U.S. Department of Commerce National Bureau of Standards

RESEARCH PAPER RP727

Part of Journal of Research of the National Bureau of Standards, Volume 13
October 1934

EFFECT OF MELTING CONDITIONS ON THE RUNNING QUALITY OF ALUMINUM CAST IN SAND MOLDS

By A. I. Krynitsky and C. M. Saeger, Jr.

ABSTRACT

The effect of maximum heating temperature on the running quality of liquid metal has been studied for 2 grades of aluminum and an aluminum—8 percent copper alloy. The running quality was measured in terms of the length of a spiral casting obtained by pouring the metal under carefully controlled conditions. The effect of various treatments of the metal was also investigated.

It was found that the relation between length of the spiral and the pouring temperature is linear. The running quality of the metals which had been heated to a maximum temperature of 850° C was in all cases less than when the metal had been heated to 750° C. Pure aluminum (99.8 percent) was found to have markedly higher running qualities than the commercial (99.2 percent) aluminum. The running quality of the aluminum—8 percent copper alloy—was not much different from that of commercial aluminum.

CONTENTS

		Page
I.	Introduction	579
II.	Materials	580
III.	Methods and apparatus	581
IV.	Results, conclusions, and discussion	582
V.	References	587

I. INTRODUCTION

In a previous paper (1)[1] a practical method has been described for determining the running quality of metals. It consists essentially in pouring, under carefully controlled conditions, a spiral casting of relatively small cross section of the design shown in figure 1. The length of the spiral obtained under a given set of conditions is a numerical measure of the running quality of the metal under these conditions. The designation "good" running quality, or "high" running quality, are to be understood as indicating that the metal produced long spirals.

In making some experiments designed primarily to demonstrate the possibilities of the method, it had been observed that the running quality of commercial aluminum, poured at a given temperature, depended on the maximum temperature to which the metal had been

[1] Figures in parentheses here and throughout the text indicate references given in the "References" at the end of this paper.

superheated previous to pouring (1). In dry sand molds it was found that the lengths of the spirals, poured at a given temperature, were in the inverse order of the 3 maximum temperatures 750, 790, and 840° C to which the metal had been superheated. In green sand molds this order was not preserved exactly, the 840° C maximum heating temperature resulting in a spiral of length shorter than that obtained for 750° C and longer than that obtained for 790° C. The present work was undertaken to study this effect more systematically but had to be discontinued before completion. It is believed, however, that the results obtained, though incomplete and not entirely conclusive, will be of some interest.

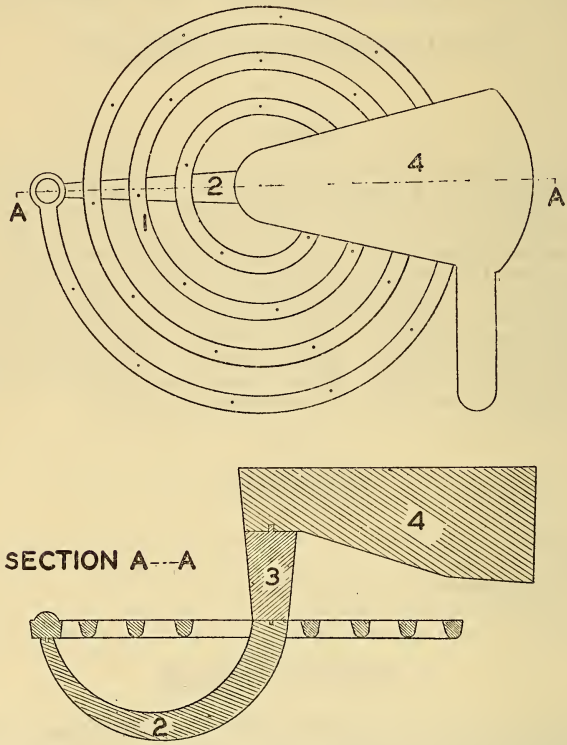

FIGURE 1.—*Spiral casting for determining the running quality of molten metals in a sand mold.*

1, Spiral; 2, hour gate; 3, down gate; 4, pouring basin and overflow

II. MATERIALS

Two grades of ingot aluminum, which will be designated as pure (Si 0.07, Fe 0.15, Cu 0.01, Al 99.8 percent) and commercial (Si 0.15, Fe 0.50, Cu 0.12, Al 99.2 percent) aluminum were used in this work and some tests were also made with an alloy of 8 percent copper with the commercial aluminum.

