Fluidity of A713 Cast Alloy with and without Scrap Addition using Double Spiral Fluidity Test: A Comparison

A.K. Birru, D Benny Karunakar, M. M. Mahapatra

Abstract**—**Recycling of aluminum alloys often decrease fluidity, consequently influence the castability of the alloy. In this study, the fluidity of Al-Zn alloys, such as the standard A713 alloy with and without scrap addition has been investigated. The scrap added was comprised of contaminated alloy turning chips. Fluidity measurements were performed with double spiral fluidity test consisting of gravity casting of double spirals in green sand moulds with good reproducibility. The influence of recycled alloy on fluidity has been compared with that of the virgin alloy and the results showed that the fluidity decreased with the increase in recycled alloy at minimum pouring temperatures. Interestingly, an appreciable improvement in the fluidity was observed at maximum pouring temperature, especially for coated spirals.

Keywords**—**A713 alloy, Fluidity, Hexachloroethane, Pouring temperature, Recycling.

I. INTRODUCTION

THE recycling of aluminum alloy scraps yield scraps significant economic advantages and energy savings, as well as environmental benefits. [1] emphasized that climate change is a subject of growing global concern. Based on International Energy Agency (IEA 2004) survey, about 19% of the greenhouse gas emissions from fuel combustion are generated by the transportation sector, and its share is likely to grow. Significant increase in the vehicles fleets are expected, particularly in China, India, the Middle East and Latin America. [2] introduced new direct technique for recycling aluminum scrap with low energy consumption and cost without intervening metallurgical processes. Measured properties include green density, compressive strength, and hardness. It was reported that the direct technique for recycled aluminum provides high productivity and about 80% green density (before sintering). In addition, the new technique provides very low air pollution emission and high metal saving, as compared with other methods.

[3] investigated on the recycling of aluminium and found that it has some negative implications on resource efficiency, costs and green house gas impact. In fact, the results revealed that the recycling losses contribute as much as around 49% of the total aluminium melting costs, adding about 44% to the cost of manufacture, and 50% of the green house gas added in production. [4] recommended that crediting primary aluminium for recycled aluminium is of vital importance, in energy consumption. For melting primary aluminium much energy is required which can be minimized by melting primary aluminium with recycled aluminum. The perspective of this recommendation is an incitement to recycle aluminium products. However, the majority of casting alloys are recycled.

Nowadays, a large number of foundries meticulously collect and process scrap at all stages, sort them by composition and make them available for re-use. One of the main concerns, when recycling aluminium or aluminium alloys scrap, is to avoid the oxide inclusions. The existence of oxide particles on the melt surface causes to contaminate the melt, which affects the melt flow in the mould and it has been the area of focus of several researchers. In the same way, [5] observed the presence of oxide inclusions in A356.2 and C357 Al-Si-Mg alloys and found that oxide film associated with the addition of Al-25wt. % (Fe, Mn, Cr) master alloy decreases fluidity. However, modifications with strontium appear to improve the fluidity noticeably.

[6] found that the formation of aluminum oxide film could lead to segregation of SiC in the melt, gas porosities, inclusions, and blocking of SiC particles by the oxide films, resulting in clustering of particles. These may be due to pushing of SiC particles by the growing α-aluminum dendrites which results in non-uniformity in the distribution of SiC particles in the fluidity. Many researchers studied the parameters which affect the fluidity of aluminium alloys such as pouring temperature, alloying elements, grain refinements and mould coating which do have appraisable effects on fluidity. [7] investigated the effect of pouring temperature on the casting fluidity of pure aluminum and aluminum alloys and found that increment in fluidity is almost in a linear manner with respect to the pouring temperature. They also emphasized that the pouring temperature is of great importance in determining the fluidity of the alloy. The result of the investigation of [8] on the fluidity of pure aluminium, aluminium-copper alloys and aluminium-magnesium alloys revealed that the fluidity linearly increases with increase in the temperature. However, for the aluminium-copper alloys and aluminium-magnesium alloys fluidity varies inversely with the solidification range. Prukkanona et al. [9] also investigated the

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fluidity of A356 alloy and observed that alloy without Sc and Zr addition had the lowest fluidity. However, adding 0.2 wt.% Zr and 0.2 wt. % Sc in the A356 alloy did not show significant increase in fluidity with respect to pouring temperature, compared to A356 + 0.2Sc and A356 + 0.4Sc. The effect of hematite (iron oxide) particles on fluidity was studied by Sharma et al. [10]. This study used sand mould and metal mould by varying the pouring temperatures at 700 ^{O}C, 720 ^{O}C, and 740 ^{O}C. They observed that increasing in fluidity is a linear function of the pouring temperature. The linear increment of fluidity with pouring temperature is obviously due to the fact that the viscosity of the metal decreases with the increase of pouring temperature.

