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Effect of Carbon Fiber Rod Reinforcement on Slurry Erosive behavior of Al6061 Composites

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Abstract

Continuous carbon fiber rod reinforced Al6061 composites were fabricated by liquid metallurgy technique. Micro-structure and slurry erosion studies were carried out on the developed composites. The influence of experimental parameters such as slurry particle size, slurry concentration and spindle rotational speed on slurry erosive wear behavior of the developed composites have been studied. The developed composites have shown an improvement in slurry wear resistance properties when compared to the matrix alloy. The worn surfaces and the slurry particles were observed using a scanning electron microscope to validate the wear mechanism.

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Keywords: Slurry Erosive Wear; Al6061 composites; carbon fiber; Metal Matrix Composites (MMC's).

1. Introduction

Metal matrix composites (MMC's) exhibit properties that are superior to the conventional monolithic alloys. They possess superior wear resistance, better strength-to-weight ratio together with high specific modulus [1-2]. In the recent years, aluminium based MMC's have gained widespread importance in aerospace and automobile industries [3]. Aluminium alloys have excellent mechanical properties coupled with good corrosion resistance. However, they possess poor wear and seizure resistance. To improve the above said properties, researchers have successfully dispersed various hard and soft materials such as such as SiC, Al_2O_3 and Si_3N_4 as reinforcements in aluminium

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alloys by different processing techniques [4-6].

Carbon fibers possess high strength, wear resistance and excellent lubricity. Due to these reasons, they have been extensively used as reinforcements in discontinuous forms to develop MMC's [7-9].However, carbon fibers exhibit high reactivity with light materials, especially with aluminium and its alloys, which limits its applications [10]. Electroless nickel followed by copper electroplating has been identified as the promising solutions to overcome the above limitations [11-12]. It is reported that these metallic coatings improve the wetting behavior of carbon fibers with aluminium, leading to improved uniform distribution of carbon fiber reinforcement, reduced interfacial reaction and higher toughness of the composites [7, 8].These days, to develop light weight structures, carbon fibers in the form of bundles are used. The use of carbon fiber rod reinforced MMC's in mining, chemical and marine environment has not gained much importance. This may be due to the fact that materials in these environments need to combat slurry type of erosion wear due to hard particles in liquid medium. Caron et al. [13] have studied the erosion wear behavior of Al5083-Al_2O_3 composites and have noticed that slurry erosion wear of the composites increased with the increase in Al_2O_3 content in the matrix material. Das et al. [14] have investigated the slurry erosive wear behavior of Al-Si alloy reinforced with SiC in acidic and NaCl media and have observed an increase in wear resistance of the composite when compared with the matrix alloy in both acidic and NaCl media. Ramesh et al. [15] have studied the slurry erosive wear behavior of Ni-P coated Si_3N_4 reinforced Al6061 composites and have reported an increase in the wear resistance in the composites when compared with the matrix alloy. However, not much information is available as regards the slurry erosive wear behavior of metallic coated carbon fiber rod aluminium based composites.

In the light of above, the present work aims at studying the slurry erosive wear behavior of Al6061- carbon fiber rod composites under various experimental conditions.

2. Experimental Procedure

2.1. Composite Preparation

Al6061 alloy in the form of cast ingots procured from M/s Fen Fee Metallurgicals, Bangalore, India was used as the matrix alloy for the fabrication of the composites. Continuous carbon fiber rods of diameters 6mm and 4mm procured from M/s RC Dhamaka, Bangalore, India were used as the reinforcements in the Al6061 alloy to fabricate the composites. Electroless nickel coating was carried out on these carbon fiber rods after their pre-treatment and sensitization process as described in our earlier works [12]. The nickel coated carbon fiber rods were further subjected to an electroplating process to plate it with copper using a conventional copper electroplating bath, whose compositions are maintained as per literature [16].The detailed methodology of fabrication of the composites is described in our previous works [17]. The obtained castings were subjected to CNC (Computerized Numeric Control) machining to fabricate samples of dimensions 40x15x15mm.

