DRY SLIDING WEAR BEHAVIOR OF AA 7075 REINFORCED SHORT COATED CARBON METAL MATRIX COMPOSITES

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ABSTRACT: The dry sliding wear characteristics of aluminum alloy 7075 reinforced with short coated carbon fiber metal matrix composites were analyzed using pin on disc apparatus. The carbon fibers were used at different wt. % of 1, 2 and 3% respectively. Stir casting method was used to prepare the cast composites. For proper wettability, the carbon fibers were coated with nickel using the principle of autocatalytic reduction. It was observed that the wear rate decreased by a maximum of 16.23% for normal load of 10N and 38.46% for sliding distance of 500m. Structure-property correlation also formed a basis for a thorough and clear understanding of the prepared composite subjected to wear parameters. It is observed that unreinforced AA 7075 composite showed heavy delamination and fracture of the transfer layer due to the abrasive action of the hardened transfer particles resulting in flake like debris.

KEYWORDS: *Wear; Aluminum Alloy; Metal Matrix Composites; Stir Casting; Surface Topography*

1.0 INTRODUCTION

Metal Matrix Composites (MMCs), like most composite materials, give essentially upgraded properties over conventional monolithic materials, for example, higher strength, stiffness, and weight ratios [1-2]. Metal matrix composites are utilized as a part of an extensive variety of superior applications. The MMCs have been utilized as a part of more than 5.5 million kgs amid the year 2006 and are discovering force in a yearly development rate of more than 8% [3]. The premier applications include aerospace, ground transportation, electronic hardware and

sports equipment's. Furthermore, the applications additionally get themselves set up in aeronautics with issues concerning propulsion and subsystem categories.

Aluminium composites consist of thin sheets of aluminium bonded with fiber reinforced adhesive. The aluminum composites during machining tend to elongate the matrix Al grains leading to the formation of many dislocation cells within the composite. This confirms the existence of internal stresses within the grains. Thus, aluminum composites of low thickness are very appealing as they bring about a drastic decrease in the dislocation density. Moreover, the dislocation cell size also becomes finer. Additionally, these composites can be fortified by precipitation; possess great corrosion resistance, high thermal and electrical conductivity and damping limit [4]. The solid interest for weight reduction in auto and aircraft manufacturing emphasizes on improvement of product designs utilizing low weight materials. The substitution of normal materials by lighter metals, for instance, aluminum combinations is, in this way, exceedingly appealing. The strong demand for weight reduction in car and aircraft fabrication urges the optimization of the design of products employing low weight materials [5]. Regardless, aluminum alloys are not satisfactorily strong for a few reasons and their reinforcement is critical. Aluminum based MMCs are noteworthy contender for these applications inferable from the high flexibility of the matrix and the high quality of the reinforcing stages. The interest for such materials is as a result of the high modulus, strength to weight ratio, fatigue strength and wear resistance [6-7]. Earlier study on MMCs addressed the behavior of continuous fiber reinforcement composite based on aluminum, zinc and titanium alloys matrices and the reinforcements used was Alumina fibers, carbon fiber, glass fiber etc. The reinforcement metal matrix offers potential for improvement in efficiency, mechanical performance and reliability over the new generation alloys [8].

Wear is a slow and progressive loss of material which are subjected to repeated rubbing action. Wear causes an enormous amount of expenditure by repairing or replacing the worn-out parts or equipment [6]. The wear resistance of metal matrix composite depends mainly on various microstructural characteristics like particle size, volume fraction, distribution of reinforcement material, and shape [7-9]. Among the different types of reinforcement, particulate form of carbon fibers reinforced with AMMC has desirable and attractive properties and can withstand higher operating temperature and oxidation resistance compared with other geometries of reinforcements such as flakes [10].

