International Conference on Innovative Research in Engineering, Management and Sciences
International Journal of Scientific Research in Computer Science, Engineering and Information Technology
© 2019 IJSRCSEIT | Volume 4 | Issue 9 | ISSN : 2456-3307

Influence of Two Stage Stir Casting and 6 wt.% Boron Carbide Particulates Addition on Mechanical Characterization and Wear Behavior of Al2618 Alloy Composites

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ABSTRACT

In the current research the production of composites, characterization, mechanical and wear behavior of 6 wt. % of micro composites have been investigated by reinforcing the 63 micron B4C ceramic particulates into Al2618 alloy. The composites were prepared by using two stage stir casting technique containing Al2618 alloy as matrix phase and B4C particulates as reinforcement. After the composite preparation, the prepared composite material was examined by using various techniques like SEM, EDS and XRD for characterizing the chemical elements and microstructures of reinforced and unreinforced material. Later, the mechanical properties and wear behavior of as cast Al2618 alloy and Al2024 -6 wt. % 63 μm B4C composites were studied. Different mechanical properties like hardness, percentage elongation, ultimate and yield strength were evaluated as per the ASTM standards. The dry sliding wear tests were conducted by using pin on disc equipment. The experiments were conducted for the sliding distance of 3000 m by varying the sliding speed and load. From the investigation, it was found that due to addition of nano B4C ceramic particles in the Al2618 alloy matrix the hardness, ultimate tensile strength and yield strength of prepared composites by stir casting were increased and the percentage elongation was decreased of the same prepared composite. Further, there was an improvement in the wear resistance with respect to the speed, load, and sliding distance for the prepared composite materials. However, with the addition of B4C ceramic particulates in the base Al2618 matrix the wear loss was decreased. The scanning electron microscope was used to study and analyze the fractography and different wear mechanisms for various test conditions of different compositions, tensile fractured surfaces and the worned surfaces.

Keywords : Al2618 Alloy, 63 μm B4C, Stir casting, Mechanical Behavior, Fractography, Wear, Worn Morphology

I. INTRODUCTION

In the modern technology the micro metal matrix composites plays a very crucial role in various application. Usually to enhance the ultimate strength or better yield of the metals the nano ceramic particles are used. But however, the ductility of nano metal matrix composites deteriorates with respect to strength by the absorption of high ceramic particles. Therefore, the ceramic particles can be significantly substituted in the place of macro particles [1].

As compared to other alloys and conventional metals, aluminum alloys are used as matrix phase in various ranges of domains like automobile, aerospace, and marine industries owing to their different physical properties like low density, good corrosion resistance, low thermal coefficient of expansion and finally the cost of production is relatively low [2, 3]. Due to these characteristics' aluminum alloy forms a very strong and good competitor in broad range of applications. But however still some of the major mechanical properties like elastic modulus, strength and wear resistance are not very much satisfactory for industrial applications; therefore, to meet the satisfactory requirements they are reinforced by various ceramic reinforcements such as B4C, SiC, graphite, etc. So as compared to other micro particles, B4C ceramic particles used as reinforcement as made a better significant choice and have recently started been using in aluminum matrix composites by offering very high hardness, enhanced strength, chemical stability and increase in thermal stability [4, 5].

Micro metal matrix composites are gradually getting to be distinctly appealing materials for cutting edge aviation applications and yet their properties can be custom- made by the proper chose of reinforcement. Among three different composites, particulate strengthened MMCs as of late discovered unique intrigue on account of their quality and firmness at a normal room and raised temperatures. It is significant to note that the flexible properties of the metal matrix composites are unequivocally affected by

few secondary parameters of the reinforcement, for example, shape, size, introduction, circulation and volume.

