International Journal of Emerging Science and Engineering (IJESE)
ISSN: 2319–6378, Volume-2, Issue-5, March 2014

The Effect of Electroless Cu Coating of SiC Particles on the Mechanical Properties of Al6061 based Cast Composite

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***Abstract*— Al6061 – SiC Composites with varying wt% of uncoated and copper coated SiC particles reinforced were prepared through stir casting technique. SiC particles were coated with copper by Electroless deposition method. The effect of PdCl2 concentration and time of stirring of the activated particles in electroless solution are reported. It is observed that density, hardness and Tensile strength increases with increase in wt% of SiC. It was also found that Copper coated SiC particles reinforced composite showed considerable improvement with respect to density, hardness and Tensile strength in compare to uncoated SiC composite due to improved wettability and better interfacial bonding. Fracture surface of tensile specimen was examined under SEM, which revealed a dimple formation, areas of brittle fracture, voids and fractured particles. Copper coating on SiC particles improved the ductility due to better interface bonding.**

***Index Terms*— Coated SiC, Electroless, Interface, Stir casting, Wettability.**

I. INTRODUCTION

Aluminium based discontinuously reinforced composite offer several advantages over conventional alloys. Metal matrix composites have become potential engineering materials for automotive, structural applications and aerospace because of their high specific strength, stiffness and wear resistance as compared to unreinforced alloys [1-3]. Ceramic particles like SiC and alumina are incorporated in to Al matrix to enhance the mechanical properties [4-5]. Properties of metal matrix composites strongly depend on the interfacial phenomenon between ceramic reinforcement and metal matrix [6-7]. Low interfacial properties and poor processability are due to low wetting behavior of SiC by molten Al. Interfacial degradation reaction occur when high processing temperatures are used in manufacture of composites which may lead to loss of particle and initiation of subsurface cracks at interfaces which is the reason for reducing the positive contribution of reinforcements to improve the strength of composites. A common solution to above problems is to apply specially designed coatings on reinforcement that improves the wetting and avoid the formation of degradable product at interfaces.

Manuscript received March 15, 2014.
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Metal coating such as Ni and Cu on reinforcements may promote wetting by reducing the surface tension of melt and changes the contact interface to metal- metal instead of metal – ceramic [8-9]. In the present investigation Electroless technique is used to coat copper on SiC particle surface. Uncoated and Cu coated SiC composites are prepared by stir casting technique. Mechanical properties of both uncoated and Cu coated SiC composites are determined.

II. EXPERIMENTAL PROCEDURE

A. Electroless copper coating on silicon carbide particles

Table 1. Steps in Electroless copper coating.

Step	process	Chemical	Concent ration	Time (min)
1	cleaning	Deionised water	-	10
2	Sensitization	$SnCl_2HCl$	20g/l 80ml/l	15
3	Rinse	Deionised water	-	10
4	Activation	$PdCl_2HCl$	1g/l 5ml/l	20
5	Rinse	Deionised water	-	10
6	Copper coating	See table 2		30

Table 2. Electroless copper solution.

Chemical	Concentration
Copper sulphat($CuSo_4.5H_2O$)	20g/l
Sodium hydroxide	20g/l
Potassium sodium tartrate	100g/l
Na_2EDTA	20g/l
Formaldehyde.	20ml/l

The Electroless copper coating on silicon carbide particles relies on sequence of cleaning, sensitising, activating and plating. The procedure and chemicals used are indicated in Tables 1and 2 respectively.

B. Processing

In present study, preparation of metal matrix composites was carried out by stir casting method. Al6061 alloy was melted and heated to desire super heating temperature of 800^0 C in crucible placed in a electrical resistance pit furnace fitted with a temperature controller. Super heated molten metal was degassed at a temperature of 780^0 C. A mechanical stirrer was used stir the melt at a certain rpm to create the necessary vortex. Copper coated SiC particles were added to molten metal. Stirring was stopped and taken out of crucible and the melt was poured in to permanent moulds.

