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COMPARISON OF ISO AND CSA TEST BAR PROPERTIES OF THREE ALUMINUM CASTING ALLOYS (CSA.HA.9 ALLOYS .S5, .SC53 AND .ZG61N-T5)

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PHYSICAL METALLURGY DIVISION

SEPTEMBER 1971

Research Report R 244

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COMPARISON OF ISO AND CSA TEST BAR PROPERTIES OF THREE ALUMINUM CASTING ALLOYS (CSA.HA.9 ALLOYS .S5, .SC53 AND .ZG61N-T5)

by

W.A. Pollard*

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ABSTRACT

The ISO and CSA test bar properties of three aluminum sand-casting alloys, .S5 (Al-Si5-M), .SC53 (Al-Si5 Cu3-M) and .ZG61N-T5 (Al-Zn5 Mg-TB), have been compared on the basis of five split melts for each alloy, one half of each melt being "as melted" and the other "degassed". Statistical analysis of the results has enabled confidence limits to be placed on the differences between the averages for each test bar type, and the proposed ISO specification minima for the alloys have been examined critically in the light of these differences.

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Direction des mines

Rapport de recherches R 244

ÉTUDE COMPARATIVE DES PROPRIÉTÉS D'ÉPROUVETTES ISO ET CSO OBTENUES À PARTIR DE TROIS ALLIAGES DE FONDERIE D'ALUMINIUM (ALLIAGES .S5, .SC53 ET .ZG61N-T5 DE LA NORME CSA.HA.9)

par

W.A. Pollard*

RÉSUMÉ

L'auteur a fait une étude comparative des propriétés d'éprouvettes ISO et CSA obtenues à partir de trois alliages d'aluminium de coulée en sable: .S5 (Al-Si5-M), .SC53 (Al-Si5 Cu3-M) et .ZG61N-T5 (Al-Zn5 Mg-TB); pour chacun de ces alliages, il a préparé cinq coulées qu'il a ensuite divisées chacune en deux parties, l'une restant "brute de coulée" et l'autre étant "dégazée". L'étude statistique des résultats a permis de déterminer jusqu'à quel point on peut se fier aux différences observées entre les moyennes obtenues pour chaque type d'éprouvette; tenant compte de ces différences, l'auteur a pu alors procéder à un examen critique des minimums que la norme ISO propose pour les alliages.

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CONTENTS

= =

TABLES

= =

INTRODUCTION

In November 1970, the secretariat of Technical Committee 79--Light Metals and their Alloys--of the International Organization for Standardization (ISO) circulated an addendum (dated 16 November 1970) to a draft recommendation (No. 2147), entitled "Minimum Mechanical Properties of Sand Casting Aluminum Alloys", to members of Working Group 5 of TC 79 for study and comment.

Through Dr. J. Convey, Director of the Mines Branch, Ottawa, who is chairman of the Canadian Advisory Committee of TC 79, the proposal was referred to Mr. J.O. Edwards of the Physical Metallurgy Division.

Six alloys included in the recommendation correspond to the following alloys of Standard HA. 9 of the Canadian Standards Association (CSA): .SG70N-T6, .SC51N-T6, .G10-T4, .S5, .SC53, and .ZG61N-T5.

In order to assess the consistency of the proposed minimum properties with the corresponding Canadian specifications, it is necessary to take into account the effect of the test bar types used in the two specifications. The first three of the alloys noted above were assessed in earlier work [(1) (2)] in which a number of test bar designs, including the ISO (the French standard test bar which was later adopted as the international standard) and the CSA, were compared. It was agreed (letter dated 12 March 1971, J.O. Edwards to A.W. Halford, Alcan) that the other three alloys should be assessed at the Mines Branch, and this work and its results are described herein.

EXPERIMENTAL

The experimental work consisted of pouring a series of five melts of each alloy, each melt being poured in two halves, the first "as melted" and the second after flushing with a nitrogen/chlorine mixture (assumed to be of higher quality). Some indication of relative gas contents was given by density measurements on specimens taken from the gauge lengths of fractured bars. This "split melt" technique was adopted so that the results might be more representative of the range of melt qualities which would be obtained in a commercial foundry.

In each half-melt, two ISO and four CSA moulds were poured (in that order), giving 8 test bars of each type. Five melts of each alloy were made, so that 40 bars of each type were tested in each melt condition.

Moulding Conditions

The moulds were made of McConnellsville sand (AFS No. 135), with 3% water, on a simple jolt-squeeze machine. The ISO design specified a cope height of 60 mm (2.4 in.) as compared with 4 in. for the CSA mould. Each mould was poured directly into the sprue, which was enlarged at the top (no additional pouring basins). In order to permit the crucible to be brought close to the central sprue of the CSA moulds, part of the cope sand was carved out after removing the snap flask.

