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EFFECT OF REINFORCEMENT OF NATURAL RESIDUE (QUARRY DUST) TO ENHANCE THE PROPERTIES OF ALUMINIUM METAL MATRIX COMPOSITES

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ABSTRACT

Metal matrix composites (MMCs) have superior mechanical strength and wear resistance as compared to base alloy. Aluminium matrix reinforced with low density discontinuous particulate composites has good potential in automobile and aerospace applications. The main challenge is to produce the light weight composite in a cost effective way to achieve the greater properties. In the present study, aluminium(A356) alloy is reinforced with quarry dust (QD) particulates using modified stir casting and the effect of quarry dust on the composites are investigated. Aluminium metal matrix composites (AMCs) have been successfully produced with different weight percentages (0, 5, 7.5 and 10) of quarry dust. Macrohardness and ultimate tensile strength of the composites have improved with the addition of reinforced particulates in the base matrix alloy. Dry sliding wear behavior of AMC_s is examined with the help of a pin on disc wear testing machine. It is found that the addition of quarry dust reinforcements increases the wear resistance of the composites. Optical and SEM images revealed the homogeneous distribution of reinforcement particles in the composites.

INTRODUCTION

Environment quality depends on our ability to control solid waste, toxic gases and contamination of water. The pollution control techniques are predominantly adopted to improve material processing and enhance the novel methods so that they produce less environmental problems. Leaving the waste material to the environment directly can cause environmental problems. Therefore, many countries are showing interest in the reuse of waste materials to minimize the hazards to environment. Wastes can be used to produce new products or can be used as admixtures so that natural sources are used more efficiently and the environment is protected from waste deposits (Mustafa Karasahin, *et al.*2007). The extraction of aggregates, coal and other mineral resources produces large volumes of waste material. These wastes arise due to a number of factors including contamination of the natural resource, the existence of local fault zones

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and overburden, and the processing of the mineral resource itself (Woolley, 1994; Rockliff, 1996 Wainwright, 2002;). Quarry dust is a by-product in the production of concrete aggregates during crushing process of rocks. Quarry dust used in concrete as fine aggregates for protecting the natural environment. About 20-25% of total production in each crusher unit is left out the quarry dust as waste material. It becomes a useful additive to the natural soil to improve its strength characteristics (Sridharan, *et al*. 2006). The utilization of quarry rock dust can be called as manufactured sand. For the Past three decades, it has been accepted as a building material in the industrially advanced countries of the west (Nisnevich, *et al*. 2003). As a result of sustained research and developmental works undertaken with respect to increasing application of the industrial waste, the level of utilization of quarry dust in the industrialized nations like Australia, France, Germany and UK has been reached more than 60% of its total production (Ilangovan, et al. 2008). Quarry dust is used for road construction and manufacture of building materials such as lightweight aggregates, bricks, tiles and autoclave blocks. The sizes of quarry dust are smaller than the 200 µm sieve compared with the river sand.

In the aluminium matrix composites (AMCs), research and development has recently shifted towards low density and low cost reinforced particulate composites which are focused for automotive, aerospace and electronics industries. Numerous research work have been reported on aluminium reinforced with most conventional ceramic particulate composites such as SiC, Al_2O_3, TiC, B_4C, MgO, Si_3N_4 and AlN.The ceramic particulates reinforced composites were expensive. Hence, continuous attempts being made to produce low cost AMCs. Limited research has been carried out on aluminium reinforced with natural resource by-products such as flyash, silica sand, and red mud particulate composites (Surappa, *et al*. 2008; Rohatgi, *et al*. 2010). In this study, Al-quarry dust composites are fabricated through liquid metallurgy route using modified stir casting technique. The results of mechanical and wear behavior of composites are compared with base aluminium alloy.

