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STUDY ON DRY SLIDING WEAR BEHAVIOR OF AL/GARNET/CARBON HYBRID COMPOSITES

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ABSTRACT
Aluminum alloy hybrid metal matrix composites (AlHMMCs) are finding increased applications in various sectors such as thermal management fields, defense, automotive and aerospace because of improved mechanical and tribological properties and hence are better substitutes for single reinforced composites. In the present study well known piston alloy Aluminum LM 13 matrix material was reinforced with low cost naturally available garnet and solid lubricant carbon to develop hybrid composites by chill casting technique. Conventional stir casting technique was used to fabricate the composites. Chill materials such as Copper, Steel, Iron and Silicon carbide were used to improve the directional solidification. The experiment evaluates the microstructure, mechanical and wear properties of the composites by dry sliding wear test using a pin-on-disc wear tester by varying the applied load from 10-50N. The result reveals that, the reinforcement particles are randomly and fine dispersed in matrix alloy as seen in microstructure. The addition of garnet and carbon reinforcement decreases the wear rate of hybrid composites. Further, directional chilling improves the wear resistance of the composites.

Keywords: *Chill cast, Garnet, Hybrid, Piston alloy, Stir cast.*

INTRODUCTION

The desire to increase the longevity of systems led to the development of hybrid metal matrix composite materials. Composites are very attractive materials, since their mechanical properties are superior to those of the individual components [1]. Hybrid metal matrix composites has been developed to overcome specific inherent deficiencies and to get more suitable qualities from the conventional monolithic and metal matrix composites. Major deficiencies of common MMCs of low wear resistance are overcome in such HMMCs [2, 3]. Aluminum based metal matrix composites (AMCs) are of lightweight high performance material systems [4]. Among the several types of aluminum alloys being used, LM13 series are extensively used in automobile applications because of their superior corrosion resistance, excellent thermal conductivity and formability characteristics [5]. Hard reinforcing material ceramic particles like SiC, Al_2O_3 and B_4C etc. are to be reinforced with Aluminum matrix composites posses a unique combination of high specific strength, high elastic modulus, good wear resistance and good thermal stability than the corresponding non-reinforced matrix alloy system [6-8]. Tribological performance of aluminum hybrid composites reinforced with graphite and granite dust particulates procured form local granite quarry and crusher unit was investigated by AnandPai et al [9] displayed a positive effect towards the improvement of mechanical properties.

Graphite is very widely used solid lubricant because of its encouraging properties like low friction, chemical inertness, absence of inherent abrasiveness, film forming ability on metal surfaces and relatively in offensive to nature [10]. The addition of an appropriate level of the graphite particulate with Aluminum Matrix Composites (AMCs) can reduce the wear rate of the AMCs. Hence carbon is considered as secondary reinforcement in the current work.

Soundness of the composite developed is highly dependent on the chilling rate as well as the dispersoid content. An increase in the rate of chilling and increase in the dispersoid content of the material both result in an increase in the UTS (ultimate tensile strength) of the material [11]. The casting of extrusion billets and rolling ingots of aluminum alloys has principally been carried out by the direct-chill (DC) casting process. The temperature gradient developed during solidification and VHC (volumetric heat capacity) of the chill used are the important parameters controlling the soundness of the composite. Maximum interface temperature attained by the chill decreases with the increase in their VHC (volumetric heat capacity) and the total heat absorbed by the chill increases with increase in VHC. Thermal properties of the end chills are used to determine the magnitude of the temperature gradients developed along the length of the casting solidifying under the influence of chills [12].

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Devarajuaruri [13] investigated effect of SiC and Al_2O_3tribological properties of AA6061 composites fabricated by stir cast processing. It was observed that high wear resistance exhibited due to presence of SiC and Gr acted as load bearing elements and solid lubricant respectively. Ajitkumar S [14] 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, B_4C and Al_2O_3. 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 [15] 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.

METHOD & MATERIAL

Materials

Aluminium alloy, LM13, was selected as a matrix material because of its excellent casting properties with reasonable strength. Its chemical composition is presented in Table 1. 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 basically a silicate, abundantly available and having hardness of 6.5-7.5 mho [Table 2]. 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. The thermo-physical properties of metallic and non-metallic chill materials are listed in Table 3.