2.2. Slurry Erosive Wear Test

Slurry erosive wear tests were carried out on the fabricated composite and matrix alloy samples by preparing slurry baths having varying amounts of silica sand of varying size and 3.5%NaCl solution in 1L of distilled water. Details of the apparatus used for these tests are as mentioned in our earlier works [18]. The fabricated samples were polished using emery paper of various grain sizes and were cleaned thoroughly with acetone and weighed using an electronic micro balance of 0.1mg accuracy. The initial weights of the samples were noted down so as to measure the slurry erosive wear loss of the specimen. These specimens were fixed to spindles such that the test surfaces were immersed completely inside the slurry cups. It was ensured that the surfaces other than the test surface were thoroughly insulated to protect them from slurry erosion. The samples were tested for different test parameters by varying conditions like spindle rotation speed (500-1250rpm), slurry concentration (100-500g/L) and slurry grain size (100-600µm). The samples were subjected to the slurry erosive wear test for fixed test duration of 5 hours under a salt concentration of 3.5%. These conditions were set based on literature to simulate the actual erosion conditions of components subjected to slurry erosive wear such as slurry pumps, torpedo blades etc.

After conducting the tests, each of the specimens were heated to evaporate the water absorbed by the carbon fiber rods and were cleaned with acetone again to remove any foreign particle clinging onto the test surface which would hinder the accuracy of measurement of weight loss. The final weights of the tested specimens were noted and the weight loss of each specimen was calculated.

These specimens were then subjected to Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDAX) tests to observe the effects of the erosive test on the specimens. The silica sands used for the slurry solution were also subjected to SEM to observe the changes in their surface morphology.

3. Results and Discussions

3.1. Microstructure

Microphotograph the developed Al6061- 6mm C_f(Carbon fiber) rod composite is shown in Fig.1. This micrograph reveals that there is a high degree of uniformity in the thickness of copper plating with no presence of gap between carbon fiber and copper coating and between matrix alloy and copper suggesting that there is a good bond between the matrix alloy and the reinforcements.

Optical microscope images of the developed composite and matrix alloy (shown in Fig.2 and Fig.3) shows that the size of the grains in the developed composites are smaller than the grains observed in the matrix alloy hence, improving the hardness of the material and also providing better mechanical properties to the composites relative to the matrix alloy. The reduction in grain size after addition of carbon fiber rods may be attributed to fact that, during the solidification of aluminum alloy, the carbon fiber rods provides effective site for nucleation and also restricts the growth of grains and modifies the matrix with more refined structure leading to improvement in hardness and strength[19,20]. Smaller the grain size, higher will be the hardness of the composites [21]. It is also observed that the cohesiveness of the aluminium grains in the composites is enhanced thereby resulting in improved strength of the material.

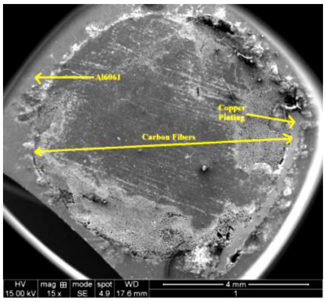
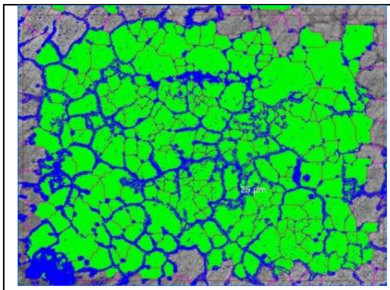


Fig.1: SEM image of the developed Al6061-6mm Cf rod composite



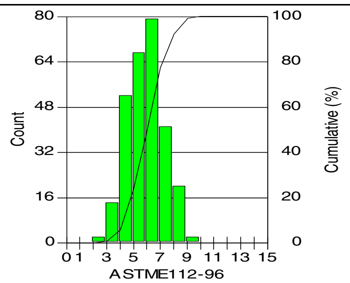


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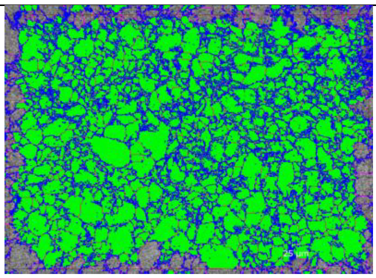
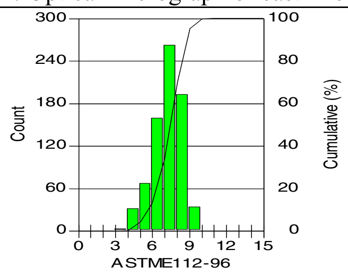
Fig.2: Optical micrograph of cast Al6061 alloy