C. Chemical analysis:

Amount of Copper coated on silicon carbide particles was estimated by dissolving the copper from SiC using nitric acid.

III. RESULTS AND DISCUSSION:

A. Effect of concentration of Palladium Chloride ($PdCl_2$).

The effect of $PdCl_2$ concentration on the weight percent of copper deposited is shown in fig 1. It can be seen that the change in weight percent of copper deposited on the surface of SiC particles with a change in $PdCl_2$ concentration from 0.25 to 1 **g l** $^{-1}$ of $PdCl_2$ is from 15 to 30.

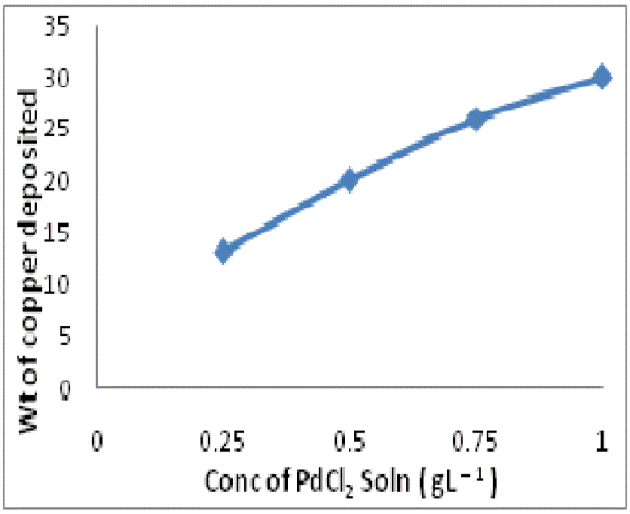

Fig.1 weight percent copper deposited as a function of concentration of $PdCl_2$ Solution

B. Effect of stirring time in electroless bath

Figure 2 shows that as the stirring time of SiC particles in the electroless bath increases, the percent of copper deposited on SiC particles also increases up to a stirring time of about 30 min. As the SiC particles activated by $PdCl_2$ are dispersed in the coating solution, the coating reaction starts. Palladium metal at the surface of SiC particles acts as a catalyst. After putting the activated SiC particles in the electroless bath, the bath should be stirred continuously to obtain a uniform coating on surface of SiC particles. The colour of electroless solution changes progressively as reaction progresses due to depletion of copper and for stirring time of 30 mins, 29 to 30 wt% of copper is deposited. After the stirring time of 30 mins there is no increase in copper deposited on SiC particles which is due to the precipitation of copper in the solution instead of further deposition of the copper on SiC surface.

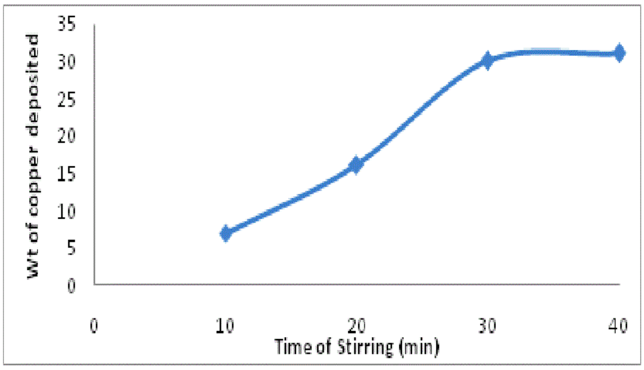

Fig.2 Weight percent copper deposited as a function of time of stirring in electroless bath

C. SEM analysis

SEM image of copper coated silicon carbide particles is shown in Fig.3.

The image clearly shows that the surface of angular silicon carbide particles is uniformly coated by copper.