B4C is one of the hard-ceramic reinforcement materials which tend to possess a low specific gravity, outstanding hardness and good high temperature melting point hence these properties make a best choice of reinforcement material for nano metal matrix composites. Different applications like pulleys, linkages in automobiles, are prepared by using Al–B4C micro composites because of the hard nano particles it acts as interface for wear resistant applications [6]. For the manufacturing of nano metal matrix composites various fabrication techniques are commonly available, like powder metallurgy, high-energy ball milling, mechanical alloying, stir casting, nano-sintering, and spray-deposition. However mechanical stir casting process is considered as one of the finest technique due to the formation of vortex which leads to disperse of micro sized B4C particles in molten aluminium without forming clustering and agglomeration and relatively low-cost. With respect to fabrication processes the proper selection of several parameters are much needed, like stirring speed in rpm, time in minutes, preheating temperature of the mould, temperature of molten matrix in degree Celsius, along with the continues uniform feed rate of the nano ceramic reinforcement in steps of two stages into the molten matrix to acquire good wetting property. By using stir casting technique and producing of components with complex geometry in huge volumes at a lower cost of production is one of the advantages, but there are several dis-advantages like small blowholes and porosity because of the improper distribution of the nano ceramic reinforcing particles between the metal matrixes which leads to deterioration in various mechanical properties. However, this type of case occurs when the calculated volume of the reinforcement is more than the matrix phase [7]. As revealed so far by performed research, even at the superior temperatures the B4C particulates contributes in enhancing various mechanical properties. The matrix deformation is successfully prevented by the existence of B4C particulates, which holds the load and lock up the micro cracks that often build up along the friction direction.

But however, insufficient information is existing with regards to the tribological and mechanical properties of B4C particulates reinforced with

Al2618 which is processed by two stage mechanical stir casting method. The aluminum–B4C

composites play an important role in the industry because of the increase demand of advanced lightweight materials in different industrial applications. Keeping in view of the above observations, it is proposed to develop Al2618 composites with 6 wt. % of 63
μm B4C ceramic particulates.

II. EXPERIMENTAL DETAILS

Materials Used

The aluminum alloys are basically classified into two categories these are cast aluminum and wrought aluminum. In the present research work Al2618 alloy is used as the matrix material which is one type of wrought aluminium alloy designated by 4 numbers, having copper as the primary element and combined with various other elements like zinc, magnesium, silicon and many more elements which are listed in chemical composition of Table 1. The melting point of Al2618 is 660˚C and the density of is 2.80 g/cm3.

Table 1- Chemical Composition of Al2024 alloy by Weight%

Zn	Mg	Si	Fe	Cu	Ni	Mn	Cr	Al
0.1	1.8	0.2	1.3	2.7	0.9	0.3	0.1	Balance

The main benefit of integrating the ceramic reinforcement material to the matrix material is to enhance different tribological and mechanical properties. In the current research nano B4C ceramic particulates have been used which is having a density of

2.52 g/cm3 which is lesser than that of Al2618 alloy [8]. Due to this reason the nano reinforcement material is added in steps of two stages during the preparation of the composites to have proper bonding between with matrix and reinforcement and to avoid agglomeration difficulty. The B4Cparticles also have high hardness, good dimensional, phase stability which makes the nano composite materials to improve fracture toughness, creep resistance and fatigue resistance

Preparation of Composites

Among various fabrication processes, mechanical stir casting processes method was used in the current research work for the preparation nano composite by using Al2618 alloy along with 6 wt. % of 63μm B4C particulates. The crucible which is made from graphite is made to place in an electrical furnace by introducing the pre-weighed Al2618 billet which was made into small pieces. The Electric furnace is heated to the temperature of 750˚C. The B4C ceramic particulates are introduced in small graphite crucible and were preheated to maximum temperature of 400˚C. The digital temperature controller was used to check the temperature of the aluminum molten melt inside the graphite crucible which was placed in an electrical resistance furnace. The degassing agent known as Solid Hexachloro-ethane (C2Cl6) was added to remove the unwanted gases present in the molten melt [9]. Furthermore, to increase the wettability between micro reinforced particulate to the metal matrix a 5 to 10 grams of magnesium was added. By using zirconium coated stirrer, the mechanical stirring was done for the molten metal to the speed of 300-350 rpm for about 5-6 minutes before adding the reinforced particles to achieve a vortex. Once the formation of vortex is achieved then the preheated B4C ceramic particles were added at a constant feed with an equal interval into the molten metal of as cast alloy in two step addition process. The melted molten liquid is poured into a pre heated die made from cast iron and finally allowed to cool at room temperature to obtain the desired samples for further process as shown in fig.1.

