PART I: GATING AND RISERING DESIGN

The first phase of the investigation was carried out to find the effect of small changes in the gating and risering of the standard "Dow" test bars (Figure 1). The following design alterations were studied:

A - Standard "Dow" design, large sprue (1-1/8 in. diameter), full 5-inch high cope.

B - Small sprue (tapered, 1/2-inch at bottom, 3/4-inch at top), height of cope decreased to 4-1/4-inches (see Figure 2).

C - Small sprue, height of cope further decreased to 3-1/2-inches, all 4 risers open.

D - As in "C", but with changed ingates and screen inserted vertically in the ingates.

Three alloys (ZK61-F, EZ33-F, HK31-F) were used in this part of the investigation and the average results of tensile tests obtained on 16 test bars for each alloy and gating design are listed in Table 3.

The original "Dow" design (design "A") has a sprue-to-ingate ratio of 1:0.835, resulting in a pressurized system. Design "B" has a much smaller sprue diameter and the sprue-to-ingate ratio amounts to 1:3.35. This produces a full sprue and consequently non-turbulent flow through the gates and no air aspiration in the sprue. It may be seen from Table 3 that in alloys EZ33 and HK31, both of which are especially sensitive to oxide skin formation, test bars cast to design "A" each showed 4 bars with flaws in the fracture, whereas in design "B" (with smaller sprue) both alloys showed no fracture flaws at all.

Very little difference was found between the results obtained on test bars of designs "B" and "C". Design "D" was found to be entirely unsatisfactory, due to insufficient screen area to allow unrestricted flow, and was, therefore, eliminated.

A statistical evaluation ("t" test) of the tensile test results, presented in Table 3 showed that differences between means for designs "A" and "B" were significant only for the UTS values of ZK61-F (at the 0.05 level), and for UTS and elongation values of HK31-F (at 0.01 level).

As a result of this limited experiment, design B(with small sprue diameter and somewhat lower risers) was chosen for the remainder of the investigation.

PART II: TEST BAR LENGTH (ZK61-T6)

The second phase of the investigation included the following design changes:

1 - Standard "Dow" bar (with small sprue), as shown in Figure 2,

2 - Test bar grips longer by 1/2-inch (each),

3 - Gauge length longer by 1/2-inch,

4 - Grips and gauge length both longer by 1/2-inch (2 + 3),

5 - Gauge diameter 12 mm, gauge length increased by 23/64-inch,

6 - Grips 1/2-inch longer, 12 mm gauge diameter and gauge length increased by 23/64-inch (2 + 5).

For each modification (designs #2 to 6), three melts of 5 moulds were poured, whereby in all cases 2 moulds (8 test bars) were cast with standard "Dow" bars (design 1) and the other 3 moulds (12 test bars) with the changed test bar dimensions. In all, fifteen melts were produced in alloy ZK61 and all 300 test bars were heat treated (T6) and tensile tested.

The average results of all tests are presented in Tables 4 to 8.

Statistical evaluation ("t" test) of the results (comparison of each of the modified designs with the standard design) showed that the only significant differences between standard bars and bars of the modified designs were for the UTS and 0.2% YS results in designs 4 and 5 and that even in these, the level of significance was low.

PART III: TEST BAR LENGTH (AZ92-T6)

The third part of the investigation was undertaken to check if the results of the second part could be repeated using alloy AZ92-T6. To reduce the number of tests, only designs 1, 4 and 6 were compared, which comprise all dimensional changes studied. Five melts were cast, three comparing the standard test bar with design 4 and two melts with design 6.

Heat treatment was carried out (according to recommendation of Dow Chemical Company) as follows: 2 hr from 260 °C (500 °F) to 410 °C (770 °F), 6 hr at 410 °C (770 °F), furnace cooled to 350 °C (665 °F), 2 hr at 350 °C (665 °F), 10 hr at 410 °C (770 °F), airblast cooling, and ageing 16 hr at 177 °C (350 °F).

Tensile test results are listed in Tables 9 and 10. Statistical evaluation ("t" test) of the results (comparison of each of the modified designs with the standard design) showed some significance in the differences between means for the 0.2% YS and elongation (% in 4D) values.

PART IV: STATISTICAL EVALUATION (ZK61-T6)

The results of Parts II and III of this investigation showed that the differences in tensile test results obtained on the standard "Dow" test bar design and on the changed designs, which incorporated longer grips and/or gauge lengths, were significant in few cases only.

To confirm the above conclusions, a statistically designed experiment was carried out to compare all the design changes and, also, to eliminate the possibility of any effect of the sequence of pouring. This part of the investigation was carried out on alloy ZK61-T6 and consisted of six melts with twelve moulds in each melt, comparing six designs (2 moulds in each melt of the same design).

Three of the designs used were the same as those used in Parts I and II of the investigation (designs #1, 4, 6), the others were similar but with grip lengths only 1/4-inch longer (at each end) than the standard design (designs #2A, 4A, 6A). The designs used in Part IV were, therefore, the following:

1 - Standard "Dow" bar (with small sprue) as shown in Figure 2.