FIGURE 2.—*Immersed crucible apparatus for sampling the molten metal.*

III. METHODS AND APPARATUS

A charge of 40 pounds of aluminum or of the aluminum-copper alloy was melted in a plumbago crucible in either a high-frequency induction furnace or in a gas-fired furnace. The molten metal was heated to a maximum temperature of either 750 or 850° C held at that temperature for 1 minute (except in the tests later referred to as "prolonged heating" in which the metal was held for 30 minutes at the maximum temperatures), and allowed to cool slowly.

The temperature was measured with a chromel-alumel thermocouple in a porcelain insulating tube and protected with a porcelain protection tube inside an iron secondary tube coated with alundum cement. The cold junctions were kept at 0° C and the emf measured with a portable potentiometer.

Prior to pouring the first casting, a sample of the molten metal at a known temperature was taken from the crucible by means of the graphite immersion device shown in figure 2. This device, containing the liquid sample, was then placed in a dry sand mold to secure a

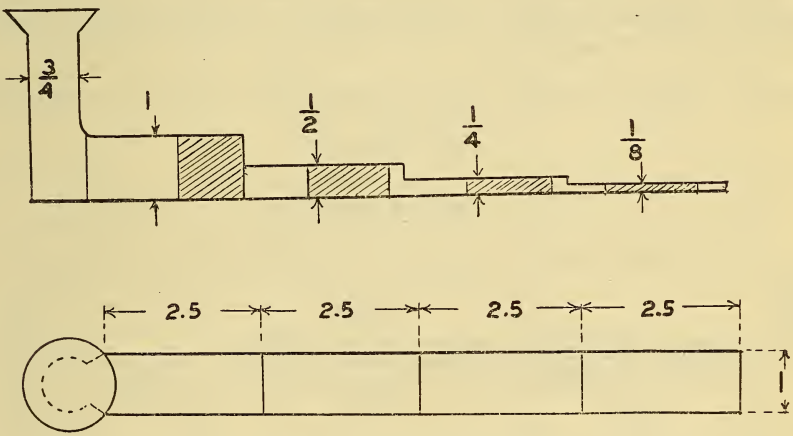

FIGURE 3.—*Stepped-bar casting.*

Shaded portions cut from bars were used in density determinations. All dimesnions are in inches.

slow rate of cooling. Longitudinal sections of the samples taken in this manner were deeply etched for visual examination.

The temperature of the metal in the crucible was then measured and a quantity of metal poured into a sand ingot mold to eliminate an excessive temperature drop due to contact with the cold lip of the crucible when pouring the test specimens. Two types of castings were poured, a spiral and the stepped-bar casting shown in figure 3. The metal was then allowed to cool until the next desired pouring temperature had been reached when another spiral and a stepped-bar casting were poured as before.

The stepped-bar castings were sectioned longitudinally and specimens for density determinations taken from one-half of the casting at the positions shown by the shaded sections of figure 3. The density determined on the half-inch section of the bar was considered to be representative of the metal cast. The remaining half of the stepped bar was deeply etched for visual examination.

All castings were made in green sand molds made of Albany 00 sand tempered to 6.0 to 7.0 percent of moisture. The molds were levelled and care was taken always to employ the same pouring height and rate.