Stir casting procedure

The composites were fabricated by stir casting method to ensure uniform distribution of the reinforcements. Stir casting is one of the low cost process out of available manufacturing techniques for AMCs, with advantage of low cost; it also offers a wide range of material and processing conditions and can manufacture composites with up to 30% volume fraction of reinforcement with better bonding of metal matrix with reinforcement particles because of stirring action [16].

Commercially available Aluminum alloy LM13 material is used and melted in a resistance furnace at around 750^0C; Garnet and carbon particulates were preheated to 700^0C. A stir casting process is used to fabricate hybrid composites reinforced with various weight fractions of garnet and carbon particulates. Fig.1 shows a sectional view of the stir casting arrangement. Combination of dispersoid varies from 3 to 12 wt.% in steps of 3wt.% of garnet and 3wt.% Carbon particulates. The size of garnet and carbon particulates dispersed is between 30 and 80 µm. Meanwhile, the molten HMMCs was well agitated by means of a mechanical mixing which was carried out for about 15 min at an average mixing speed of 760 rpm. The melt was next poured into a sand mold with a chill attached to it at one end. Different molds are prepared with different chill materials like copper, steel, iron and silicon carbide.

Specimen preparation

The same type of mold was used to sand-cast a specimen in which case no chill was used. The chills were of 150 mm long, 35 mm high and 25 mm thick in dimension. The moulds produced plate-shaped ingots of dimensions 150x120x25mm. Fig. 2 shows the arrangement of mold used for casting specimens. Specimens for all the tests were selected only at the chill end of the casting and all the specimens were heat-treated by aging before testing. Properties such as hardness, tensile strength of the developed hybrid composites were tested as per ASTM standards. The HMMC specimens were prepared according to ASTM standards. The specimens were taken from chill end by using cast aluminum alloy, LM13, as matrix and garnet and carbon particles as reinforcing materials.

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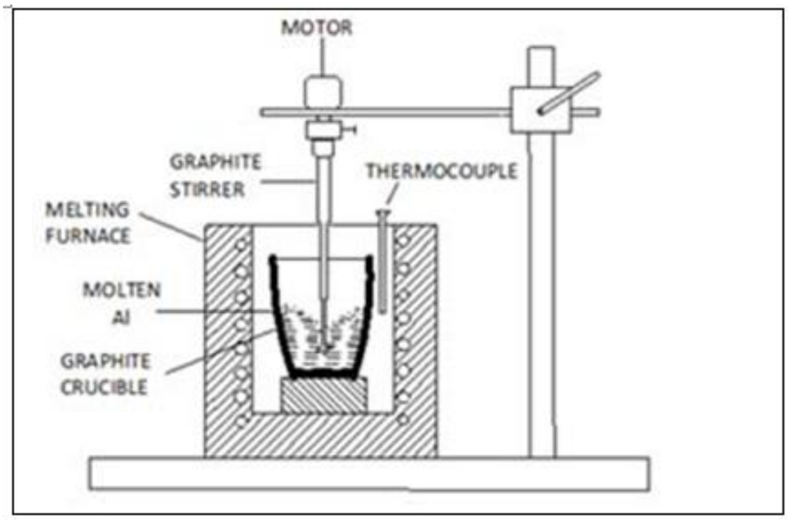

Figure 1: Stir cadsting setup

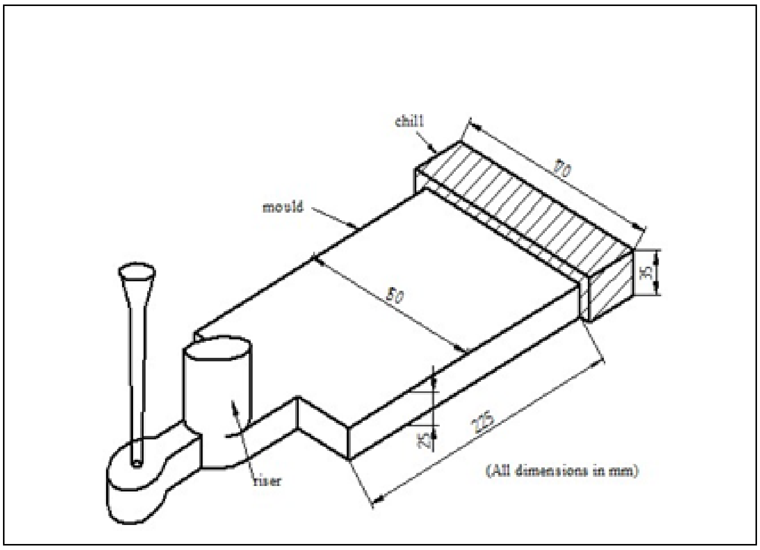

Figure 2: Sand mold with chill

Table 1. Chemical composition of matrix material (Al-alloy LM 13)