2A - Test bar grips longer by 1/4-inch (each).

4 - Grips and gauge length each longer by 1/2-inch.

4A - Grips longer by 1/4-inch and gauge length longer by 1/2-inch.

6 - Grips longer by 1/2-inch, 12 mm gauge diameter and gauge length increased by 23/64-inch.

6A - Grips longer by 1/4-inch, 12 mm diameter and gauge length increased by 23/64-inch.

Table 11 presents all results obtained in the experiment.

The data for UTS, 0.2% YS, and elongation on 4D and 5D, were treated as five 3-factor factorial experiments, the factors being design (6 levels), melts (6 levels) and order of pouring (2 levels). The analysis of variance gave the following results:

Ultimate Strength: Although the design, melt and order variances were all significant when compared with the error variance, the design variance was only of the same order as the melt variance, that is, differences due to design modifications are approximately the same as those obtained between nominally similar melts.

0.2% Yield Strength: Design variances were not significant at the 0.05 level.

Elongation: The design variance was only weakly significant for the 4D elongation (the other non-significant) and the low values given by designs #4, 6A, 6 and 4A may be noted.

Practical foundry considerations showed that the lengthening of the test bars should not exceed approximately 1-inch in total. Since the lengthening of the grip ends by 1/4-inch each was found to be sufficient from the point of view of gripping the bar and avoiding failure in the grips during the tensile test, designs #4 and 6 were discarded. Design #2A had to be discarded also because the gauge length was too short for 5D elongation measurements. The remainder of the statistical analysis was, therefore, carried out only for the three remaining designs (#1, 4A and 6A).

Within-Mould and Within-Melt Variability: Average variances were obtained (by pooling sums of squares) over the six melts and twelve moulds of designs #1, 4A and 6A for UTS, and elongation at 4D and 5D.

For UTS, design #6A gave significantly lower variabilities (both within-mould and within-melt at 0.05 level) than the other two designs.

For elongation at 4D, differences between within-mould variances were not significant (below 0.05), but the within-melt variance of design #1 was significantly higher than that for the other two designs.

For elongation at 5D, the variance (both within-mould and within-melt) of design #4A was generally lower than the other two designs.

To sum up, within the limitations of these tests it would seem that design #4A would give the highest level of tensile properties and, with the exception of the UTS results, the lowest within-mould and within-melt variability of the designs tested.

Since also from the foundry point of view it is easier to cast the somewhat (0.7 mm) larger gauge diameter bar, it was decided to propose the choice of design #4A as the final redesign of the "Dow" bar.

PART V: FINAL EVALUATION (AZ92, EZ33, ZK61)

The results of the first four parts of the investigation were discussed at a meeting held by some members of ISO/TC79/WG5 attending the 68th Casting Congress of the American Foundrymen's Society in Atlantic City, N. J., in May 1964. Present were Messrs. P. A. Fisher, Magnesium Elektron Ltd., (representing the United Kingdom at WG5), K. E. Nelson, Dow Chemical Company (representing the U.S.A.), and B. Lagowski and J. W. Meier (representing Canada). It was agreed to add an additional experiment which would repeat the comparison of the most successful design modifications for three alloys. The alloys, which were chosen to represent different characteristics, were as follows: AZ92 (low elongation), EZ33 (sensitivity to oxide formation) and ZK61 (high strength and high elongation).

The experiment included, therefore, three alloys, four melts for each alloy and twelve moulds in each melt. The first and twelfth mould were considered as control test bars and were, therefore, cast in the standard "Dow" design (#1), the other moulds were cast alternatively to designs #4A and 6A (five moulds to each design in each melt).

The results of the tensile tests are listed in Tables 12 to 14.

Statistical analysis of the data resulted in the following comparison of test bar designs on the basis of within-mould and within-melt variances:

The within-melt and within-mould variances were calculated for each property (UTS, 0.2% YS, El at 4D and 5D), each alloy and each melt.

The variances thus obtained were then averaged (weighting according to degrees of freedom) over the six melts in each condition. The significance of differences between variances was then estimated by applying the variance ratio test to pairs. The coefficients of variation for each condition using the average variances and the overall mean for each group of six melts are summarized in Table 15.

It will be seen that the most significant differences between variances of bar types were obtained for the ZK61 results. For the ultimate tensile strength the standard (design #1) test bar has lower variability than the other two designs, whereas in the elongation, design #4A (and in some cases design #6A) shows lower variability than the standard design.

In the EZ33 alloy only the yield strength results show significant differences and for these design #4A has the lowest variability.

For AZ92 alloy there was a trend (in yield strength and to some extent in elongation at 5D) for design #6A to have significantly lower variability than the other designs.

No overall trend is shown by the results if all alloys are considered.

In general, the results of Part V are similar to those of Part IV, and the conclusion reached to propose design #4A as the final redesign is upheld.

CONCLUSIONS

1. This limited scale investigation on the design of the "Dow" test bar for sand-cast magnesium alloys showed that

(a) a smaller sprue,

(b) a gauge length longer by 1/2-inch, to enable the use of elongation measurements based on a gauge length equal to 5 gauge diameters, and

(c) longer (by 1/4-inch each side) grip ends, to ensure a better grip of the test bar and avoid shearing off at the ends during the test, have no significant effect on the results of the test bars.