The required literature has been studied in the field of Metal matrix composites (MMC) for a thorough understanding. This literature survey provides brief ideas about the developments in MMCs. The survey has been made for different methods on the reinforcements and also the different testing procedures for the improvement of the mechanical property, and also improved strength over the weight reduction. The literature survey was also made for different techniques available for electro less coating of the carbon fibers which is reinforcement for aluminum. Vannan et al. [10] conducted experiments on the effect of coating parameters on coating morphology of basalt short fiber as reinforcement. They found that interfacial between reinforcement and matrix plays a very important role in the property of the metal matrix composites. By coating the surface of the reinforcement, this can be achieved. Electro less coating method is done for the weight deposition of the copper on the basalt fiber. Coating method has three processes in which thickness of the coating depends on sensitization time, activation time and metallization time. Vizhian et al. [11] have analyzed the effect of change in composition of basalt fiber, which is fabricated under squeeze infiltration technique. Elastic property of the material, due to the fiber orientation and the length of fiber are studied. The comparison is made between the experimental and theoretical results. It was found to be good improvement in the Young's modulus. When the reinforcement percentage increased from 2.5 to 10%, Young's modulus was observed to be increased by 13.26%. Rams et al. [12] have conducted experiments on the mechanical property of the composites through nano indentation. In this study, carbon fiber is coated with the nickel coating. This reinforcement is added with AA6061 aluminum powder and is made compact and heated to about 650-9500C. Coating improves the wet ability of the reinforcement. The formation of a transient Al-Ni inter metallic surface with the reinforcement and matrix, and also homogeneous distribution of the reinforcement lead the composite to have better properties. Based on literature, there have been very few efforts regarding wear studies of AA 7075 which is the strongest alloy of the aluminum family as a matrix material for coated carbon fiber reinforced composites. Thus, the objective of this work was to study the wear characteristics of aluminum alloy 7075 /short coated carbon fiber composite and also carry out the micro structural study of worn out surfaces of the composite material through optical microscopy.

2.0 MATERIALS AND METHODS

2.1 Preparation of Chopped Carbon Fibers

The PAN based continuous carbon fibers long strands which are winded in the spool are shown in Figure 1.The continuous carbon fibers had to be cut to a smaller length of 1mm. The continuous carbon fibers were separated from the spool and cut to length of approximately 30cm and placed on the manual printing press cutting machine.

Figure 1: Spool of PAN based carbon fibers

Figure 2: Chopped carbon

A manual feed of 1mm and less was given to machine for the cutting of carbon fibers as shown in Figure 2. The short carbon fibers were at first cleaned with acetone solution for about 10 minutes so that the carbon strands maintained the best possible smoothness with the surfaces. This smoothness tends to increase the amount of carboxyl groups on the carbon fiber surface, thus effectively promoting the interfacial adhesion between the carbon fiber and aluminum matrix [13].

2.2 Electro Less Nickel Coating

The carbon fibers were then placed in a hot oven around 200°C; the acetone solution was evaporating which drying up the fibers. The coating procedure included 3 distinct stages, for example, i) Sensitization arrange (S): In this stage the carbon filaments were plunged in a solution of 12gms/ltr of $SnCl_2$. $2H_2O$, they were sensitized for 15mins under continuous mixing. The carbon filaments were dried utilizing filter paper and soaked in the 40ml/ltr arrangement HCl for 5 minutes. ii) Activation stage (A): In this stage, first, the strands were washed with refined water and after that they were presented to the aqueous solution of 0.5 grms/ltr of $PdCl_2$ with agitation in order to activate the specimen to receive metal ions. In order to obtain uniform hardness, the continuous stirring was done at 600 rpm for 10 mins [14]. This procedure prompts the development of the Pd sites on the surface of the carbon fiber, which will additionally help in the metallization, iii) Metallization arrange (M): The procedure of metallization begins

with warming the activated carbon fibers on the hot stove at 150˚C for 20 minutes to enable the pyrolitic covering around the fibers. The pH is kept up with 11 to 13 by including NaOH pellets onto the arrangement. Sodium Hydroxide (NaOH) was used as the neutralizing agent. The process of pH neutralization or pH adjustment was achieved by adding NaOH. An increase of 1 pH unit required 1/10th the amount of NaoH required to achieve the previous increase. This stage was completed with a steady fomentation at 80˚C. The process of coating preparation was carried out in a sequential manner. When the electro less coating was completed, the coated carbon fibers were attached to each other,resulting in a decrease in wettability of nickel coated carbon fibers on the aluminum metal matrix composites. For the separation of these nickel coated fibers without affecting the coating of the surface, the fibers are immersed in the solution of 20grams/litre solution of Sodium dodecyl sulphate ($NaCL_2H_2SO_4$). Surfactants improves the dispersion ability of the carbon fibers in the aqueous solution and dispersion ability of the sodium dodecyl sulphate is good compared with other solutions such as polyethylene glycol or dodecyl benzene sulphonic acid. The fibers were dipped in the solution for 5 days for the proper dispersion to take place. The optimized coating for prescribed sensitization, activation and metallization was selected from Table 1. The mean thickness of 0.64 μm obtained from trail no. 3 was used for optimized coating. The smallest value of mean thickness had been identified so as to maintain uniform coating over the carbon fibers thus owing to uniform wet ability over the matrix.

