

Fractographic and three body abrasion behaviour of Al-Garnet-C hybrid chill cast composites

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Abstract. Fractographic and tribological behaviour of hybrid composite of aluminum alloy LM13 matrix with garnet and carbon was investigated. Conventional stir casting technique was used to fabricate the composites with chill cast technique. Various chill materials like Copper, Steel, Iron and Silicon carbide were used to improve the directional solidification. The garnet being added ranges from 3 to 12 wt-% in steps of 3wt-% and constant 3wt-% of carbon. The experiment evaluates the mechanical, fractographic and three body abrasion behaviour of the hybrid composites for various parameters of load, garnet and chills. Microstructural characterization of the composite samples revealed a uniform distribution of reinforcements with minimum clustering. SEM was used to examine worn surfaces. The addition of garnet and carbon reinforcement decreases the wear rate of hybrid composites. Fracture behaviour showed the changes from ductile mode to brittle mode of failure. Further, directional chilling with copper chill improves the wear resistance of the composites.

1. Introduction

Composites play a vital role in every field of construction and present day scientific and technological progress has resulted from progress in the field of composites [1]. Incorporation of two or more reinforcements in the matrix is the recent trend to achieve the desirable properties to meet high-tech structural and functional applications including aerospace, defence, automotive, and thermal management areas, as well as in sports and recreation, when compared with conventional metals and single reinforced metal matrix composites (MMCs) [2,3].

In general, hybrid composites are made as an alternative approach to improve the overall properties of composites by adding insoluble two or more reinforcements to the base matrix [4]. Many researchers exploited the various forms of artificial reinforcements in aluminum alloy matrices such as SiC, SiO₂, Al₂O₃, BN, B₄C, WC, TiC etc for tailoring the required properties [5,6]. The hard ceramic reinforcements impart hardness to the composite. The investigation carried out by S. Basavarajappa [7] begins with fabrication of Al 2219/SiCp/Gr hybrid composites using liquid metallurgy technique, followed by the wear study using conventional tribometer apparatus for different parameters like sliding speed, applied loads and a discussion of effect of reinforcements. The wear resistance increases with the rise in dispersoid content. At higher loads, the wear mechanism changes to delamination. The

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influence of tool rotational speed on wear properties of Al/SiC/Gr was discussed by Devaraju Aruri et al [8], along with a discussion of mechanical properties and dispersion of reinforcement particles to observe the high wear resistance due to presence of SiC and Gr elements. Anju S. [9] has reported that BN additions are particularly useful to further improve the wear resistance of SiC reinforced MMCs. The ceramic hybrid composite can exhibit improved wear resistance properties and anti-seizure behavior with addition of small percentage of self-lubricating material like carbon which acts like a solid lubricant. The carbon being soft, grease and ability to withstand very high temperature makes the alloy very high wear resistant and self-lubricating material by forming a tribolayer between the contact surfaces [10]. Microstructural studies have revealed uniform distribution of carbon in the matrix with improved mechanical and tribological properties. But with increasing carbon content, leads to weakening of matrix and increases wear rate. Hence 3wt% of carbon is considered as secondary reinforcement in the current work [11,12]. M Uthayakumar studied the influence of graphite on wear behavior of Al6061/Al₂O₃/SiC hybrid composite. It was discovered that addition of Graphite particles decreases the microhardness but immensely increases the dry sliding wear resistance of the samples [13]. Similar result was observed by many researchers with the addition of Gr with Al6061 SiC and Al₂O₃. Joel Hemanth [14] investigated effect of chills on wear behavior. M Babic reinforced 1wt%Gr and 10wt%SiC with A356 to investigate the tribological properties. The MML formed by the graphite reduces the wear drastically [15].

Rapid and directional solidification is one of largely accepted method to obtain finer microstructure and improved properties which can be achieved by the application of chills. Although the sand cast composite results in some defects like porosity, the application of chills will improve the directional solidification to achieve finer microstructure with improved mechanical properties. Ajit kumar S [16] studied the effects of different ceramics size and volume fraction on wear behavior of aluminum matrix composites. A number of composites were manufactured by reinforcing SiC, B₄C and Al₂O₃. The composite having 30% volume fraction of 20 µm SiC gives the best wear performance. Effect of reinforcement on wear behavior of aluminum hybrid composites was investigated by N Radhika [17] revealed that the aluminum alloy reinforced with 9 wt-% alumina and 3 wt-% graphite has highest wear resistance compared to unreinforced alloy.

The experimental results revealed that the addition of reinforcement improves the wear rates. Although there are several studies reported in the literatures on wear behavior of aluminum metal matrix composites, no published work has been seen on the effect of garnet reinforcement on dry sliding wear of LM13 series HMMCs. Hence, the present research work has been undertaken, with an objective to explore the use of garnet with carbon as reinforcing materials in LM13 alloy.