2. It is, therefore, proposed to submit to Magnesium Elektron Ltd., the revised test bar design (Figure 3) for further study and, if British industrial try-outs are successful, to submit it to ISO/TC79/WG5 for approval as ISO reference test bar for sand-cast magnesium alloys.

3. It is proposed to the Chairman of the Magnesium Committee, Light Metals Division, American Foundrymen's Society, to submit the revised design (Figure 2) to the Executive Committee of the Light Metals Division, AFS, for approval as an AFS Recommended Practice.

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TABLE 1

Nominal Compositions of Magnesium Casting Alloys

Alloy	Al %	Zn %	Mn %	R.E. %	Th %	Zr (sol) %
AZ92	9	2	0.3	-	-	-
EZ33	-	3	-	3	-	0.7
HK31	-	-	-	-	3	0.7
ZK61	-	6	-	-	-	0.8

TABLE 2

Heat Treating Schedules

	Solution Heat Treatment			Ageing		
	Temperature		Time	Temperature		Time
Alloy	°C	°F	hr	°C	°F	hr
AZ92-T6	410	770	20*	175	350	16
EZ33-T5	-	-	-	170	340	10
HK31-T6	565	1050	2	205	400	16
ZK61-T6	500	930	2	130	265	48

* 2 hr 260°C to 410°C, 6 hr at 410°C, 2 hr at 350°C, 10 hr at 410°C.
All alloys cooled from solution temperature in air blast.

TABLE 3

Comparison of Tensile Properties of Test Bars of Various Gating Designs

Alloy	Sprue Design	Ultimate Tensile Strength, kpsi				Elongation, % in 2 in.				Number of rejected bars	
		max	min	ave	Standard deviation	max	min	ave	Standard deviation	Flaws in fracture	Misrun
ZK61-F	A	39.7	37.2	38.4	0.765	12.0	7.5	9.7	1.388	1	0
	B	40.6	37.6	39.0	0.955	12.0	8.5	10.0	1.540	1	0
	C	41.6	37.6	39.2	0.933	14.0	8.0	10.5	1.705	2	0
	D	40.5	36.2	38.5	1.460	12.0	7.0	9.8	1.570	0	2
EZ33-F	A	26.1	21.0	23.8	1.490	6.0	3.0	4.7	0.962	4	0
	B	25.7	22.4	23.9	0.990	6.5	3.0	4.4	0.860	0	0
	C	26.5	22.4	24.2	1.440	7.0	3.0	4.6	1.240	1	0
	D	26.8	23.2	24.7	1.227	6.5	3.5	5.1	0.930	1	6
HK31-F	A	23.8	20.9	22.9	0.784	12.0	6.0	9.0	1.645	4	0
	B	24.6	22.9	23.8	0.570	12.0	9.0	10.4	0.880	0	2
	C	24.7	23.1	23.9	0.500	12.0	9.0	10.5	0.886	0	2

TABLE 4

Comparison of Tensile Test Results of Alloy ZK61-T6 (Part II)

Design No.		UTS, kpsi	0.2% YS, kpsi	El, % in 4D
1	max	46.5	33.6	10.0
(3 bars with flaws	min	44.3	29.6	5.5
	ave (8)	45.4	31.0	7.5
	St.d*	0.760	1.020	1.422
2	max	47.5	33.6	9.5
(11 bars with flaws)	min	43.0	29.6	5.0
	ave (12)	45.4	31.2	7.0
	St.d	0.984	0.929	1.142
Significant at level		N.S.**	N.S.	N.S.

* standard deviation.
** not significant at 0.05 level.

TABLE 5

Comparison of Tensile Test Results of Alloy ZK61-T6 (Part II)

Design No.		UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D
1	max	47.5	33.6	10.5	9.0
(3 bars with flaws)	min	43.6	29.2	5.5	3.0
	ave (8)	45.8	31.1	7.5	6.5
	St.d*	0.950	1.237	1.322	1.342
3	max	48.2	34.2	11.5	11.0
(3 bars with flaws)	min	44.1	29.6	5.0	4.0
	ave (12)	46.2	31.6	7.5	7.0
	St.d	1.160	1.465	1.702	1.721
Significant at level		N.S.**	N.S.	N.S.	N.S.

* standard deviation
** not significant at 0.05 level.

TABLE 6

Comparison of Tensile Test Results of Alloy ZK61-T6 (Part II)

Design No.		UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D
1	max	48.0	34.3	13.5	13.0
(2 bars with flaws)	min	45.5	32.1	6.5	5.0
	ave (8)	46.7	32.9	9.5	8.0
	St.d*	0.574	0.533	1.798	2.060
4	max	47.3	33.5	12.5	11.0
(6 bars with flaws)	min	45.2	31.5	5.5	5.0
	ave (12)	46.6	32.8	8.5	7.5
	St.d	0.565	0.596	1.790	1.640
Significant at level		N.S.**	0.1	N.S.	N.S.