Table 1: Mean thickness of nickel coating on carbon fiber

Trial no.	S time (min)	A time (min)	M Time (min)	Mean thickness (μm)
1	5	5	1	0.7546
2	5	10	2	0.7680
3	5	15	3	0.6400
4	10	5	2	0.6600
5	10	10	3	0.8010
6	10	15	1	0.7250
7	15	5	3	0.7593
8	15	10	1	0.9364
9	15	15	2	0.7883

2.3 Mixture of Composites by Liquid Stir Casting Technique

The challenging factor in a preparation of composite is to maintain the proper dispersion of reinforcement to achieve a defect free microstructure or the matrix and fiber interface. The liquid state stir casting is preferred rather than any other processes because of its uniform distribution of fibers in the matrix during the mixture preparation. This involves high

melting temperature and constant stirring. The carbon fiber used at the different wt. % of 1, 2 and 3% with the total weight including the Al is 3 Kg. The long Aluminum ingots were cut into the required size and placed in the crucible which had a capacity of 5 kg. The crucible was then placed in the stir casting machine and constantly heated till the Al melted i.e. up to 700˚C. The coated carbon fibers and the moulds where the molten metal to be poured were placed in the muffle furnace and heated for 500˚C. The carbon fibers maintained the same temperature until they were transferred to the Al melt. When the Al melted at 700˚C the Magnesium metal powder with wt. % of 0.3 of total weight (10 grams) was poured into the melt. This reduced the surface tension of the Al and encouraged the uniform mixture of the carbon fiber in the Al melt. The stirrer was placed one third to the height of the crucible which would be partly immersed in the Al melt. The stirrer was rotated at speed of 320 RPM which formed the vortex in the melt. The heated weighed carbon fibers were poured into the crucible to be mixed with the Al melt. When the carbon fibers were poured simultaneously, the stirrer had to be stirred at the constant speed in order to help the fiber to be immersed in the Al melt and allow the fibers to spread wide over inside the crucible. Stirring was continued until the matrix and the reinforcement interacted with each other and promoted wettability. Then the melt with the crucible were removed from the heater and poured into the heated mould. After the melt was poured, it was then left out for cooling for around 3 hours and the mould specimen was separated for any testing process. It is imperative to note that, in stir casting process; the matrix metal is thoroughly penetrated into the bundle of fibres and is well bonded to every single fibre. It has been already reported in the earlier studies that, as the carbon fibre content increases, the uniformity of distribution of the fibres in the composite increases up to 4% fibre content and beyond this, the uniformity of distribution of fibres decreases because of the agglomeration of fibres in the composites [15].

2.4 Hardness Test

The hardness of the material was determined by a Brinnell hardness testing machine. A fixed amount of force was made to act on the surface in order to observe the nature of indentation. Specimen as shown in Figure 3 for the hardness test was prepared as per the ASTM standard E10. The specimens prepared were 30mm diameter and 10mm thickness. The Brinell hardness test was carried out with a ball indenter of 2.5mm. The load was applied on the specimen for about 30 seconds. Different readings were taken from different locations. After that, applied load was removed and indentation mark was observed through the optical

microscope which was integrated to the load applying unit. The size of the indentation mark was measured.

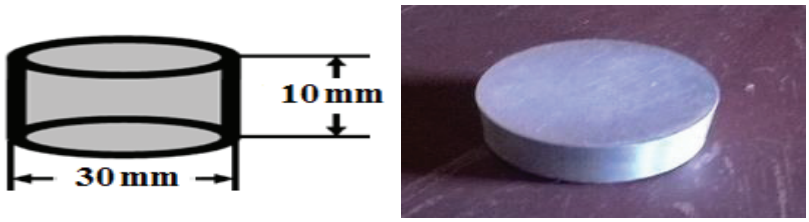


Figure 3: Dimensions of the specimen used for Hardness test.

2.5 Wear Test

This test was conducted to know the wear property of the material. The wear rate under different condition was calculated by conducting the test using the pin-on-disk machine. In order to conduct the wear test of the composite, the specimen was prepared from the casting as per the ASTM standard G95-99, and wear rate was investigated through the pin on disk apparatus. The composite samples were machined into disks with 20 mm in diameter and 5 mm in thickness. The samples were ground using emery papers to obtain a surface finish close to 0.1 μm. Prior to the experiments, specimens were weighed in the microbalance and then it was inserted in the machine. The experiment was carried out for loads varying from 10 to 40 N in steps of 10 N. The test was carried out for variable sliding distance of 500mm to 2000mm in steps of 500mm.

