MADEVA NAGARAL
V AURADI
SHANAWAZ PATIL
BHARATH V
and
NAGARAJ N

Influence of micro graphite particles on the microstructure and wear behaviour of aluminium 6061 alloy composites developed by two step casting process

In the present research, the effect of micron sized graphite addition on the microstructure and wear behaviour of Al6061 alloy has been studied. The Al6061 alloy metal matrix composites reinforced with 6, 9 and 12 varying wt.% of graphite particles were fabricated by novel two step stir cast route which helps in improving the wettability of Al6061 alloy matrix with graphite particles. The created composites were exposed to microstructural studies and wear properties evaluation. Microstructural characterizations of achieved samples were carried out by SEM microscopy, EDS and XRD patterns. The occurrence of graphite particles were confirmed by the XRD patterns. The wear behaviour of Al6061 alloy with 6, 9 and 12 weight percentages of graphite composites were evaluated using pin on disc wear apparatus. All the experiments were conducted by varying applied loads of 1, 3 and 5 kg at 400 rpm sliding speed and varying sliding speeds of 100, 200, 400 and 600 rpm at 5 kg constant load. Wear mechanisms were studied by using SEM micrographs of worn surfaces and wear debris.

Keywords: Al6061 alloy, graphite particles, microstructure, wear, worn surface, wear debris

1.0 Introduction

The metal matrix composites (MMCs) with aluminium (Al) as the matrix are used for light weight fundamental application and electronic enclosures. Metal network composites have ascended as an indispensable class of materials for fundamental primary, wear and electrical applications, essentially on account of their ability to show preferred quality over weight-solidarity to cost extents when stood out from indistinguishable solid materials. Among MMCs aluminum metal matrix composites (AMMCs) are being considered as a new moved materials for its light weight, high strength, high modulus, low coefficient of warm extension and extraordinary wear resistance properties [1, 2].

Al6061 alloy is one type of wrought alloy having magnesium (Mg) and silicon (Si) as the major alloying elements. Al6061 alloy is an average strength Al alloy which is selected in this study due to its practical usages and proper mechanical properties, and its ability to cast, extrude, roll and machine etc. Aluminium 6061 has higher resistance towards corrosion and therefore is used in industries like marine, automobile, and construction. Automobile applications especially engine parts pushed researchers for improvements in properties of Al alloys [3, 4]. At room temperature, Al6061 alloy possesses excellent properties; however it shows poor high temperature behaviour. Further, it is necessary to improve the tribo-mechanical properties of aluminium alloys by adding conventional reinforcements to form aluminium matrix composites (AMCs). The monolithic aluminum alloys can be added in different compositions by suitable manufacturing methods, to develop composite materials with novel properties. Further, literature review on previous investigation reveals that only a very few studies have been made on the use of 100 to 125 micron sized graphite as reinforcement to synthesize aluminum-graphite composites by two stage liquid melt technique. Optimized two stage stir casting technique is developed for the composite preparation. Prepared aluminum- graphite composites are then subjected to evaluation of their wear properties [5].

It is also evident from the earlier research that several investigators processed MMCs by using different matrices and reinforcement combinations. These MMCs are processed by liquid metallurgy route and powder metallurgy techniques [6, 7, 8]. By their work, it is noted that, it is very difficult to mix these hard or soft non-metal or ceramic reinforcements

Messrs. Madeva Nagaral, Deputy Manager, Aircraft Research and Design Centre, HAL, Bangalore 560037, V Auradi, Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumkur 572103, Shanawaz Patil, School of Mechanical Engineering, Reva University, Bangalore 560064, Bharath V, Department of Mechanical Engineering, KNS Institute of Technology, Bangalore and Nagaraj N, Department of Mechanical Engineering, APS Polytechnic, Bangalore, Karnataka, India. E-mail: madev.nagaral@gmail.com

into the aluminium alloy. An optimized process is required to fabricate aluminium based MMCs, to enhance the wetting behaviour and to have uniformity of particulates in the matrix.

Al6061 is a mixture of metal with lower density and moderate strength, but lacks in wear resistance with more ductility. In order to improve negative aspect this alloy is reinforced with micron sized graphite particles. The behaviour of aluminium 6061 alloy reinforced with graphite is synthesized and the microstructure and wear properties are evaluated.

2.0 Experimental details

2.1 Materials and Composites Preparation

Metal composites with 6, 9 and 12 wt.% of graphite particulates with 100-125 micron size were created by mix technique for projecting. Aluminum 6061 composite (Fenfee Metallurgical Pvt. Ltd., Bangalore) is picked as network because of its more prominent projecting properties, strength, formability, heat treatment nature, great erosion obstruction, machinability and wide applications in a few areas and so on while graphite particles with a size of 100-125µm were used as fortifications (Fig.1). The substance design of the Al6061 amalgam used in the current investigations is addressed in Table 1.

Graphite particles of range between 100 to 125µm (Supplied by Bioaid and Scientific Industries, Bangalore, Karnataka, India) are used for the present study. The SEM analysis of graphite particulates are carried by using SEM, at BMSCE, Bangalore, Karnataka, India. The composition of graphite particles is shown in the Tables 2 and 3 contain the various properties of graphite.