In order to secure information which might throw some light on the cause of the behavior of aluminum which had been superheated, special treatments were given to a number of the melts. Some were treated with various amounts of zinc chloride which was introduced into the liquid metals by means of a small inverted graphite crucible. The side wall of the crucible was perforated to facilitate the reaction of the chloride and the molten metal. In other melts oxygen was passed for 5 minutes through the molten aluminum at 850° C to promote the formation of aluminum oxide. Finally, some tests were made using commercial aluminum which had been continuously exposed to the weather for a period of 75 days.

IV. RESULTS, CONCLUSIONS, AND DISCUSSION

The lengths of the spirals obtained under various conditions are plotted in figures 4, 5, and 6 while in table 1 are given selected values taken from the straight lines drawn through the plotted points.

TABLE 1.—*Running quality of pure and commercial aluminum and aluminum 8-percent copper alloy*

Pouring temperature	Lengths of spirals in inches												
	High frequency furnace				Gas-fired furnace								
	Untreated maximum temperature		Metal held for 30 minutes at maximum temperature		Untreated maximum temperature		Treated with oxygen at maximum temperature	Weather exposed ingots maximum temperature		Treated with zinc chloride: 0.75% $ZnCl_2$ maximum temperature		Treated with zinc chloride: 0.50% $ZnCl_2$ maximum temperature	Treated with zinc chloride: 0.25% $ZnCl_2$ maximum temperature
	750° C	850° C	750° C	850° C	750° C	850° C	850° C	750° C	850° C	750° C	850° C	850° C	850° C
	PURE ALUMINUM												
°C													
700	14.1	11.4	-------	-------	13.3	12.5	11.8	-------	-------	12.7	12.0	-------	-------
750	25.6	21.5	-------	-------	24.6	23.0	20.2	-------	-------	21.2	21.0	-------	-------
	COMMERCIAL ALUMINUM												
700	7.9	7.6	8.2	8.2	9.5	8.2	7.1	9.3	8.8	10.2	8.5	-------	-------
750	15.0	14.8	15.4	15.4	18.0	15.8	15.3	18.5	17.0	18.8	16.8	-------	-------
	ALUMINUM-8 PERCENT COPPER ALLOY												
700	-------	-------	-------	-------	10.0	7.9	-------	-------	-------	10.3	9.2	8.8	8.0
750	-------	-------	-------	-------	18.4	15.4	-------	-------	-------	17.5	17.0	16.8	15.6