Figure 1: Al2618-B4C composites after casting

Testing of Samples

The prepared samples obtained from casting are cut in to an appropriate size of

5 mm thickness and 15 mm diameter, and then subjected to mirror polishing at different levels for microstructure study. Initially, with 1000grit size emery paper the cut samples were polished and then succeed by polishing with Al2O3 suspension on a polishing disc by using soft cloth which is made from velvet. Further the diamond paste of 0.3 microns was used for polishing. Finally, the Keller's reagent chemical was used for etching of the polished surface and at lastly subjected to microstructure study by using the scanning electron microscope (SEM).

The hardness test is done on the polished surface of the specimens by using Brinell hardness for both reinforced of unreinforced materials. The hardness test machine as used for conducting hardness test as a ball indenter of 5 mm diameter and 250kg load for a dwell period of 30 seconds and 5 different set of readings were taken at different locations on the polished surface of the specimen and the average was considered. As per the ASTM E8 [10] the tensile study was carried out on the cut specimens with the use of electronic universal testing machine at room a temperature to study different tensile properties like percentage of elongation, yield strength, and ultimate tensile strength. Fig.2 shows the size of tensile specimen as per ASTM standards used for testing

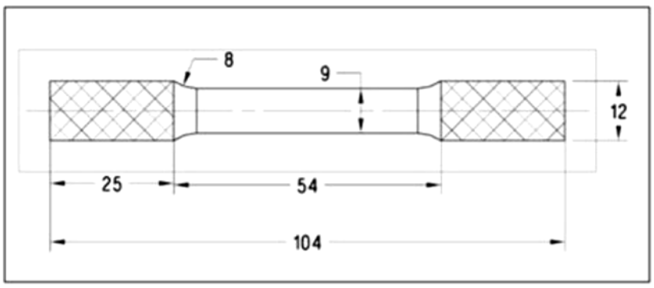


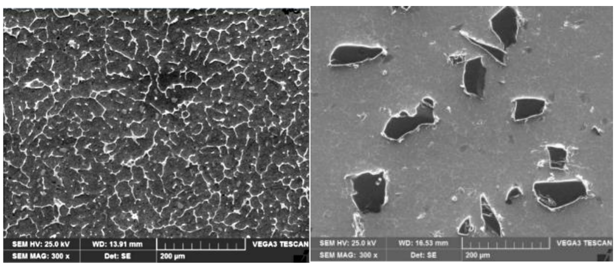
Figure 2: Dimensions of tensile test specimen in mm

The pin on disc machine (DUCOM, TR-20LE) was used to conduct wear test for the study of wear behavior. The dry sliding wear tests were performed on both reinforced and unreinforced materials by having a diameter of 8mm and height of 30mm as per ASTM G99 standards. The wear machine counter disc was made of EN32 steel material. Before the start of the testing process, the acetone liquid is used for cleaning of the disc and test pin surface. The various investigations were led at 3000m sliding distance and 400rpm steady sliding velocity through varying loads of 10N, 20N, 30N and 40N. Similarly, tests were conducted at 40N constant load through varying speeds of 100, 200, 300 and 400rpm. Among testing's, the test pin was kept opposite and stationary to the spherical steel disc while the circular plate was pivoted. The fundamental weight of the test pins samples was measured by using Digital Electronic machine by measuring the accuracy of 0.0001 g. After each test, the acetone liquid was used for cleaning of the worned surface. To measure the wear misfortune the test pin was weighed prior and then after the surface is worned. The measured weight reduction was further changed and calculated into volumetric wear misfortune. Fig.3 demonstrates the wear specimens utilized for the wear investigation.