Melting and Casting

Pre-alloyed commercial ingot was used for all melts. Small additions of zinc and magnesium were made to the . ZG61N alloy to bring the composition closer to the middle of the specification range. Chemical analysis results are shown in Table 1.

The alloys were melted in carbon-bonded silicon carbide crucibles in gas-fired injector furnaces. The standard melt size was 70 lb. The second half of each melt was degassed by flushing with a mixture of 10% Cl_2 and 90% N_2 for 10 minutes. Efficiency of degassing was checked with a low-pressure tester.

The ISO test bars were poured at 720°C (1328°F) (standard "ISO temperature") and CSA moulds at 680°C (1256°F) for all alloys.

None of the alloys required heat treatment, but the . ZG61N alloy was aged at room temperature for 21 days before testing.

RESULTS

Density results are shown in Table 2, and it will be seen that in each case an increase in density was observed in the second half of the melt, showing that degassing was effective in improving the soundness of the test bars. The high density difference between the two halves of Melt 1 in . ZG61N alloy is thought to have been due to segregation of zinc to the second half (see Table 1) as well as to the improved soundness caused by degassing. As mentioned above, a small addition of zinc was made to each melt of this alloy and, in the case of Melt 1, it seems likely that insufficient stirring after the addition caused the zinc to remain in the bottom of the crucible until stirred by degassing in the second half.

The tensile test results are given in detail in Tables 3 to 5. Averages in these tables are of eight determinations. No results were rejected, even if there was an obvious flaw in the fracture or if the bar broke outside the gauge marks. Such rejection would have complicated statistical analysis. In addition, the tendency to flaws etc. reflects to some extent the inherent characteristics of the mould design, so that the inclusion of abnormally low results is a necessary part of the over-all assessment of the test bars.

Reference to Tables 3 to 5 will show that, with very few exceptions, the properties of the CSA test bars were higher than those of the ISO bars. This and other aspects of the results are analysed statistically as described in the next section.

STATISTICAL ANALYSIS

The ultimate tensile strength and elongation results for each alloy were first analysed as a three-factor (Bar Type, Melt, Quality) factorial experiment, using the averages given in Tables 3 to 5. The individual test-bar results could not be included in this analysis (as a fourth factor or replication) because they could not be regarded as independent observations (see Brownlee [3], p. 134).

The second-order interaction was used as the estimate of error and in all cases none of the first-order interactions was significant, so they were "pooled" with the higher interaction to test the main effects.

Table 6 summarizes the significance-test results for the main effects. In all cases the bar type effect was significant, and, with the exception of the elongation of the . ZG61N alloy, there was a strong quality ("as melted" versus degassed) effect. The melt effect was more variable.

The principal object of the statistical analysis was to assign confidence limits to the differences between the "grand means" of Table 6. This necessitated estimating the standard deviations of those means by an analysis of variance for each bar type, treating the results as a simple "between and within batch" type of experiment (Brownlee [3], p. 52 and p. 134). The results shown in Table 6 constitute the limits between which the true value of the difference between the two means lies with 95% probability.

DISCUSSION

The conclusions of the work are summed up quantitatively in Table 6 and the most relevant subject for discussion is the general validity of these figures. Because the precision of predicting differences between means generally increases in proportion to the square root of the number of observations, a very much more extensive investigation would have been necessary to give a useful increase in precision.

Although it is appreciated that a relatively limited number of melts were carried out for each alloy, the density and mechanical property results showed that there were significant differences in melt quality between the "as melted" and the degassed material.

It is felt that, with the possible exception of the .S5 elongation, the tensile properties obtained were typical of those to be expected in the commercial foundry. The minimum elongation values, both for the CSA and for the proposed ISO specifications for .S5, seem extremely low compared with both the values obtained and the accepted typical values.

Although the differences in Table 6 were for the "grand means", examination of the "difference" columns of Tables 3 to 5 shows that, in general, both good and poor quality melts gave similar differences, so that the over-all average results probably have general validity. This is an important point, because rejection for below-specification properties usually involves melts of poor or borderline quality.

An interesting result of the present work was the absence of any significant interaction between bar type and quality. This is in contrast to earlier work [2] on other alloys, in which the ISO (French) bar was generally less sensitive to melt quality (i.e., showed less tensile property variation between as-melted and degassed melts) than other test bars, including the CSA. This effect was observed for several alloys (.SC51, .SG70, and .C4). The comparatively minor changes in casting conditions between the two investigations--for example, in the present work all ISO moulds had 2-in. copes and were poured at the standard "ISO temperature" of

720°C--do not suggest obvious reasons for the difference, nor do other differences such as the absence of heat treatment in the present work.