The estimated amount of Al6061 alloy ingots are placed in the furnace for melting. The melt was heated to 750ºC. By the utilization of thermocouple the melt temperature is measured. Once the melt reaches to 750ºC degassers (solid hexachloroethane-C_2Cl_6) are introduced into the melt. Vortex was created by using the chromium steel stirrer, which was coated with zirconia. The impeller speed was maintained at 300 rpm and the depth of immersion of the impeller is 60% of the height of the molten matrix material. Once the vortex is made then the preheated graphite particles in steps of two stages are introduced into the melt by a persistent feed rate, which includes distributing the whole weight mixture of reinforcements in two equivalent weights. At every stage vigorous stirring carried out before and after incorporation of alumina particles to prevent particle clustering and to ensure that the micro particles are homogeneously dispersed in the melt. With continuous stirring, the molten metal is discharged into preheated cast iron die. The Al6061-graphite composite specimens with 15 mm diameter and 120 mm length are obtained after casting.

Table 1: Al6061 alloy chemical composition

Elements (wt. %)	Al6061 (as per ASTM standard)	Al6061 (actual)
Mg	0.8 - 1.2	0.89
Si	0.4 - 0.8	0.64
Fe	Max. 0.7	0.23
Cu	0.15 - 0.40	0.17
Ti	Max 0.15	0.10
Cr	0.04 - 0.35	0.07
Zn	Max. 0.25	0.03
Mn	Max. 0.15	0.07
V	Max. 0.05	0.01
Al	Balance	Balance

Table 2: Chemical composition of graphite particles

Elements	Composition wt. %
Carbon	99.9
Others	0.01

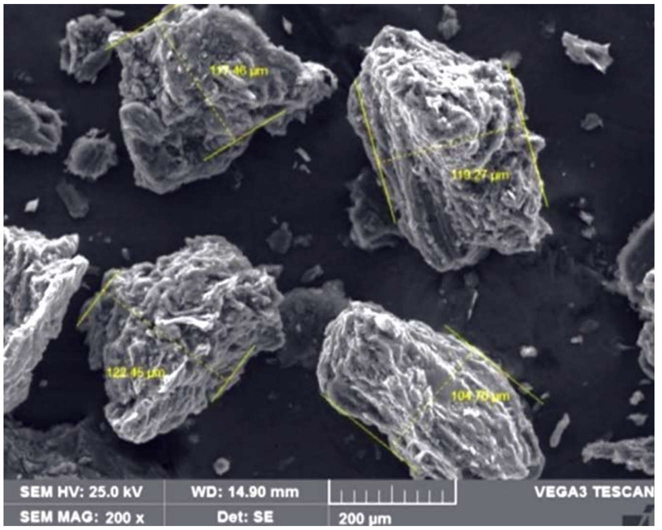

Fig.1: SEM micro-photograph of 100-125micron sized graphite utilized in the present study

Table 3: Properties of graphite particles

Density (g/cc)	2.20
Melting point (ÚC)	2900
Poisson's Ratio	0.14
Modulus of Elasticity (GPa)	10-15
Hardness (HV)	1.7 Moh's
Compressive Strength (MPa)	110
CTE µm/mÚC	9.6
Thermal Conductivity W/mK	86

2.2 Testing of Composites

The size, shape and conveyance of graphite particles present in Al6061 compound composites are finished using SEM instrument (TESCAN VEGA 3 LMU, Czech Republic). The machine is associated with JED 2300 assessment programming programme for EDX examination. For SEM, examples are sliced to get 15 mm width and 5 mm tallness.

The cut examples are made level surface utilizing belt processor. Then, at that point the examples are cleaned on a progression of silicon carbide emery papers with coarseness size of 300 to 1000. Completing is done by hand on miniature material by fine cerium oxide. Delivered tests are carved to uncover the legitimate granular construction utilizing Keller's reagent. The scratching arrangement comprises 95 ml of H_2O, almost 2.5 ml HNO_3, likewise 1.5 ml HCl and 1 ml HF. Subsequent to drawing, the examples are washed and altogether dried.

X-ray diffraction studies are conducted on Al6061 alloy composites in order to recognize different phases of Al alloy matrix composites. For XRD studies Al6061 with 6 and 12 weight percentages of graphite composites were selected. For this purpose prepared composite samples are cut to 15 mm diameter and 2 mm height in size specimens and same polishing method is carried as in the case of SEM. XRD studies are carried out by a Panalytical XRD using Cu-K alpha radiation. The 2θ range is selected such that all the intense peaks of the material phases predictable are covered.