Materials and Experimental Procedures

Materials

In the present study, a commercial casting grade aluminium alloy (A356) is employed as the matrix material due to good fluidity and good corrosion resistance. The main compositions of matrix alloy are 7.14 and 0.35 weight percentages (wt. %) of Si and Mg. The A356 alloy was supplied by Vignesh Alloy, Coimbatore. The presence of silicon and magnesium, it can be maintained liquids state typical casting temperature and improve wetting of reinforcement by the liquid alloy. A356 alloy belongs to a group of hypoeutectic Al-Si alloy (Akhlaghi, *et al.* 2004). The quarry dust is obtained from SSS Blue Metals, Namakkal, Tamil Nadu, India. The compositions of the waste depends on the mineralogy of the rock source and consist of silica (SiO_2), aluminium oxide (Al_2O_3), iron oxide (Fe_2O_3) and alkali metal (K, Na, Ca, Mg) oxides. The density of the quarry dust is 1.9-2.0 gm/cc. The quarry dust particles are irregular in shape with sizes ranged from 30 to160 µm. Their chemical compositions of alloy and quarry dust are shown in Table 1 and 2.

Specimen Preparation

A batch of cleaned aluminium alloy ingot is placed inside the stainless steel crucible of modified (with bottom pouring) electric stir casting furnace. The A356 alloy is melted under an argon atmosphere. The preheated weighed reinforced particles are wrapped by aluminium foil and introduced in to molten alloy at around 750 °C. The alumina coated mechanical stirrer is slowly lowered in to the molten metal and maintains constant speed of 500 rpm to create vortex. Stirring is carried out to ensure both incorporation and

Table 1. Chemical Composition of A-356 in weight percentage

Si	7.14
Fe	0.39
Cu	0.06
Mn	0.25
Mg	0.35
Ti	0.02
Al	Balance

Table 2. Chemical Composition of Quarry dust in weight percentage

SiO_2	60.13
Al_2O_3	16.07
Fe_2O_3	8.28
CaO	9.89
MgO	5.42
SO_3	0.11
Na_2O	0.08
K_2O	0.02

uniform distribution of the reinforcement particles in the molten aluminium alloy. Subsequently, degassed and molten metal is poured in to a preheated spilt type cast iron permanent mould. The detailed composites production procedure has been explained in the literature (Ramesh, *et al*. 2013).

Tests Procedures

The Brinell hardness test is carried out using a 5 mm diameter tungsten carbide indenter with a 750 kg load as per ASTM E10-08 standard. An average hardness value is taken at six different locations from each polished sample. The tensile test is carried out for both the alloy and composites on FUT 40 model (40000 N) machine in accordance with ASTM B557M standard. Three specimens are tested on each wt. % of composites specimens. The average values are recorded at room temperature.

The dry sliding wear characteristics of Al alloy and A356-quarry dust composite specimen are tested using pin on disc machine as per ASTM G 99 standards. Cylindrical pin specimens of 10 mm diameter and 20 mm height are machined from 12.5 mm rod. The EN32 steel disc hardness having 63Rc used as counter surface. The test is performed on different parameters such as applied load (20-40N), sliding speed (1m/s) and sliding distance (1500m). The weight loss of the pin is measured by 0.0001g resolution digital balance. Reinforced particle distribution and Worn surfaces of pin were observed using the Olympus microscope (BX51M) and scanning electron microscope-(JEOL JSM-6390) with EDX facilities.

RESULTS AND DISCUSSION

Effect of Quarry Dust on the Mechanical Properties

Fig.1 shows the relation between the weight percentage of quarry dust particles and macrohardness of the A356-quarry dust composites. Fig. 1 shows the increase in the hardness with an increasing weight percentage of reinforcing particulates on matrix alloy. The hard reinforced particles offered resistance to surface plastic deformation during the indentation and the quarry dust particles render their inherent property of hardness to the soft matrix which significantly increases the hardness value. The reduction of the ductility of A356-quarry dust composite is due to the presence of hard quarry dust particles reinforced with soft Al matrix alloy. The uniform dispersion of particles and improved bonding between the reinforcement and matrix alloy which eventually enhances the hardness (Ali Mazahery, *et al.* 2011; Ramesh, *et al*. 2009; Kalaiselvan, *et al*. 2011).

