Comparative fluidity study of AA7075 unreinforced alloy and Al₂O₃ reinforced composite.

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Abstract. Aluminium alloys are used extensively in the automobile and aerospace areas. The reason behind this is the high strength to weight ratio of aluminium and its alloys. As requirement for better materials arose, the existing aluminium alloys evolved into composite forms. Composites can enhance the mechanical properties of the metal matrix. The property which gets improved depends upon the reinforcement. But the problem associated with composites is their poor fluidity. There are only a handful of researches conducted to evaluate the effects of reinforcing agents on composite fluidity. Fluidity is expressed in terms of fluidity length or flow length. It is defined as the maximum length the molten metal will flow in a long channel before solidifying. In this work, the fluidity characteristics of AA7075 alloy and AA7075 alloy reinforced with aluminium oxide (Al₂O₃) are explored. It was found that the fluidity length of aluminium alloy AA7075 decreased by almost 20 cm on addition of the reinforcing agent, aluminium oxide. This may be due to the tendency of alumina particles to cluster together or accumulate in the aluminium matrix. This increases the viscosity and thereby reduces the fluidity length.

1. Introduction

Aluminium casting alloys have attracted much research interest as light-weight constructional materials in recent years, owing to their high castability, low density, low shrink rate, and relatively high specific strength. Aluminium composites are fast replacing the aluminium alloys, as they have better properties than the latter. Aluminium is light and only one-third the density of steel. Also like copper, it has a high conductivity for heat and electricity. Other properties include excellent corrosion resistance in most environments, and good castability. It is also suitable for recycling as the remelting of scrap requires only five per cent of the total energy needed to extract the same amount of primary metal from bauxite ore. When adding reinforcements into the aluminium matrix we can focus on enhancing the otherwise poor properties of the matrix. Many ceramics such as flyash, hematite, boron carbide, silicon carbide, aluminium oxide etc. are used as such reinforcing agents. Nowadays aluminium composites are in use instead of aluminium alloys. But when casting large, thin walled sections and some complex parts, there arises a problem of incomplete or uneven filling of molten metal. In the case of magnesium and aluminium alloys this problem is quite severe. Also they are very prone to oxidation. Researchers have found this area interesting and have investigated on the same. Hence it is essential to investigate the fluidity of the composites as well.

From the past literatures, it is seen that a detailed study has been carried out on the effects of the adding reinforcements into the aluminium matrix. But these works are focused on the mechanical properties of the composites. It is observed that the mechanical properties of the matrix metal were
improved considerably in most cases. The problems associated with the composites are uneven distribution of the reinforcements in the matrix, clustering of these particles and their tendency to move towards the flow tip and stop the flow early. This reduces the fluidity of the metal. Fluidity is one of the major castability attributes. Therefore the fluidity of such composites has to be investigated.

AA 7075 is used mostly in highly stressed structural applications. Aluminium 7075 is an aluminium alloy, with zinc as the primary alloying element. AA7075 aluminium alloy includes zinc, magnesium, copper and lesser quantities of iron, manganese, silicon, titanium, chromium and other materials. It has excellent mechanical properties. AA7075 alloy shows good ductility, high strength, toughness and good fatigue resistance. It is also corrosion resistant, especially when compared with 2000 series of aluminium alloys. AA7075 is more prone to embrittlement due to micro segregation. AA7075 is commonly used in aircraft structural parts. 7000 series alloys such as 7075 are often used in transport applications. They are also used in marine, automotive and aviation industry because of their higher specific strength. The composites made from AA 7075 offers high strength, fracture toughness, wear resistance and stiffness. These same properties lead to its use in rock climbing equipment, bicycle components, inline skating-frames and hang glider airframes are commonly made from 7075 aluminium alloy. 7075 is used in the manufacturing of M16 rifles and AR-15 style rifles. Table 1 shows the chemical composition of AA7075 purchased.

C. Saravanan et al. [1], the various reinforcement materials of aluminium alloy and their properties are described in this paper. The problems associated with stir casting method in fabrication of composites are found to be porosity, uneven distribution of reinforcement particles and chemical reactions between matrix and reinforcement materials. Proper selection of reinforcement material and parameters are inevitable for obtaining a sound cast product.