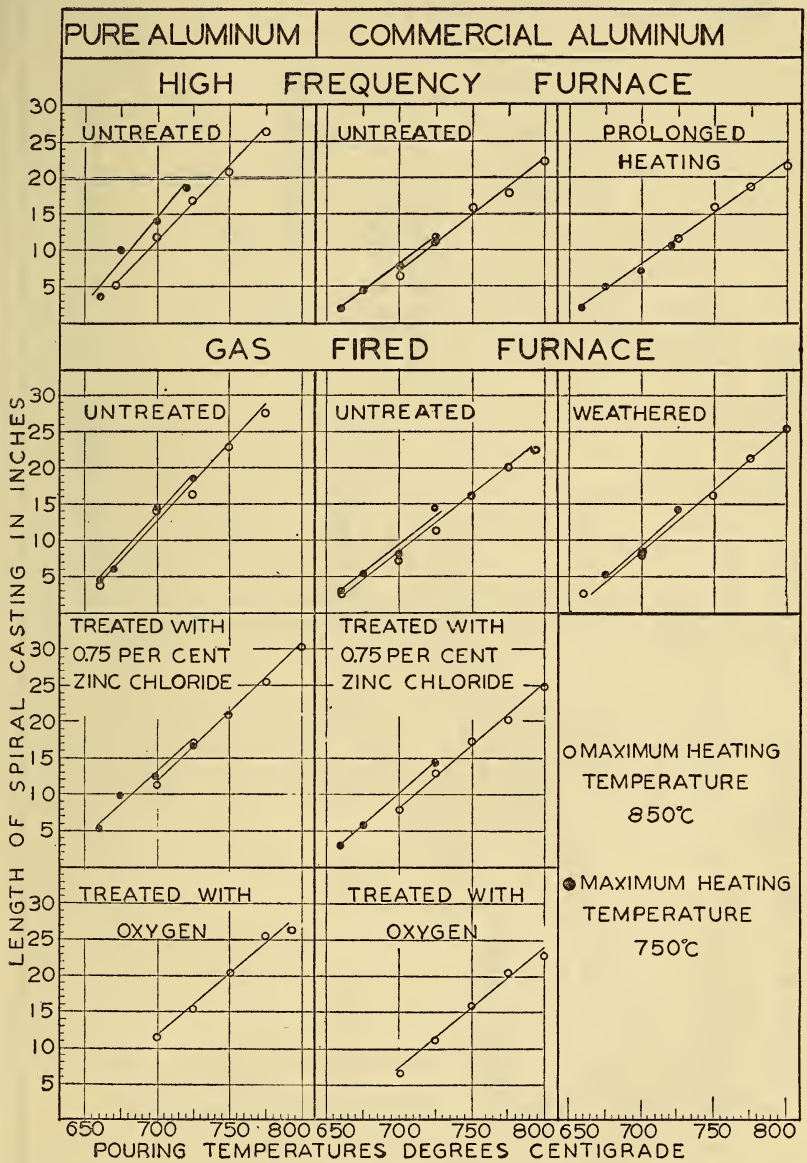

FIGURE 4.—*Running qualities of pure and commercial aluminum, treated and untreated, heated in high-frequency induction and gas-fired furnaces to maximum temperatures of 750 and 850° C.*