2.6 Examination of worn surfaces and XRD

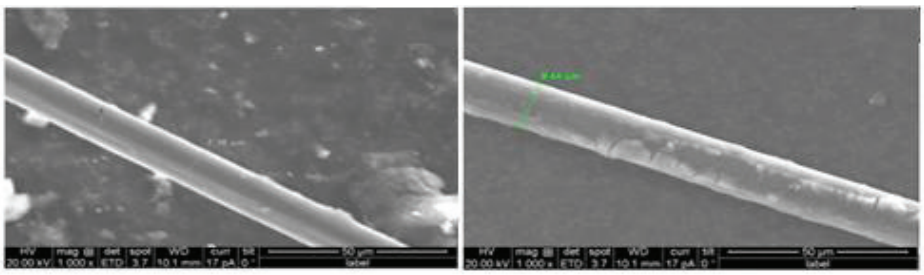
The worn surfaces of the alloy and composites disk were observed using a scanning electron microscope. The microstructures of AA7075 and AA7075/coated carbon fiber MMCs were studied using a scanning electron microscope (JEOL 840A JSM) possessing a magnification capacity of X50, X1000, X2000 and accelerating voltage of 20 kV with a working distance of 10 mm and an optical microscope (Nikon Microscope LV150 with Clemex Image Analyser). The XRD patterns were recorded using a PANalytical X-ray diffractometer with 2β range of 10-90°. The presence of nickel was observed with the graph plotted intensity vs. the angle 2β and the software PCPDFWIN to determine the mixture solution which is allotted for the peaks.

3.0 RESULTS AND DISCUSSIONS

3.1 Morphology of Electroless Nickel Coating

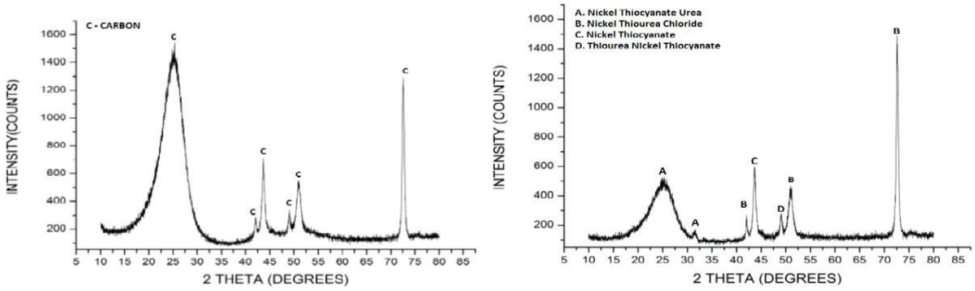
Figure 4(a) shows the morphology of uncoated carbon fibers having a mean diameter of 7.16μm. Figure 4(b) clearly shows the coating thickness of 0.64μm which was used as the optimum coating thickness (Table 1) of nickel on the carbon fibers. This convened a carbon fiber diameter of 7.16+(0.64×2)=8.44μm. The uniform coating was maintained over the carbon fibers by employing uniform wettability over the matrix in order to give good adhesion and protection. The X-ray diffractions for the uncoated and nickel coated carbon fibers had been studied in order to examine the diffraction occurred when the light beam came in contact with the object.

Figure 5 shows the XRD pattern for uncoated and coated carbon fibers. From Figures 5(a) and 5(b), the angle 2β shows the angle of refraction of light to the reference beam. The intensity of peaks (C) and (B) were a simple way of characterizing the presence of carbon and nickel content in the fibers. The Figure 5(a) clearly witnesses relatively weak nickel pattern which was due to the near surface carbon containing functional groups of the fibers. This uncoated carbon fiber showed a carbon content of 93.12% presence in the processed carbon fiber. After electroless nickel coating, this carbon content weakened due to renewed nickel coating. The presence of nickel content was purely assigned to Nickel Thiourea Chloride. The effect of electroless nickel coating can be distinctly seen in Figure 5b wherein, the spectrum shows a strong Nickel Thiourea Chloride line and a relatively weak carbon line.



(a) (b)

Figure 4: SEM micrograph of (a) uncoated carbon fiber diameter and (b) coated carbon fiber diameter



(a) (b)

Figure 5: X-ray diffraction of (a) uncoated carbon fiber and (b) nickel coated carbon fiber.