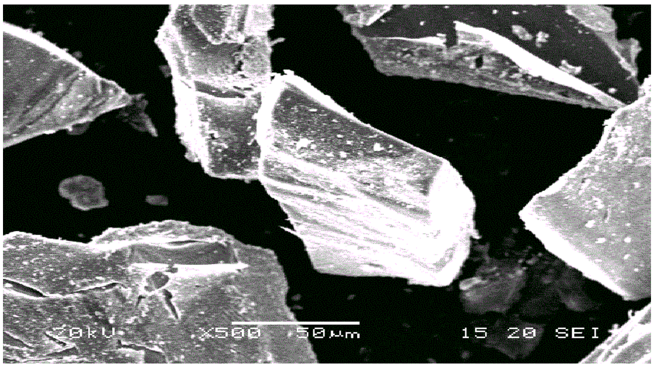

Fig.3 SEM image of Cu-coated SiC particles.

D. XRD/EDX analysis.

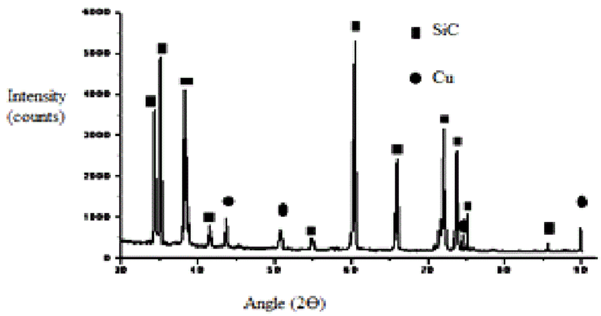

Fig 4. XRD of copper-coated silicon carbide particles.

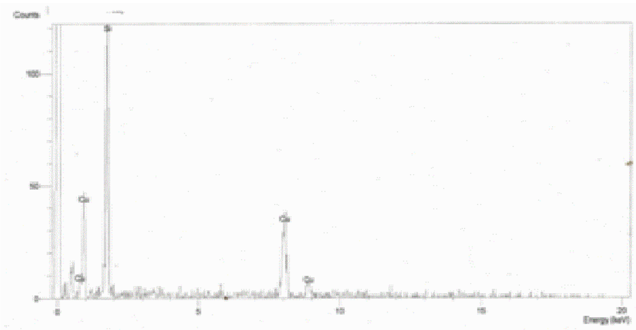

Fig **5.EDX of copper-coated silicon carbide particle**s.

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X-ray diffraction studies (Fig. 4) clearly indicate the presence of copper on SiC particle surface.. EDX analysis (Fig. 5) also confirms copper coating on SiC.

E. Microstructure

The microstructure of uncoated SiC based Al composites examined under optical microscope are shown in fig 6a – c. microstructure shows SiC particles distribution with random orientation throughout the matrix. Fig 7a – c shows the microstructure of Cu coated SiC based Al composites. It is observed that there is a uniform distribution of Cu coated SiC particles within matrix since Electroless Cu coating on SiC improves the interfacial bonding between SiC and matrix and there are no visible traces of any porosity and inclusions in the interfacial regions.

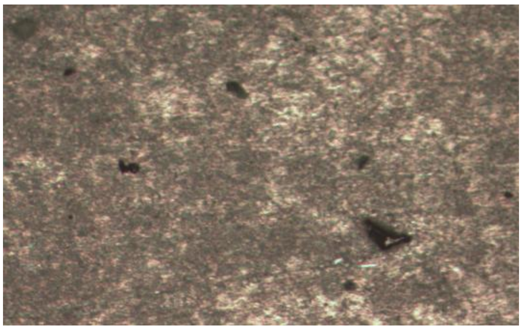
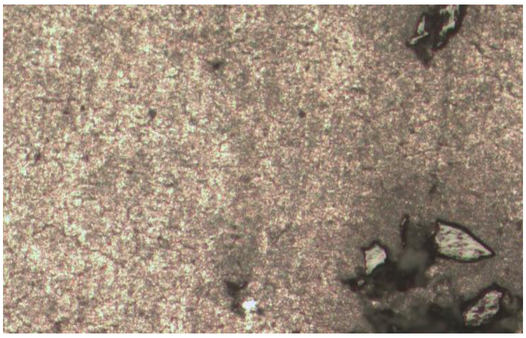