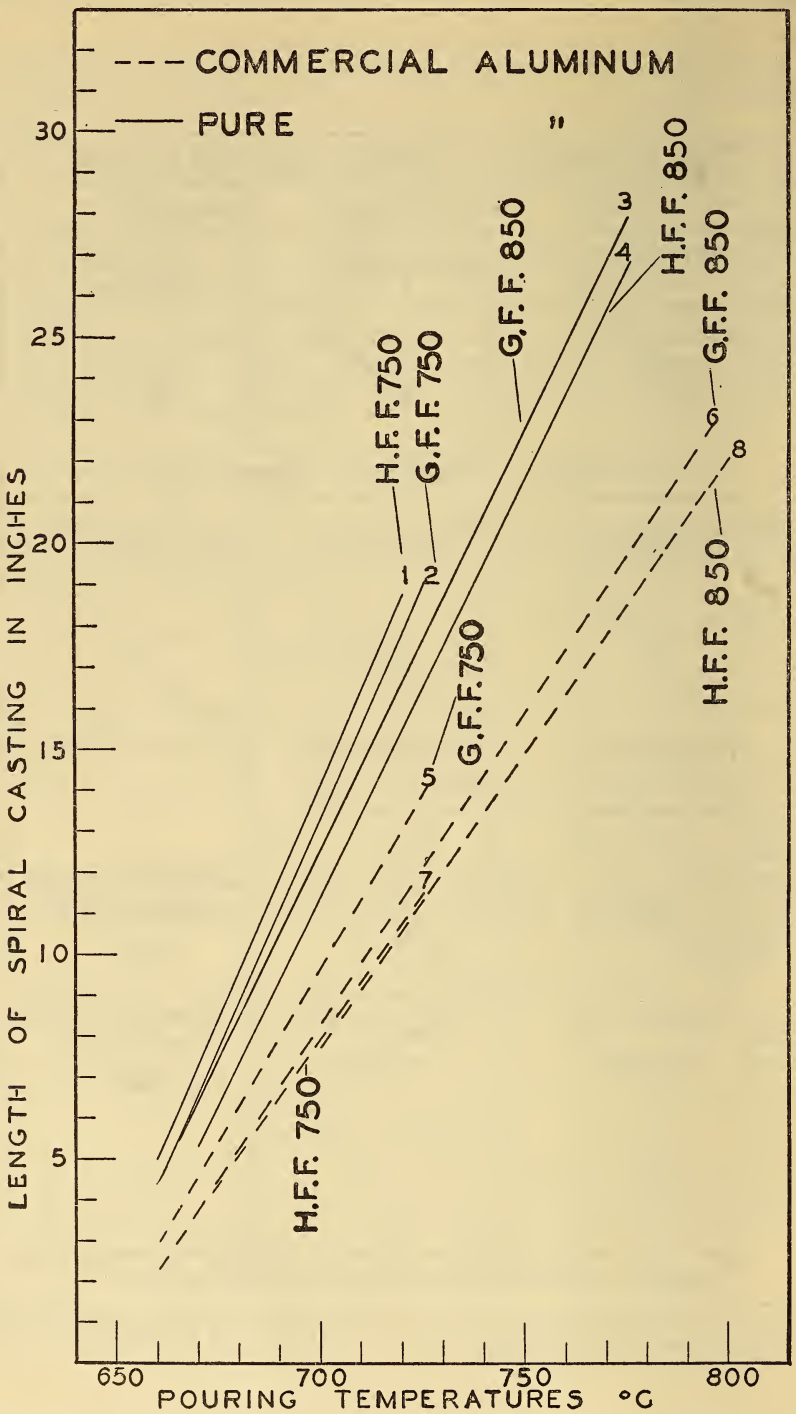

FIGURE 5.—*Running qualities of pure and commercial aluminum heated in high-frequency induction (H.F.F.) and gas-fired (G.F.F.) furnaces to maximum heating temperatures of 750 and 850° C.*

Observations shown in figure 4.

It should be pointed out that the series of points corresponding to any given straight line are observations obtained with a single crucible of metal. Each point represents the pouring of 1 spiral, and successive points represent successive pourings from the same crucible where all conditions, save the pouring temperature, are substantially the