RECOMMENDATIONS

From the results summarized in Table 6, it is seen that some of the minimum properties proposed in ISO Draft Recommendation 2147 are inconsistent with present CSA minima. To make the specifications more consistent, certain changes in the ISO values are proposed as shown in Table 7. The detailed considerations which led to these changes are as follows:

For .S5 alloy the difference between the average CSA and ISO tensile strength results was 1.11 kpsi, with relatively narrow confidence limits. Thus, an ISO minimum of 16 kpsi (about 11 kgf/mm^2) would seem consistent with the CSA minimum of 17 kpsi. Although there was a difference of about 1.5% between the average elongations of CSA and ISO bars because of the extremely low minimum values in both CSA and ISO specifications (i.e., 3% as compared with the typical 9%), it is obviously illogical to lower the ISO minimum by a corresponding amount. This point is emphasized by the fact that the lowest value in all of the present work was 6.5%, obtained on a bar the fracture of which contained a large flaw.

The difference between means for the UTS of .SC53 was 1.63 kpsi. It is therefore suggested that 18 kpsi (i.e., 2 kpsi lower than the CSA minimum of 20 kpsi) would be a more appropriate ISO value than the proposed 21 kpsi. The minimum elongation of SC53 is 1% in both cases and could not be reduced (omission would be the only possibility), although the results suggest that a lower value would be expected from the ISO bar.

The proposed ISO minimum for the UTS of ZG61N seems excessively low. The difference between means was 1.6 kpsi, with comparatively wide confidence limits. It is therefore suggested that 32 kpsi would be an appropriate level based on Canadian practice and the results of the present work. The ISO chemical composition limits for this alloy are wider than those for the CSA alloy and this presumably is the reason for the low UTS specification. The minimum elongation of 3% proposed in Table 7 is based on the upper confidence limit (0.96%) of the difference between means.

SUMMARY

The differences between tensile property values from CSA and ISO test bars for the three alloys have been established, and confidence limits have been estimated by statistical analysis of the results. The proposed ISO minima have been critically analysed on the basis of these differences and, as a consequence, alternative values more consistent with corresponding CSA minima have been suggested in several cases (see Table 7).

REFERENCES

1. ALCAN report, "Comparison of Mechanical Properties of Sand Cast Aluminum Alloys Employing CSA, German and French National Test Bar Designs", Aluminum Company of Canada, Limited, Montreal, Quebec, August 1964.

2. W.A. Pollard and J.W. Meier, "Investigations on Sand-Cast Aluminum Alloy Test Bars", Mines Branch Research Report R150, January 1965; or Symposium on Sand Cast Aluminum Alloy Test Bars, at 29th Int. Foundry Congress, Detroit, 1962, published by The American Foundrymen's Society, 1963, 54 pp.

3. K.A. Brownlee. Industrial Experimentation. Chemical Publishing Company Inc., New York, 1953 (4th Edition).

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WAP: (PES)lm

TABLE 1

Chemical Analysis Results

Melt No.	Quality*	S5		SC53				ZG61N					
		Si %	Fe %	Si %	Cu %	Mn %	Fe %	Zn %	Mg %	Cr %	Fe %	Si %	Ti %
1	1	4.95	0.24	4.86	3.25	0.47	0.36	5.46	0.60	0.54	0.34	0.13	-
	2	5.00	0.25	4.77	3.17	-	-	6.53	0.47	0.52	0.40	0.15	-
2	1	4.90	0.25	4.85	3.24	0.50	0.43	6.13	0.56	0.44	0.32	0.22	0.20
	2	4.76	0.27	4.74	3.22	0.52	0.43	6.03	0.59	0.42	0.31	0.23	0.19
3	1	4.84	0.19	4.70	3.21	0.52	0.43	6.06	0.62	0.48	-	-	-
	2	4.87	0.19	4.73	3.19	0.52	0.43	6.06	0.62	0.49	-	-	0.20
4	1	5.06	0.26	4.78	3.13	0.48	-	6.04	0.56	0.46	-	-	0.20
	2	5.06	0.26	4.84	3.13	0.52	-	6.22	0.60	0.49	-	-	0.20
5	1	5.03	0.26	4.80	3.18	0.47	-	5.75	0.56	0.47	-	-	0.19
	2	5.06	0.25	4.70	3.19	0.50	-	6.14	0.61	0.49	-	-	0.20
CSA**		4.5 - 6.0	0.80 Max.	4.0 - 6.0	2.0 - 4.0	0.30 - 0.70	0.80 Max.	5.0 - 6.5	0.50 - 0.65	0.40 - 0.60	0.5 Max.	0.25 Max.	0.15 - 0.25
ISO**		4.0 - 6.0	0.8 Max.	4.0 - 6.5	2.0 - 4.5	0.2 - 0.7	1.0 Max.	4.5 - 6.0	0.20 - 0.70	0.15 - 0.60	1.0 Max.	0.30 Max.	0.10 - 0.30