Fig. 6(a) Al6061-2% SiC



(b) Al6061- 4% SiC

(c) Al6061- 8% SiC

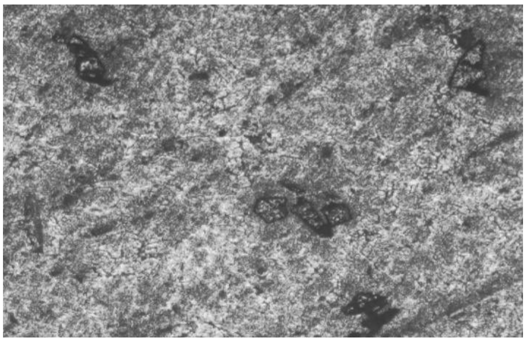
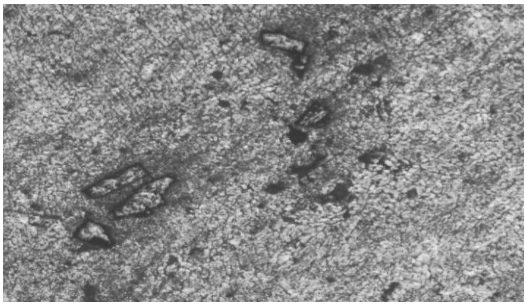
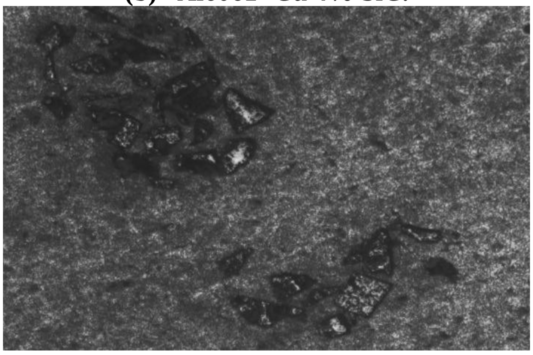


Fig. 7(a) Al6061- Cu 2% SiC



(b) Al6061- Cu 4% SiC.



(c) Al6061- Cu 8% SiC

F. Density & Porosity

Theoretical densities were calculated using Rule of mixtures. Experimental density of manufactured composites was determined by Archimedes principle. The composite samples were first weighed in air and then tied with string and weighed while hanging in water. The density was determined using the following formula:

$\rho_c = (ma \times \rho_w)/ (ma - mw)$

Where,

ρ_c = Density of specimen (Kg/ m3)

ρ_w = Density of water (Kg/m3)

ma = Weight of sample in air (kg)

mw = Weight of sample in water (kg).

The density was also measured by measuring the weight and volume of the specimens. The volume was determined by measuring the accurate dimensions of the specimen.

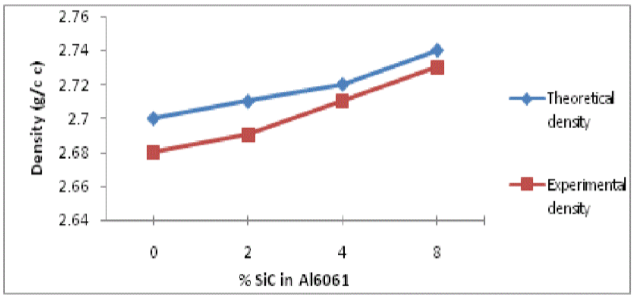


Fig.8 Theoretical & Experimental Density variation with wt% of SiC addition in Al6061 - SiC matrix composite.

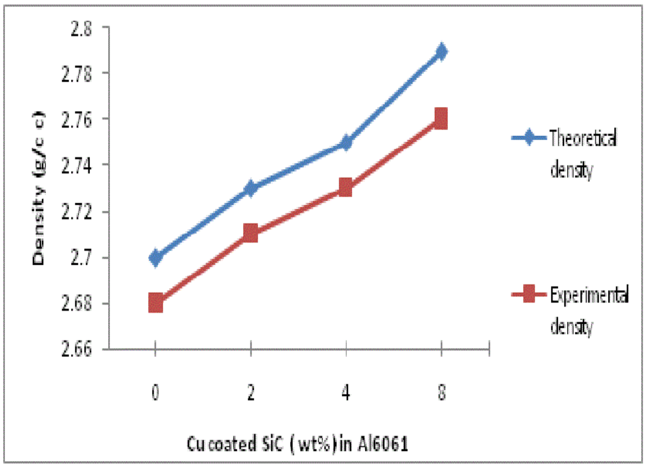


Fig. 9 Theoretical & Experimental Density variation with wt% of Cu - coated SiC addition in Al6061 - SiC matrix composite.