* standard deviation
** not significant at 0.05 level.

TABLE 7

Comparison of Tensile Test Results of Alloy ZK61-T6 (Part II)

Design No.		UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D
1	max	47.7	34.0	12.0	11.0
(4 bars with flaws)	min	45.4	31.1	6.5	6.0
	ave (8)	46.6	32.4	10.0	8.5
	St.d*	0.639	0.641	1.840	1.485
5	max	48.6	36.1	13.5	10.0
(6 bars with flaws)	min	46.0	31.7	6.0	5.5
	ave (12)	47.4	33.3	9.5	8.0
	St.d	0.700	0.994	1.480	1.275
Significant at level		0.001	0.001	N.S.**	N.S.

* standard deviation
** not significant at 0.05 level.

TABLE 8

Comparison of Tensile Test Results of Alloy ZK61-T6 (Part II)

Design No.		UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D
1 (5 bars with flaws)	max	48.3	34.7	12.5	10.5
	min	46.0	31.7	6.5	6.0
	ave (8)	47.0	33.1	9.0	8.0
	St.d*	0.690	0.792	0.770	1.190
6 (9 bars with flaws)	max	48.3	36.0	13.0	12.5
	min	45.7	31.7	6.0	5.0
	ave (12)	47.2	33.0	9.0	8.0
	St.d	0.747	0.864	1.451	1.628
Significant at level		N.S.**	N.S.	N.S.	N.S.

* standard deviation

** not significant at the 0.05 level.

TABLE 9

Comparison of Tensile Test Results of Alloy AZ92-T6 (Part III)

Design No.		UTS, kpsi	0.2 % YS, kpsi	El, % in 4D	El, % in 5D
1	max	47.9	26.6	4.5	-
(6 bars with flaws)	min	43.9	24.1	2.5	-
	ave (24)	46.0	25.4	3.5	-
	St.d*	1.10	0.750	0.590	-
4	max	48.0	26.7	4.0	3.5
(6 bars with flaws)	min	42.7	23.0	2.5	1.5
	ave (36)	45.5	24.9	3.0	2.5
	St.d	1.372	0.935	0.338	0.575
Significant at level		N.S.**	0.05	0.02	-

* standard deviation
** not significant at 0.05 level.

TABLE 10

Comparison of Tensile Test Results of Alloy AZ92-T6 (Part III)

Design No.		UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D
1	max	47.0	25.8	4.0	3.0
(2 bars with flaws)	min	42.9	23.6	3.0	1.0
	ave (16)	45.1	24.8	3.5	2.0
	St.d*	1.192	0.655	0.412	0.462
6	max	49.2	26.0	4.0	4.0
(6 bars with flaws)	min	42.0	24.1	2.0	1.0
	ave (24)	45.6	25.2	3.0	2.5
	St.d	1.39	0.476	0.629	0.83
Significant at level		N.S.**	0.05	0.05	N.S.

* standard deviation
** not significant at 0.05 level.

TABLE 11

Comparison of Tensile Test Results of Alloy ZK61-T6 (Part IV)

Design No.		UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D
1	max	47.8	33.7	15.0	12.5
	min	44.9	30.1	7.0	4.5
	ave (40)**	46.5	31.5	10.6	8.5
	St.d*	0.69	0.84	2.12	1.88
2A	max	48.1	34.5	15.0	12.0
	min	45.4	30.3	7.0	6.0
	ave (40)	46.6	31.9	10.3	8.3
	St.d	0.65	0.90	2.01	1.76
4	max	47.2	33.3	14.0	12.0
	min	44.5	30.1	7.0	5.0
	ave (34)	46.0	31.5	9.0	8.4
	St.d	0.75	0.83	1.70	1.60
4A	max	48.2	34.0	14.0	11.0
	min	45.7	30.1	7.0	6.0
	ave (43)	46.9	32.0	10.0	8.1
	St.d	0.67	0.99	1.71	1.63
6	max	47.6	33.9	13.0	12.5
	min	44.9	29.8	5.0	4.5
	ave (37)	46.2	31.5	9.0	9.1
	St.d	0.73	0.89	1.71	1.70
6A	max	47.3	33.0	15.0	14.0
	min	45.2	30.0	7.0	5.5
	ave (35)	46.3	31.5	9.7	9.0
	St.d	0.62	1.01	1.59	1.67

* standard deviations in this table were computed from all the results for each design and therefore include between-melt variability (cf. Tables 13, 14, 15).