3.2 Hardness

Specimens for the hardness test were prepared as per the ASTM standard E10. The Brinell hardness test was carried out with a ball indenter of 2.5mm. The load of 5 N was applied on the specimen for about 30 s. The hardness tests were conducted on a B scale for various percentage of coated carbon fiber content and the results obtained are shown in Figure 6. It can be observed that as the wt. % of short coated carbon fiber increased, the hardness value increased. In fact, as the percentage of short coated carbon fiber reinforcement content was raised by 1 percent, the hardness increased by 10. 60%, 2 and 3 percent have led to increase the hardness by 13.63% and 18.18% respectively. Hence it can be thoroughly construed that, an increase in wt. % of reinforcement, composite will have significantly higher value of hardness than the monolithic alloy to a certain level. The reason for the increase in hardness may be because of the presence of short coated carbon fiber, which acted as a barrier to indentation movement. The increase of hardness number was attributed to dislocations generated due to coefficient of thermal mismatch between carbon fibers and aluminum alloy matrix [16]. These dislocations generated at the vicinity of carbon fibers contributed to work hardening, leading to increase in hardness. Further, carbon fibers also acted as obstacles for dislocation motion, offering large resistance to plastic deformation during the hardness test, which results in improved hardness values of metal matrix composites with the increase of the content for coated carbon fiber reinforcement [13, 16-17].

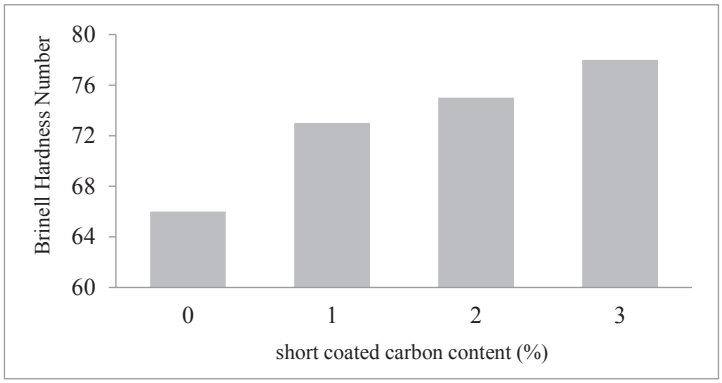


Figure 6: Variation of Brinell hardness number with respect to percentage of short coated carbon fiber

3.3 Wear performance

The sliding distance effect on the wear rate of AA 7075/short coated carbon fiber dispersed metal matrix composites. Figure 7(a) shows the variation wear rate with respect to sliding distance. It is clearly observed that, the wear rate increased significantly from distance of 500 to 1000 mtrs, increases marginally from distance 1000m to 1500m. Beyond, this the wear rate again increases from 1500 to 2000m.

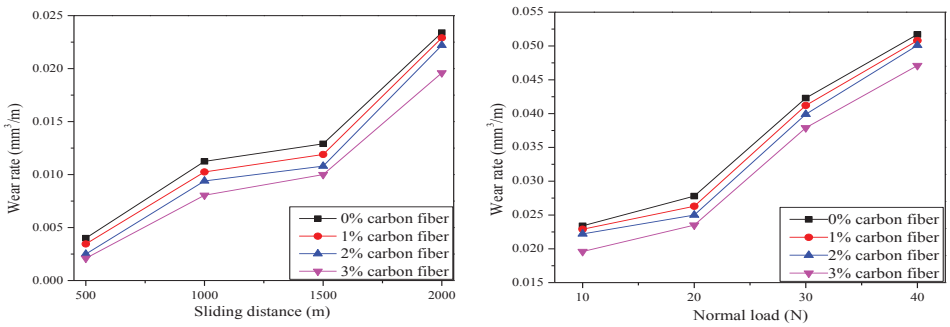


Figure 7: Variation of wear rate (mm^3/m) for different, (a) sliding distance and (b) normal load on the specimen

It is apparent that the content of wt. % of carbon fiber, sliding distance and load greatly influenced wear characteristics of AA 7075/ short coated carbon MMCs. It is clearly observed from Figures 7(a) and 7(b) that, as the wt. % of short coated carbon fiber dispersion increased in the Al 7075 alloy, the wear rate decreased. For a sliding distance of 500mm, the wear rate of unreinforced AA 7075 and 3% coated carbon MMCs were found to be 0.0039 and 0.0024 respectively which corresponded to 38.46% decrease in wear loss. Subsequently, at an applied load of 10N,

the wear rate of unreinforced AA 7075 and 3% coated carbon MMCs were found to be 0.0234 and 0.0196 respectively. Hence, almost 16.23% reductions occurred in the wear rate of coated carbon MMCs compared with that of unreinforced AA 7075.