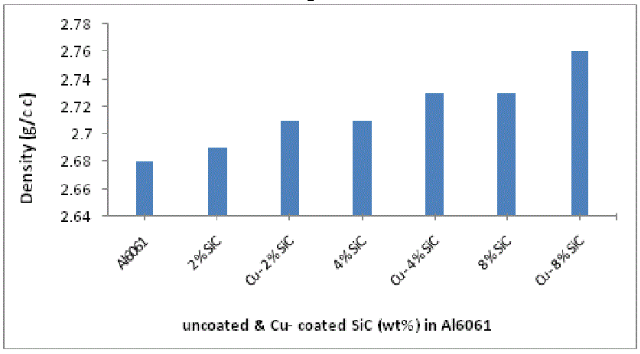


Fig.10 Experimental Density variation with wt% of Uncoated & Cu- coated SiC addition in Al6061 - SiC matrix composite

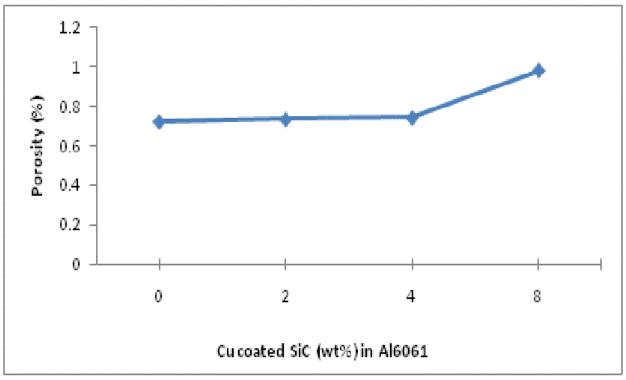


Fig. 11 Porosity variation with wt% of Cu- coated SiC addition in Al6061 - SiC matrix composite.

Figure 8 and 9 shows the theoretical and experimental densities of uncoated and Cu coated SiC composites. Figure 8 shows linear increase in the experimental densities, the values are lower than that of the theoretical densities (as expected from the rule of mixtures). The increase in density of composites may be due to the presence of SiC particles which enhances the density of base alloy because the SiC particles have higher density than the aluminum. Figure 10 shows the experimental density of uncoated and Cu coated SiC composites. It is revealed that density of Cu coated SiC composites increases than the uncoated SiC composites for the same reinforcement content because of the presence of copper on the surface of silicon carbide reinforcements will form Al-Cu liquid eutectic and its flow in to porous areas provide a strong ductile bond between reinforcement and matrix. Copper is one of few elements that have relatively high solubility in Al. D. Mandal *et al*. [10] in their work on Effect of wt% reinforcement on microstructure and mechanical properties of Al–2Mg base short steel fiber composites state that density of composites was higher compared to Al–2Mg matrix and also increases with increasing wt% of Cu coated steel fibers.

In spite of rigorous degassing of the melt, cast composites contain some amount of porosity. The porosity values are obtained from the theoretical density values calculated using the rule of mixtures. It is observed from fig.11 that % of porosity increases with increasing wt% of Cu coated SiC particles in Al6061-SiC matrix. Previous studies have also reported an increase in porosity with increase in wt% of particle addition [11]. During preparation of composites, incorporation of higher wt% of SiC particles required longer stirring time which also results in increased entrapment of gas.