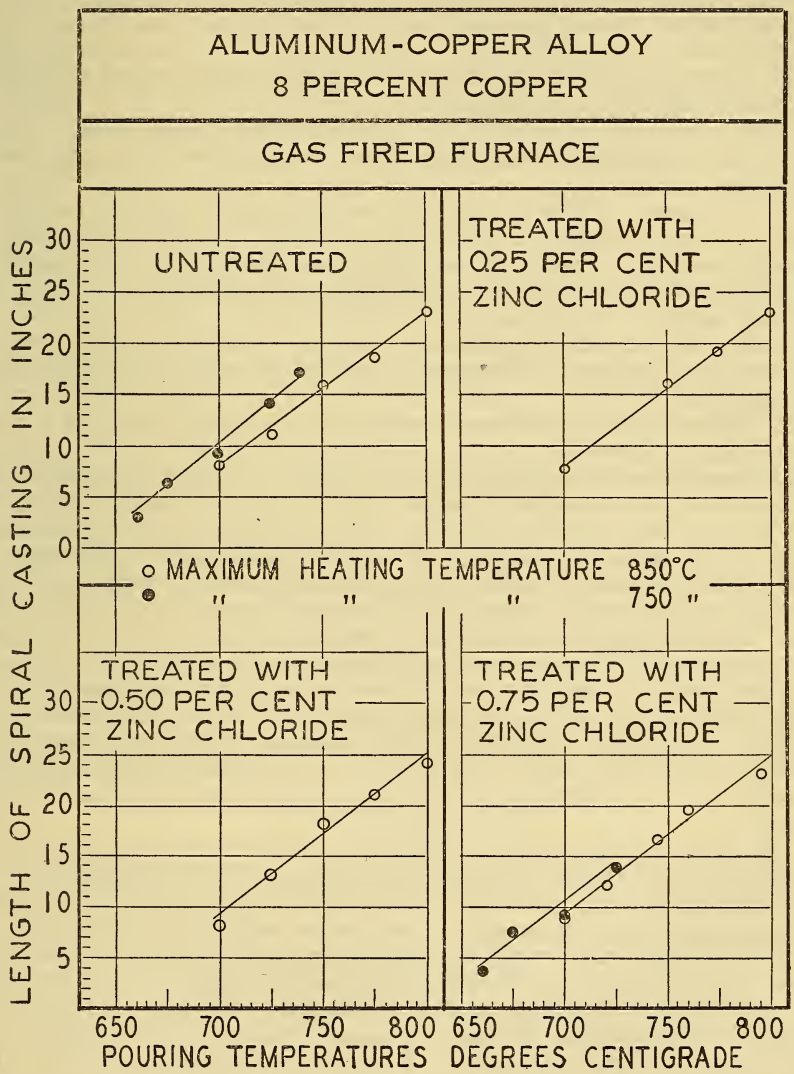

FIGURE 6.—*Running quality of aluminum—8-percent copper alloy melted in gas-fired furnace.*

same. Thus, the points in one such series are probably located relative to each other with far greater precision than could be expected if each point were obtained from a different melt.[2]

[2]A few check heats would have thrown some light on the reproducibility of the slopes of these straight ines, but unfortunately the work had to be discontinued before this was done.

There can be but little doubt that for a given pouring temperature the metals studied have a higher running quality when they have been superheated to 750° C than when they have been superheated to 850° C since no exception to this rule has been found. The magnitude of this effect has not been accurately established but seems, on the average, to correspond to about 10 percent in spiral length.

From table 1 and figures 4, 5, and 6 the following additional conclusions seem warranted:

1. The relation between pouring temperature and length of spirals is linear from 660° to at least 800° C.
2. The running quality of the pure aluminum, regardless of how the metal is treated, is markedly superior to that of the commercial aluminum.
3. Treatment with zinc chloride has apparently little or no effect on the running quality. The effect obtained was slightly beneficial in the case of the commercial aluminum and the alloy but detrimental in the case of the pure metal. The differences are too small, however, to have any real significance.
4. Treatment with oxygen had little or no effect in the case of commercial aluminum but produced shorter spirals in the case of the pure metal.
5. The weathered commercial aluminum behaved the same as the unweathered material.
6. Commercial aluminum heated to 750° C in the gas-fired furnace produced spirals markedly longer than the same metal heated to 750° C in the induction furnace. This single instance is scarcely sufficient to establish with any certainty an effect due to the type of furnace as the observed effects obtained in the other 3 instances where comparison is possible, were small and random.
7. Visual examination disclosed that the metals treated with oxygen contained a great number of both large and small cavities.

The density of castings made of commercial aluminum was invariably greater than that of the castings made of pure aluminum cast under comparable conditions. The differences, however, were evidently due in large part to the presence of cavities in the pure metal and no definite correlations could be found between density and other factors.

All samples taken by the immersed crucible method as well as a number of the stepped bars of pure aluminum formed large internal pipes whereas in the case of the commercial aluminum all the stepped bars and most of the immersion samples were free from such pipes.

The microstructures suggested that porosity in the pure aluminum was mostly in the form of intercrystalline shrinkage crevices while in the commercial aluminum it was in the form of bubble-like cavities.

Saito and Hayashi (2) found a linear relation between length of spiral and pouring temperature of aluminum from 680 to 760° C but obtained the same length of spiral at 880 as at 760° C. Their observations appear to be substantiated in more recent work by Saito and Matsukawa (3) on the viscosity of molten metals measured by means of a rotating cylinder.

The linear relation extending from 660 to 800° C found in the present work does not necessarily contradict the results of Saito and Hayashi, since these authors did not investigate the region between 760 and 880° C. The present results, however, are in exact agree-

ment with those of Courty (4) who finds that the linear relation holds from 658 up to 890° C.