[11] studied the effect of addition of trace elements of sodium, strontium, titanium, antimony and sulphur on the fluidity. The fluidity decreased with combined additions of sodium, strontium and titanium among which the sodium + titanium addition decreased the fluidity to a maximum extent. On the other hand, the additions of antimony sulphur and titanium increased the fluidity in these alloys. Fleming et al. [12] conducted experiments on double spiral fluidity test on high purity aluminum (99.9), 195 alloy (high purity), 356 alloy (high purity), 220 alloy and aluminum-zinc commercial alloy (40E), by applying various mould coatings, namely $ZnCo_3$, $CaCo_3$, NH_4Cl, NH_4BF_4, NH_4NO_3 and $(NH_4)_2CO_3$, approximately 0.0762 mm thick. They found that (C_2Cl_6) hexachloroethane mould coating significantly improved the fluidity among the said alloys.

[13] investigated on the fluidity of aluminum alloys and found that it increases with increasing the melt superheat. However, increasing the temperature has negative effect on the fluidity of some aluminum metal matrix composites. The probable reason may be high volume percentage of composites, especially while using SiC in aluminums alloys, the formation of Al_4C_3, which restrict the fluidity. Recently, Birru et al. [14] compared the fluidity on single spiral fluidity test by varying the pouring temperatures at 680 ^{O}C, 715 ^{O}C and 780 ^{O}C of A206, A195, A518, A220, A713 and A40E alloys. The major alloying elements of these alloys are approximately same and the fluidity for A206 alloy and A713 alloy exhibited almost the same. The fluidity was constant initially then increased with increase in the temperature beyond 715 ^{O}C. It was also observed that the fluidity for 518 alloys initially increased linearly up to 715 ^{O}C and beyond this temperature, the rate of increment of fluidity was not severe. Yet, not so much work has been published on the fluidity of recycled aluminium alloys, especially on double spiral fluidity test. Hence, in the present study, the authors made an attempt to compare the fluidity of most popular aluminium-zinc alloy (A713 alloy) which is obtained by mixing recycled aluminium turning chips (25 per cent) with the virgin A713 alloy.

II. Experimental Procedure

The material used in the present experimentation was the A 713 alloy. Table I shows the details of composition of the material.

TABLE I
Composition Of A713 Alloy Used In The Present Investigation

Alloy	Proportion of constituting elements (wt. %)				
	Zn	Cu	Mg	others	Al
A713	7.5	0.5	0.4	> 0.5	Balance

Double spiral metallic pattern (rectangular cross-section) of dimensions 71.12 cm x 1.27 cm and 0.3175 cm thick was employed for these experiments, which was designed by Flemings et al. [12] The cores were prepared with silica sand with the addition of molasses in standard proportions and mixed uniformly until they get the bonding nature. After the cores were removed from the core boxes, they were backed for 2 hours at 150 ^{O}C. Fig. 1 shows cores making mould boxes and cores with metallic screen. Fig. 2 and 3 show the schematic diagram of single fluidity test mould designed by Fleming et al. [12] and green sand moulds were prepared with double spiral fluidity test. One part of the mould cavity was coated with hexachloroethane (C_2Cl_6) and the other without coating.

In the first set of experimentation, virgin A713 alloy was used for the fluidity test. Similarly, for the second set of experimentation, 25 percent scrap was added in the form of turning chips to the A713 alloy and it was ensured that its composition would be same as the virgin A713 alloy.