The properties of aluminium alloy A356 reinforced with aluminium oxide and A356 alloy reinforced with boron carbide are compared by Vishnu Vardhan et al. [2]. The properties of these composites when compared to matrix alloy were found to be better. Also it was found that aluminium oxide enhances the wear resistance of the matrix whereas boron carbide addition improves the hardness of the matrix. In addition to this, both the reinforcements enhance other properties like strength and stiffness.

Thiensak Chucheep et al. in [3] used sand spiral test to evaluate the fluidity of rheo slurry in semi-solid casting. The water test has been employed as a method to test fluidity of a material for several years. But for slurries and composites it is usually difficult to find fluidity by using water fluidity test as the dynamic viscosity of water and composite are different. Thus here sand spiral test is used to find the fluidity. Microstructure is also observed to identify how the metal is distributed.

Feifan Chen et al. [4] discuss a method to observe the real time mold filling process. Mold filling can be observed, live, using special X-ray equipment called X-ray radiography. But this method was found expensive as the apparatus used is costly. The real time filling gives us a better insight into the filling of alloys or composites. With the help of Euler-Lagrangian methods, the flow behaviour as well as the particle distribution of investment casting of A356/SiCp composites was simulated.

D. Caliari et al. [5] has studied the sand spiral tests and its reliability. One of the problems associated with the spiral fluidity test method is its poor repeatability. The use of standard Archimedean spiral can be a solution to this problem. Also it was seen that many researchers has found ways to optimize the flow behaviour of the molten metal. The authors also used the software Nova Flow & Solid to simulate the fluidity and hence confirm the reliability of the spiral method.

John Campbell [6] discusses about aluminium and its relevance in the present industrial scenario. The methods to predict the fluidity is also explained. The sand spiral method, strip test and vacuum fluidity tests were compared and it was found that spiral method is much more suitable for composite casting. The designation of aluminium alloys are explained elaborately in this textbook.
Roger Lumley [7] compares various processes of aluminium and its applications. Stir casting, squeeze casting and compo casting of aluminium are explained in this book. A slightly detailed designation of aluminium cast alloys is also given. Stir casting was found to be more cost effective than other methods with compo-casting following the stir casting method.

S. Dhanalakshmi [8] discusses about the preparation of hybrid composites. The aluminium-aluminium oxide-boron carbide composite preparation and its characteristics are studied in this paper. Hybrid materials offer better mechanical characteristics than composites with single reinforcements. But the influence of additions of two or more composites is yet to be evaluated.

There are several reinforcing agents that enhance the mechanical properties of the metal matrix. The mechanical property which gets improved is decided by the reinforcement. But with the addition of reinforcement, the fluidity of the composite may get compromised. Here aluminium oxide is selected as the reinforcing agent. The major advantage of adding aluminium oxide is the increased wear resistance. Since aluminium 7075 is used in aircraft fuselage skins, it is essential to have good wear resistance. Addition of aluminium oxide also improves the strength and specific stiffness of the matrix material. But how the addition of aluminium oxide affects the matrix in terms of fluidity and the corresponding microstructural characteristics are to be determined.

In the present study, Aluminium-aluminium oxide (Al-Al2O3) composite is stir-cast. The unreinforced aluminium alloy (AA7075) and aluminium oxide reinforced AA7075 composite are tested to find their fluidity behaviour. A comparison between the fluidity lengths (Lf) are carried out.

2. Methodology

2.1. Aluminium 7075

The chemical composition of the aluminium alloy AA7075 is given in the table 1.

| Elements | Zn    | Cu   | Mn   | Mg   | Fe   | Cr   | Ti   | Si   | Al   |
|----------|-------|------|------|------|------|------|------|------|------|
| Weight % | 5.224 | 1.572| 0.061| 2.206| 0.174| 0.202| 0.034| 0.122| Balance |

2.2. Sand spiral test

The metal matrix composites have 10 to 50 times the viscosity of the parent metal. This increase in viscosity leads to reduced fluidity of the MMC. Fluidity comprises of many attributes mainly, flowability and fallibility. Thus it is essential to evaluate the fluidity of the matrix composites as they have at least one reinforcement material dispersed in their matrix. For this study, sand spiral test is used to determine the flow characteristics of the unreinforced and aluminium oxide reinforced metal matrix composite.