The wear tests are carried out to determine the wear behaviour of the materials. Dry sliding wear experiments are conducted on Al6061 alloy and graphite reinforced MMCs and according to ASTM G99 [9] standard, using a computerized pin-on-disc (Make: DUCOM Instruments Pvt. Ltd., Model: TR20LE) wear testing apparatus. This contains

Fig.2: Wear test specimen

TABLE 4: WEAR TEST CONDITIONS

Pin material	Al6061 with Graphite composites
Disc material	EN32 steel disc - 65 HRC
Track dia., (mm)	90
Load (kg)	1, 3 and 5
Sliding speed (rpm)	100, 200, 400 and 600
Temperature	Room temperature
Sliding distance (m)	2000

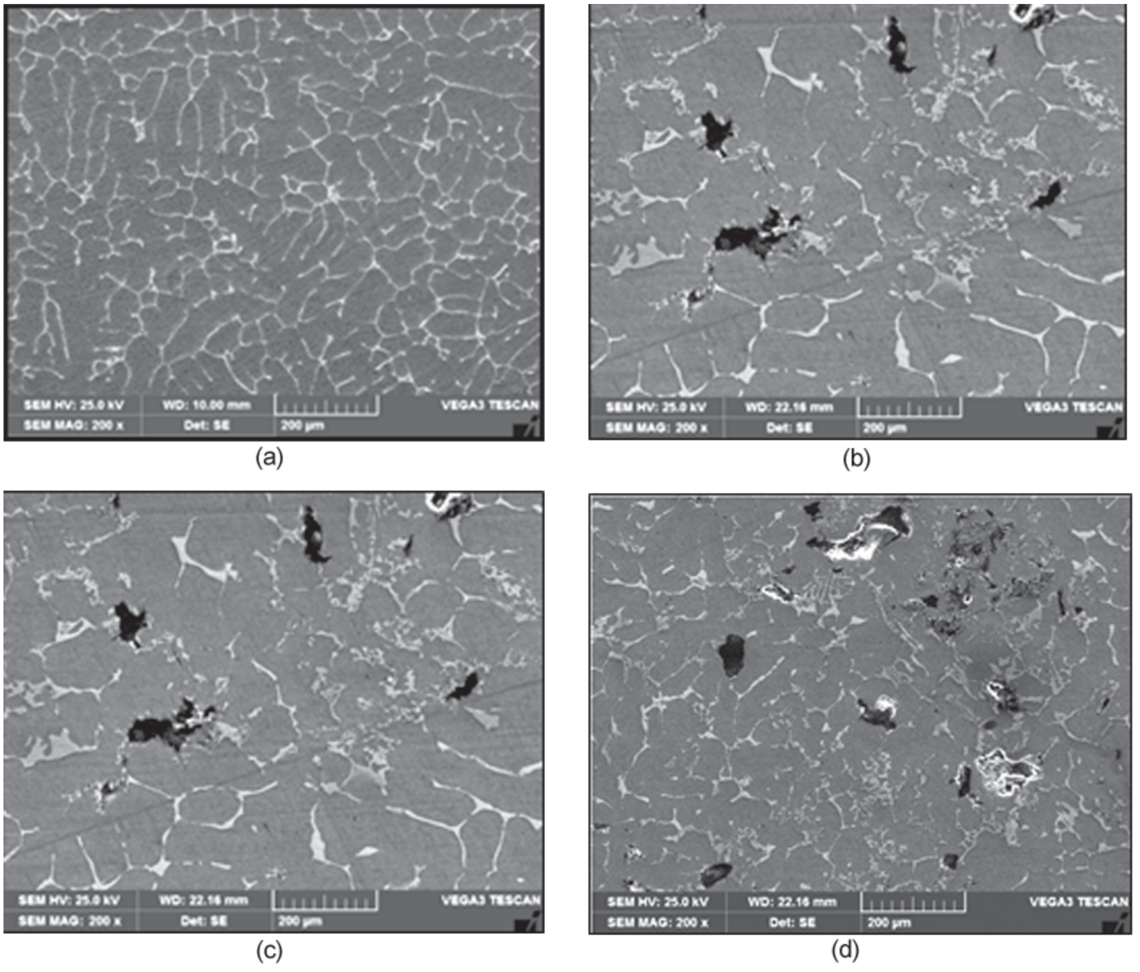

Fig.3: (a-d) SEM micrographs of (a) Al6061 alloy (b) Al6061-6 wt.% graphite (c) Al6061-9 wt.% graphite (d) Al6061-12 wt.% of graphite composites

EN-32 steel disc, having HRC65 hardness and maximum track diameter of 160 mm. The 8 mm diameter cylindrical specimens and 25 mm height are used for tests as shown in Fig.2. The wear loss of the pin in microns and weight loss in grams are recorded during every test using LVDT of 1.0 µm least count and the corresponding volumetric wear loss is evaluated.

In the present work, wear behaviour of composites under different parameters are studied. Wear tests are conducted by utilizing parameters like load (kg), sliding speed (rpm) and sliding distance (m). After the test, worn surfaces and debris are presented for studies, to understand the wear mechanism. The important parameters for wear studies are listed in the Table 4.