Figure 3: Wear test specimen

III. RESULTS AND DISCUSSION

Microstructural Study



(a) (b)

Figure 4: Showing the SEM microstructure photographs of (a) As cast Al2618 alloy & (b) Al2618-6 wt. % B4Ccomposite

To examine SEM images, the samples were preferred from the middle segment from the cylindrical specimens. Fig.4a and b shows the SEM microstructures of as cast Al2618 alloy and the composite of 6 wt. % of micro B4C reinforced with Al2618 alloy. The microstructure of as cast Al2618 alloy comprises of fine grains of solid solution of the aluminium along with an ample distribution of inter-metallic precipitates. In additionally, the prepared micro composite shows the great bonding among the framework and the reinforcement alongside the uniform homogenous circulation of micro estimated B4C particulates without any agglomeration and bunching in the composites. This is essentially because of the practical mixing activity accomplished all through by two stage addition process of B4C. By the uniform distribution of particle in matrix, the grain limit of the lattice obstructs the grain improvement and opposes the separation development of grains amid stacking.

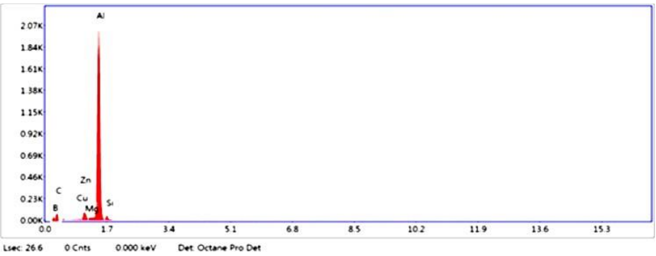


Figure 5: Showing energy dispersive spectrum analysis of Al2618-6 wt. % of 63µm B4C composite

Energy dispersive spectrum analysis (fig.5) confirmed the existence of nano B4C particulates in the form of B (Boron) and C (Carbon) elements in the Al2618 alloy base matrix.

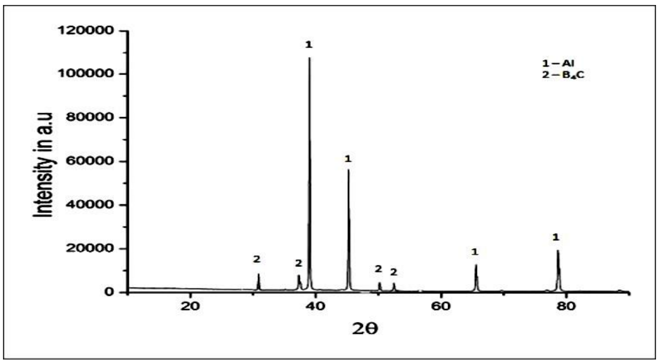


Figure 6: Showing XRD analysis of Al2618-6wt. % of 63µm B4C composite Fig.6, shows the XRD (X-ray diffraction) pattern of the Al2618-6 wt. % micro B4C and the occurrence of Al and nano B4C phase are evidently seen. It can be observed that peak height increases and then decreases on 2-theta scale indicating the presence of different phases of material. In fig. 6it is visible that X-ray intensities of peak are higher at 38˚, 45˚, 65˚& 78˚indicating the presence of aluminium phase. Similarly, it is observed the peaks for different phases of boron carbide at 31˚, 37˚, 50˚ and 54˚.

Hardness

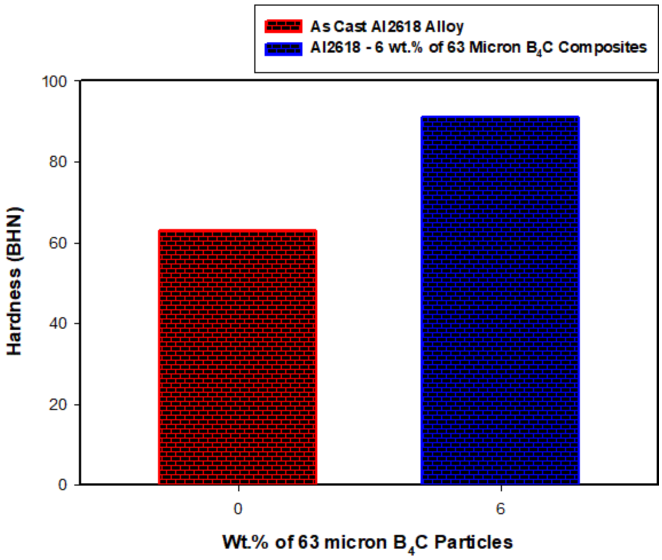


Figure 7: Hardness of Al2618 alloy and 63 µm B4C composites

The hardness is a mechanical parameter demonstrating the capability of resisting of prepared materials to indentation under a static load. The addition of 6 wt.