** number of test results after rejecting test bars with flaws.

TABLE 12

Comparison of Tensile Test Results of Alloy AZ92-T6 (Part V)

Melt No.		Design 1 (Standard)				Design 4 A				Design 6 A			
		UTS, kpsi	0.2% YS kpsi	El, % in 4D	El, % in 5D	UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D	UTS, kpsi	0.2% YS kpsi	El, % in 4D	El, % in 5D
UB	max	42.3	24.4	4.0	3.0	45.3	25.0	3.0	2.5	48.3	25.0	4.0	3.0
	min	36.4	21.0	1.0	1.0	37.9	22.3	1.5	1.5	36.7	21.9	1.0	0.5
	ave	(8) 39.3	23.1	2.2	1.8	(20) 41.5	23.5	2.3	1.8	(20) 42.2	23.6	2.4	2.0
UC	max	46.6	24.9	4.0	3.5	47.8	25.9	3.5	3.0	46.1	24.5	3.5	3.0
	min	42.3	23.6	2.5	2.0	42.6	22.1	2.0	1.5	40.2	22.8	1.0	1.0
	ave	(7) 44.1	24.4	32.2	2.8	(19) 45.2	24.3	2.7	2.5	(18) 43.0	23.6	2.7	2.0
UD	max	45.8	24.5	4.5	4.0	45.9	25.2	6.0	5.5	45.8	24.9	4.5	3.5
	min	39.8	21.7	2.5	2.0	40.2	22.9	1.0	0.5	39.6	22.0	1.5	1.0
	ave	(8) 43.9	23.4	3.5	3.0	(20) 43.4	23.9	2.9	2.5	(19) 42.9	23.4	3.0	2.0
UE	max	42.8	23.7	3.5	2.5	46.5	25.4	4.0	3.5	45.5	24.3	4.0	3.5
	min	41.2	21.8	2.0	1.5	41.7	21.8	2.0	1.5	40.0	22.7	1.5	1.0
	ave	(6) 42.1	22.9	2.4	2.0	(20) 43.8	24.0	2.9	2.2	(18) 42.6	23.5	2.7	1.9
Total of 4 melts	max	46.6	24.9	4.5	4.0	47.8	25.9	6.0	5.5	48.3	25.0	4.5	3.5
	min	36.4	21.0	1.0	1.0	37.9	21.8	1.0	0.5	36.7	21.9	1.0	0.5
	ave	(29) 42.3	23.5	3.0	2.5	(79) 43.5	23.9	3.0	2.0	(75) 42.7	23.5	2.5	2.0
	St.d*	2.18	0.89	0.71	0.59	1.78	0.82	0.73	0.77	2.08	0.69	0.67	0.73

*Within Melt Averages obtained from pooled "within-melt" variances.

TABLE 13

Comparison of Tensile Test Results of Alloy EZ33-T5 (Part V)

Melt No.	Design 1 (Standard)				Design 4A				Design 6A			
	UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D	UTS, kpsi	0.2% YS kpsi	El, % in 4D	El, % in 5D	UTS, kpsi	0.2% YS kpsi	El, % in 4D	El, % in 5D
TX max	25.2	18.1	5.0	4.0	28.8	19.7	5.0	4.5	25.0	18.8	5.0	4.0
min	21.0	16.9	2.5	2.0	20.8	17.7	2.0	1.5	21.4	17.3	2.0	1.5
ave	(8) 23.7	17.4	3.6	3.3	(20) 24.9	18.6	3.5	3.3	(20) 23.8	18.2	3.1	3.0
TY max	25.7	18.7	5.0	4.5	26.5	19.0	6.0	5.0	28.3	19.9	5.0	4.5
min	24.1	16.8	3.0	2.5	24.2	17.3	3.5	2.5	24.1	17.0	3.0	2.5
ave	(8) 25.0	17.5	4.3	3.8	(20) 25.7	18.0	4.7	3.8	(20) 25.5	18.0	4.1	3.6
TZ max	26.6	17.8	6.0	5.5	27.5	18.7	5.5	5.0	28.0	18.6	6.0	5.5
min	24.7	16.7	4.0	3.0	24.7	17.5	3.5	2.5	24.6	17.6	3.5	2.5
ave	(8) 25.5	17.3	5.0	4.1	(20) 26.1	18.1	4.5	3.7	(20) 26.2	18.2	4.9	4.7
UA max	28.0	18.6	6.0	5.0	28.3	18.4	8.0	6.5	27.6	19.3	6.0	5.5
min	25.1	17.4	4.5	3.5	26.4	17.3	4.0	3.0	24.1	17.5	3.0	2.0
ave	(8) 26.1	17.8	5.0	4.3	(20) 27.1	17.9	5.3	5.0	(20) 26.2	18.0	4.9	4.3
Total max	28.0	18.7	6.0	5.5	28.8	19.7	8.0	6.5	28.3	19.9	6.0	5.5
of 4 min	21.0	16.7	2.5	2.0	20.8	17.3	2.0	1.5	21.4	17.0	2.0	1.5
melts ave	(32) 25.0	17.5	4.5	4.0	(80) 25.9	18.2	4.5	4.0	(80) 25.4	18.1	4.5	3.9
St.d*	0.89	0.44	0.71	0.83	1.10	0.37	0.75	0.69	1.14	0.60	0.75	0.85

* Within Melt Averages obtained from pooled "within-melt" variances.