3.0 Results and discussion

3.1 Microstructural Analysis

Fig.3(a-d) shows the SEM micrographs of Al6061 alloy and graphite reinforced composites. Fig.3(a) shows the SEM micrograph of as-cast Al6061 alloy. It confirms that there is less porosity and grins are visible properly. Fig.3(b-d) shows the SEM images of Al6061 with 6 to 12 weight percentages of graphite. It is observed that in the two stage reinforcement mixing stir casting method of Al6061 alloy composites; the SEM micrographs of Al6061 alloy with 6, 9 and 12 wt.% of graphite composites revealed the uniform distribution of graphite particles in the matrix. There is no agglomeration of particles in 6 and 9 weight percentages of graphite composites as seen in Fig.3(b) and 3(c). Further, little agglomeration happened in Al6061 with 12 weight percentage of Gr composites due to lesser density of graphite, which increases the quantity of reinforcement by volume.

EDS analysis is also carried on the 6 and 12 weight percentages of graphite reinforced specimens which clearly showed the presence of C (carbon) peaks confirming the presence of graphite as shown in Fig.4(a-b). Fig.4(a) shows the elemental analysis of Al6061 with 6 weight percentage of graphite composite using EDS which confirm the elements like C, Mg, Si, Mn, Fe, Cu, Ti and Zn in Al alloy matrix composite. Fig.4(b) shows the elemental analysis of Al6061 with 12 weight percentage of graphite composite using EDS which confirm the elements like C, Mg, Si, Mn, Fe, Cu and Ti in Al alloy matrix composite. The distribution of Gr particles in Al6061 alloy composite is confirmed by the presence of Gr in the form of carbon (C).

The XRD is carried out in a θ-2θ diffractometer Panalytical using Cu Kα radiation, with 35 kV of voltage and 50 mA current. In Fig.5(a-b) the peak observed for the Al6061 with graphite composite is at 27Ú, 42Ú and 60Ú approximately, similar observations were made by various authors [10].

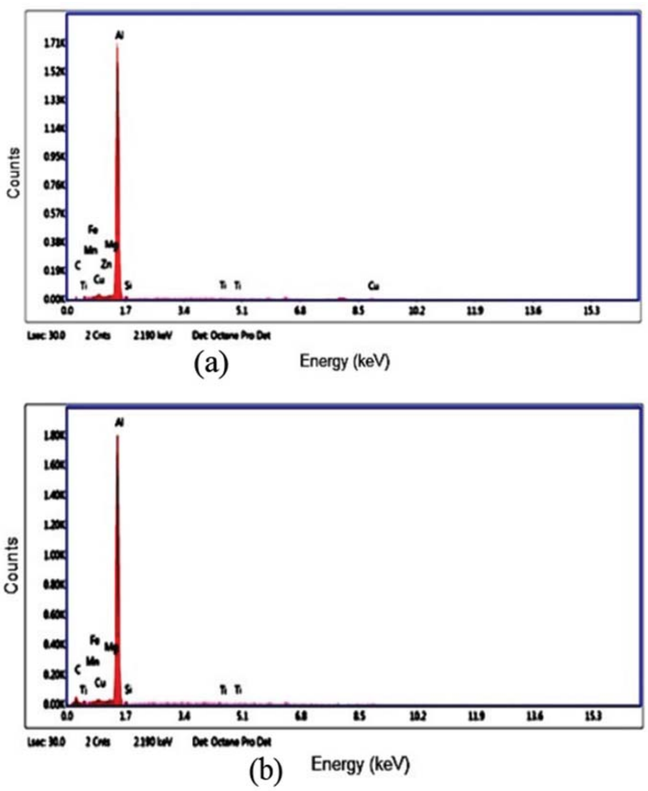

Fig.4: (a-b) EDS spectrum of (a) Al6061-6 wt.% graphite (c) Al6061-12 wt. % graphite composite

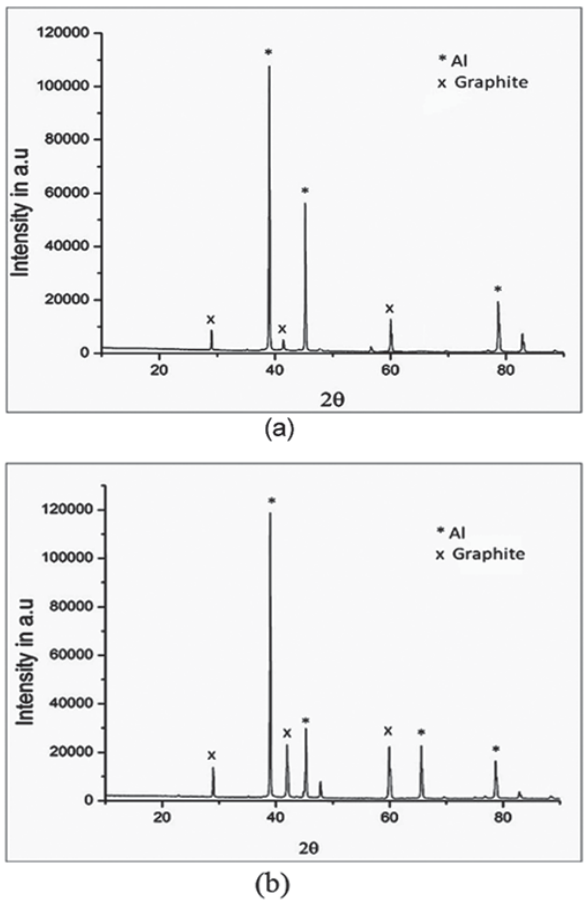

Fig.5: (a-b) X-ray diffractograms of Al6061-6 wt. % graphite (b) Al6061-12 wt.% graphite composite

3.2 Wear Behaviour

In the present investigation wear behaviour of Al6061 alloy, Al6061 with 6,9 and weight percentages of Gr composites are evaluated according to ASTM G-99 standard.