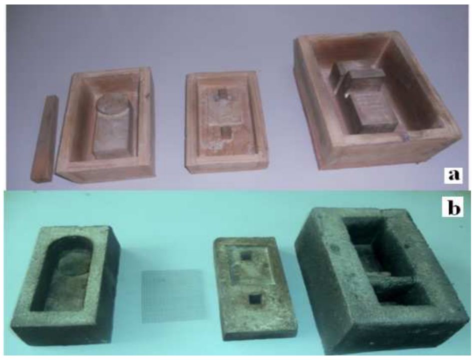

Fig. 1 a) Left to right –sprue, bottom runner core box, top runner core box, pouring basin core box, b) Left to right – Bottom runner core, metal screen, top runner core, pouring basin core

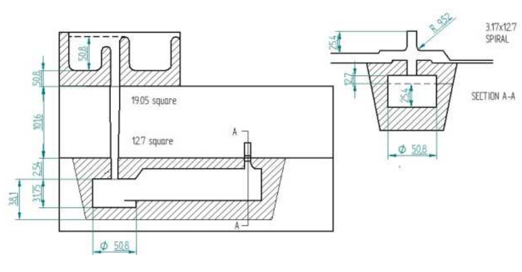

Fig. 2 Schematic diagram of single fluidity test mould [12]

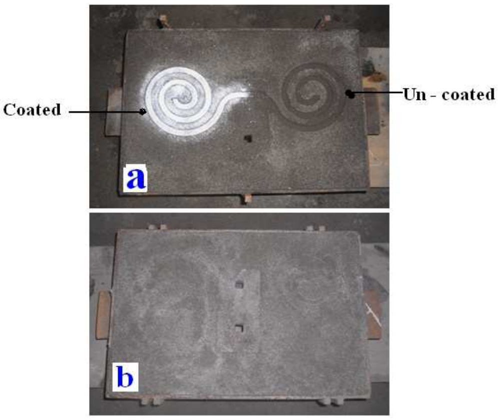

Fig. 3 Green sand moulds made to investigate the fluidity a) cope and b) drag

Fig. 4 Double spiral casting of A713 alloy with gating system

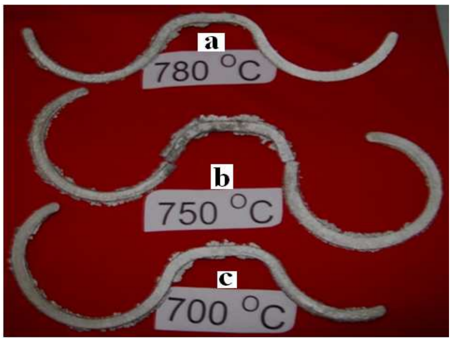

Fig. 5 Spiral test casting of A713 alloy without scrap addition, poured at a) 780 ^{O}C, b) 750 ^{O}C c) 700 ^{O}C (Left side coated and right side un-coated)

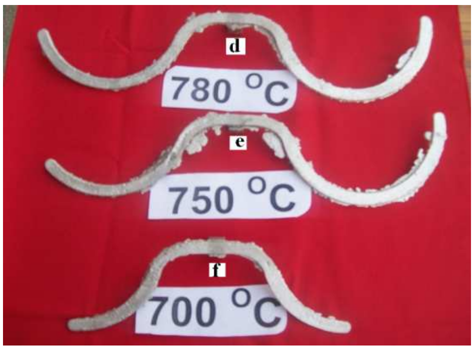

Fig. 6 Spiral test casting of A713 alloy+ 25 per cent scrap addition, poured at d) 780 ^{O}C e) 750 ^{O}C f) 700 ^{O}C (Left side coated and right side un-coated)

The proportion of A713 alloy and 25 per cent scrap was adjusted, as the main goal was to obtain alloy with the same major chemistry as that of A713 alloy. Moulds were prepared for all the test spirals and the moulding properties were maintained same for all the moulds.

The molten metal was poured in to the mould through the pouring basin at 700 ^{O}C, 750 ^{O}C and 780 ^{O}C. During the time of pouring the temperature was measured with the help of a calibrated K-type chromel-alumel thermocouple.

After the casting was solidified, cope and drag were dismantled. Double spiral casting with gating system is shown in the Fig. 4 and this arrangement would permit comparison of mould variables in a single casting. For example, for checking the effect of particular mould coating, one spiral would be coated and other would serve as reference standard. Fig. 5 and 6 show the coated and non coated double spiral fluidity castings of the virgin A713 alloys and A713 with 25 per cent scrap addition respectively.

