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STRENGTH OF CHILLED ALUMINUM ALLOY-BOROSILICATE GLASS-FLYASH HYBRID COMPOSITES

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ABSTRACT

The paper presents the findings of the research conducted on chilled LM25-borosilicate glass-flyash hybrid composites cast with varying weight percent reinforcement (3%, 6%, 9% and 12%). The composites are cast with the help of metallic and non-metallic end chills that are judiciously placed in the sand mould. The composites are tested for the evaluation of their strength by drawing the specimens from near, as well as away from the chill end. This is done to study the effect of chilling on the mechanical properties of the composites. Microstructural analysis of the cast composites is done to determine the quality of dispersion of the reinforcements within the matrix.

Keyword: LM-25 aluminum alloy, borosilicate glass, fly-ash, end chills, stir casting.
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1. INTRODUCTION

1.1. Hybrid Composites

Technological advancements in various fields are throwing up challenges for metallurgists to come up with materials with tailorable properties. This has rendered no one particular type of material suitable for a specific application. Hence, researchers around the world have centered their study on the fabrication of composite materials with different types of reinforcements within the matrix. This has given rise to the concept of hybrid composites that are composed of one matrix phase and two or more reinforcement phase. Hybrid metal matrix composites consists of soft, ductile matrix of either aluminium, titanium, cobalt, copper and their alloys. The reinforcements are generally hard, brittle ceramics such as silicon carbide, aluminum oxide, boron carbide, titanium carbide etc. [1-3].

Aluminium has found widespread applications in the field of automotive and aerospace applications owing to its excellent strength-to-weight ratio, formability and resistance to corrosion, good thermal and electrical conductivities in comparison with the nonferrous metals [4]. It is also easy to add suitable reinforcements/alloying elements into aluminum while casting to bring about improvements in the material's physical, mechanical and thermal properties. Thus, aluminum matrix composites (AMCs) have caught the attention of researchers and the acceptance of industries worldwide. To make AMCs more commercially viable, it is important to bring down the fabrication cost along with the incorporation of cheaper and more readily available reinforcements which include industrial, agricultural wastes and/or byproducts. Particulate reinforced AMCs can be produced in large scale through the most economic stir-casting method. It is also very easy to introduce low-cost particulates into the molten melt while stir casting and produce superior AMC with excellent mechanical and thermal properties [5]. The paper explores the possibility of improving the mechanical properties of the AMC through the incorporation of easily available particulate reinforcements such as quartz and flyash.

1.2. Chill Casting of Aluminum Alloys

Aluminum alloys pose a challenge in casting due to their inherent ability to solidify over a varied range of temperatures. This characteristic makes feeding of the aluminium alloys into the mould cavity quite difficult [6-7]. The casting defects arising due to this can be avoided with the aid of suitable end chills placed judiciously within the sand mould. End chills extract heat from the melt quickly and help to setup directional solidification of the molten melt in the mould cavity producing defect free castings [8-9]. The ability of the chill to extract heat from the melt at a rapid rate depends on its volumetric heat capacity (VHC). The VHC of the chill is evaluated from the empirical formula given in Equation 1.

$$VHC = V_C \times C_{P_C} \times \rho_C \qquad 1$$

Where V_C, C_{P_C}, ρ_C are the volume, specific heat capacity and density of chill material. Higher the VHC higher is the ability of the chill material to extract heat quickly from the melt and setup a steep solidification gradient [10]. In the present investigation, copper, mild steel metallic chills and silicon carbide and graphite non-metallic chills are used to cast the required AMCs. Table 1 illustrates the thermo-physical properties of the selected end chill materials.

Table 1 Thermo-physical properties of end chills

Chill Material	Density (g/cc)	Specific heat Capacity (J/kg K)	Thermal Conductivity (W/m K)	Volumetric Heat Capacity (2.5cm chill thickness) (J/K)
Copper	8. 96	410	380	344. 4
Mild Steel	7. 70	465	66	335. 7
Graphite	1.95	710	150	129. 8
Silicon carbide	3.21	650	120	195. 6

2. MATERIALS

2.1. Matrix Material

LM25 aluminum alloy is used as the matrix material in the current research work. Table 2 depicts the elemental composition of LM25 on weight percent basis. LM25 finds its extensive applications in the production of castings that possess excellent structural and mechanical properties. LM25 is commercially available in basically four forms of heat treatment in both chilled and sand castings and is thus used as a high strength casting alloy.