3.2.1 Effect of sliding distance on volumetric wear loss

Fig.6 shows the effect of siding distance on the volumetric wear loss of as-cast Al6061 alloy, 6, 9 and 12 weight percentages graphite reinforced composites at 5 kg constant load and 400 rpm sliding speed for a distance of 2000m.

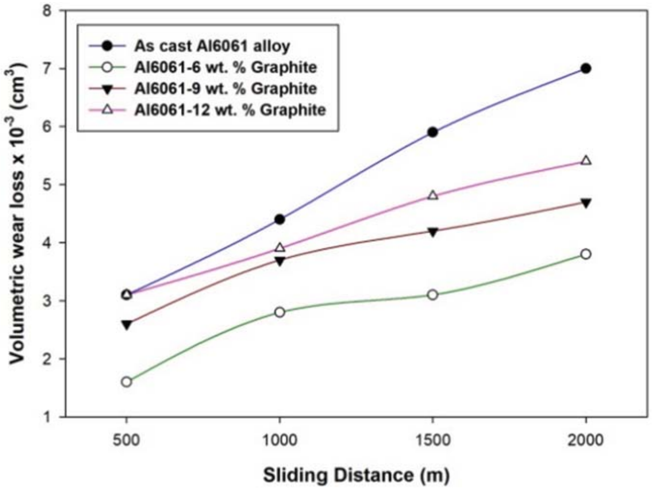

Fig.6. Volumetric wear loss as a function of sliding distance at 5 kg constant load and 400 rpm sliding speed for Al6061 alloy and its graphite composites

From the Fig.6 it is evident that the as sliding distance increases from 500 m to 2000 m the volumetric wear loss increases in Al6061 alloy and also same behaviour is observed in the case of Al6061 with 6, 9 and 12 weight percentages of graphite composites. Further, it is noted that the reinforcement particles decrease the wear loss of composites compared to unreinforced alloy. Al6061 with 6 weight percentage of graphite particulates reinforced composites are showing more wear resistance compared to 9 and 12 weight percentage of graphite reinforced composites. Further, 9 and 12 weight percentages of graphite composites shown good resistance to wear compared to Al6061 alloy.

3.2.2 Effect of applied load on volumetric wear loss

Fig.7: shows the effect of load on the volumetric wear loss of as-cast Al6061 alloy, 6, 9 and 12 weight percentages of graphite particulates reinforced composites at constant 400 rpm sliding speed for a distance of 2000 m at varying loads of 1 kg, 3 kg and 5 kg.

It is found that, with increase in load from 1 kg to 5 kg, the volumetric wear loss increased in base alloy and also in 6, 9 and 12 weight percentages of graphite reinforced composites. In graphite reinforced MMCs the volumetric wear loss is less as compared with the base Al6061 alloy. Also the lowest volumetric wear loss is observed for Al6061 with 6

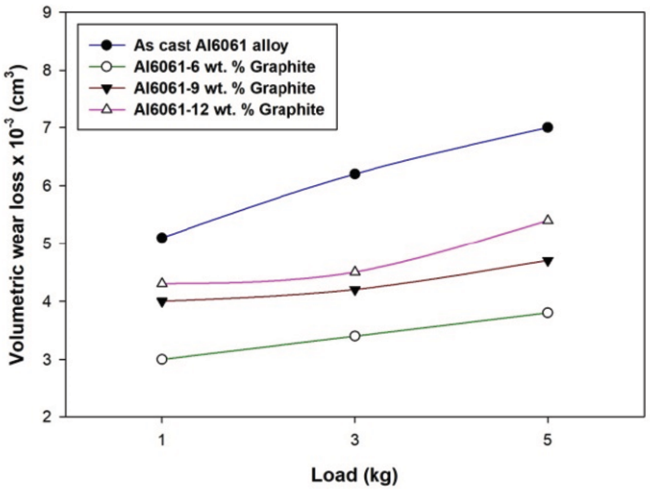

Fig.7: Volumetric wear loss as a function of applied load at constant sliding speed of 400 rpm for Al6061 alloy and its graphite composites

weight percentages of graphite composites. The wear loss of both as-cast alloy and composites increases steadily with increase in load up to 5 kg. The increase in wear loss with enhanced load of all the materials undergone for test can be attributed to the larger extent of plastic deformation at increased loads and this is in line with other researcher Girish et al. [11]. Further, an increase in load has resulted in higher extent of grooving in Al 6061 alloy and 9 and 12 weight percentages of graphite reinforced composites. From the Fig. 7, composites with 9 and 12 weight percentages of Gr particulates showing more volumetric wear loss as compared to 6 weight percentage of Gr composites.