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Over:	0	
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Field Area:	919119.2	µm²
Total Area:	919119.2	µm²

Fig.3: Optical micrograph of cast Al6061 -6mm Cf rod composite

3.2. Slurry Wear Loss

3.2.1. Effect of Reinforcement

Fig.4 shows the variation of slurry erosive wear loss ofAl6061 matrix alloy and Al6061-C_f rod composite (6mm and 4mm C_f rods). It is observed that there is a significant reduction in the weight loss in the developed composites when compared to the matrix alloy. It is observed that for the specified test conditions, there is a reduction of 34% and 52% in the weight loss of the 4mm and 6mm Al6061- C_f rod composites respectively, when compared to the matrix alloy. The improved slurry wear resistance of the developed composites when compared with the matrix alloy can be attributed to the following reasons: Firstly, with the increase in amount of carbon fiber reinforcement the hardness of the composite increases. This increase in hardness results in better wear resistance. This fact has been well established in our earlier works [17]. Secondly, Al6061 alloy forms a highly stable passive oxide layer on reacting with water when the test surface is exposed to the slurry/NaCl solution [22]. This oxide layer provides insulation to the test surface from erosive and corrosive wear of the slurry solution. In addition to the oxide layer formed, in the case of developed Al6061-Cf rod composites there is a formation of copper oxide layer during slurry erosion process. The presence of carbon fibres in the composites reduces the effective area of aluminium alloy in the composite exposed to slurry bath and minimises the formation of corrosion pits on the test surface leading to cracking of grains in the matrix alloy [14].

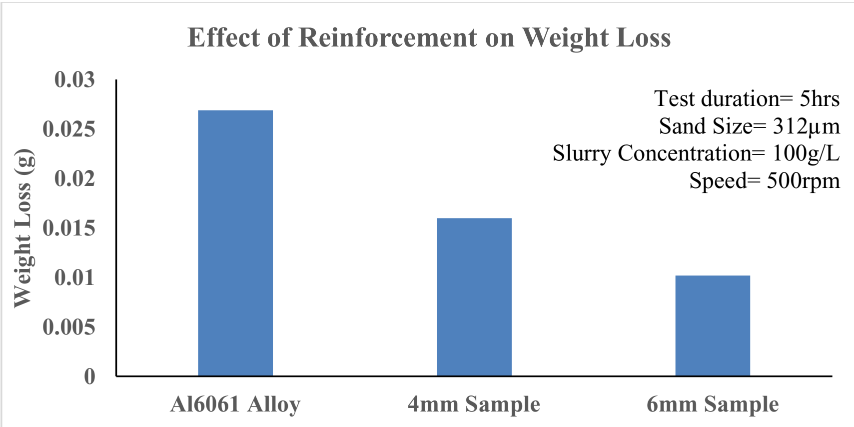

Fig.4: Effect of reinforcement on weight loss in Al6061 alloy and Al6061-Cf rod composites

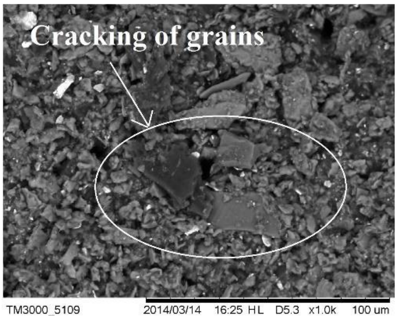

Fig.5(a): Cast Al6061 alloy

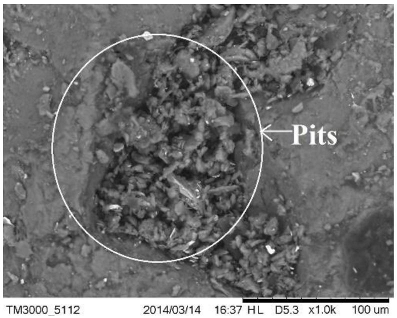

Fig.5(b): Al6061-4mm C_f rod composite

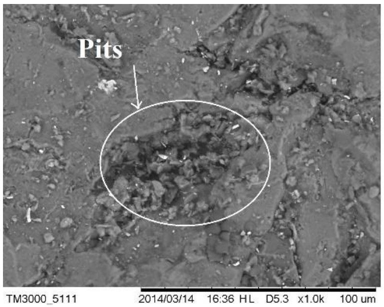

Fig.5(c): Al6061-6mm C_f rod composite

This finally results in further beneficial effects as regards limiting the direct exposure to slurry in inhibiting the corrosion process, leading to improved slurry wear resistance. These phases act as barriers to prevent corrosion and

