Effect of Iron-intermetallics on the Fluidity of Recycled Aluminium Silicon Cast Alloys.

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Abstract—The effect of Fe content on the fluidity of recycled aluminium silicon cast alloy has been investigated in both un-modified and Mn-neutralized states by spiral fluidity test. Increasing Fe decreases the fluidity due to the formation of β-Al_5FeSi and α-$Al_{15}(Fe,Mn)_3Si_2$-intermetallic compounds in un-modified and Mn-neutralized states respectively. At a constant Fe level Mn-neutralization increased fluidity. Manganese neutralization was found to be an effective way of improving the fluidity of recycled aluminium-silicon alloys at a constant concentration of Fe.

Keywords—Aluminum-silicon alloys; Fluidity; Iron-intermetallics; Manganese; Neutralization

I. INTRODUCTION

RECYCLING of aluminium is popular due to several economic and environmental reasons. Recycling of aluminium requires only 5 percent of the energy for primary aluminium production and saves raw materials such as carbon and alumina. Moreover, waste products can be recycled instead of being sent to landfill and conserves the natural resources [1].

Thin wall aluminium-silicon alloy castings often are advantageous because of their light weight structure, which enables for increased payload and reduced energy consumption in aerospace and automobile applications. There has been a growing demand to meet the stringent requirements of the design engineers for producing thinner section castings having good mechanical properties. Aluminum-silicon cast alloys have been considered as promising materials to meet these requirements due to their low density, superior corrosion resistance, high specific strength and specific stiffness combined with good castability [1,2]. However, thin wall castings of these materials can pose manufacturing problems like cold shuts which are associated with mold filling due to poor castability.

Castability is the ability of an alloy to be cast to a given shape with a given process without formation of casting defects [3]. Alloy dependent phenomena that determine castability are fluidity, macrosegragation, hot tearing and porosity. Fluidity is an empirical measure of the distance a liquid metal can flow in a special channel before being stopped by solidification[4]. It is necessary to obtain molten aluminum with high fluidity to avoid the need for overheating. Overheating aluminum increases the chance of successive problems, including gas porosity, solidification shrinkage, and dross formation. There are two types of fluid test that are widely used for measuring fluidity of an alloy; one is the fluidity spiral test and the other is the Ragone test, or vacuum fluidity test [1,5]. The first method measures the length the metal flows inside a spiral-shaped mold. The second method measures the length the metal flows inside a narrow channel when sucked from a crucible by using a vacuum pump.

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The factors determining fluidity can be basically divided into:

- metallurgical variables, such as composition, superheat, latent heat, surface tension, viscosity and mode of solidification and
- mold/casting variables, such as part configuration, cooling rate, degree of super heat, mold material and its surface characteristics.
- Test variables including applied metal head, channel diameter and oxide/particle content.

Di Sabatino and co-workers [1] studied the effect of the casting temperature, concluding that the alloy superheat, i.e. casting temperature minus liquidus temperature, plays the most important role in enhancing fluidity. Research data has demonstrated that fluidity is inversely proportional to the solidification interval (liquidus temperature minus the solidus temperature) of an alloy. Oxide films, that are solid at the metal pouring temperature can significantly raise surface tension and reduce the ability of metal to fill finer details. Sabatino et al [1] investigated the effect of oxide inclusions on fluidity, concluding that increasing oxides content decreases fluidity, particularly at a low pouring temperature.

During the investigation of the fluidity of A380 die casting alloy it was observed that an increase in the Fe content decreases the fluidity of the alloy. Addition of 1.5 and 1.7 wt per cent Fe to the A380 alloy caused 4 and 6 percent decrease in fluidity, respectively [6]. In the study of effect of trace addition on fluidity of pure aluminium, iron was found to decrease the fluidity as illustrated in Fig. 1.