The tensile strength of A356 alloy and composites are presented in Fig. 2.The tensile strength of the composites increases with the increase in the reinforced particulate content upto 7.5% weight fraction. Hence, the addition of quarry dust particles with A356 matrix alloy above 7.5 wt. % is not beneficial in the perspective of tensile strength. The results suggest that increased tensile strength may be attributed due to the thermal expansion values between matrix alloy and reinforcing particles induced residual stresses and increases dislocations density during rapid solidification in the composite fabrication process. This residual stress changes the effect of mechanical properties and micro structural characterization (Ali Mazahery, *et al*. 2011; Dinaharan, *et al*. 2011). The decrease in the tensile strength may be due to the increase in the closed pores and inter particle spacing in the matrix which initiated more cracks and reduced the load bearing capacity of composites reinforced with higher weight fraction of particles (Suresh, *et al*. 2003).

As the concentration of the particulates in the composites increases, they are not separated by the ductile aluminium alloy matrix. Therefore, cracks will not be arrested by ductile matrix and would get propagated easily. The compressive strength of the quarry dust particulate influences the reduction in the tensile strength of base matrix alloy in the higher weight fraction of quarry dust particulate filled on composites. The interfacial reactions due to the presence of oxides establish the weak bonds between matrix alloy and reinforcements of Al-quarry dust composites. The tensile strength decreased with addition of 10 wt. % of quarry dust reinforced composite due to develop stress concentration on sharp edge of the particles, these may increase the fracture (Rajesh *et al.*2011). Fig. 3 shows the elongation percentage of the Al-quarry dust composites. The % elongation of the AMCs decreases when increases the wt. % of particulates. It could be observed that the gradual reduction in ductility of the composites. Increasing the wt. % of quarry dust particulates in the composite resists the flow ability of aluminum matrix and thus, the reduction in the ductility.

Effect of Quarry Dust on the Wear Properties

Fig. 4 shows the micro wear curve of the specimens with 0, 5, and 7.5 weight percentage of quarry dust reinforced in A356 alloy. The wear test is carried out for constant normal load of 19.63 N, sliding speed of 1 m/s and sliding distance as 1500m. The wear has increased linearly with increasing time of all specimens. The wear of the composites decreases with the increase in weight fraction of quarry dust reinforcement with base matrix alloy. A356 specimen showed higher wear than AMCs. Many researchers also reported that the wear rate of the AMCs has decreased with increase the weight fraction of ceramic particulates reinforced with aluminum alloy.

This is because of the presence of hard reinforced particles which will increase the overall bulk hardness of the base matrix alloy. The variation of micro wear of 7.5 % weight fraction quarry dust reinforced AMCs with normal loads of 19.62, 29.43 and 39.24 N at a constant sliding speed of 1 m/s and sliding distance of 1500 m is shown in Fig. 5. The wear of 7.5 wt. % composites increases with increase in normal load. From Fig.5 non linear wear regime at initial stage is observed due to bottom surface of composite pin is not firmly contact with disc surface. After few seconds, steady state wear regime is significantly obtained in all AMCs specimens. It proved that the consistent wear transition at all normal loads. The reasons for reducing the wear at more weight fraction of composite in the initial stages are due to the quarry dust reinforced particles acting as load carrying elements and prevention of the plastic deformation and adhesion of matrix material against the normal load. It is reported (Manish, *et al.* 1992; Ramachandra *et al.* 2007) the later stages of wear regime, induced stresses higher than the fracture strength of the reinforced phase and therefore the base aluminum matrix is in direct contact with the steel disc counter face therefore produced large plastic strains resulted more wear in the matrix alloy. The worn hard QD particles get removed from their location in the matrix material and get assorted with the wear debris. The wear debris containing matrix material, worn particles from quarry dust and iron from the disc get mixed forming mechanically mixes layer (MML) and the MML act as load bearing elements (Venkataraman, *et al*. 2000).