% of 63µm B4C particulates to the Al2618 alloy with respect to unreinforced alloy can lead to the variation in the hardness which can be observed from figure 7. There is a noticeable increase from 62.9 BHN to 91.1 BHN for aluminum composites. This can be credited to the because of the of harder micro B4C ceramic particles in the lattice than base alloy, and the higher constraint to the localized matrix deformation during indentation as an outcome of the presence of harder phase. Furthermore, the B4C, as other fortifications fortify the matrix by making of higher density dislocations amid cooling to room temperature because of the distinction of co-efficient of thermal expansion developments between the B4C and grid Al2618 compound. The variance in the strain is developed between the reinforcement and the matrix alloy obstructs the movement of dislocations, by resulting in the enhancement of the hardness of the prepared composites [11, 12].

Ultimate Tensile Strength and Yield Strength

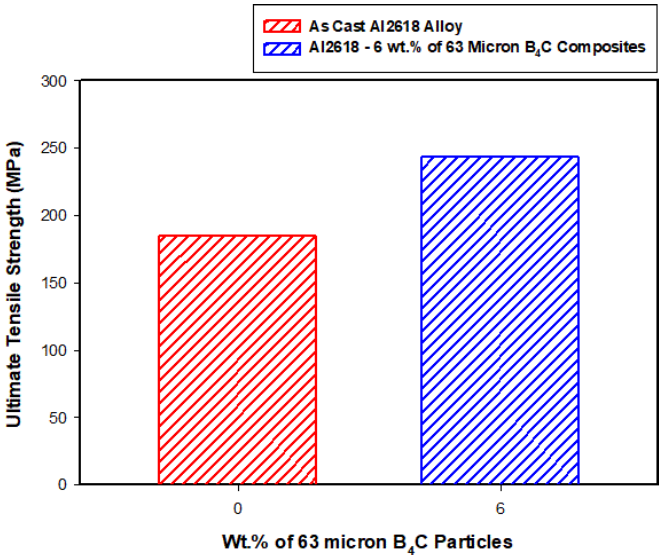


Figure 8: Ultimate tensile strength of Al2618 alloy and 63μm B4C composites Figure 8 represents the plot of ultimate tensile strength (UTS) with 6 wt. % of 63

micron B4C dispersoids in metal lattice composite. As a component of weight rate of B4C particles the calculated estimations of ultimate tensile strength were plotted. When compared to base Al2618 alloy with 6 wt.% of B4Ccomposites, there has been an increase of 31.4% in UTS. Because of legal contact between the framework mixture and the supporting materials there is a major increase in strength. Better the grains estimate better is the hardness and additionally the better quality of composites prompting to enhance the wear resistance [13]. The improvement in UTS is credited by the hard ceramic B4C particulates, which confers value to the framework mixture, in this way by giving improved solid rigidity. The expansion of these hard-micro particles may have offered rise to huge lasting compressive unease created along with cementing because of contrast in coefficient of developed between flexible matrix and brittle particles. The improvements of quality are likewise attributed to closely packing of the reinforcement and thus little inter particulates spacing in the lattice.