Taghaddos et al [7] found that increasing iron content decreased the fluidity of both unmodified and Mn-modified 413 alloy, due to the formation of β-Al_5FeSi and α-Al_{15}(Fe,

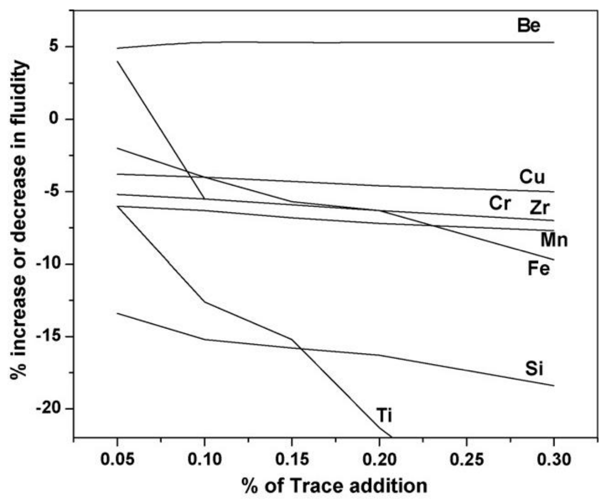

Fig. 1. The effect of trace addition on fluidity of pure aluminium.

$Mn)_3Si_2$-intermetallics. β-Phase intermetallics were the most detrimental phases to fluidity. As result the fluidity of Mn-modified melts is better than un-modified ones at constant iron content. For effective modification of β-phases, the ratio of Fe to Mn should be kept about 2:1, as reported by several previous researchers [7,8].

Fluidity values of pure metals and eutectic alloys are greater than those of alloys solidifying over a temperature range [6]. This is the reason for the wide practical preference for eutectic or near eutectic alloys for foundry purposes, particularly for casting with thin sections. However, Al-Si alloy system displays a slight exception to this rule with its maximum fluidity shifting to the hypereutectic region.

II. MATERIALS AND METHODS

Metal from automobile wheels was melted in the oil fired crucible furnace and cast into 4 kg ingots. Chemical analysis of the cast material gave the composition (in wt. Percent) shown in Table I. This cast material is referred to as the base alloy.

TABLE I
COMPOSITION OF THE CAST MATERIAL.

Element Wt. (Per cent)												
Si	Fe	Mg	Mn	Cu	Ca	Sr	Be	Cr	Pb	Sn	Ti	Al
6.92	0.12	0.36	<0.02	<0.05	0.018	0.003	0.001	0.0	0.1	<0.05	0.15	Bal Al

The base alloy was modified by addition of iron and manganese to produce nine different alloys. Preparation of the alloys was carried out in a Silicon Carbide crucible in an electrical resistance muffle furnace. Nominal compositions (in wt. Per cent) of the alloys are presented in Table II.

Coverall 11 flux was added at the beginning of melting. The weight of this flux was 0.3 per cent of the weight of charge. After melting the ingots, specific amount of iron was added to the melt at 750 ^{o}C. The melt was stirred for three minutes to ensure the dissolution and homogeneity of iron in

TABLE II
NOMINAL COMPOSITION (WT. PER CENT) OF PREPARED ALLOYS.

Sample No	Element (Wt. %) Fe	Mn
1(Base)	0.12	<0.02
2	0.7	<0.02
3	0.7	0.35
4	1.0	<0.02
5	1.0	0.5
6	1.4	<0.02
7	1.4	0.7
8	1.8	<0.02
9	1.8	0.9

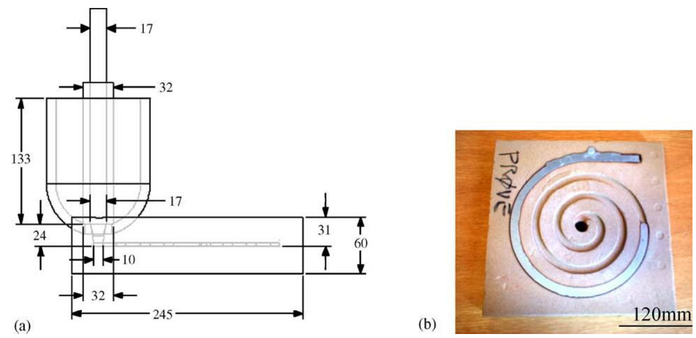

Fig. 2. The experimental setup for fluidity test.

the melt. Mn was added to adjust the chemical composition of the alloy. After composition adjustment, 0.4 wt. Per cent nitro-10 degasser tablet was put into the melt using a special cup.