TABLE 14

Comparison of Tensile Test Results of Alloy ZK61-T6 (Part V)

Melt No.		Standard Design (1)				Design 4 A				Design 6A			
		UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D	UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D	UTS, kpsi	0.2% YS, kpsi	El, % in 4D	El, % in 5D
TT	max	48.2	33.4	15.5	13.0	47.6	34.0	13.5	11.0	46.8	34.6	14.0	12.5
	min	46.3	32.2	9.0	8.0	44.7	31.5	7.5	6.5	44.4	30.8	7.5	6.5
	ave	(8) 47.4	32.9	12.3	10.1	(20) 46.6	32.6	10.3	8.9	(17) 45.6	31.8	10.3	9.6
TU	max	46.1	32.1	12.5	10.5	46.9	33.6	12.0	10.0	49.9	32.8	12.0	11.0
	min	44.1	30.6	7.5	6.5	44.1	30.0	6.0	4.5	43.4	30.2	7.5	7.0
	ave	(8) 45.5	31.3	10.6	9.0	(18) 45.5	32.1	9.0	7.6	(16) 45.4	31.6	9.5	9.2
TV	max	45.9	32.6	14.0	11.0	46.8	33.6	13.0	11.5	46.0	32.8	13.5	13.0
	min	44.1	30.0	7.0	6.5	41.3	30.8	7.0	6.5	43.6	29.4	6.5	6.0
	ave	(7) 45.0	31.3	11.5	9.8	(15) 45.3	32.1	9.5	9.1	(13) 44.7	31.2	10.0	9.4
TW	max	45.5	32.2	14.0	12.5	45.6	32.6	12.0	11.5	48.5	32.2	12.0	11.0
	min	43.4	29.4	7.0	6.5	43.6	30.1	5.0	4.5	42.4	29.6	5.5	5.0
	ave	(7) 44.6	30.7	9.6	8.8	(16) 44.9	31.3	8.4	8.0	(15) 44.3	31.3	8.5	8.4
Total	max	48.2	33.4	14.0	13.0	47.6	34.0	13.5	11.5	49.9	34.6	14.0	12.5
of 4	min	43.4	29.4	7.0	6.5	41.3	30.0	5.0	4.5	42.4	29.4	5.5	5.0
melts	ave	(30) 45.6	31.5	11.0	9.45	(69) 45.7	32.1	9.5	8.4	(61) 45.1	31.5	9.6	9.1
	St.d*	0.71	0.74	2.45	2.14	0.91	0.77	1.64	1.45	1.26	0.85	1.76	1.90

*Within Melt Averages obtained from pooled "within-melt" variances.

TABLE 15

Statistical Evaluation of Tensile Test Results (Part V)

Alloy	Property	Within Mould						Within Melt					
		Coefficient of Variation, %			Significance (F test)			Coefficient of Variation, %			Significance (F test)		
		1	4A	6A	1 and 4A	1 and 6A	4A and 6A	1	4A	6A	1 and 4A	1 and 6A	4A and 6A
ZK61	UTS	1.53	1.95	2.33	S*	S	-	1.56	2.00	2.79	-	S	S
	YS	1.55	2.31	2.76	S	S	-	2.35	2.40	2.69	-	-	-
	El 4D	21.4	15.6	18.7	S	S	-	22.1	17.4	18.3	S	S	-
	El 5D	23.2	16.0	21.5	S	-	S	23.7	17.3	20.9	S*	-	S*
AZ92	UTS	4.49	4.06	4.41	-	-	-	5.15	4.07	4.87	-	-	-
	YS	3.96	3.55	2.55	-	S	S	3.79	3.43	2.93	-	-	S
	El 4D	25.3	27.5	24.4	-	-	-	25.3	26.6	24.7	-	-	-
	El 5D	25.3	32.2	33.2	-	-	-	24.1	34.5	36.7	S*	-	-
EZ33	UTS	2.84	3.82	4.21	S	S	-	3.56	4.23	4.48	-	-	-
	YS	2.00	1.55	2.43	-	-	S	2.51	2.05	3.32	-	-	S
	El 4D	15.3	15.3	15.8	-	-	-	15.8	16.7	16.7	-	-	-
	El 5D	19.1	18.4	19.6	-	-	-	20.7	17.3	21.9	-	-	S*

S* = 0.1 S = significant at <0.1 level.