* 1 - "As Melted".
2 - "Degassed".

** Specification limits.

TABLE 2

<u>Density Results (g/cc)</u>

(Averages of two determinations)

Melt No.	Bar Type	S5 Quality* 1	S5 Quality* 2	S5 Diff.	SC53 Quality* 1	SC53 Quality* 2	SC53 Diff.	ZG61N Quality* 1	ZG61N Quality* 2	ZG61N Diff.
1	ISO	2.668	2.689	0.021	2.771	2.778	0.007	2.777	2.829	0.052
	CSA	2.671	2.686	0.015	2.772	2.778	0.006	2.779	2.828	0.049
2	ISO	2.674	2.688	0.014	2.752	2.773	0.021	2.791	2.816	0.025
	CSA	2.666	2.683	0.017	2.746	0.770	0.024	2.794	2.815	0.021
3	ISO	2.660	2.670	0.010	2.750	2.770	0.020	2.791	2.815	0.024
	CSA	2.659	2.680	0.021	2.746	2.768	0.022	2.794	2.815	0.021
4	ISO	2.672	2.675	0.003	2.746	2.766	0.020	2.790	2.814	0.024
	CSA	2.663	2.675	0.012	2.745	2.769	0.024	2.785	2.813	0.028
5	ISO	2.672	2.685	0.013	2.746	2.766	0.020	2.792	2.812	0.020
	CSA	2.665	2.680	0.015	2.746	2.766	0.020	2.795	2.813	0.018

* Quality 1 - "As Melted".
2 - "Degassed".

TABLE 3

Tensile Test Results for .S5 Alloy

(Averages of eight determinations)

Melt No.	Quality*	UTS, kpsi			0.2% Y.S., kpsi			Elongation %**		
		Bar Type		Diff.	Bar Type		Diff.	Bar Type		Diff.
		ISO	CSA		ISO	CSA		ISO	CSA	
1	1	19.5	21.0	1.5	6.8	6.4	-0.4	13.0	14.0	1.0
	2	21.2	21.8	0.6	7.1	6.6	-0.5	17.0	17.0	0
2	1	20.1	21.4	1.3	6.9	7.3	0.4	10.5	15.0	4.5
	2	21.2	21.8	0.6	6.8	7.5	0.7	15.5	16.5	1.0
3	1	19.2	20.6	1.4	6.5	7.2	0.7	11.0	14.0	3.0
	2	19.2	21.0	1.8	6.5	7.7	0.8	10.0	12.0	2.0
4	1	19.9	21.0	1.1	6.8	7.3	0.5	12.5	15.0	2.5
	2	20.1	20.9	0.8	7.0	7.4	0.4	14.0	15.5	1.5
5	1	20.5	21.5	1.0	6.5	7.2	0.7	17.0	17.0	0
	2	21.0	21.8	0.8	6.9	7.3	0.4	17.5	18.0	0.5
Grand Means		20.2	21.3	1.1	6.8	7.2	0.4	13.7	15.3	1.6
Specification Minima		17.0	17.0					3.0	3.0	

* Quality 1 - "As Melted".
2 - "Degassed".

** For CSA on 4D.
For ISO on 5D.

TABLE 4

Tensile Test Results for .SC53 Alloy
(Averages of eight determinations)