erosion [23]. This provides an additional wear resistance to the developed composite. the presence of carbon fibers in the composites reduces the effective area of aluminium alloy in the composite exposed to slurry bath and minimizes the formation of corrosion pits on the test surface, leading to cracking of grains on the matrix alloy [14].The volume fraction of the reinforcement used in the matrix is quite high and since slurry wear is caused by simultaneous erosion and corrosion, there is a drastic reduction in the slurry wear of the developed composites.
This result is justified by the following SEM images shown in Fig.5, which was taken at test duration of 5 hours, for a slurry concentration of 100g/L using 312µm sand with the slurry spindle being maintained at a constant speed of 500 rpm.

3.2.2. Effect of Slurry Concentration

The variation of the weight loss of the Al6061 matrix alloy and the developed Al6061- C_f rod composites (4mm and 6mm $C_f$rods) with the variation of concentration of the slurry solution is as shown in Fig.6. For matrix alloy and composites, the weight loss of the specimens, for a given test duration and spindle speed, increases with the increase in concentration of silica sand in the slurry solution. It is observed that the developed Al6061- C_f rod composites possess a greater wear resistance when compared to the base Al6061 alloy. With the increase in slurry concentration, the probability of the impingement of the sand particle on the test surface of the specimen increases, resulting in an increased wear loss of the test specimen, hence resulting in a greater wear rate of the test surface of the specimen [24].

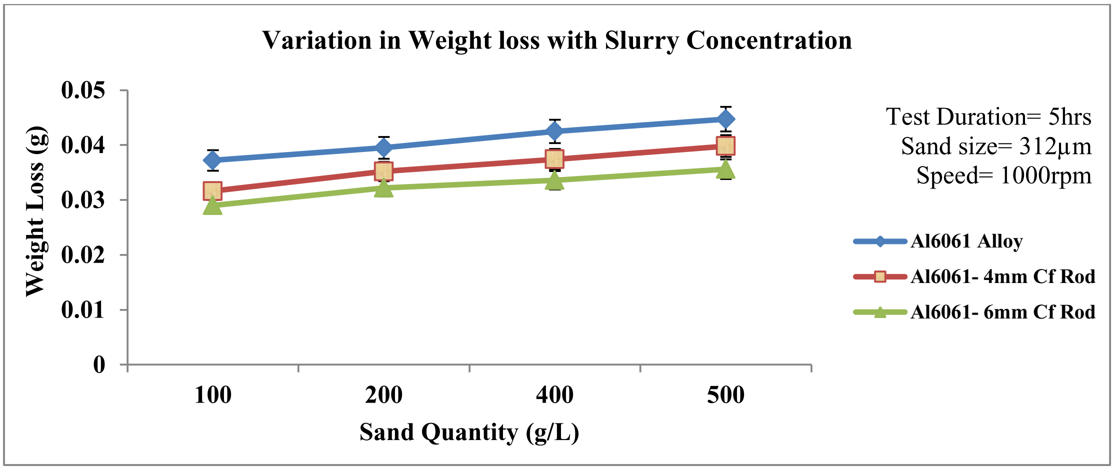

Fig.6: Variation of the weight loss of Al6061 alloy and Al6061-C_f rod composites for different slurry concentrations

3.2.3. Effect of speed of rotation

The variation in the weight loss of the Al6061 alloy and the developed Al6061- C_f rod composites (4mm and 6mm C_f rods) with the variation in the speed of rotation of the spindle to which the test specimens are attached are as shown inFig.7. It is observed that with the increase in speed of rotation of the spindle the weight loss of the Al6061 alloy and the developed Al6061- C_f rod composites (4mm and 6mm C_f rods) is found to increase. It is observed that the developed composites have a greater wear resistance when compared to the matrix alloy samples under all the test speeds of the spindle. With the increase in speed of rotation of the spindle increases the relative impact velocity of the slurry particles on the test surface, hence causing them to possess higher kinetic energy during impact there by resulting in higher weight losses on the test surface of the specimen [25].