2. Material and method

2.1. Matrix material

Commercially available and generally known piston alloy multicomponent Al-Si-Ni-Cu-Mg alloy with lower concentrations of Fe and Mn was selected as the matrix in the work because of its excellent casting properties with reasonable strength. Aluminum has low melting point and high ability to hold the reinforcement. It is suitable for automotive application with its excellent thermo-physical properties.

2.2. Reinforcing materials

Low cost naturally available garnet and self-lubricating carbon is used as the reinforcement. The garnet particles with size of 25 µm and carbon with average size of 45 µm were used as the reinforcement materials for fabrication of composites. Garnets are naturally occurring substances and are highly cost effective. It is chemically inert at high temperature. Constant 3wt% carbon improves the self-lubricating behavior of chill cast composites. Chill materials of various materials are used to control the rate of solidification to promote directional solidification.

2.3. Chill materials

Different metallic and non-metallic materials with different volumetric heat capacity and thermal conductivity such as copper, Iron, steel and silicon carbide are used in this investigation. Thermo-physical properties of the chills, improves the properties. Five types of molds having different chills and one with no chill were used to investigate the influence of volumetric heat capacity on microstructure, mechanical and wear characteristics.

2.4. Stir casting method

The composites were fabricated by conventional stir casting method to ensure uniform distribution of the reinforcements. Stir casting setup shown in figure 1 is one of the low cost process out of available manufacturing techniques for AMCs, with advantage of low cost and flexible for different low melting temperature materials. Various parameters of this process can be altered to tailor the desired properties of the composite. Better bonding of metal matrix with reinforcement particles can be achieved because of stirring action [18]. In the present work billets of Aluminum alloy LM13 melted in a resistance furnace at around 750°C ; Preheated garnet and carbon particulates were reinforced and poured in the sand mold with different chills such as copper, steel, iron and silicon carbide. One mold without the chill also prepared to study the effect of chill and compare the results. Figure 2 shows position of the chill in the mold.

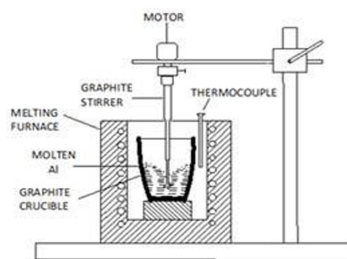


Figure 1: Stir casting setup

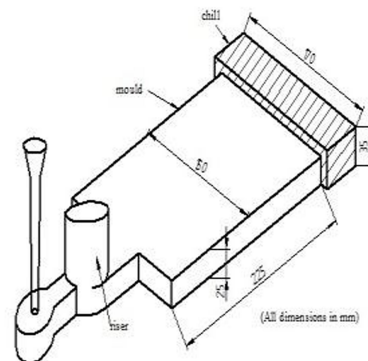


Figure 2: Sand mold with chill

Table 1. Details of the sand abrasion testing machine		
Sl.No.	Description	Particulars
1	Abrasive material	AFS 50/70 Quartz sand
2	Abrasive flow rate	0.35 kg/min
3	Rubber wheel material	Chlorobutyl rubber
4	Rubber wheel diameter	228.6 mm
5	Rubber wheel speed	250rpm
6	Specimen dimension	(76 x25.4 x12.7)mm
7	Load	1 to 5 kg

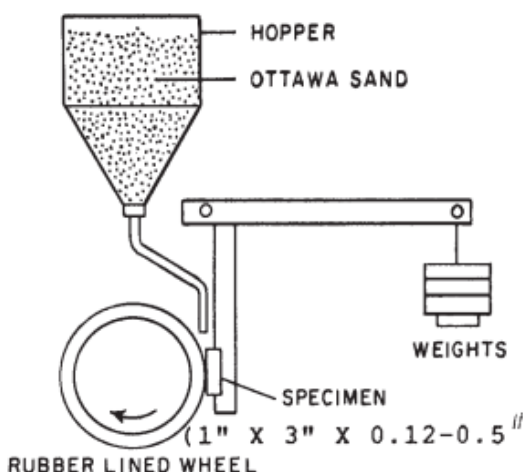


Figure 3: Sand abrasion tester

3. Testing

3.1. Microstructural examination

Specimen is prepared from chill end of the composite. Specimen of same dimension is taken from composite prepared without chill. The distribution of garnet and carbon in the cylindrical samples of the composite are analyzed using scanning electron microscope (SEM). Samples were polished and etched with Kellers reagent to investigate interfacial bonding between matrix and the reinforcement.