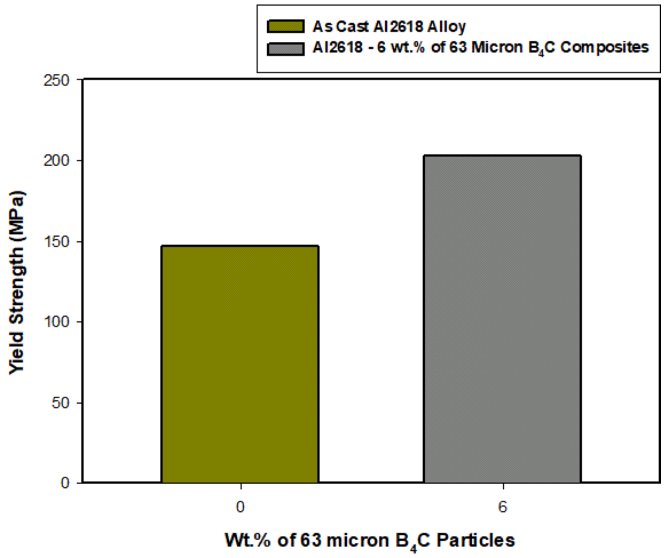


Figure 9: Yield strength of Al2618 alloy and 63μm B4C composites

By noticing that the character of the prepared composites it is extremely dependent on the volume or weight division of the reinforcement leads to the increase in yield quality. Figure 9 showing the variation in yield strength (YS) of Al2618 alloy matrix with 6 wt. % of micro B4C particulates reinforced composites. It is noticed that by adding 6 wt. % of 63 micron B4C particles the yield strength is improved from 147.2 MPa to 202.9 MPa. The expansion in Yield strength of the nano composite is clearly because of the hard B4C ceramic particles which contribute to the quality by delectating the Al alloy network and bringing more quality resistance of the composite against the connected ductility load. On account of micro particle strengthened composites, the uniformly distributed hard ceramic particles in the grid make limitation till the plastic stream, in this way giving upgraded quality to the composite [14].

Percentage Elongation

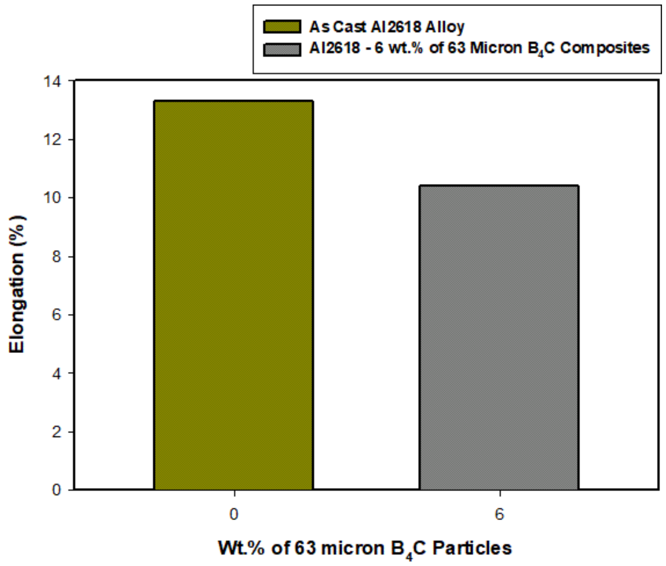
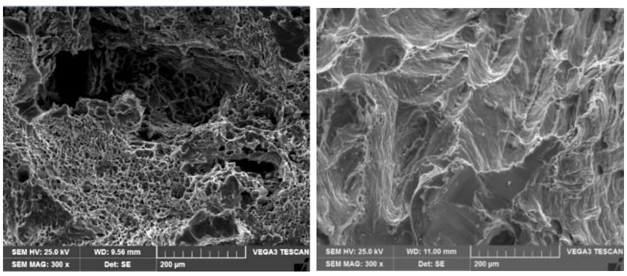


Figure 10: Percentage elongation of Al2618 alloy and 63µm B4C composites Figure 10 representing the impact of micro B4C content on the elongation (ductility) of the composites and the flexibility of the composites reduces essentially with the 6 wt. % B4C prepared composites which can be noticed from the chart. This diminishing in rate prolongation in association with the matrix and reinforcement is a most frequently occurring disadvantage in particulate prepared MMCs. The decreased malleability in nano composites can be assigned to the closeness of B4C ceramic particulates which may get broken to small dendrites by stirring process by having a sharp corner that make the prepared composites distorted to limited part initiate and increase [15]. The delicate collision that happens because of the contact of the hard B4C ceramic particles bringing on expanded locality stretch focus locales may like manner be the reason.