Table 2 Chemical composition of LM25

Elements	Composition (weight percent)
Zinc	0.10
Magnesium	0.35
Silicon	7.00
Copper	0.20
Manganese	0.10
Iron	0.20
Nickel	0.10
Lead	0.10
Aluminium	Balance

2.2. Borosilicate Glass Reinforcement

Incorporation of low cost, easily available, industrial and agricultural byproducts as reinforcement is much appreciated to make the AMCs more cost effective and sustainable. Glasses in various forms are available as byproducts of industrial waste recycling and are finding increased adaptation within the various metal matrices as potential reinforcements [11]. The available literature indicates that glass reinforced AMCs exhibit enhanced mechanical properties in comparison with the matrix alloy [12-14]. In the present work borosilicate glass powder (100 micro-meters) is selected as reinforcement as there is very little work involving the employment of borosilicate glass which has very good thermal, chemical and mechanical properties. Table 3 depicts the composition of the borosilicate glass.

Table 3 Composition of borosilicate glass

Elements	Composition (weight percent)
Silicon di oxide	81
Boron Oxide	13
Sodium Oxide	4
Aluminium Oxide	2
Miscellaneous Traces	Balance

2.3. Fly-Ash Reinforcement

Fly-ash is another industrial byproduct which is produced in large quantities after combustion of coal in thermal power plants. Fly-ash has lower density, is easily available and is very economical [15]. Thus, an effort has been made in the current research work to incorporate fly-ash particles as reinforcement within the LM25 matrix. Table 4 illustrates the elemental composition of the fly-ash used in the present work.

Table 4 Composition of fly-ash

Elements	Composition (weight percent)
SiO_2	81
Al_2O_3	13
Fe_2O_3	4
CaO	2
MgO	Balance

3. COMPOSITE COMPOSITION

The required metal matrix composites are cast with varying weight percent composition of reinforcements. Table 5 depicts the composition of borosilicate glass and fly-ash selected in the present analysis.

Table 5 Composition of fabricated composite

Composition of the composites	Borosilicate glass (BS) (Wt.%)	Fly-ash (FA) (Wt.%)
LM25+0%BS+0%FA	0	0
LM25+5%BS+0%FA	5	0
LM25+10%BS+0%FA	10	0
LM25+0%BS+5%FA	0	5
LM25+0%BS+10%FA	0	10
LM25+5%BS+5%FA	5	5
LM25+10%BS+10%FA	10	10

4. CASTING AND COMPOSITE SPECIMEN PREPARATION

LM25 is melted at approximately at 730°C in a resistance furnace. The reinforcements comprising of borosilicate glass particulates and fly-ash are preheated to around 400°C to remove any moisture content and volatile particles. The preheated reinforcements in required quantity are weighed using an electronic balance and are introduced into the molten LM25.

The melt is then stirred with the help of a conical electric-driven agitator rotating at 500 rpm for approximately 5 minutes. The melt was then introduced into the air-dried sand mould consisting of judiciously placed chills. Figure 1 illustrates the dimensions of the sand mould used. Figure 2 shows the preparation of sand mould with pre-inserted end chills.

The materials for specimens required for tensile strength test are drawn from both near the chill end and 15mm away from the chill end. The required material is cut from the cast composite on the milling machine using end mill. The tensile test specimens are then made according to ASTM standards with the help of a CNC machine.

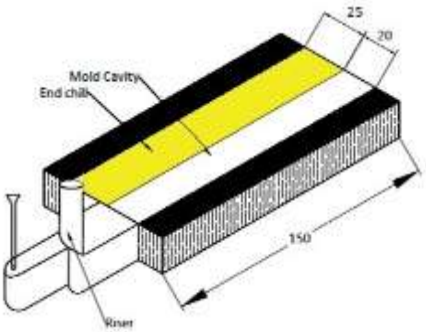


Figure 1 Sand mold dimensions

Figure 2 Sand mould with pre-inserted chills

5. TESTING PROCEDURE

Tensile strength test is conducted to obtain the Ultimate Tensile Strength (UTS) and to ascertain the effect of addition of reinforcements to the LM-25 matrix alloy in varied weight percent. This test is conducted as per ASTM-E8M standard in electronic tensometer (model-ER3) with computerized data acquiring unit.

6. RESULTS AND DISCUSSIONS

6.1. Ultimate Tensile Strength (UTS)

Figure 3 illustrates the UTS values obtained for the specimens drawn near the chill end. The results indicate that both chilling as well as the chill material employed during the casting has a pronounced effect on the UTS of the hybrid composites. MMCs cast with the aid of copper end chill possessed higher UTS value in comparison with the MMCs cast with the help of other end chills. Also, the MMCs cast with the help of metallic end chills resulted in higher UTS as opposed to the MMCs cast with the aid of non-metallic end chills. This is due to higher VHC value possessed by the metallic chills in general and copper chill in particular. Higher VHC results in faster extraction of heat from the melt thus inducing a steeper solidification gradient in the casting which produces sound, defect-free castings with improved properties.

Also, the variation of the weight percent reinforcement in the LM25 matrix affects the tensile strength of the composite. The load transfer mechanism in a MMC is always from the soft and weak matrix to the hard and tough reinforcements. Hence, the MMCs are strengthened as much of the applied load is carried by the stiffer reinforcements [16]. Thus, the additions of stiffer reinforcements such as borosilicate glass and fly ash have resulted in the increase of tensile strength of the composite in comparison with the tensile strength of LM25 matrix.