III. Fluidity Spiral Test Results Of A713 Alloy Without Scrap Addition

The fluidity test results of A713 alloy using spiral with and without coating are shown in Fig. 7. In case of un-coated spiral, when the pouring temperature was increased from 700 ^{O}C to 750 ^{O}C, the fluidity length increases from 17 cm to 34 cm. For the pouring temperature between 750 ^{O}C to 780 ^{O}C, the fluidity length decreases from 34 cm to 24 cm. Correspondingly, for coated spiral, the graph reveals that when the pouring temperature was raised from 700 ^{O}C to 750 ^{O}C, the fluidity length increases from 29 cm to 35 cm. For the pouring temperature between 750 ^{O}C to 780 ^{O}C, fluidity length decreases from 35 cm to 26 cm.

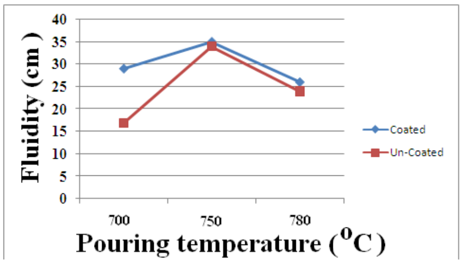

Fig. 7 Fluidity of A713 alloy without scrap using coated and un-coated spiral

IV. Fluidity Spiral Test Results Of A713 Alloy With Scrap Addition

Fig. 8 shows the spiral test results of the fluidity of A713 alloy with 25 per cent scrap addition. The graph reveals that in the case of un-coated spiral, when the pouring temperature was raised from 700 ^{O}C to 750 ^{O}C, the fluidity length increase from 12 cm to 19 cm. For the pouring temperature between 750 ^{O}C to 780 ^{O}C, the fluidity length increases from 19 cm to 22 cm. Similarly, for the coated spiral, when the pouring temperature was raised from 700 ^{O}C to 750 ^{O}C, the fluidity length increases from 13 cm to 24 cm. For the pouring temperature between 750 ^{O}C to 780 ^{O}C, fluidity length remained constant i.e., 24 cm.

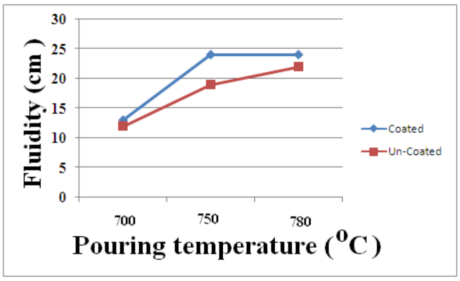

Fig. 8 Fluidity of A713 alloy with 25 per cent scrap addition using coated and un-coated spiral

V. Discussion

Table II and Table III show the fluidity test results of A713 virgin alloy and A713 alloy with 25 per cent scrap addition respectively. Mould coating has a substantial impact on the fluidity of A713 alloy as well as on the A713 alloy with 25 per cent scrap addition. Fluidity of the said alloy can be categorized in to four cases which are explained below.

TABLE II
FLUIDITY DOUBLE SPIRAL TEST RESULTS OF A713 ALLOY WITHOUT SCRAP ADDITION

Pourin g Temp. (^{O}C)	Fluidity length (cm)		Increase of fluidity from un-coated to coated spiral (cm)	% Increase in fluidity
	Un-coated	Coated		
700	17	29	12	70.59
750	34	35	1.0	2.94
780	24	26	2.0	8.33

TABLE III
FLUIDITY DOUBLE SPIRAL TEST RESULTS OF A713 ALLOY + 25% SCRAP

Pouring Temp. (^{O}C)	Fluidity length (cm)		Increase of fluidity from un-coated to coated spiral (cm)	% Increase in fluidity
	Un-coated	Coated		
700	12	13	1.0	8.33
750	19	24	5.0	26.31
780	22	24	2.0	9.09

Case I: Without Scrap & without Coating: When the pouring temperature was increased from 700 ^{O}C to 750 ^{O}C, the fluidity increases from 17 cm to 34 cm. For the pouring temperature range between 750 ^{O}C to 780 ^{O}C, the fluidity decrease from 34 cm to 24 cm.

Case II: Without Scrap & with Coating: When the pouring temperature was increased from 700 ^{O}C to 750 ^{O}C, the fluidity increases from 29 cm to 35 cm. For the pouring temperature range between 750 ^{O}C to 780 ^{O}C, the fluidity decrease from 35 cm to 26 cm.