Fig. 6 shows the variation of coefficient of friction with increased content of quarry dust particles at a normal load of 19.63 N for a sliding distance of 1500N. It is observed that coefficient of friction of composites decreases with increased content of quarry dust particles. The coefficient friction and frictional force of the contact surface are continuously monitored during the test. Composite with 7.5 wt.% quarry dust reinforcement in A356 shows minimum average coefficient of friction of 0.75 and base aluminum material exhibited an average coefficient of friction in the of 0.80. This trend in the variation of coefficient of friction may be due to good bonding, correlated with particle isolation can cause particle transferring from the matrix to the pin and disc interface. The particle acts as load bearing elements which can be attributed to improvement in anti frictional behavior of reinforced particle (Ramesh, *et al*. 2009).

Morphological Properties

Fig. 7a shows the optical micrograph of Al-quarry dust composite that ensures the uniform dispersion of quarry dust particle in A356 matrix alloy. The wear pattern of 7.5 wt. % composite indicates that the deep grooves and scratches on the sliding direction. Fig 7.b shows the image of wear specimen under an applied load of 39.24 N and a sliding velocity of 1.0 m/s. A moderate deformation layer can be seen on top surface region of the specimens. The closer to the surface of high load composite specimen shows the more plastic deformation of the surface region due to high shear strain. At the high load removal of deformation layer between surfaces leads to develop a micro cracking in subsurface and plugging the reinforcement from base matrix alloy. It has been observed that an increase in fracture of the reinforced particles due to longer testing time (Babic Miroslav, *et al*. 2010). The SEM micrograph of worn 7.5% quarry dust reinforced composite pin tested with high applied load of 39.24N and at sliding speed of 1.0 m/s is presented in Fig. 7c. It is noticed that increasing of applied load resulted in damage of contact surface which was not protected with surface damage. Fig. 8 shows the EDS analysis of the 7.5 wt. % composite worn surface after being wear tested. The small peaks in the profile indicated that the presence of irons, oxides and carbides at composite. The larger amount of iron content in the worn surface of composites might be further confirmation of a higher degree of sliding wear for 7.5 wt.%. It significantly enhances the wear resistance owing to the prevention contact between the surfaces.

CONCLUSION

Quarry dust reinforced A356 composites were successfully fabricated by using a modified bottom pouring stir casting setup. The mechanical properties of composites are more effective than that of the base alloy. There is a significant improvement in the