G. Hardness

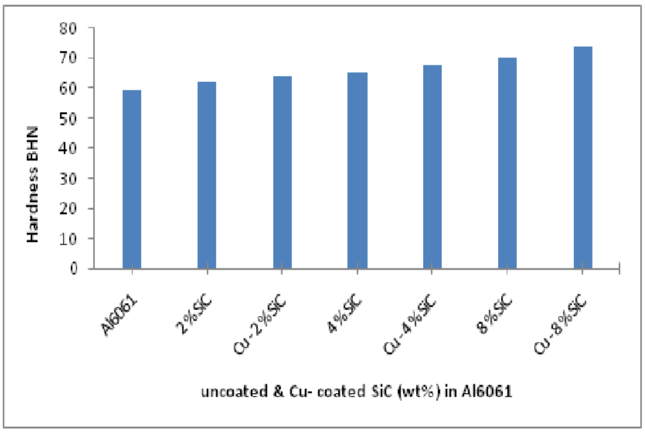


Fig. 12 Variation of hardness of uncoated and Cu coated SiC addition in Al6061 - SiC matrix composite

Hardness of Al6061-SiC base composite with uncoated and Cu coated SiC particles is shown in fig 12. It is observed that there is a significant improvement in hardness with addition of reinforcement. The hardness value is influenced by volume fraction of SiC. Maximum hardness was observed in case of Al606/Cu - 8% SiC composite. Diffusion of copper in to the matrix increases the hardness of composite. Copper is one of the few elements that have relatively high solubility in Al. thus the product Al(Cu) solid solution is mechanically tougher than pure Al matrix [12]. Dutta and Bourell *et al*. [13] found that microhardness of Al–SiC composites improved due to the presence of a higher dislocation density in the matrix. In case of copper-coated SiC, cleaner and improved interface bonding leads to a higher microhardness values. Rohatgi et al. [14] reported that Mg improves wettability and additionally there is a possibility of formation of MgO and MgAl2O4 at interface giving rise to greater hardening and strengthening in the composites.

H.Tensile Strength

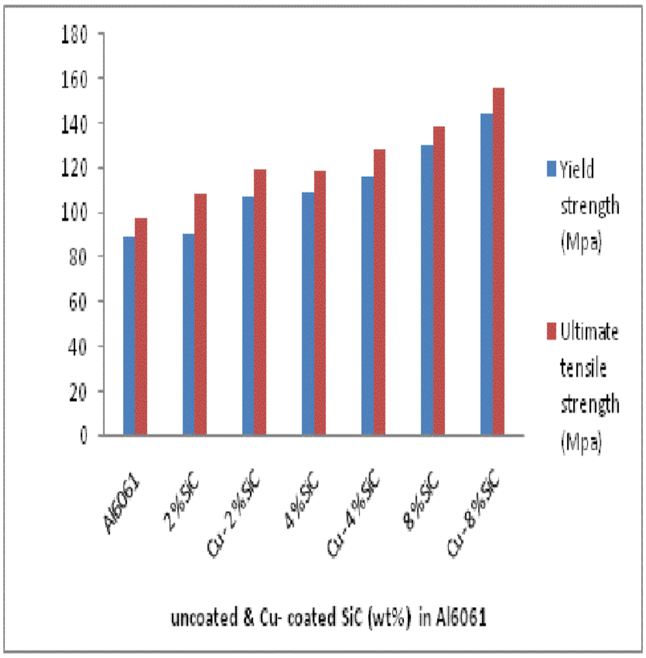


Fig. 13 Variation of ultimate tensile strength for uncoated and Cu coated SiC addition in Al6061 - SiC matrix composite

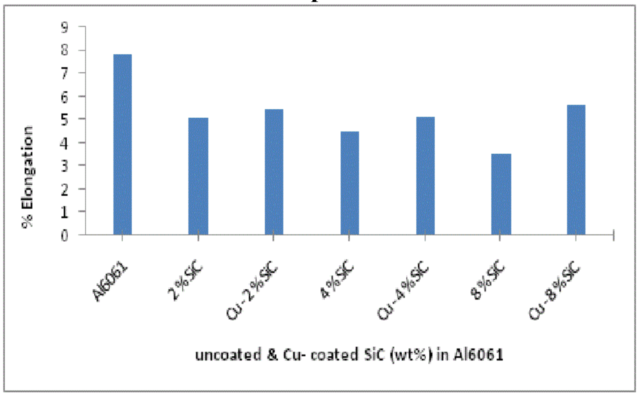


Fig. 14 Variation of % Elongation for uncoated and Cu coated SiC addition in Al6061 - SiC matrix composite