For this purpose a sand mould was made with the required spiral shaped cavity. For the preparation of sand mould a spiral shaped pattern was made. A 3D model of the spiral shape with required dimensions were modelled using Rhinoceros software. The spiral model had first inner diameter of 15mm and last inner diameter of 75mm and the outer diameter of 25mm for first turn and 85 mm for last turn. The rectangular cross-section had dimensions of 9.1x7.6mm. The length of the spiral was 1.2 meters. The spiral consists of 3.5 turns. Figure 1show the model designed to make the 3D print of the spiral shaped pattern. The section 3.3 of chapter 3 in textbook Castings by John Campbell explains this procedure in detail [6]. The same have been followed in by Thiensak Chucheep [4].
Figure 1. 3D model of the spiral shaped pattern

This model was then 3D printed at the Fablab, functioning in the Architecture block of Government Engineering College Thrissur. The material used for pattern making was Polylactic acid (PLA). Figure 2 shows the 3D printed spiral pattern.

Figure 2. 3D printed spiral pattern

The spiral pattern was used for preparation of the sand mould. Green sand with coarse texture was used as the moulding material. The mould was preheated before pouring the materials. The materials were stir casted in the stir casting setup available at the foundry lab. The stirrer speed was set at 300 rpm and the stirring time was 5 minutes. The materials were heated to a temperature of 650°C. Figure 3 shows the sand mould prepared using the 3D printed spiral pattern.

Short-pouring was adopted as the method to find out the flowability length of the castings. For comparison the pure AA 7075 was first melted and casted in the spiral mould. After the completion of casting pure aluminium alloy, the composites were cast. For stir casting of the unreinforced composite, the AA7075 alloy blocks have been machined into small pieces with the help of power hacksaw so that pieces will easily fit the crucible. AA 7075 alloy was cleaned using water and soap solution thoroughly and then dried. It was then weighed using a weighing balance. Predetermined weight of aluminium oxide is preheated at 400°C. The sand mould prepared earlier was also preheated to avoid lower solidification times due to the huge difference in the temperatures of molten metal and sand mould. After that the aluminium alloy weighing 166 grams was added to the crucible. An electrical
A furnace was used to heat and melt the AA7075 alloy. The temperature was then raised to 650°C. The chunks of AA7075 were completely melted at this temperature and afterwards the melt was poured into the sand mould prepared.

A similar approach is carried out for AA7075-aluminium oxide composite. Aluminium-aluminium oxide (Al-Al₂O₃) was cast with 10 wt. % of aluminium oxide as reinforcement. The AA7075 alloy chunks of weight 150 grams was first added into the crucible and heated. After reaching a temperature of 600°C the preheated aluminium oxide particles were added into the crucible containing melt AA7075 alloy. Then the mixture was stirred at a stirring speed of 300 rpm for 5 minutes.

3. Result and discussions

3.1. Sand spiral test of AA7075 alloy
166 grams of aluminium alloy 7075 was added into the graphite crucible of the stir casting equipment. Then the alloy was heated and melted by increasing the temperature up to 650°C. Afterwards, the molten metal was poured into the sand mould prepared earlier. The sand mould contained a spiral cavity of length 1.2 meters.

Figure 3. Sand mould prepared: (a) cope and (b) drag of the sand mould

Figure 4. Spiral test of AA7075 (a) spiral cast product before breaking the mould and (b) spiral cast product separated from the mould
The figure 4 shows the spiral test result of AA7075 unreinforced alloy. Figure 4 (a) shows the cast product in the spiral cavity of the sand mould. Figure 4 (b) shows the spiral cast product taken out after carefully breaking the sand mould. From the figure it can be seen that the melt flow completed almost 1.5 turns. The fluidity length was measured and the value was found to be 57.5 centimetres.