Elements	Zn	Mg	Si	Fe	Mn	Ni	Al
% by wt	0.5	1.4	12.0	1.0	0.5	1.5	Balance

Table 2.Chemical composition of Garnet

Elements	Al	Al_2O_3	Fe	FeO	Si	SiO_2	O
% by wt	10.84	20.48	33.66	43.30	16.93	36.21	38.57

Table 3.Thermo physical properties of chill materials

Material of chill block	Density kg/m^3	Specific heat J/kgK	Thermal conductivity
Copper	8.96	0.448	1.022
Steel	7.85	0.421	0.109
Cast iron	7.61	0.401	0.160
Silicon carbide	2.36	1.095	0.039

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TESTING

Hardness test

Hardness tests were performed using a Vickers hardness testing machine on ASTM standard specimens. Each test result was obtained from an average of at least three samples of the same location. Soundness of the test castings was assessed.

Tensile test

Tension tests were conducted at ambient temperature on computerized universal testing machine of 60 ton capacity in the load range of 0–600 kN. The specimens for mechanical tests were selected at three different locations along the length of the casting (at 15, 110 and 210 mm from chill end) and were prepared according to AFS standards. The values reported in the tests are the average of three repetitions on the same sample at the same location [10].

Microstructural examination

Microscopic examination was conducted on all the specimens using a metallurgical optical microscope. DiluteKellers etchant proved to be the best and was therefore used. Photomicrographs were taken of all the specimens tostudy their micro constituents especially the distribution of garnet.

Sliding wear test

Wear test for the samples are conducted using pin-on-disc computerized (DUCOM make) wear testing machine (Figure 3). The specimen is a pin of size 8 mm in diameter and 25 mm long (Figure 4) whereas the disc is of alloy steel having hardness of HRC 62. Before the test the surface of the pin was cleaned with acetone and weight loss method (LVDT attached to the specimen used to measure change in length) was adopted to ascertain wear loss. Test was carried out by applying normal load on pin from 10 to 50 N in steps of 10 N at constant disc speed [11].