3.2.3 Effect of sliding speed on volumetric wear loss

Fig.8 highlighted the influence of sliding speed on the volumetric wear loss of as-cast Al6061 alloy, 6, 9 and 12 weight percentages of graphite reinforced composites at constant 5 kg load and for a sliding distance of 2000 m at

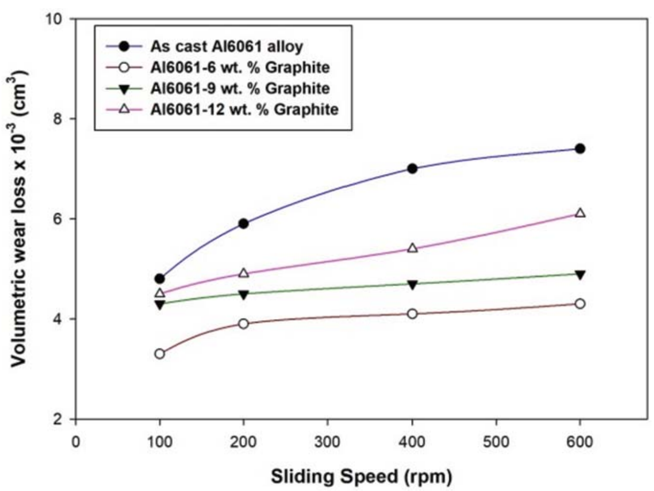

Fig.8. Volumetric wear loss as a function of sliding speed at constant load of 5 kg for Al6061 alloy and its Graphite composites

varying speeds of 100, 200, 400 and 600 rpm. It is observed that, the volumetric wear loss is increased in base alloy and also in 6, 9 and 12 weight percentages of graphite composites as speed increases. In graphite reinforced MMCs the volumetric wear loss is less as compared to the base Al6061 alloy. Also the lowest wear loss is observed for Al6061 with 6 weight percentage of graphite composites.

At higher sliding speeds the existing strong lubricating film gets thickened and may get divided. Further, in case of damage to the strong film, the fragments get stopped up between the rubbing surfaces bringing about higher friction. Additionally in this sliding speed temperature rise is high resulting in more plastic disfigurement of mating surfaces prompts greater asperity intersections as an outcome of which the volumetric wear misfortune increments, comparable perceptions were made by Rajkumar et al. [12].

Further, in all the conditions with respect to sliding distance, applied normal load and sliding speeds graphite reinforced composites shown more wear resistance over the base Al6061 alloy. From the Fig.6, 7 and 8 composites with 6 weight percentage of graphite particles exhibited the superior wear resistance as compared to 9 and 12 weight percentages of graphite reinforced composites. These 9 and 12 weight percentages of graphite reinforced composites shown good wear resistance as compared to base Al6061 matrix.

3.3 Worn Surfaces and Wear Debris

Fig. 9 (a-c) is the SEM photographs of the worn surface of the Al6061 alloy (Fig.9a), 6 weight percentage of graphite (Fig.9b) and 12 weight percentage of graphite (Fig.9c), after the sliding distance of 2000 m under an applied load of 5 kg and sliding speed of 400 rpm.

The examination of Al6061 alloy contains grooved regions on the worn surface. From Fig.9(b) the worn surface of Al6061-6 weight percentage graphite composite reveal smooth wear tracks and free from the peeling of matrix material which is evident from the reduction in wear loss compared to Al6061 alloy. Further, 6 weight percentage of graphite composites are showing adhesive wear action with oxide film, graphite particles are visible on the worn surface. The worn surface image of Al6061 with 12 weight percentage graphite composite is seen in Fig.9 (c), which indicates more adhesive wear tracks as compared to 6 weight percentage composites, this shows more wear loss due to decrease in hardness as weight percentage of graphite content increases.

Fig.10 (a-b) shows the SEM images of wear debris of Al6061 alloy (Fig. 10a) and graphite composites (Fig. 10b) at an applied load of 5 kg, 400 rpm sliding speed and 2000 m sliding distance.

Wear debris (Fig.10a) of as-cast Al6061 alloy indicates elongated structures showing severe plastic deformation in the sliding direction, and similar results were reported by Rajesh et al. [13] in wear behaviour of other ceramic reinforced