Case III: With scrap & without coating: When the pouring temperature was increased from 700 ^{O}C to 750 ^{O}C, the fluidity increases from 12 cm to 19 cm. For the pouring temperature range between 750 ^{O}C to 780 ^{O}C, the fluidity increases from 19 cm to 22 cm.

Case IV: With scrap & with coating: When the pouring temperature rises from 700 ^{O}C to 750 ^{O}C, the fluidity increases from 13 cm to 24 cm. For the pouring temperatures between 750 ^{O}C to 780 ^{O}C, there is no appreciable increment in fluidity and it remains constant i.e. 24 cm.

In comparison with the above cases, interestingly, for A713 alloy with 25 per cent scrap addition at high pouring temperatures, variations in the fluidity are approximately same as that of the virgin A713 alloy. Earlier researchers, [15] also added scrap (turning chips) by 20% and 50% respectively to the standard A356 alloy. Comparisons were made between the fluidity measurements with 20% and 50% scrap additions. It was reported that recycled material increases the oxide content of the molten metal, which significantly decreases its fluidity. Similarly, [16] investigated the effect of oxide inclusions on the fluidity of Al-4.5wt%Cu-0.6wt%Mn and A356 alloys. The oxide inclusions in the melt decreased the fluidity considerably, especially at low pouring temperatures. This phenomenon is due to the critical solid fraction that stops the flow, which depends on the grain size and the amount of oxide inclusions in the flow channels. The spiral test results are compared with coated (C_2Cl_6) side with virgin A713 alloy and A713 alloy with 25% scrap additions.

From the Case I & II, with the increase of fluidity from un-coated to coated spiral, the per cent increase of fluidity were observed in the pouring temperature at 700 ^{O}C. Fluidity has increased by 70.59 %. At 750 ^{O}C also the fluidity has increased by 2.94%. At 780 ^{O}C, fluidity increase is 8.33%. Similarly, from the Case III & IV, the increase in fluidity from un-coated to coated spiral, at the pouring temperature at 700 ^{O}C was 8.33 %. At 750 ^{O}C also the fluidity has increased by 26.31%. At 780 ^{O}C the increases in fluidity is 9.09%, which is approximately same as virgin A713 alloy. It might be possible that the percentage of recycled aluminium - zinc alloy does not significantly affect fluidity at the higher pouring temperatures with the 25 per cent scrap additions owing to hexachloroethane coating. Therefore, recycling of aluminium - zinc alloys are recommended at an industrial level.

The increment in the fluidity at elevated temperatures was approximately same for Case IV and it might be due to the weakening of A713 alloy oxide particles with 25% scrap additions, thus fluidity was substantially improved. Similarly, [17] found that on coated spirals (hexachloroethane) the oxides that were present in the alloy were weakened or eliminated and hence the fluidity was improved. For A713 alloy with 25 per cent scrap addition, it might be the same cause for minimum variations in the fluidity at high pouring temperatures. It might be possible that the addition of aluminium - zinc alloy scrap does not significantly affect fluidity at higher pouring temperatures with the 25 per cent scrap addition. Therefore, aluminium - zinc alloys scrap are recommended at an industrial level. Addition of 25% turning chips to the A713 alloy has decreased the fluidity at minimum pouring temperatures. However, with the increase in the pouring temperature fluidity has increased. Moreover, it can be expected that the inclusion of oxide particles was influenced by the mould coatings due to the pouring temperature. Further systematic investigations are, however, needed to confirm the type of oxide particles.

VI. Conclusion

Based on the investigations carried out, the following major conclusions can be drawn:

1. An appreaseable improvement in the fluidity of A713 alloy without scrap addation was observed due to hexachloroethan mould coatings, particularly at minimum pouring temperatures.
2. Adding 25 per cent scrap to A713 virgen alloy decreases its fluidity, escepecially at minimum pouring temperatures. However, appraisable improvement in the fluidity was observed at elevated pouring temperatures. Hence 25 per cent scrap addition is permissible for the said alloy.
3. The percentage of aluminiun - zinc alloy scrap does not have significant influence on fluidity at the higher pouring temperatures with the 25 per cent scrap additions. Therefore, it is recommended to the casting industries that scrap addition of the said alloy is beneficial with proper control of alloy composition.

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