Melt No.	Quality*	UTS, kpsi			0.2% Y.S., kpsi			Elongation %**		
		Bar Type		Diff.	Bar Type		Diff.	Bar Type		Diff.
		ISO	CSA		ISO	CSA		ISO	CSA	
1	1	25.7	26.9	1.2	14.7	15.5	0.8	2.0	2.5	0.5
	2	25.3	26.5	1.2	13.4	13.6	0.2	2.0	3.0	1.0
2	1	23.7	26.4	2.7	16.4	16.6	0.2	2.0	2.5	0.5
	2	26.9	28.1	1.2	15.7	16.9	1.2	3.0	3.0	0
3	1	24.6	26.1	1.5	17.0	16.2	-0.8	2.5	3.0	0.5
	2	25.8	28.4	2.6	16.3	16.1	-0.2	2.5	3.0	0.5
4	1	23.8	25.9	2.1	16.9	17.0	0.1	1.5	2.0	0.5
	2	25.7	27.6	1.9	16.6	17.1	0.5	2.0	2.5	0.5
5	1	24.1	25.3	1.2	18.1	18.7	0.6	1.5	1.0	-0.5
	2	26.5	27.1	0.6	17.7	18.1	0.4	2.0	2.0	0
Grand Means		25.2	26.8	1.6	16.3	16.6	0.3	2.1	2.4	0.3
Specification Minima		21.0	20.0					1.0	1.0	

* Quality 1 - "As Melted".
2 - "Degassed".

** For CSA on 4D.
For ISO on 5D.

TABLE 5

Tensile Test Results for ZG61N Alloy
(Averages of eight determinations)

Melt No.	Quality*	UTS, kpsi			0.2% Y.S., kpsi			Elongation %**		
		Bar Type		Diff.	Bar Type		Diff.	Bar Type		Diff.
		ISO	CSA		ISO	CSA		ISO	CSA	
1	1	34.7	35.1	0.4	22.6	23.3	0.7	6.0	6.0	0
	2	36.6	37.3	0.7	25.2	26.4	1.2	5.5	5.5	0
2	1	34.4	36.9	2.6	25.8	26.8	1.0	3.5	5.0	1.5
	2	37.6	38.4	0.8	28.0	28.3	0.3	3.5	4.5	1.0
3	1	35.0	36.6	1.6	25.9	26.7	0.8	4.0	5.0	1.0
	2	38.0	39.8	1.8	28.0	28.4	0.4	4.5	5.0	0.5
4	1	32.5	35.9	3.4	25.9	27.2	1.3	3.0	5.0	2.0
	2	38.3	40.2	1.9	28.4	29.0	0.6	5.0	6.0	1.0
5	1	36.0	35.2	-0.8	26.2	26.8	0.6	5.0	4.0	-1.0
	2	37.8	40.8	3.0	28.1	30.2	2.1	5.0	6.0	1.0
Grand Means		36.0	37.6	1.6	26.4	27.3	0.9	4.5	5.2	0.7
Specification Minima		27.0	34.0					4.0	4.0	

* Quality 1 - "As Melted".
2 - "Degassed".

** For CSA on 4D.
For ISO on 5D.

TABLE 6

Summary of Statistical Analysis Results

Alloy	Property	Grand Mean, CSA	Grand Mean, ISO	Difference	95% Confidence Limits of Differences Between Means**	Level of Significance of Main Effects*		
						Bar Type	Melt Quality	
.S5	UTS, kpsi	21.26	20.15	1.11	0.92 to 1.30	S	S	S
.S5	Elong., %	15.28	13.71	1.57	0.80 to 2.34	S	S	S
.SC53	UTS, kpsi	26.80	25.17	1.63	1.29 to 1.97	S	n.s.	S
.SC53	Elong., %	2.38	2.05	0.33	0.14 to 0.52	S	S	S
.ZG61N	UTS, kpsi	37.63	36.03	1.60	0.97 to 2.23	S	n.s.	S
.ZG61N	Elong., %	5.19	4.50	0.69	0.42 to 0.96	S	n.s.	n.s.

* From Bar Type/Melt/Quality Analysis of variance, using "within treatment" means.

S Indicates significant above the 5% level; n.s., not significant.

** From "Between and Within Treatment" analysis of variance for each bar type taken separately.

TABLE 7

Typical and Minimum Properties

Alloy	Property	Typical Properties CSA x	Specification Minima CSA	Specification Minima Proposed ISO +	Specification Minima Suggested ISO *
S5	UTS, kpsi	19	17	17 (12 kgf/mm^2)	16 (11 kgf/mm^2)
	Elongation, %	9	3	3	3
SC53	UTS, kpsi	25	20	21 (15 kgf/mm^2)	18 (13 kgf/mm^2)
	Elongation, %	3.5	1	1	1
ZG61N	UTS, kpsi	39	34	27 (19 kgf/mm^2)	32 (23 kgf/mm^2)
	Elongation, %	5	4	4	3

x CSA HA.9 - 1968 Appendix A except S5 which is from HA.9 - 1958.

+ ISO/TC 79/GT 5 (Secr. 20) 27E. Addition to Draft Recommendation 2147.

* Modifications to ISO proposals on basis of present work (see text).