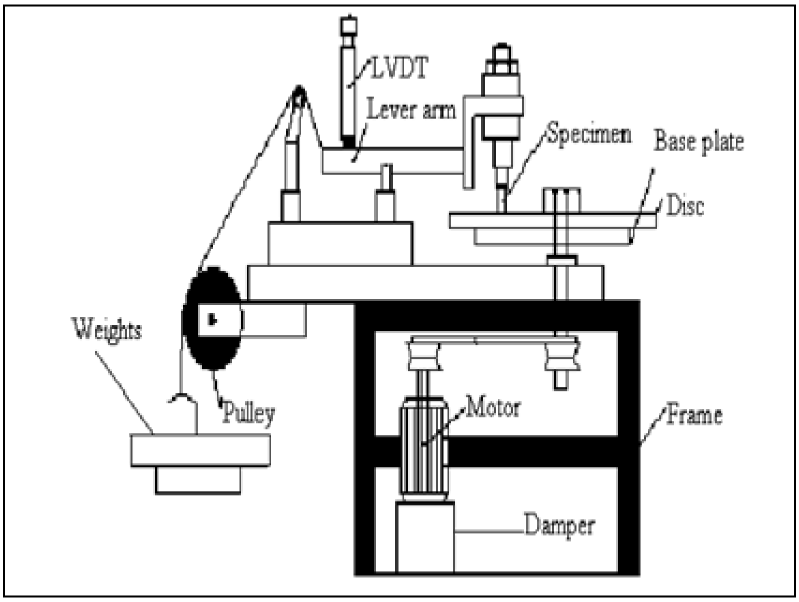

Figure 3: The pin-on-disc apparatus

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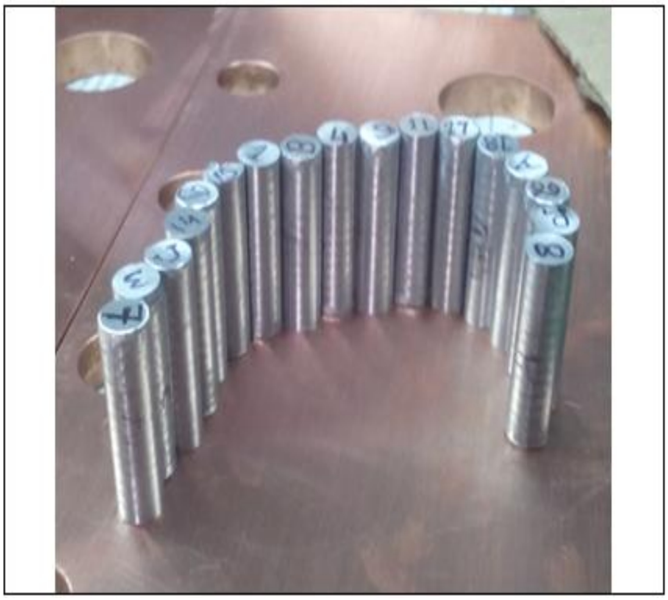

Figure 4: Samples for wear test

RESULT & DISCUSSION

In the present investigation, of all the chills, copper chill was found to be the most effective because of its high VHC. Dispersoid content up to 9 wt.% was found to increase the mechanical properties and therefore it is considered as the optimum limit. Hence the present discussion is mainly based on Al–garnet-carbon composite with 9wt.%dispersoid cast using the copper chill.

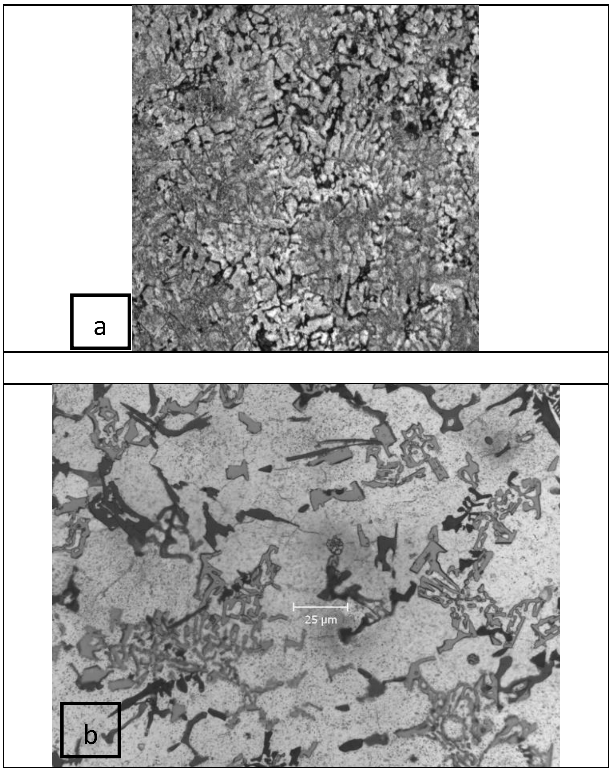

Figure 5: Microstructure of chill cast composite

Figure 5 shows the optical micrographs of aluminum composites reinforced with 9wt% garnet-3wt% carbon with different chill materials. Figure 5(a) shows microstructure of 9wt.% garnet and 3wt% carbon using Copper chill. The VHC of the copper chill block not only favors directional solidification but also accelerates solidification. Faster cooling rates give rise to finer structures and improved mechanical properties [14, 15]. Optical micrographs of hybrid composites show clearly the uniform distribution of garnet and carbon in the matrix, and no void and discontinuities were observedFigure 5(b). There is a good interfacial bonding between the particles and matrix material.