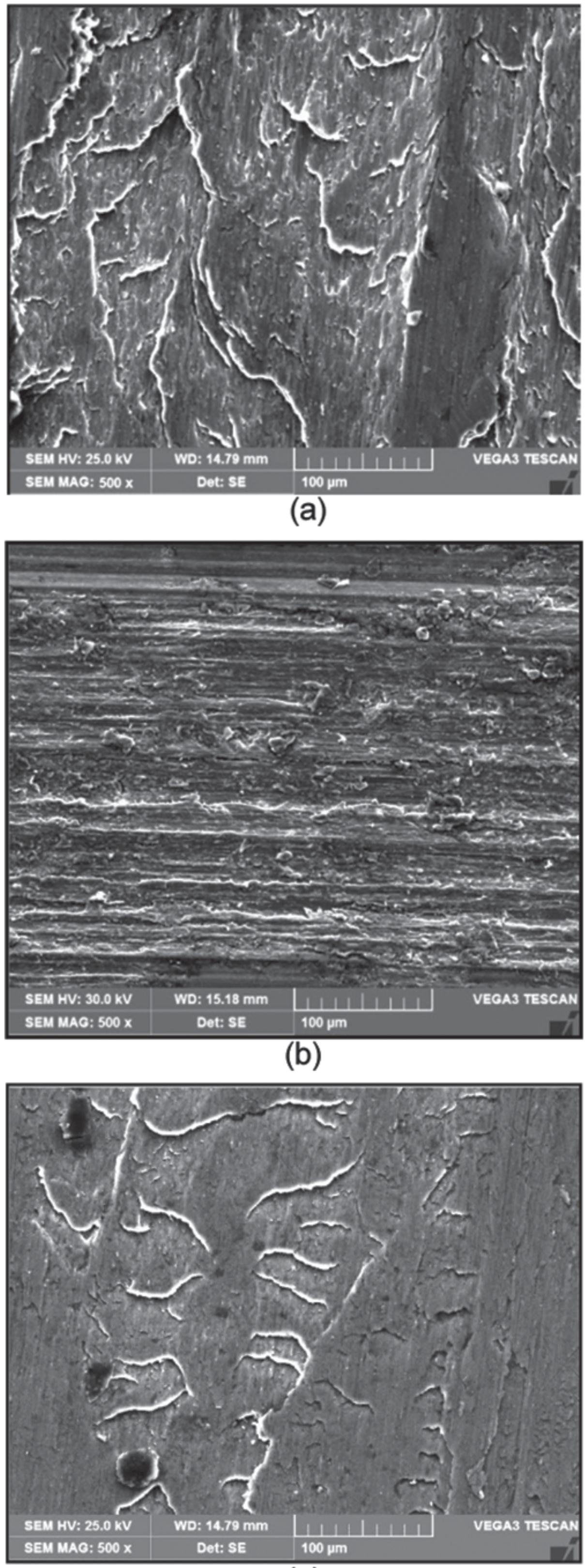

Fig.9: Worn surfaces SEM of (a) Al6061 alloy (b) Al606-6 wt. % graphite (c) Al6061-12 wt. % graphite composite at 5 kg load and 400 rpm sliding speed

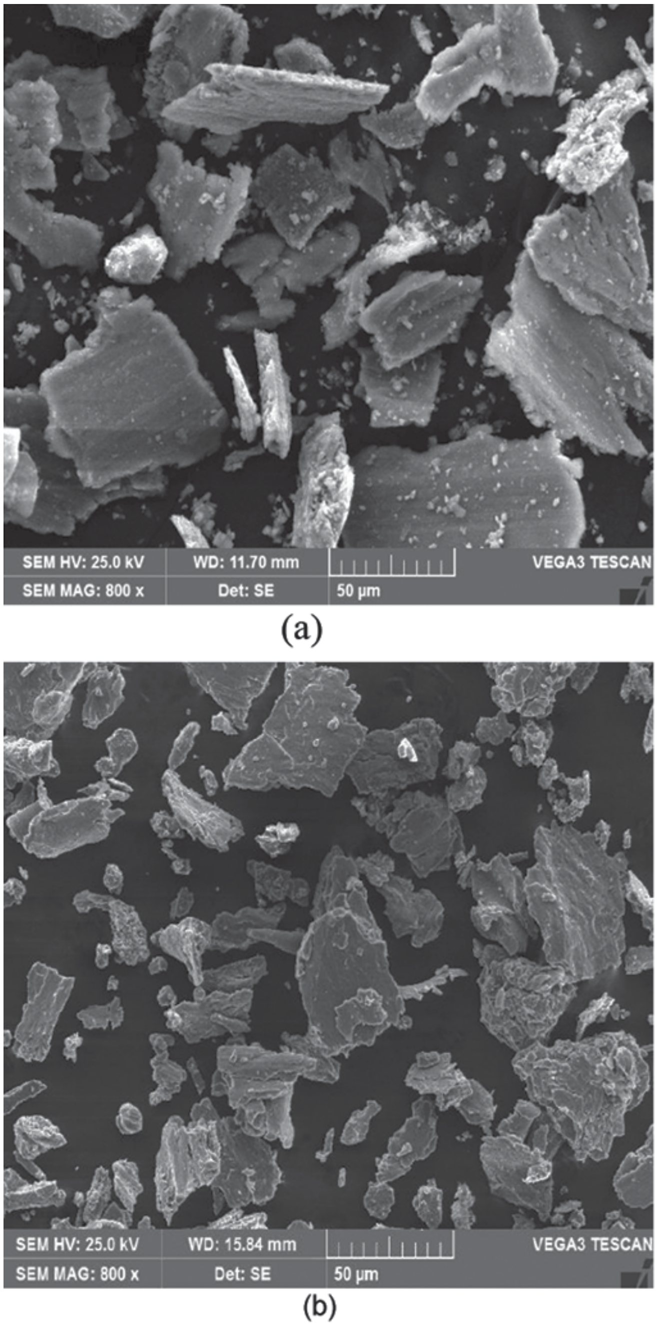

Fig.10: SEM micrographs of wear debris of (a) Al6061 alloy (b) Al6061- 6 wt. % graphite composite at 5 kg load and 400 rpm sliding speed

composites. From Fig.10 (b) it is observed that the wear debris of Gr composites is finer when compared to that Al6061 alloy. The debris sizes of Al6061 alloy and micro Gr composites are in the range of 50-100 µm and less or nearer to 50 µm, respectively.