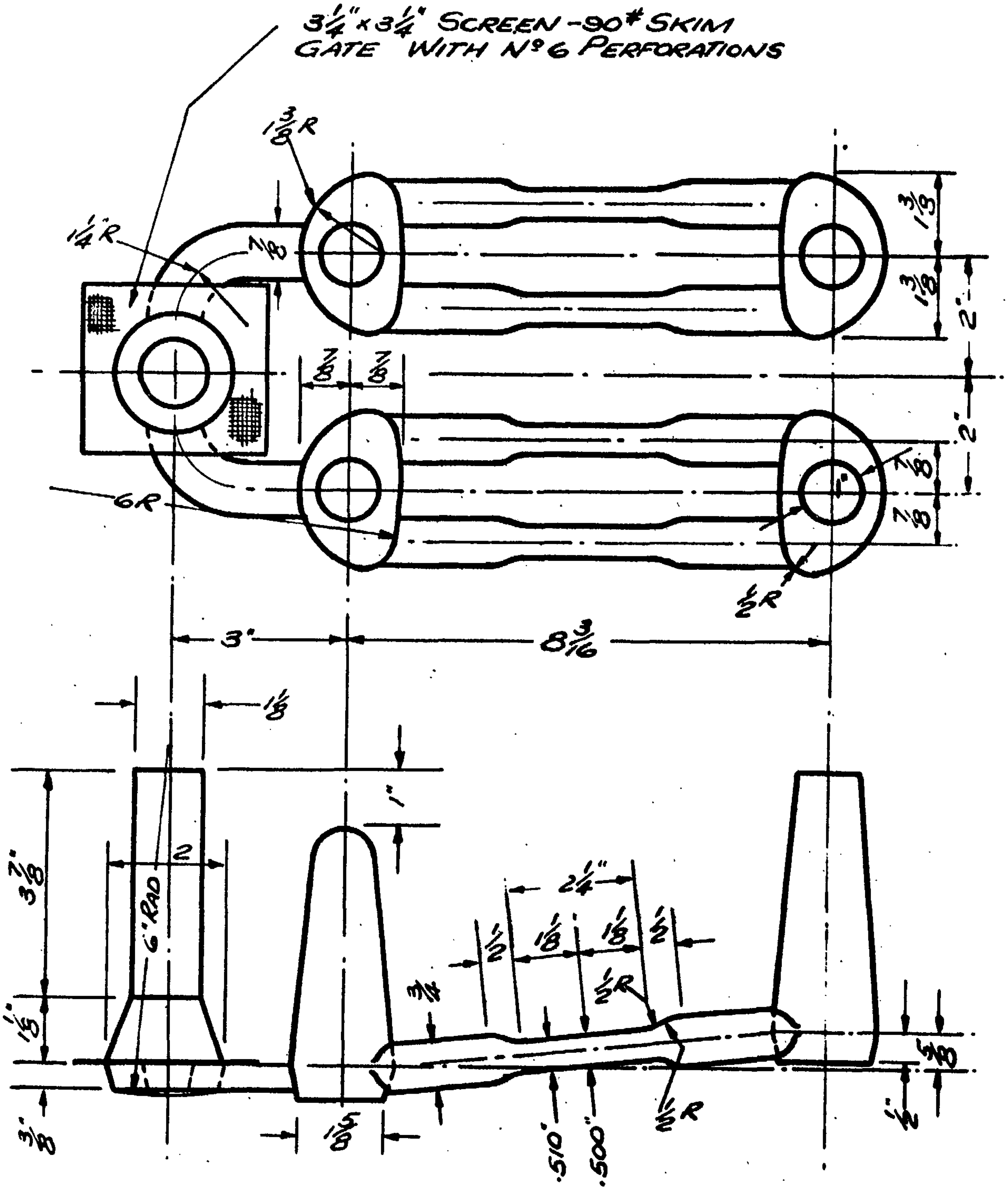

Figure 1. Test bar design according to Canadian standard CSA.HG.1-1963 and U. S. Federal Specification QQ-M-56.