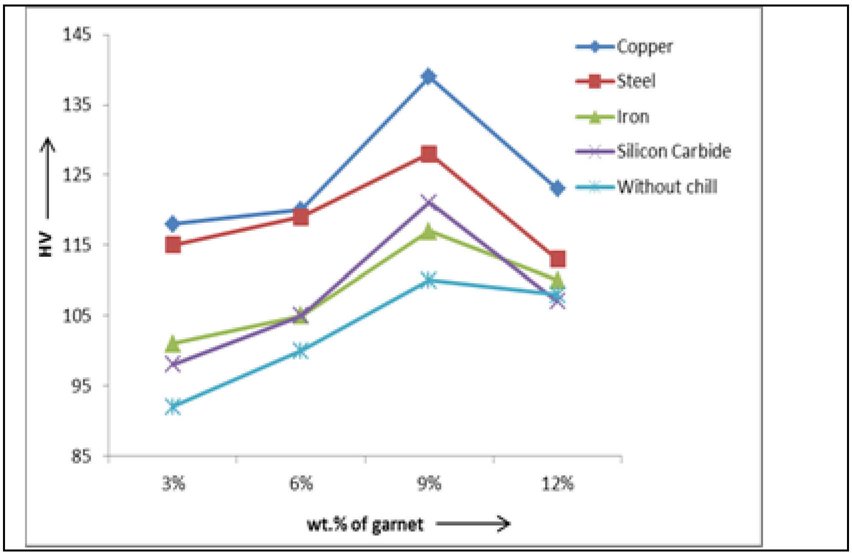

Figure 6: Hardness v/s wt% of garnet

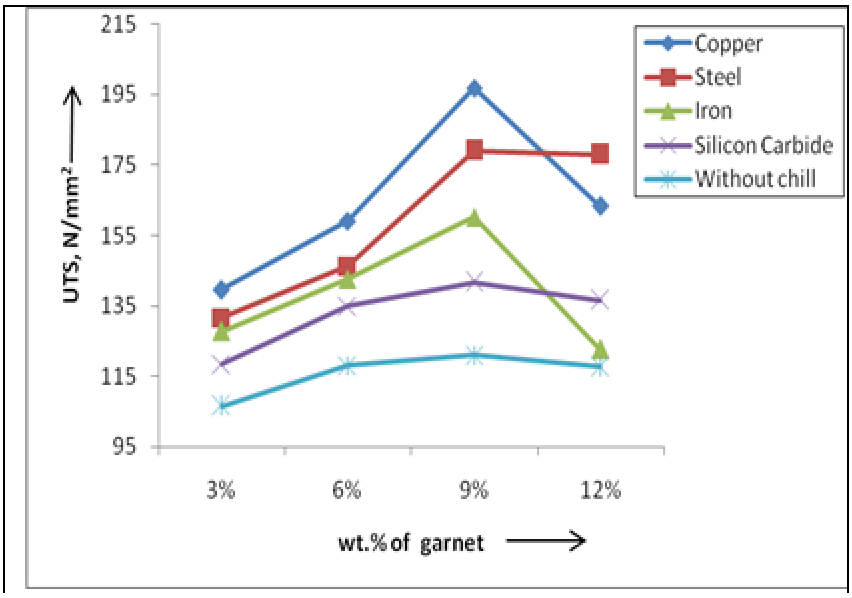

Figure 7: UTS v/s wt% of garnet

Figure 6 shows hardness of chilled HMMCs cast with different wt. % of garnet using various types of chills with different volumetric heat capacity. The results of micro hardness test (HV) conducted on chilled MMCs samples revealed an increasing trend in matrix hardness with an increase in reinforcement content (up to 9 wt.% garnet). Results of hardness measurements also revealed that copper chill has an effect on hardness of the composite.

Figure - 7 shows the UTS of the MMCs near the chill end for composites cast using different types of chills of 25 mm thickness. It is evident from these results that the MMC with the highest UTS is the one cast with a copper chill, followed by those cast with a steel chill, cast iron chill and a silicon carbide chill, in that order. This is because the copper chill has the highest volumetric heat capacity (VHC) and hence extracts heat most

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quickly from the MMC during casting, followed by steel, cast iron and silicon carbide, in that order. The results confirm the positive relationship between UTS and the dispersiod content [14-16]