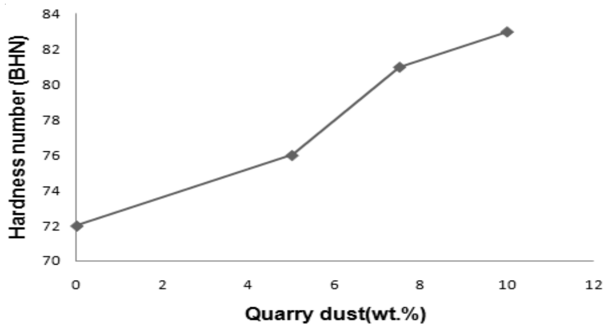

Fig. 1 Effect of quarry dust addition on the hardness

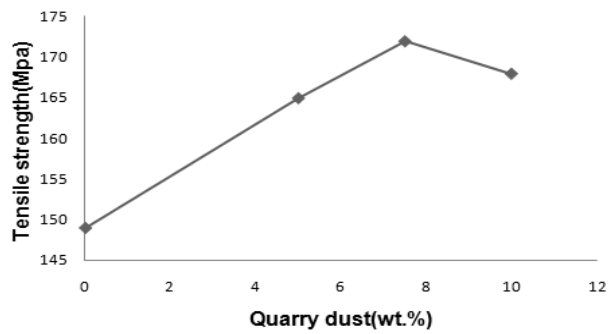

Fig. 2 Effect of quarry dust addition on the tensile strength

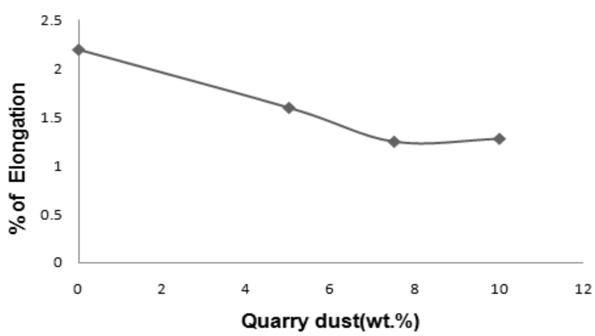

Fig. 3 Effect of quarry dust addition on the % of elongation

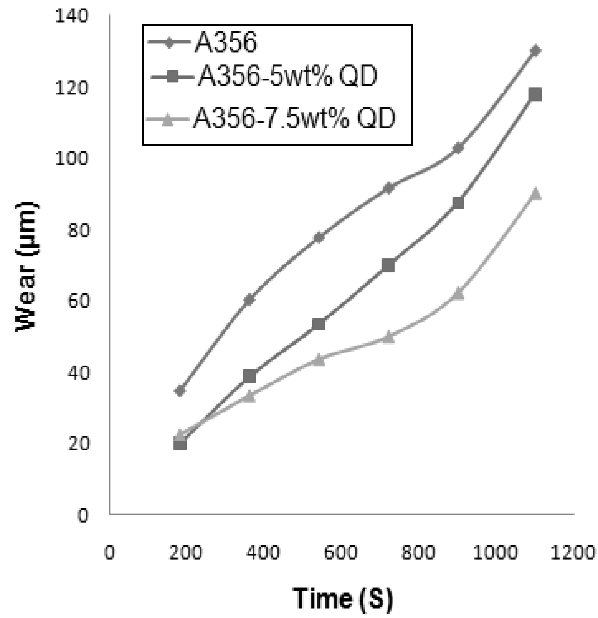

Fig. 4 Effect of quarry dust addition on the wear

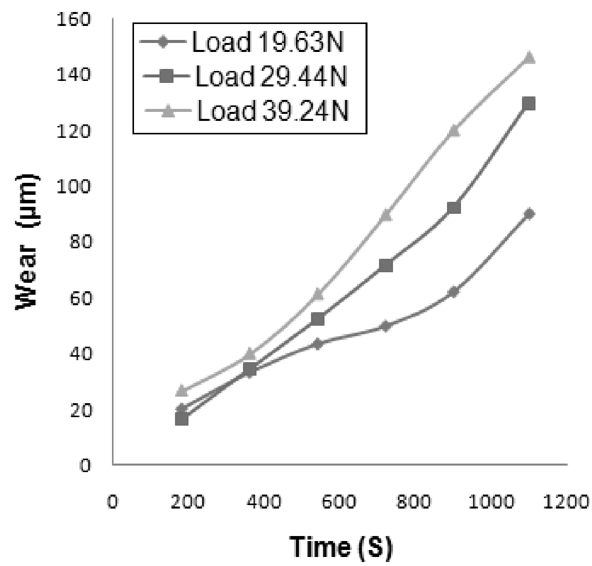

Fig. 5 Effect of load variation on the wear

tensile strength and the hardness with addition of quarry dust particulates. The tensile strength of matrix alloy and Al-quarry dust composites has enhanced from 150MPa to 172MPa. The tensile strength of 7.5% quarry dust composite is 15% greater than the monolithic alloy. From the tensile test results, the addition of quarry dust more than the 7.5 weight fraction into A356 alloy does not lead to an improvement of its tensile strength. The hardness of Al–QD composites showed a maximum hardness of 82 BHN at 10% QD reinforcement and it exhibits 13.7% improvement of hardness when compared to corresponding matrix alloy. The decrease in micro wear of 7.5% QD reinforced composite was 24.3% less than that of matrix alloy over the normal load of 19.63 N, sliding speed of 1 m/s and sliding distance as 1500m. Microstructure revealed that the uniform distribution can be obtained using preheated wrapped Al foil techniques. The cast metal is effective in wetting with particulates and better interface bonding with matrix alloy due to addition of magnesium.