3.2. Mechanical properties

Hardness and ultimate tensile strength of the samples are tested using Vickers hardness tester and tensile testing machine respectively. The Vickers hardness test has received fairly wide acceptance for research work because it provides continuous scale of hardness, for a given load, from very metals with a DPH of 5 to extremely hard materials with a DPH of 1,500. With the Rockwell hardness test, or the Brinell hardness test, it is usually necessary to change either the load or the indenter at some point in the hardness scale, so that measurements at one extreme of the scale cannot be strictly compared with those at the other end. The Vickers hardness test uses a square-base diamond pyramid as the indenter.

3.2. Abrasion test

Samples of rectangular shape of dimension (76 x25.4 x12.7)mm are prepared for three body abrasion testing. Figure 3 shows the sand abrasion tester as per ASTM G65 standard. Silica sand of 50 μm is used as abrading particles. Details of the sand abrasion tester is tabulated in table 1.

4. Results and discussion

4.1. Effects of reinforcements.

The effect of garnet and carbon on the hardness, ultimate tensile strength and abrasion wear of the composite obtained from Vickers hardness test and tensile test are investigated for the effect of dispersoid and chill effect. From Fig. 4 it is observed that ultimate tensile strength of the hybrid composite increases with the addition of garnet and reaches maximum for 9wt.% garnet with chill material composite. The influence of the weight fraction of garnet as well as carbon on the weight loss of hybrid composites is shown in Fig. 5. It was observed that the weight loss decreased with increasing weight percentage of the reinforcement's upto 9wt% of garnet. The garnet hard ceramic particles act as the obstacles to the movement of dislocation. The garnet particles in the matrix alloy provide protection to the softer matrix. Thus, limiting the deformation and also resists the penetration and cutting of slides on the surface of the composites. It was previously reported that the hard ceramic particles in the Al matrix materials could enhance the hardness and wear resistance of these materials drastically. This result is a good agreement with the result of V.C.Uvaraja[18].

4.2. Effect of cooling rate/chilling

An increase in cooling rate (using a copper chill) induces finer intermetallic particles than those that form when applying a lower cooling rate (when using iron, stainless steel, non-metallic chill). Because the formation of intermetallics is a diffusion- controlled process relating to the rejection of atoms of elements into the front of the solidifying interface, increasing the cooling rate will delay the formation of these compounds. On the other hand, there is no sufficient time to complete nucleation and growth of the intermetallic particles. In addition, by increasing the cooling rate, the temperature of intermetallic formation is reduced, leading to a decrease in the time available for further growth [19, 20]. This fact can be considered the main reason for refining the intermetallic compounds at the higher cooling rates.

4.3. Morphological analysis

The SEM micrograph of the fractured surface of chill cast composite is shown in figure 6. Figure 6(a) shows the fracture of 9wt% garnet with ductile fracture with large cleavage. Figure shows the fracture of 12wt% garnet composite with brittle fracture with number of dimples on the surface. Figure 7 shows the worn surface of the 9wt% garnet with chill cast at various loads. Figure 7(a) wear behavior at low load of 1kg with fine scratches and Figure 7(b) shows the sharp groove for higher load of 5kg.

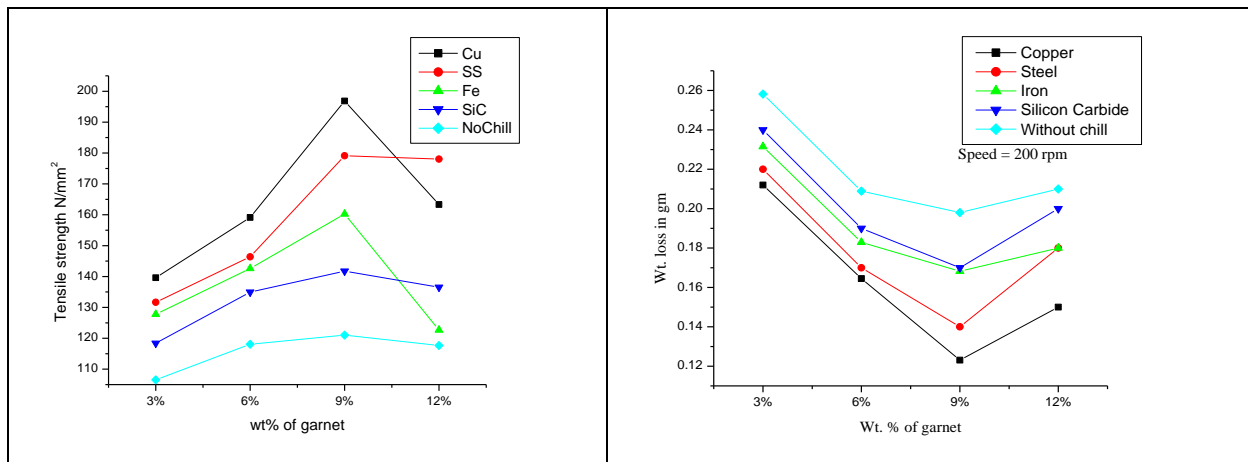


Figure 4 Ultimate tensile strength v/s wt% of garnet

Figure 5 Weight loss v/s % of garnet for abrasion test.