The experimental setup for fluidity testing consisted of a fluidity spiral mold made of CO_2 silicate sand shown in Fig. 2(a) and (b). This experimental setup has been used successfully in previous work [3]. The molten aluminum alloy was poured into the mold which had been preheated to 400 ^{o}C with an electrical resistance furnace.

The metal was poured from the furnace at a temperature of 750 ^{o}C. The time taken to transfer the melt from the furnace to the spiral mold was constant. This ensured that the melt entered the spiral mould at a constant temperature of 720 ^{o}C. The length of the spirals of the different alloys was recorded as shown in Table III.

III. RESULTS AND DISCUSSIONS

Effect of Fe concentration on the fluidity of un-modified and Mn-modified melts is shown in Table III. Increasing Fe content from 0.2 to 1.8 wt percent decreased fluidity length in both cases. Clearly, base alloy has a much higher fluidity length than the alloys with 0.7, 1.0, 1.4 and 1.8 wt per cent iron additions. The decrease in fluidity length of un-modified alloys due 0.7, 1.0, 1.4 and 1.8 wt per cent iron addition to the melt is about 7.5, 15, 18 and 23.0 per cent respectively. Fluidity of Mn-modified alloys is, however, less sensitive to Fe content. At a constant Fe concentration, the fluidity of modified alloys is slightly more than un-modified ones as illustrated in Fig. 3. The Mn neutralization is therefore a better

TABLE III
THE LENGTH OF THE SPIRALS OF THE DIFFERENT ALLOYS.

Sample No	Element (Wt %)		Fluidity length (cm)				% decrease in fluidity
	Fe	Mn	First	Second	Third	Average	
1(base	0.2		88.2	86.8	86.0	87.0	
2	0.7		82.3	81.0	78.3	80.5	7.5
3	0.7	0.35	83.0	81.4	79.8	81.4	6.4
4	1.0		76.0	73.4	72.0	73.8	15
5	1.0	0.5	76.9	74.7	73.4	75.0	13.8
6	1.4		72.6	70.5	69.6	70.9	18.5
7	1.4	0.7	74.2	73.1	71.8	73.0	16
8	1.8		69.0	68.3	63.7	67.0	23
9	1.8	0.9	72.7	71.9	66.6	70.4	19

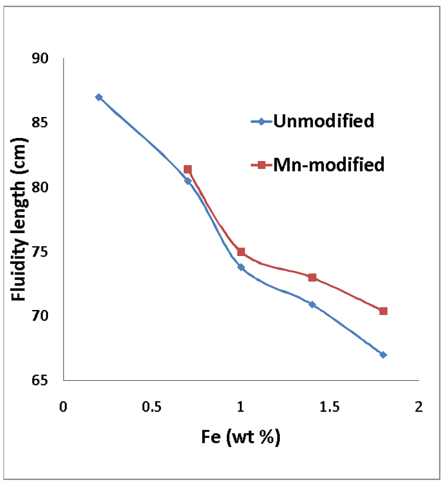

Fig. 3. The effect of Fe on the fluidity of un-modified and Mn-modified alloys.

method of improving fluidity of aluminium alloys containing iron.

Fig. 4 shows microstructure of un-modified alloys, consisting of Large and thin platelet phases that are characterized as β-intermetallic compounds. These platelet intermetallics which usually form as primary phases in high-iron alloys, act as inclusions which restrict interdendritic connections after liquid and mass feeding. These inclusions contributed to a decrease in fluidity accompanied by increase of melt viscosity. Therefore, fluidity descending in un-modified alloys is attributed to presence of large and thin platelet β-intermetallics.