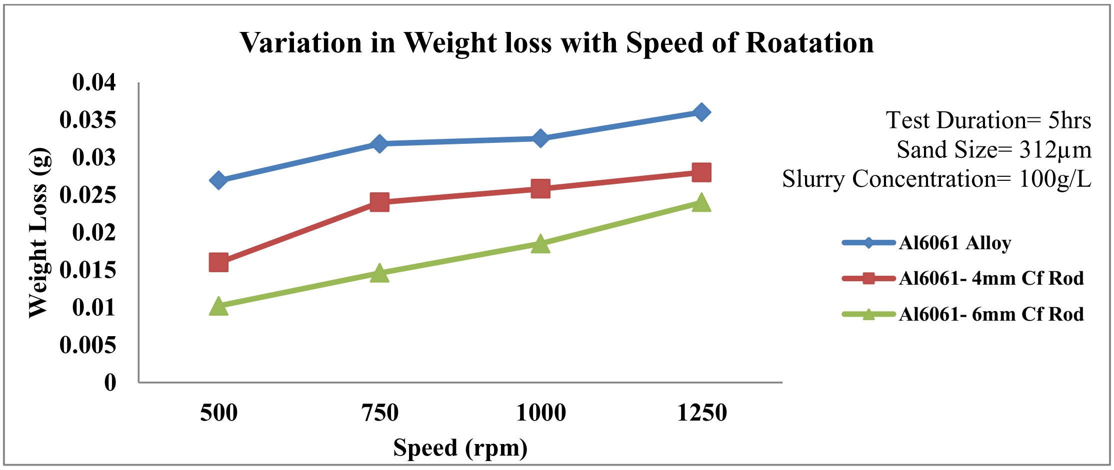

Fig.7: Variation of the weight loss of Al6061 alloy and Al6061-Cf rod composites with the speed of rotation

3.2.4. Effect of Grain Size of Sand in Slurry

The variation of the weight loss of the Al6061 alloy and the developed Al6061- C_f rod composites (4mm and 6mm C_f rods) with the variation in the grain size of the silica sand used in the slurry solution is as shown in Fig.8. The weight loss of both the matrix alloy and the developed composites are found to increase with increase in grain size of the silica sand used in the slurry solution. Here, it is observed that the increase in weight loss of the developed composites is relatively less when compared to the base matrix alloy samples due to increased hardness of the composites in comparison to the base matrix alloy, hence resulting in an improved wear resistance. Smaller the particle size, lesser is the impact energy it possesses at a given velocity of impingement [26]. Hence, the bigger grains possess higher kinetic energy due to their heavier mass when compared to smaller grains, resulting in a significant weight loss due the increased slurry erosive wear of the test surface of the specimen. Further it is reported that the smaller particles having lighter mass do not possess sufficient kinetic energy to initiate the erosion on the surface of the test specimen. Whereas, the larger grains possess sufficient kinetic energy to remove the material efficiently, hence resulting in removal of the material from the test surface thereby resulting in the erosion of the test surface [27].

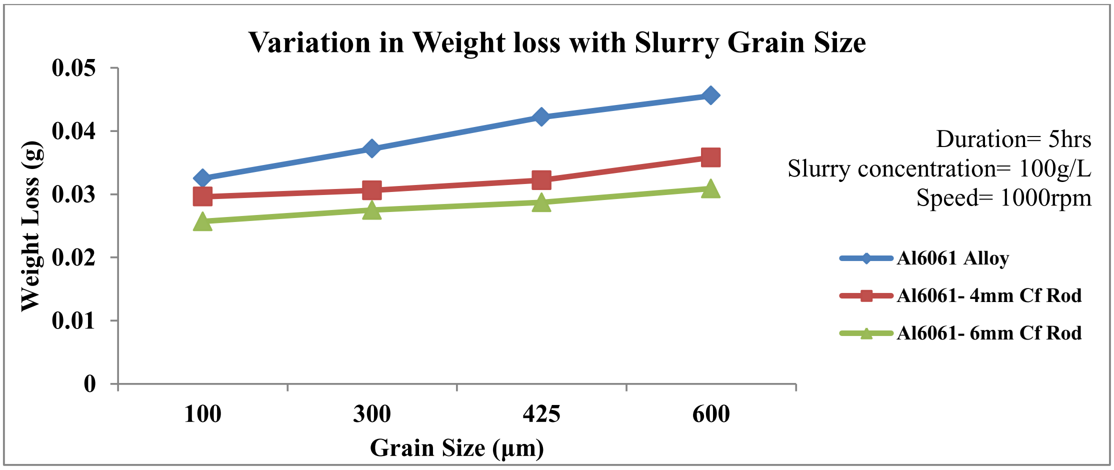

Fig.8: Variation of the weight loss of Al6061 matrix alloy and Al6061- C_f rod composites with the sand particle size