Tensile strength of composites is expected to increase with increasing wt % SiC particles. The yield strength of composites increases with increasing wt% of SiC because distance between the SiC particles decreases with increasing wt% of SiC. Composites strengthening can be achieved when there is good interface bonding between the matrix and SiC particles. It is observed for figure 13 that Copper coating on SiC particles improves the yield strength and ultimate tensile strength because it forms a good interface bonding between copper and aluminium and additional solid solution strengthening by dissolution of copper in Al matrix.

Ductility is indicated as % of elongation is lower for all the composites in comparison to the matrix and decreases with increasing wt% of SiC particles. Fig 14 shows that Ductility is enhanced for Cu coated SiC composites in compare to uncoated SiC composites because of the improved wetting behavior of SiC by molten aluminium and avoids the formation of degradation products at interfaces.

I. Fracture surface

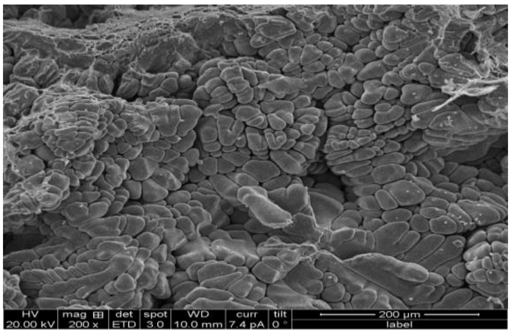
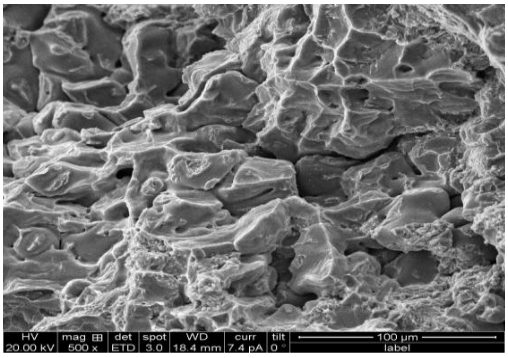
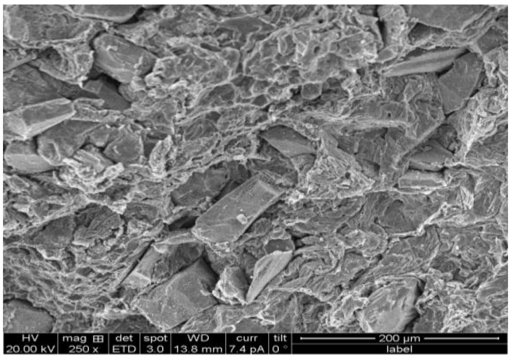