Microstructures of modified alloys have been shown in Fig. 5 and Fig. 6. Most of β-intermetallics have been transformed to α-intermetallics in the forms of Chinese script or polyhedral morphologies. Increasing Fe and Mn concentration in modified alloys has increased volume percentage of primary α-intermetallics. These intermetallics formed sludge, which decreased fluidity at a lower rate than that of unmodified alloy.

The fluidity of the melt is affected by both the morphology and volume percentage of intermetallics [6]. The platelet and needle β- phases have largest surface to volume ratio and therefore have the largest interfacial area with the melt and are the most harmful intermetallics to decrease the fluidity. In

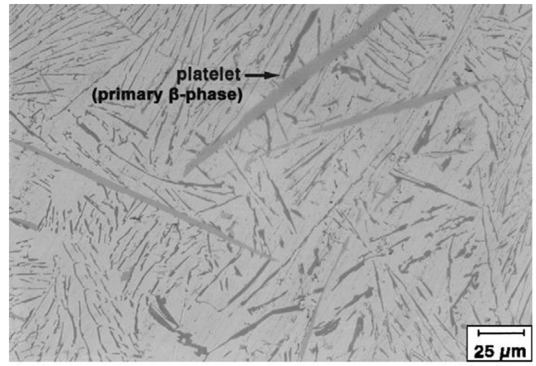

Fig. 4. Microstructure of unmodified alloy containing 1.4 per cent Fe.

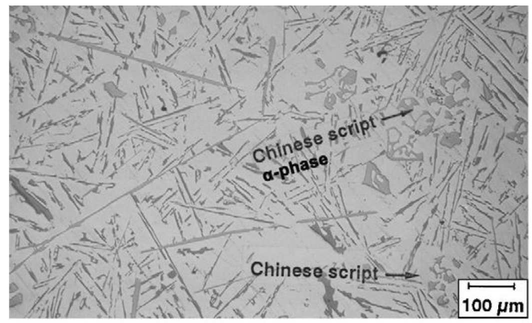

Fig. 5. Microstructure of the Mn-modified alloy containing 1.4 per cent Fe.

Mn-containing alloys the effect of α-phase is less detrimental than β- phase to the fluidity. Even though the volume fraction of Fe-intermetallics in Mn-modified alloys is more than un-modified ones, but α- phases decreases the fluidity very slightly. Therefore, the fluidity of Mn-modified alloys is better than un-modified alloys at the same Fe content (Fig. 3).

IV. CONCLUSION

The following conclusions can be made regarding this work:

1) Increasing iron content decreases the fluidity of both un-modified and Mn-modified recycled aluminium silicon alloy, due to the formation of β-Al_5FeSi and α-$Al_{15}(Fe, Mn)_3Si_2$-intermetallics. However β-intermetallics are the most detrimental phases to fluidity.
2) The fluidity of Mn-modified melts is better than un-modified ones at constant iron content.

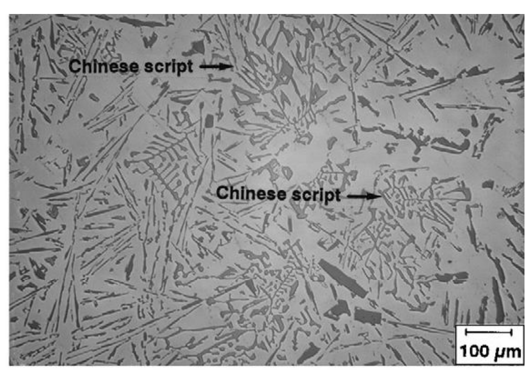

Fig. 6. Microstructure of the Mn-modified alloy containing 1.8 per cent Fe.

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