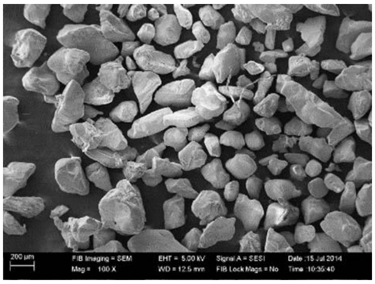

Fig.9(a): ~100 µm sand particle

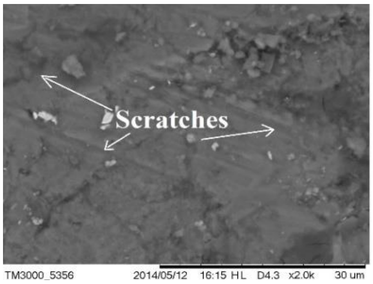

Fig.9(b): Surface of specimen eroded by ~100 µm sand

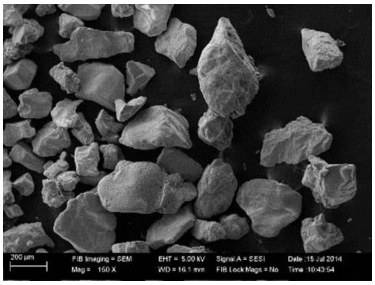

Fig.9(c): ~312µm sand particle

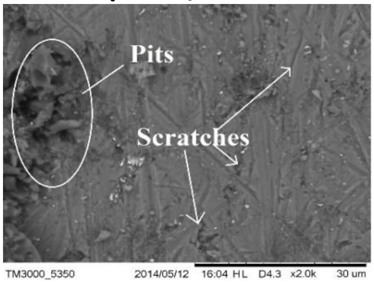

Fig.9(d): Surface of specimen eroded by ~312µm sand

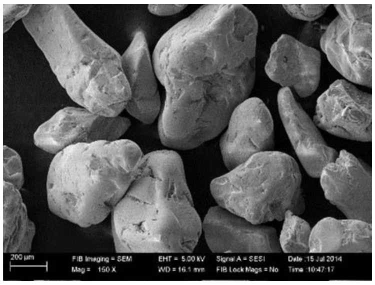

Fig.9(e): ~600 µm sand particle

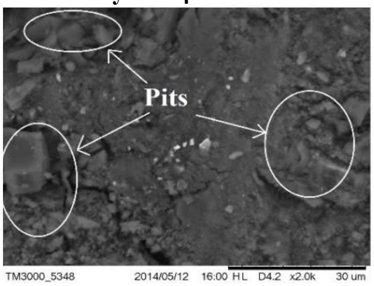

Fig.9(f): Surface of specimen eroded by ~600 µm sand

It is also noted that smaller the grain size, more the number of particles available per unit volume and hence higher the number of inter-particulate collision that results in retardation of the particle velocity and hence reducing the kinetic energy of the particle and thereby reducing the effect of the impact of the particle on the test surface of the specimen [28]. Large sized sand particles are capable to dig in and plough out the material owing to their high contact stresses developed. As far as small sized particles are concerned, their closure type of structure results in increased scratching rather than ploughing out leading to lower material removal [29]. This fact can be justified by the following SEM images of the Al6061-6mm C_f rod composite and erodent sand particles of varying sizes (100µm, 300µm and 600µm) as shown in Fig.9.

4. Conclusion

The slurry erosive weight loss of both matrix alloy and developed composites increases with increase in slurry concentration, rotational speed of slurry and size of impinging particles. However, under all the conditions of the test studied it is observed that the developed composites exhibited improved wear resistance when compared with the matrix alloy. Further, increase in the amount of carbon fibers as reinforcements in the matrix alloy has resulted in enhanced slurry erosive weight loss resistance. SEM studies on the worn surfaces of alloy and composites have clearly demonstrated that erosion, corrosion and the combination of both are the prominent wear mechanisms involved in the slurry erosion.

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