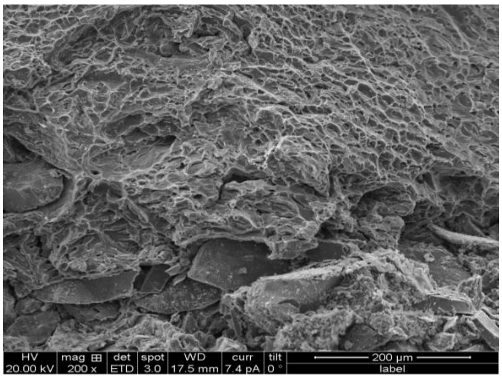
Fig. 15 (a) Al6061



(b) Al6061+ 2% SiC



(c) Al6061+ 4% SiC



(d) Al6061+ 8% SiC

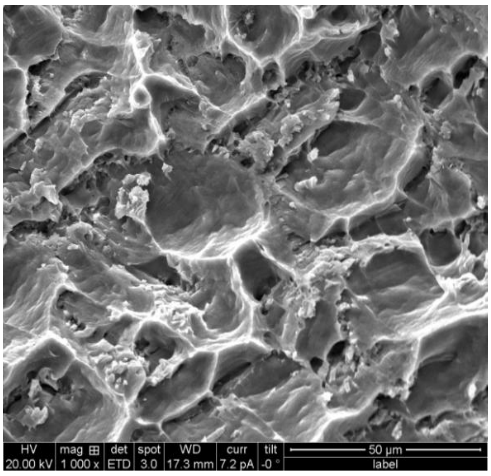
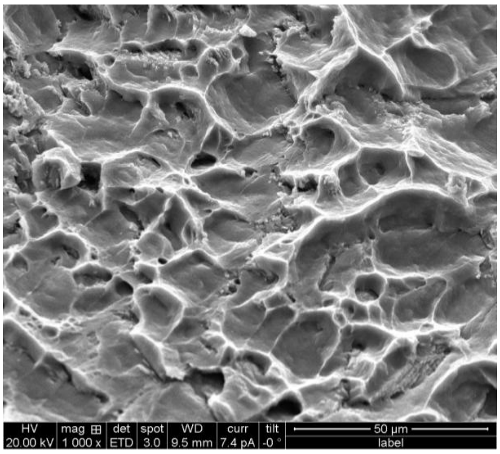
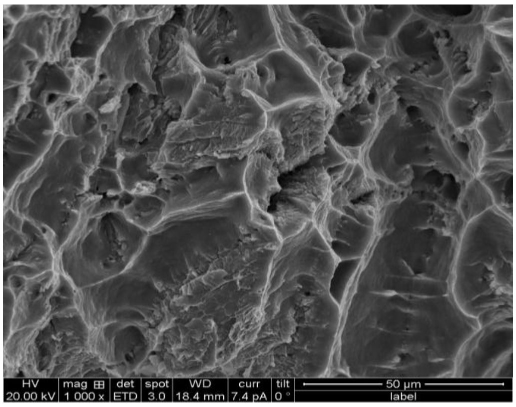


Fig. 16 (a) Al6061 + Cu-2% SiC



(b) Al6061 + Cu-4% SiC



(c) Al6061 + Cu-8% SiC

Fracture surface of Al6061-SiC based composite with varying wt% of uncoated and Cu coated SiC are shown in fig 15a-d & 16 a-c. It is observed that fracture mechanism of Cu coated SiC composites are mainly dominated by dimple formation indicating the ductile nature of fracture. In uncoated SiC composites cracks are initiated at SiC- matrix interface and propogate through the interface linking up with other cracks. In case of Cu coated 8wt% SiC composites, there is more dimple formation and there is no evidence of fractured particles indicating ductile nature of the fracture. In case of uncoated 8wt% SiC composite shows areas of brittle fracture, voids and fractured particles rather than dimple formation. Possibly because of larger interface area and higher level of porosity at the interface associated with increased particle content promoting crack initiation and propagation.

Baron et al. [15] have reported that steel preform reinforced composites show failure to occur within the interfacial intermetallic phase. Copper coating on SiC acted as barrier between SiC particle and matrix and also minimizes the formation of reaction phases. From the results of tensile test and from fractography it can be concluded that intermetalics at Al-SiC interface makes composite more brittle but copper coating on SiC particles form good interface which resist the crack propogation.

IV. CONCLUSIONS

1) After suitable sensitization and activation treatment, SiC particles were successfully coated with up to 29wt% to 30wt% copper using a copper sulphate solution of electroless plating.
2) A uniform distribution of Cu coated SiC particles are obtained in the matrices of Al6061 using vortex method.
3) There is a significant improvement in hardness, ultimate tensile strength and ductility when SiC particles were coated with copper using electroless technique.
4) Fracture mechanism of Cu coated SiC composites are mainly dominated by dimple formation indicating the ductile nature of fracture.

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