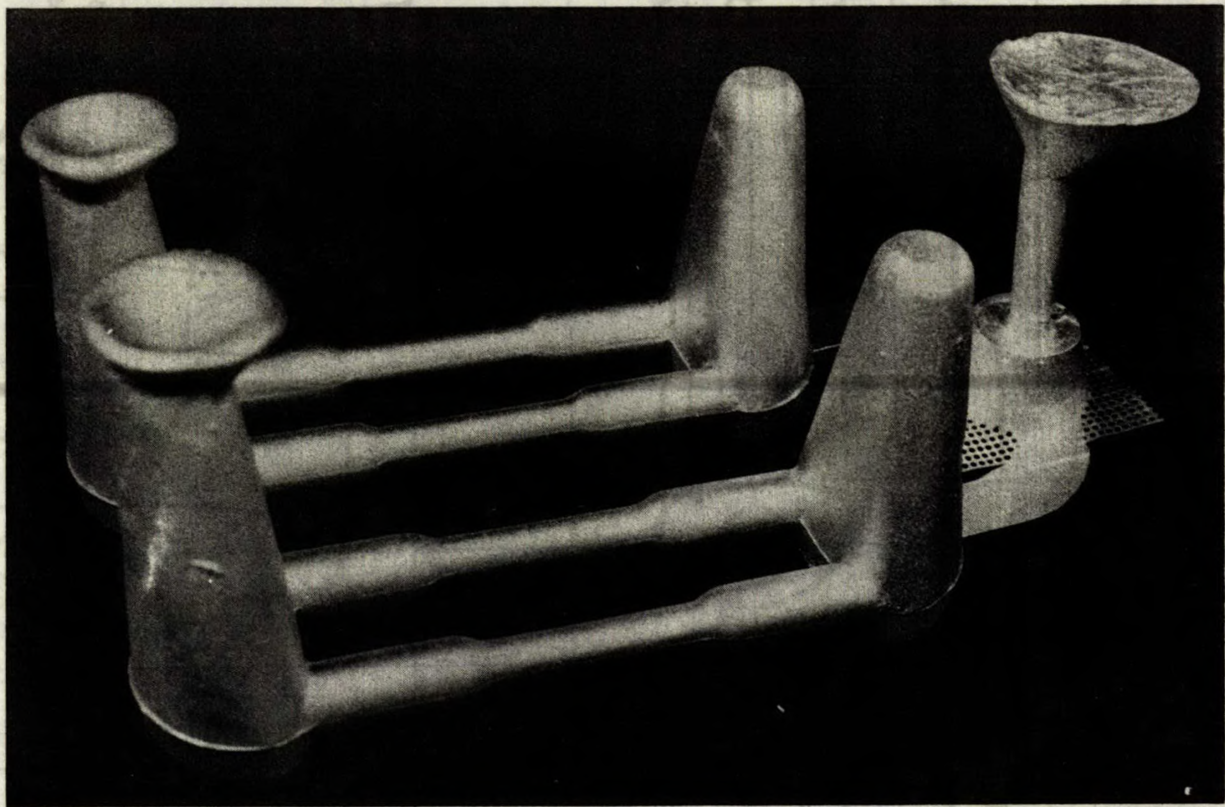

Figure 2. Modified test bar casting (Design #1), as used in the Mines Branch foundry.

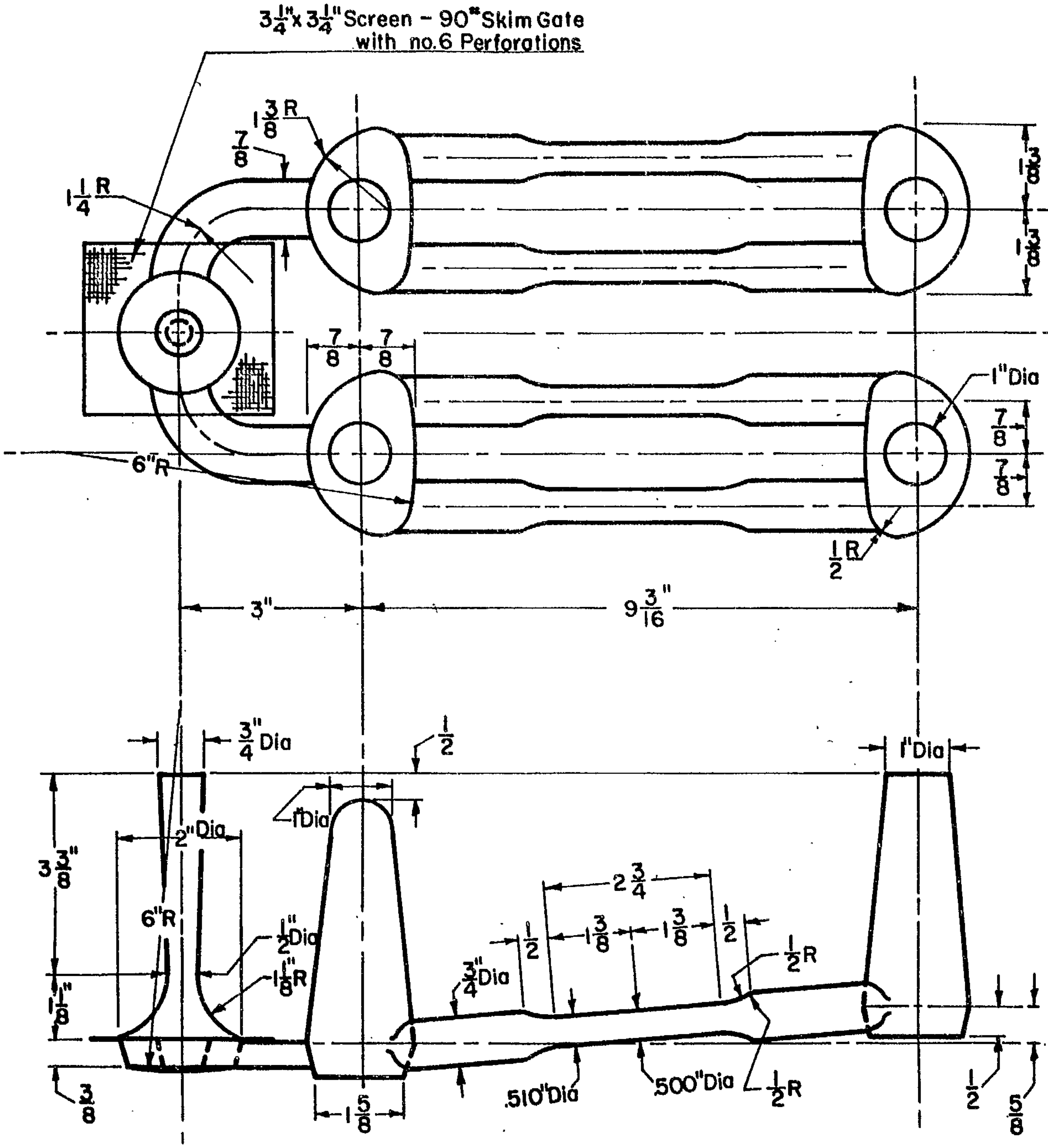

Figure 3. Modified test bar design (Design #4A), proposed for use as reference bar.