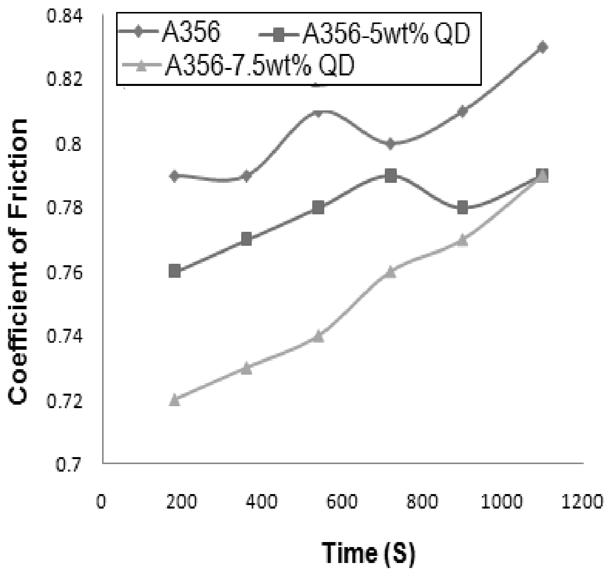

Fig. 6 Effect of QD addition on the coefficient of friction

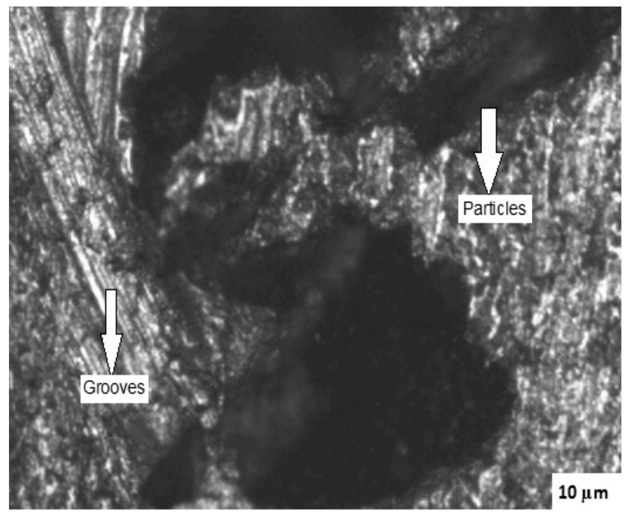

Fig. 7a Optical micrograph of AMC (7.5 wt. % QD)