Fracture Studies



(a) (b)

Figure 11: Sample of Fracture surfaces of the tensile test (a) Al2618 matrix alloy (b) Al2618-6wt. % B4C composite

After tensile testing the fracture surfaces (fig.11a-b) of as cast alloy and micro composite samples were characterized by using SEM images to study the mechanism of the fracture. The as cast Al2618 alloy fracture manner is a ductile fracture manner which can be seen in fig.11-a and has huge number of hollow shaped structures and grains are visible. Fig.11b shows that structures have less ductile failure because of reinforcing the 6 wt. % of B4C. The reason for failure of composites during tensile test is because that micro particles cracking all along with matrix material get fracture, and de- bonding between the boron carbide particulates and Al matrix alloy interface. Small voids are observed in the case of 6 wt. % B4C composites, fractured surfaces showed limited stresses at the interfaces is more and small cracks at reinforcement particles mechanism is observed.

Wear Behavior

The varying load at 400rpm along x axis for Al2618 alloy and micro B4C composites wear loss along y axis is represented in the figure 12. Since the load is increased from 10N to 40N the wear loss is also increased but it is lesser in the case of 63µm B4C ceramic reinforced composite

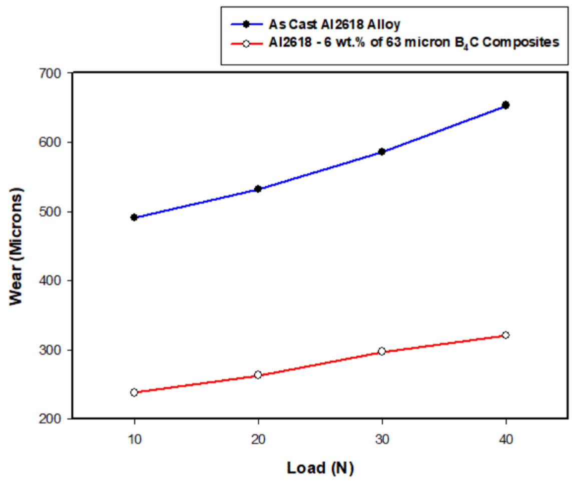


Figure 12: Wear loss of Al2618 alloy and 63µm B4C composites at varying loads and 400rpm constant speed

More wear loss is observed for matrix alloy and for the composites at higher loads varying from 10N to 40N. At maximum loads the pin exceeds the critical value at the temperature of sliding surface. As eventually the load increases on the pin there is also an increase in the wear loss of both the unreinforced alloy and reinforced composite. But it is practically observed that the wear loss of the composites reduces with 6 wt. % B4C ceramic reinforcements in the matrix alloy. This enhancement in the wear resistance of the micro composites is with wt. % of reinforcement is mainly due to the high hardness of B4C particulates which acts as like a barrier for the material loss [16].

The dependence of all the wear loss of Al2618 matrix alloy along with B4C composites on sliding speed is shown in Fig. 13. As the sliding speed (rpm) is increased from 100 rpm to 400 rpm, the losses are also increased for both Al2618 aluminium matrix alloy and its constituent composites due to wear. But although at every sliding speeds, the wear loss of the composites is much lesser, when compared with the matrix alloy.

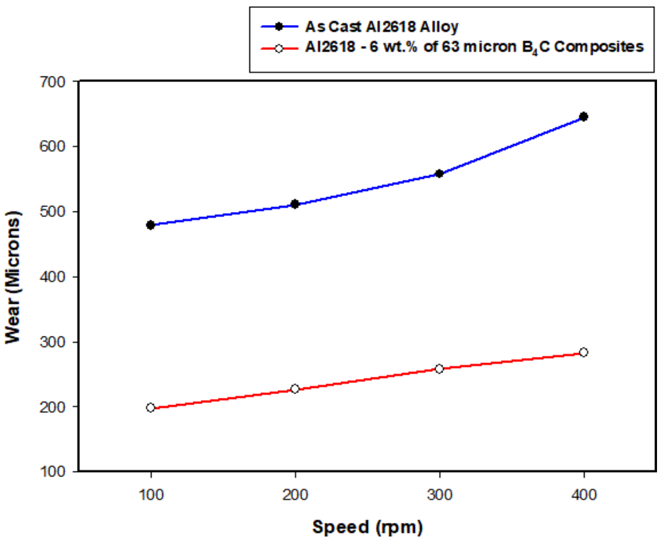
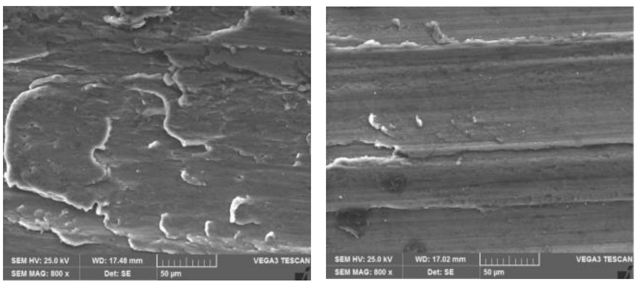