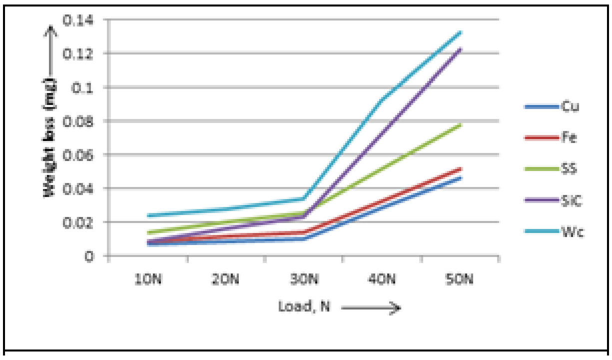

Figure 8: Weight loss v/s load

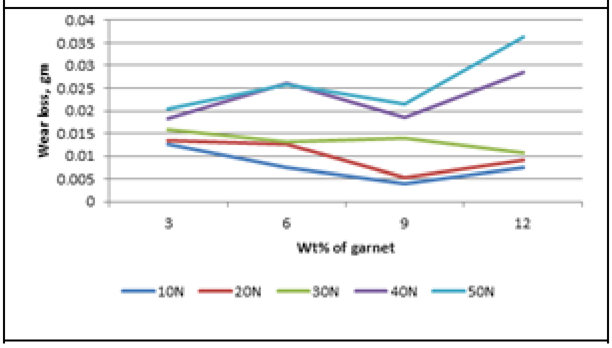

Figure 9: Weight loss v/s wt% of garnet

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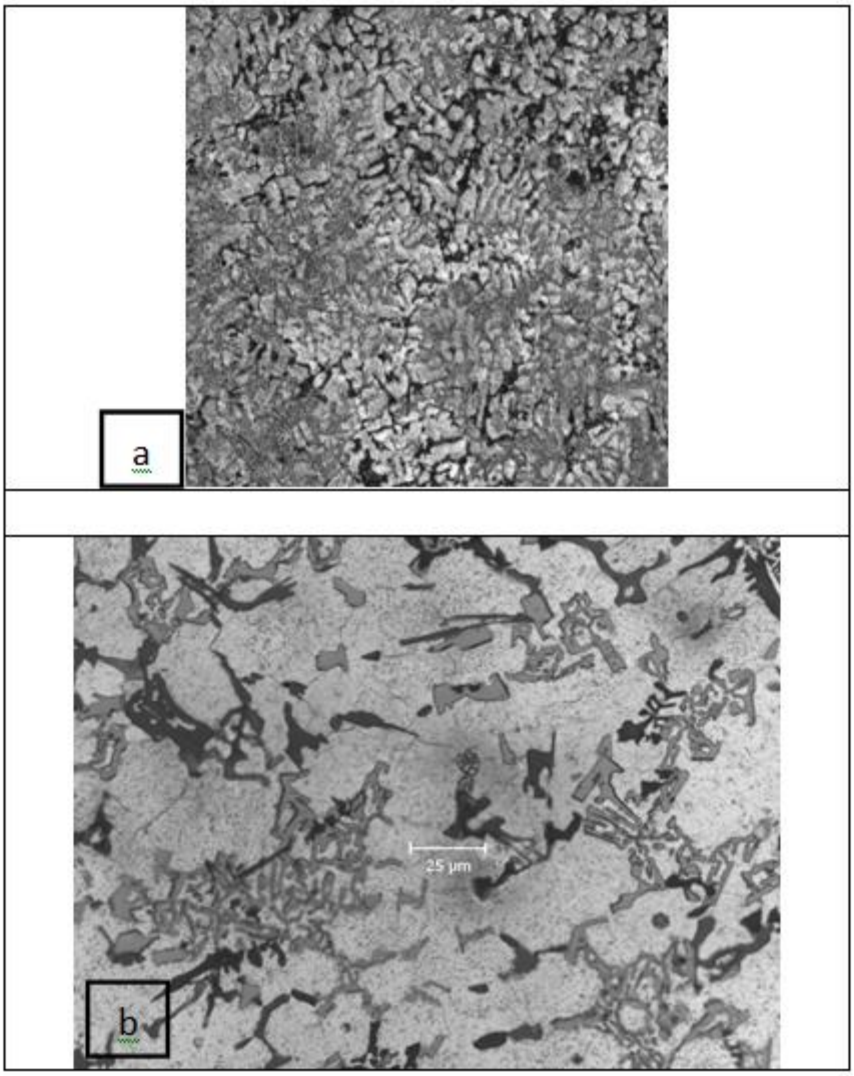