3.2. Sand spiral test of AA7075 reinforced with Al2O3

150 grams of aluminium alloy 7075 was added into the crucible of stir casting equipment. Then the metal was melted at 650°C. The preheated aluminium oxide of weight 16.5 grams was added into the graphite crucible containing this Aluminium 7075 melt. Then the mechanical stirrer was immersed into this mixture and was stirred at 300 rpm for about 5 minutes to ensure uniform distribution of aluminium oxide particles in the AA7075 matrix.

Figure 5.2 shows the cast product of AA7075 alloy reinforced with 10 wt. % of aluminium oxide. Figure 5.2 (a) shows the cast aluminium-aluminium oxide matrix composite in the sand mould. The figure 5.2 (b) shows the same cast product separated from the mould, after carefully removing it from the sand mould. It can be observed that this matrix composite melt travelled only a 3/4th of a turn. The fluidity was measured and the value was found to be 38 centimetres. Some pores can be seen on the outside of the spiral product. Also a crack line can be seen at the middle portion on the cast product. But the surface texture of the cast product was better than that of the unreinforced alloy.

4. Conclusions

In this work, the fluidity study of AA7075 reinforced with aluminium oxide and AA7075 unreinforced alloy was carried out. From the results the following conclusions were obtained.

The fluidity length of aluminium alloy AA7075 without any reinforcement had a fluidity length of 57.5 cm. For 10 wt. % of aluminium oxide added to the AA7075 matrix, the fluidity reduced from 57.5 cm to 38 cm. This result is due to the tendency of particles to form agglomerates or clusters. Aluminium oxide particles in the melt adhere to each other and form clusters or agglomerates. These clusters of aluminium oxide particles hinder the flow of the molten metal. That is, it leads to increased viscosity. This increase in viscosity leads to reduced fluidity. These agglomerates cause incomplete filling and other casting defects like porosity or cracks. Therefore it is best to limit the aluminium oxide concentration even though it enhances the mechanical properties.

As the behaviour of the matrix metal’s fluidity reduced with the addition of just one reinforcement, the addition of more than one reinforcement may drastically reduce the composite fluidity. Such
composites with two or more reinforcement are called hybrid composites. There have been no studies about the fluidity of hybrid composites.

References

[1] Saravanan C, Subramanian K, Ananda Krishnan V and Sankara Narayanan R 2015 Effect of particulate reinforced aluminium metal matrix composite – A review Mechanics and Mech. Eng. 19, No. 1 23–30.

[2] Dr. Vishnu Vardhan T, U. Nagaraju, Dr. Harinath Gowd G and Ajay V 2017 Evaluation of Properties of LM 25-Alumina–Boron Carbide MMC with Different Ratios of Compositions. Int. J. of Appl. Eng. Res. ISSN 0973-4562 12, Number 14 pp. 4460-67.

[3] Feifan Chen, Haidong Zhao, Gang Zhu, Paixian Fu and Lijun Xia 2015 Experimental and numerical analysis of flow behaviour and particle distribution in A356/SiCp composite casting Exp. Thermal and Fluid Sci. 68 39–47.

[4] Thiensak Chuheep, Rungsinee Canyook, Tanate Rattanochaikul, Somjai Janudom, Sirikul Wisutmethagoon and Jessada Wannasin 2011 A fluidity study of semi-solid rheo-slurry of AC4C Al alloy in gravity sand casting Adv. Mater. Res. 337 pp 439-42.

[5] Daniele Caliari, Franco Bonollo and Giulio Timelli 2015 Fluidity of Aluminium Foundry Alloys: Development of a Testing Procedure La Metallurgia Italiana - n. 5

[6] John Campbell Castings: 2nd edition. Butterworth-Heinemann (2003).

[7] Roger Lumley 2011 Fundamentals of aluminium metallurgy: Production, processing and applications. Woodhead Publishing Limited.

[8] S. Dhanalakshmi, N. Mohanasundararaju and P. G. Venkatakrishnan 2014 Preparation and mechanical characterization of stir cast hybrid Al 7075-Al2O3-B4C metal matrix composite Appl. Mechanics and Mater. 592-94 pp 705-10.