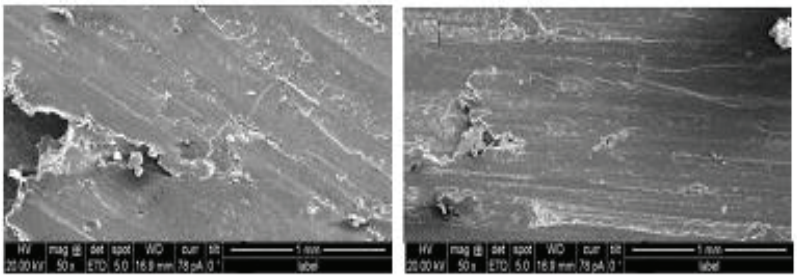
This decrease in wear rate can be attributed to the lubricating nature of coated carbon fibers. It is to be noted that the carbon fibers are composed of multiple cylindrical shells during the coating process. These shells are attacked by weal wan der Waals forces. Thus, during the wear tests, the individual shells of the coated carbon fibers get worn when they come in contact with the pin on disc leading to the formation of a thin film. This film acts as a solid lubricant between the pin on disc and the composite [16, 18]. With the increase in the percentage of carbon fibers in the AA 7075 matrix, it is more possible that a thicker carbon film is formed covering the entire wear surface leading to decrease in wear rate. However, this case may also observe a huge possibility of decrease in the non-uniformity of distribution of fibres because of the agglomeration of fibres in the composites which has been reported [15]. The steady state of the wear rate decrease can be attributed to the uniform distribution of coated carbon fibers in the matrix. The results showed the wt.% of short coated carbon fiber in the Al 7075 matrix increased, the wear resistance property of composite gained higher values than the monolithic material for the sliding distance and load.

3.4 Examination of worn surfaces

Figure 8 shows the wear tracks of AA7075 matrix material that were observed using a scanning electron microscope (JEOL 840A JSM) with a magnification capacity of 50 X. It shows severe plastic deformation and fracture of the transfer layer due to the abrasive action of the hardened transfer particles. Figures 8(a) and 8(b) show distinct grooves and ridges running parallel to one another in the sliding direction. It can be seen from the micrographs that the grooves were wider and deeper in AA7075/0%carbon fiber MMC as compared with that of AA7075/3%carbon fiber MMC when tested under similar conditions.

According to Figure 8(b), the worn surface of 3% coated carbon fiber composite showed marginal plastic deformation as it was significantly covered with lubricating carbon film. This is due to higher carbon fiber content, and the amount of carbon film formed was significantly higher, leading to higher lubrication [18]. It is observed that 0% carbon fiber reinforced AA 7075 composites (Figure 8a) go through a severe plastic deformation, resulting in flake like debris [19]. These flakes were formed due to the formation of micro-cracks at the interface, growth of

the cracks and finally peeling off from surface as the wear continues [15, 18]. A closer view showed grinding marks of aluminum alloy flakes, whereas in the 3% carbon fiber reinforced composite, marks were comparatively lesser due to higher level of hardness.



(a) (b)

Figure 8: SEM images of worn surface of (a) AA7075/0%carbon fiber MMC and (b) AA7075/3%carbon fiber MMC.

4.0 CONCLUSION

The objective of this work is to give a constituent relationship between the metal and the fiber. The mixture of this composite is subjected to the dry sliding wear. Nickel has uniformly been coated on the carbon fibers by autocatalytic reduction.

- The AA7075/short coated carbon fiber MMCs show increased hardness with the increase of the coated carbon weight fraction.
- The MMCs exhibit decrease of wear loss due to lubricating property and strengthening effect of coated carbon fibers. AA7075/ carbon fiber MMCs with 3% carbon fibers show reduction in wear loss by 16.28% and 38.46% for normal load of 10N sliding distance of 500mm respectively, when compared with that of unreinforced AA7075 MMC.
- The SEM micrographs show deeper and wider grooves leading to severe plastic deformation in AA7075/0%carbon fiber MMC as compared to that of AA7075/3%carbon fiber MMC when tested under similar conditions.

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