Figure 5: Microstructure of chill cast composite

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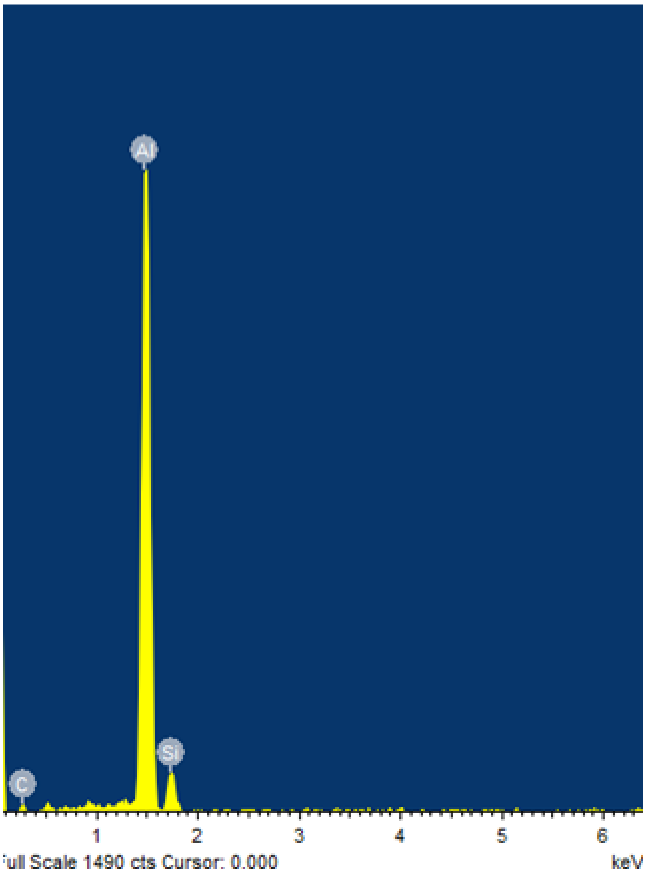

Figure 11: EDAX of the composite

Variation of weight loss of hybrid composite with respect to load is shown Fig 8. It was observed that weight loss increases for all applied loads. From 10 N to 30 N, marginal increase of wear rate was observed, whereas drastic increase from 30 N to 50 N. This trend can be attributed to the plastic deformation of the material. At low loads (10 N and 30 N), temperature rise over the sliding surface had less effect on the plastic deformation. Increased load (40 N) on the specimen leads to increase in temperature over the sliding surface even at low sliding velocities. Due to this high temperature, plastic deformation of the surface occurred leading to the adhesion of pin surface onto the disc [17-19]. This adhesion results in more material removal, thereby drastically increasing the wear rate.Fig 9 indicates the effect of wt.% of reinforcement on weight loss.

The SEM micrographs of the worn surface of 9wt-% composite specimen's slide at load of 50 N are shown in Fig. 10. The worn surface of the Al LM13 matrix composite (Fig. 10b) clearly exhibits the presence of deep permanent grooves, micro cutting, grain pullouts and fracture of the oxide debris, which may have caused the increase of wear loss [20]. This morphology shows that the matrix has undergone significant severe plastic deformation. However, the worn surfaces of the other composites (Fig. 10a) exhibit finer grooves and slight plastic deformation at the edges of the grooves. As the garnet weight fraction increases the surface morphologies also have been changed. The surfaces also appear to be smooth because of the graphite reinforcement content [21].

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.Volumetric Heat Capacity (VHC) of end chill and chill material (copper) which takes into account the rate of chilling does significantly affect the strength and hardness. In the present investigation, of all the chills, copper chill was found to be the most effective because of its high VHC. Dispersoid content up to 9 wt.% was found to increase the mechanical properties and therefore it is considered as the optimum limit.

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SEM studies of the worn surfaces and wear debris revealed that the wear mechanism involved with the Al–12% Garnet composites was oxidative wear with severe plastic deformation. The wear mechanism with the Al–9% Garnet hybrid composites was oxidative wear with delamination wear. With the Al/9% Garnet /3% Gr hybrid composites, delamination wear was the prominent wear mechanism. A uniform graphite film on top of the worn surface helped to decrease both the wear loss and friction coefficient. Therefore, severe wear was avoided with the Al/9% Garnet/3% Gr composites.

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