4. Conclusions

The Al6061 alloy with graphite particles MMCs are effectively produced by stir cast route with different weight percentages of reinforcement. The produced composites (Al6061-6, 9, 12 weight percentages of graphite) are effectively synthesized via stir casting with two-stage additions of reinforcement. The uniform dispersion of graphite particles from the SEM two stage additions of alumina particles in Al6061 matrix has resulted in uniform dispersion of reinforcing particles as obvious from SEM studies. The EDS study showed the existence of graphite particles in produced composites and the XRD patterns of Al6061-6 and 12 weight percentages of graphite composites were analyzed. XRD investigations validate the existence of graphite phases in the Al6061 alloy matrix. The wear resistance of Al6061 alloy was enhanced with the addition of graphite particles. Applied load and sliding speed affected the wear behaviour of as cast alloy and also graphite reinforced composites. Further, Al6061 alloy with 6 weight percentages of graphite reinforced composites exhibited superior wear resistance.

References

[1] G Pathalinga Prasad, H C Chittappa, Madeva Nagaral, V Auradi, (2019): "Effect of the reinforcement particle size on the compressive strength and impact toughness of LM29 alloy-B_4C composites", *Structural Integrity and Life*, 19, br. 3, pp. 231-236.

[2] Madeva Nagaral, V Auradi, S A Kori, Vijayakumar Hiremath, (2019): "Investigations on mechanical and wear behaviour of nano Al_2O_3 particulates reinforced AA7475 alloy composites", *Journal of Mechanical Engineering and Sciences*, 13, 1, pp. 4623-4635.

[3] Pankaj R jadhav, B R Sridhar, Madeva Nagaral and Jayasheel I Harti, (2020): "Mechanical behaviour and fractography of graphite and boron carbide particulates reinforced A356 alloy hybrid metal matrix composites", *Advanced Composites and Hybrid Materials*, 3, pp. 114-119.

[4] C. S. Ramesh, R. Keshavmurthy, B. H. Channabasappa, S. Pramod, (2009): Influence of heat treatment on slurry erosive wear resistance of Al6061 alloy, *Materials and Design*, 30, pp. 3713-3722.

[5] T. S. Kiran, M. Prasanna Kumar, S. Basavarajappa, B. M. Vishwanatha, (2014): Dry sliding wear behaviour of heat treated hybrid metal matrix composite using Taguchi techniques, *Materials and Design*, 63, , pp. 294-304.

[6] Aparmit Shivam, Amit Singla, Amit Chauhan, (2017): Wear analysis by Taguchi technique of Al6061 based hybrid composite reinforced with SiC and Al2O3, *International Journal of Mechanical and Production Engineering Research and Development*, 7, 4, pp. 371-380.

[7] T. Lokesh, U. S. Mallik, (2017): Dry sliding wear behaviour of Al-Gr-SiC hybrid metal matrix composites by Taguchi techniques, Materials Today Proceedings, 4, pp. 11175-11180.

[8] V. V. Monikandan, M. A. Joseph, P. K. Rajendrakumar, (2016): Dry sliding wear studies of aluminium matrix hybrid composites, *Resource Efficient Technologies*, 2, 1, pp. S12-S24.

[9] V. M. Ravindranathan, G. S. Shivashankar, S. Basavarajappa, Siddesh Kumar N. G., (2017): Dry sliding wear behaviour of hybrid aluminium metal matrix composite reinforced with boron carbide and graphite particles, Materials Today Proceedings, 4, pp. 11163-11167.

[10] T. Ram Prabhu, V. K. Varma, Srikanth Vedantam, (2014): Tribological and mechanical behaviour of multilayer Cu-SiC and Gr hybrid composites for brake friction material applications, Wear, 317, pp. 201-212.

[11] B. M. Girish, B. M. Satish, H. R. Vitala, (2011): Effect of nitriding on wear behaviour of graphite reinforced aluminium alloy composites, *Journal of Surface Engineered Materials and Advanced Technology*, 1, pp. 73-79.

[12] K. Rajkumar, S. Santosh, (2014): Effect of nano and micro graphite particle on tribological performance of aluminium metal matrix composites, *Applied Mechanics and Materials*, 592-594, pp. 917-921.

[13] S. Rajesh, A. Gopala Krishna, P. Rama Murthy Raju, M. Duraiselvam, (2014): Statistical analysis of dry sliding wear behaviour of graphite reinforced aluminium MMCs, Procedia Materials Science, 6, pp. 1110-1120.