Figure 13: Wear loss of Al2618 alloy and micro B4C composites at different speeds and at constant load (40N)

Additionally, as sliding speed is kept on increasing there is noticeable increase in wear loss also because of softening of the micro composite at increased temperature due to rubbing action. The increase in temperature resulting due to higher sliding speeds also leads to plastic deformation of the test piece. Therefore, there is increased delamination contributing to enhanced wear loss.

Worn Morphology

The Worn surface microphotographs studies of as cast Al2618 alloy and micro B4C reinforced composites are examined by using SEM. Figure 14 characterize the worn surfaces of matrix material Al2618alloy (fig. 14a) and the micro composite surface which is tested at 40N load and 400rpm sliding speed by reinforcing of 6 wt. % of 63 micron B4C (fig. 14b) particles in base materials From fig. 14a it shows in the sliding direction the particular edges and depressions running parallel to each other. It can be seen from the micrograph the cracks are deeper and wider spreading lattice combination Al2618 when compared with micro composites under similar conditions. Because of the sliding of oxide molecule in the reinforced composite it might be seen from figure14b that a break likewise on the well-used outer surface of the Al2618-6 wt. % B4C composite. On account of micro composites, a thick layer could be seen, which shields the basic matrix from being in contact with the sliding partner and along these lines minimizing the volumetric wear misfortune. Therefore, the layer framed on the nano composites gives a self-protective cover to the hidden material as a result repressing the metal-metal contact.



(a) (b)

Figure 14: Shows the SEM microphotographs of worn surfaces of (a) as cast Al2618 alloy (b) Al2618-6 wt.%B4C composites at 40N load and 400rpm speed

Applications

Aluminium alloys like Al2024, 2014, 2219 and 7075 are most widely used materials for the aerospace applications. Especially, in the manufacture of aircraft components like wing root fittings, hinges, bulkheads and the frames Al 2XXX and 7XXX series are using, due to their high strength properties. In the aircraft design and manufacturing weight of the component plays vital role as weight of the aircraft is directly affecting fuel consumption. Since, Al2618-B4C micro composites exhibits superior properties, these composites can be used for the fabrication of wing root fitting and hinge design. The major advantage of using these composites is weight saving due to reduced cross sectional area of the components.

IV. CONCLUSION

In this research, by using stir casting fabrication technique the nano B4C/Al2618 micro composites have been fabricated by considering 6 wt. % of reinforcement. The microstructures, mechanical properties like hardness, yield strength, ultimate tensile strength, percentage elongation, and fractography and wear behavior of the prepared samples are studied as per ASTM standards. The matrix is almost free from pores in as cast alloy and uniformly distributed of micro particles in the prepared composite, which is explained from the SEM microphotographs. The XRD and EDS analysis confirms the existence of B4C ceramic particles in the Al2618 alloy matrix. Compared to unreinforced material the various mechanical properties of Al2618-6 wt. % micro B4C composite are superior and enhanced. Due to strain localization, the fracture surface of the composite material consists of small voids. These small voids were then coalesced during the tensile loading, ensuring in the structure of a dimple appearance at the cracked area of surface. The wear resistance of Al2618-6 wt. % B4C composite is significantly superior to that of the unreinforced material. Further, the wear loss of Al2618 alloy matrix and 63 micron B4C particle reinforced composites increased with the increase in load and speed.

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