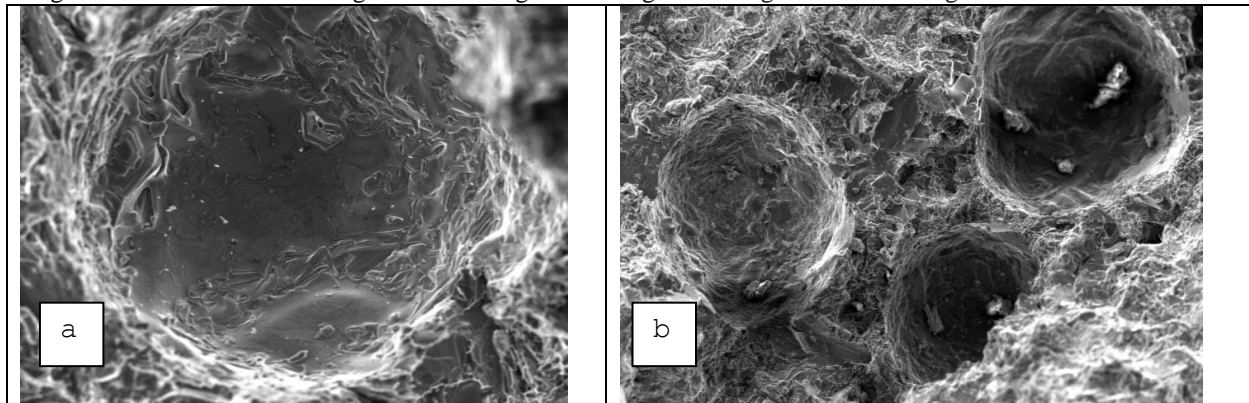


Figure 6: Fractograph of the hybrid composite.

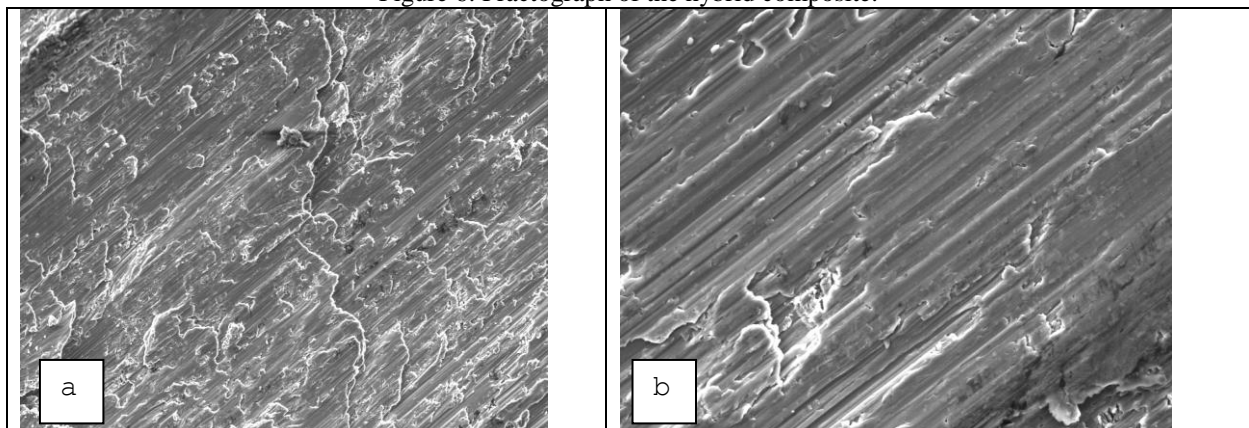


Figure 7: Worn morphology of the hybrid composite

5. Conclusion

Aluminum matrix garnet-carbon reinforced composites were successfully cast by stir casting route using different end chill materials. Microstructural studies indicate good bonding with consistency in the matrix. Specimen with 9wt% garnet + 3wt% of carbon with copper chill exhibits improved mechanical, fracture and abrasion properties. Thermo-physical property of chills attributes the improvement in the behavior of the composite. Fracture behavior changes from ductile to brittle as the weight percentage of reinforcement increases in the matrix.

6. References

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