The fact that the spirals obtained with the 8 percent copper alloy were slightly longer than those obtained with the 99.2 percent aliminum is also in agreement with the results of Courty (4) who found that as copper was added to aluminum the lengths of the resulting spirals decreased up to about 2 percent copper content and thereafter increased, the 7 percent alloy yielding about the same spiral length as the 99.3 percent grade of aluminum, and the 8 percent alloy yielding a slightly longer spiral. However the conclusion, which seems to be established, that pure aluminum yields longer spirals than the commercial grade, apparently contradicts the results of Losana (5) who finds a greater fluidity for 98.32 percent aluminum than for 99.26 percent aluminum.

No satisfactory explanation is offered for the decrease in the length of the spirals resulting from superheating to 850° C. Gas absorption by the molten aluminum during melting was suggested in the previous work as a possible explanation of this phenomenon. At the present time it is generally accepted that hydrogen is the gas most readily absorbed by molten aluminum. Methods of removing hydrogen from molten aluminum or aluminum alloys with chlorine, chlorine mixed with nitrogen, or chlorine compounds have been studied by a number of investigators (6,7,8,9,10). The lack of consistent improvement in running qualities from the zinc chloride treatment makes it doubtful that the superheating effect is due to absorption of hydrogen.

According to other investigators (11,12,13) the running quality of aluminum may be affected by the presence of aluminum oxide. Treatment with oxygen produced very little effect except in one case where the treatment resulted in distinctly shorter spirals. This leaves the explanation of the effect on the basis of aluminum oxide formation a probable one.

While no further work is planned at present, it is hoped that opportunity will be offered at some future time to carry this work to a more satisfactory conclusion.

V. REFERENCES

1. C. M. Saeger, Jr. and A. I. Krynitsky, *A practical method for studying the running qualities of a metal cast in foundry molds.* Trans. Amer. Fdymen's Assoc., **39**, 513 (1931).
2. D. Saito and K. Hayashi, *Recherches sur la fluidité de metaux et des alliages.* Memoirs of the College of Engineering. Kyoto Imperial University, **II**, no. 4, 83–100 (1919); **III**, no. 6, 165–178 (1924).
3. D. Saito and T. Matsukawa, *Measurement of viscosity of molten light alloys, copper alloys, and cast iron at high temperatures by the rotating cylinder method.* Memoirs of the College of Engineering, Kyoto Imperial University, **VII** no. 2, (March 1932).
4. M. A. Courty, *Contribution a l'étude de la coulabilité.* Revue de Métallurgie, **28**, 169–182, 194–208 (1931).
5. L. Losana, *Sulla fluidità dei Metalli e leghe allo stato liquido.* Il Notiziario Chimico-Industriale, **2**, no. 3 (1927).
6. D. R. Tullis, *Note on the treatment of aluminum and aluminum alloys with chlorine.* J. Inst. Metals, **40**, no. 2, 55–63 (1928).
7. W. Rosenhain, J. D. Grogan, and T. H. Schofield. *Gas removal and grain refinement of aluminum alloys.* J. Inst. Metals, **44**, no. 2, 305–330 (1930).
8. D. Hanson and I. G. Slater, *Unsoundness in aluminum sand castings.* J. Inst. Metals, **46**, no. 2, 187–237 (1931).

9. R. Sterner-Rainer, *Uber das Auftreten Kleiner Mengen von Gasen und Oxygen in Aluminium und im Al-Legierungen.* Zeitschrift fur Metallkunde, **23**, 274–279 (1931). Metallurgist, **7**, 189–190 (1931).
10. G. Masing, *A few problems in non ferrous castings.* Metals & Alloys, **4**, no. 8, 109–113 (1933).
11. R. J. Anderson, The Metallurgy of Aluminum and Aluminium Alloys. published by Henry Carey Baird & Company, **744** (1925).
12. R. J. Anderson, Secondary Aluminum, published by The Sherwood Press, Inc., Cleveland, Ohio, 145 (1931).
13. R. deFleury, *Some notes on the founding of light alloys.* Trans. Amer. Fdymen's Assoc., **33**, 235–260 (1926).

WASHINGTON, July 21, 1934.