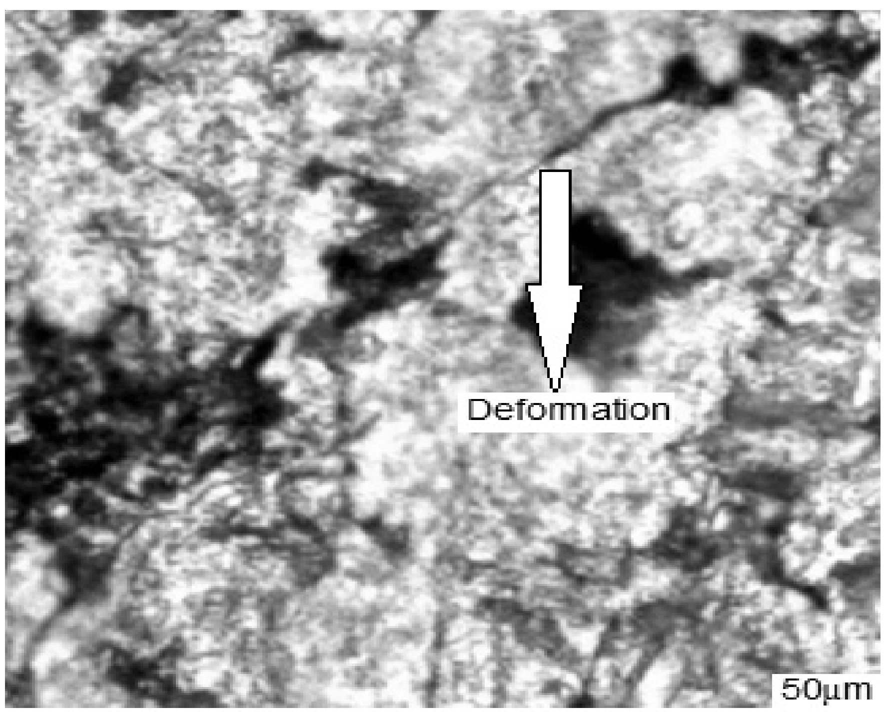

Fig. 7b Optical micrograph of wear test specimen (Load-39.24 N)

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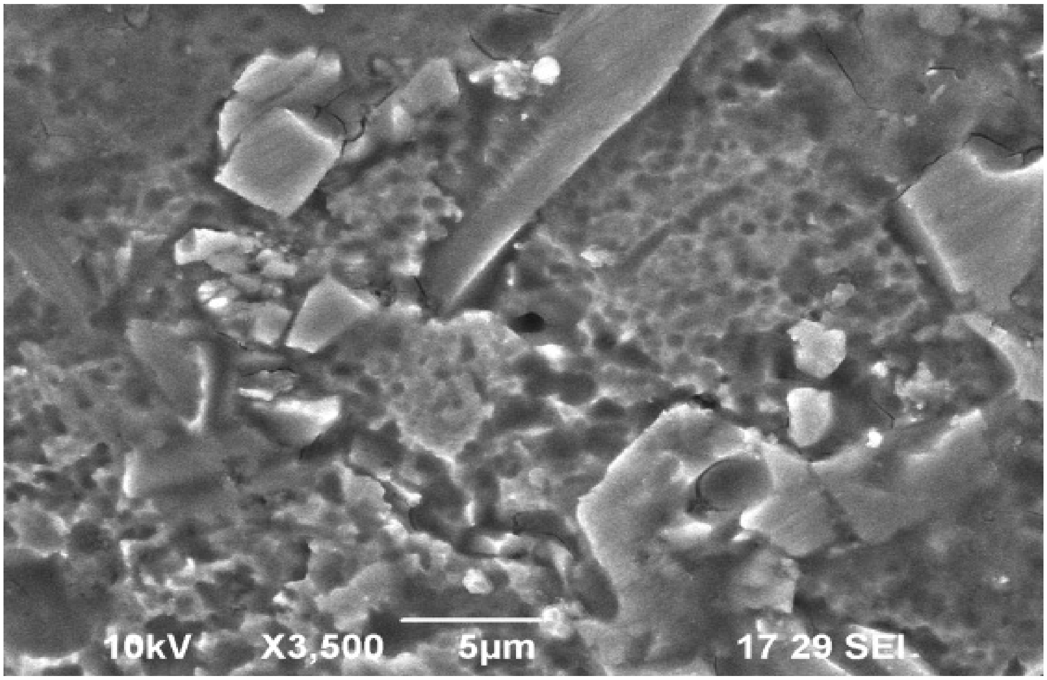

Fig. 7c SEM image of wear test specimen (Load- 39.24 N)

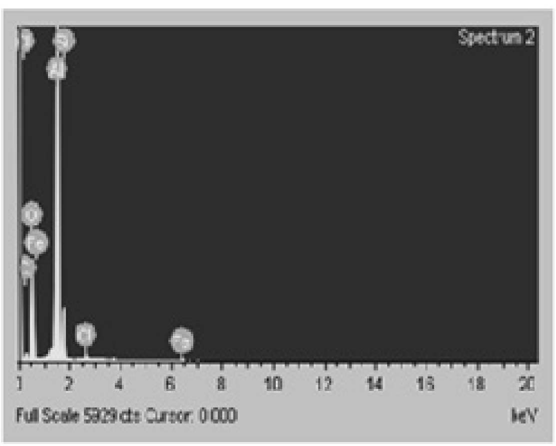

Fig. 8 EDAX analysis of AMC (7.5 wt. % QD)

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