It is also observed from the results that the UTS of the MMC increased with the weight percent reinforcement content within the matrix. This is due to the fact that yielding in MMCs occurs at the weaker interface and/or at the sharp, pointed edges of the hard reinforcements [17]. The increase in the weight percent of such reinforcements within the matrix leads to a reduced yielding due to an increment in the number of points of stress concentration [18].

Results indicate that the UTS of MMCs are higher than the UTS of the unreinforced LM25. UTS of unreinforced chilled LM25 are 155 N/mm2 cast with the aid of copper chill. This UTS value increases to 188 N/mm2 for LM25/(10%BS), 182 N/mm2 for LM25/(10%fly ash) and 196 N/mm2 for LM25/(10%BS+10%fly ash) composite cast through the employment of copper end chill.

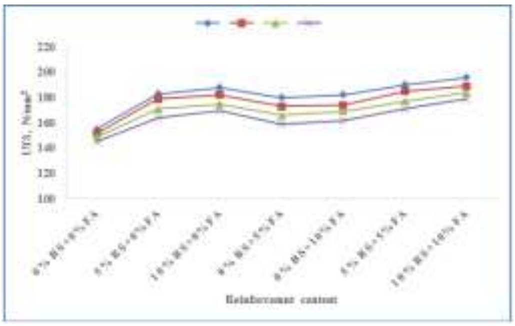


Figure 3 UTS of hybrid composite specimens drawn near the chill end

Figure 4 illustrates the UTS values obtained for the specimens drawn 15mm away from the chill end. The analysis of the results show that the UTS values have decreased for MMC specimens drawn away from the chill end than those values for MMC specimens drawn at the chill end (Figure 3). This shows that chilling results in denser, defect-free castings with improved strength values.

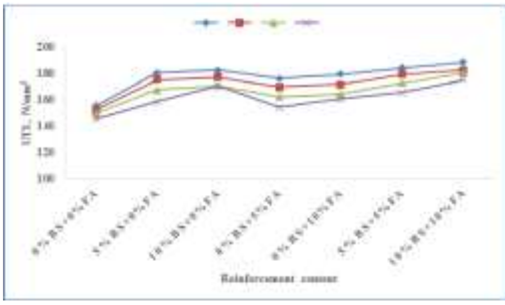
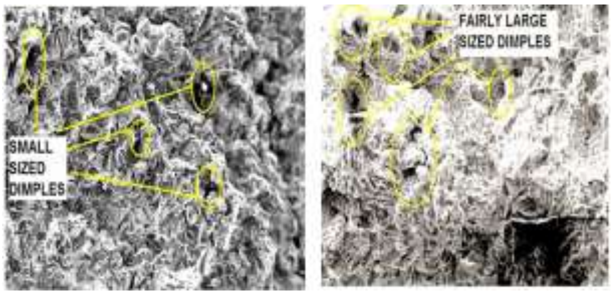


Figure 4 UTS of hybrid composite specimens drawn 15mm away from the chill end

6.2. Fractographic Analysis

Fractrographic analysis is made through the SEM images of the fractured surface to evaluate the effect of chilling and chill materials on the strength of the composites. Figure 5 illustrates the SEM images of the cast MMCs under the employment of selected metallic and non-metallic end chills.



a) **b)**

Figure 5 Fractographs of MMCs (LM25+10%BS+10%FA) at magnification of 300X.

(a) MMCs cast with copper end chill (b) MMCs cast with silicon carbide end chill

The size of the dimples in the fracture surface exhibits a direct proportional relationship with strength and ductility of the MMCs. Finer dimple size is a clear indication of a higher strength and ductility of the fractured surface. The fractographs of MMCs cast with copper end chill illustrates a finer dimple size, whereas, the fractograph of MMC cast with the aid of silicon carbide end chill depicts a fairly large dimple size. Thus, the MMCs cast with copper chill possess a higher UTS as compared to MMCs cast with silicon carbide end chill.

7. CONCLUSION

The experimentation work carried out leads to following conclusion:

- Chilling has a greater effect on the strength of the composites.
- The specimens drawn from near the chill end exhibit higher tensile strength compared to the strength of specimens drawn away from the chill end.
- Chills with higher VHC promote directional solidification of the melt resulting in sound castings. Thus, metallic chills are preferred over non-metallic chills.
- Chilled hybrid composites demonstrate higher strength as opposed to the strength of chilled LM25 matrix alone. This emphasizes that incorporation of hard ceramic reinforcements into soft metal matrices is advantageous in improving the strength of the composite.
- Synergistic effect of borosilicate glass and flyash reinforcements help in increasing the tensile strength of hybrid composites.

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