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CHARACTERIZATION OF SiC PARTICLE REINFORCED COPPER MATRIX COMPOSITE WITH COPPER WIRE STRUCTURE

Composites have become a very important class of materials in our everyday life. In the present work, the effect of a copper wireframe structure in SiC particle reinforced copper matrix composites on the compressive strength and other physical properties was analysed. SiC particle reinforced copper matrix composites with and without a copper wireframe structure were fabricated by the powder metallurgy method and sintering was performed at 700°C in atmospheric condition. The copper wire used for making the wireframe structure has diameters of 0.2 and 0.3 mm. A scanning electron microscope (SEM) with magnification of 500X was used to characterize the sintered composites. In addition, hardness tests were performed on a Vickers hardness testing machine and compression testing was carried on a UTM machine. It was observed that the formation of Cu reinforced with 5-7 wt.% SiC and 0.1-0.2 wt.% copper wireframe structure composites was successful. It can be concluded that the hardness of the Cu-SiC composite rises with the increase in the wt.% of reinforcement, while the copper wireframe structure in the composite had a negligible effect on the hardness. However, the addition of the copper wireframe structure resulted in increased compressive strength.

Keywords: **metal matrix composite, copper wireframe structure, SEM, hardness, compressive strength**

INTRODUCTION

Copper has high thermal and electrical conductivity, superior resistance to oxidation and corrosion, a high melting point, and high formability; therefore, it can be widely used in various engineering applications [1-4]. Although silver has the highest electrical conductivity of all metals, due to its higher cost copper and aluminium are mostly used in a wide variety of applications. Between copper and aluminium, copper has higher conductivity and strength [5]. Metal matrix composites (MMCs) have a higher value of abrasion resistance, specific stiffness, dimensional stability, specific strength, thermal conductivity, and creep resistance as compared to their base metal and can be used in engineering applications at higher temperatures [6]. To increase the strength of the copper matrix, silicon carbide (SiC) particles can be used as a reinforcement material [7].

Cu-SiC composites have very high potential in high temperature engineering applications and other applications where good thermal and electrical conductivity are required, like electrical contact materials in relays, contactors, switches, circuit breakers, and electronic packaging [7, 8]. From the extensive literature review, it was observed that most of the work in the field of copper based silicon carbide MMCs has focused on varying parameters like the weight percentage of SiC particles in the copper matrix, sintering temperature, compacting pressure, particle size of the reinforcement and the manufacturing process. Celebi Efe et al. [9] observed that the hardness, relative density and electrical conductivity of Cu-SiC composites grows with an increase in the particle size of the SiC added to the composite. This may attribute to the improved bond between the matrix and the reinforcement [10]. Prosviryako [11] pointed out that the hardness of Cu-SiC composites rises with the increase in SiC particle reinforcement content but only up to 25 wt.%, after that its hardness starts to decrease. The author explains that this behaviour is due to an intense reduction in the microstructural homogeneity and increased porosity of the sintered specimens. The properties of MMCs are also influenced by the sintering temperature, which should be in the temperature range between 70-90% of the melting point of the lower melting point constituent in the MMC [12].

MMCs are mainly fabricated by two methods, i.e. by liquid metal processing and the powder metallurgy method. Liquid metal processing offers a lower cost but has many drawbacks like non-uniform distribution of the ceramic particles or fibers due to agglomeration and dendritic segregation, as well as undesirable chemical reactions at the interface due to the high temperature of the melt. These drawbacks can be minimized by using the powder metallurgy method. However, due to the presence of a significant amount of residual porosity caused by poor wetting of the SiC and Al_2O_3 particles by the metal matrix, relatively poor physical and mechanical properties were observed [13]. The choice of a particular method for fabrication depends upon the property requirements and future applications [14]. Moreover, the difference in properties is not so significant and the producer selects the method of fabrication according to his/her requirement. Moustafa et al. [13] applied a nickel coating on SiC and Al_2O_3 reinforcement particles and observed a higher relative density and lower porosity content compared to the composites with the uncoated reinforcement due to the good adhesion between the reinforcement and the Cu matrix. Madesh et al. [15] considered copper metal matrix materials with 70 wt.% copper powder, 15 wt.% tungsten carbide and 15 wt.% groundnut shell ash in their study and observed enhanced hardness with a diminished corrosion rate. Kargul and Konieczny [16] reinforced a copper metal matrix with carbon steel and T15 HSS steel particles and observed a rise in the abrasion resistance of the composites.

In the present work, the metal matrix composite microstructure and mechanical properties were improved by adding reinforcement materials. The fabrication of the metal matrix composite was done by the powder metallurgy method where copper was taken as the matrix material and silicon carbide was the reinforcement material. There was also an addition of a copper wireframe structure to the MMC to ascertain its influence on the various properties of the metal matrix composite.

FABRICATION OF METAL MATRIX COMPOSITE (MMC)

Copper powder having a grain size of 10 μm was taken as the matrix material while SiC powder of 10 μm grain size was selected as the reinforcement material. Both the copper powder and SiC powder were purchased from Shubhmets Chemicals, Metals and Pharmaceuticals, Mumbai, India. Copper wire 0.2 and 0.3 mm in diameter was also used to make the copper wireframe structure. As the MMC is fabricated by the powder metallurgy method, the following procedures were chosen:

a) Cu-SiC powder mixture preparation

Firstly, the copper powder and SiC powder were used in the required proportions by weight and then mixed homogenously. Mechanical mixing was performed in the presence of toluene using a planetary ball milling machine (PM 100 – RETSCH). Tungsten carbide balls having a diameter of 10 mm (powder to ball ratio 1:10) were used as the milling medium and the machine was operated at 200 rpm for one hour. In this process, Polyvinyl chloride was also added to the powder to assist in bonding of the powder particles during the sintering operation. The powder mixture with polyvinyl chloride as the binder is depicted in Figure 1a.

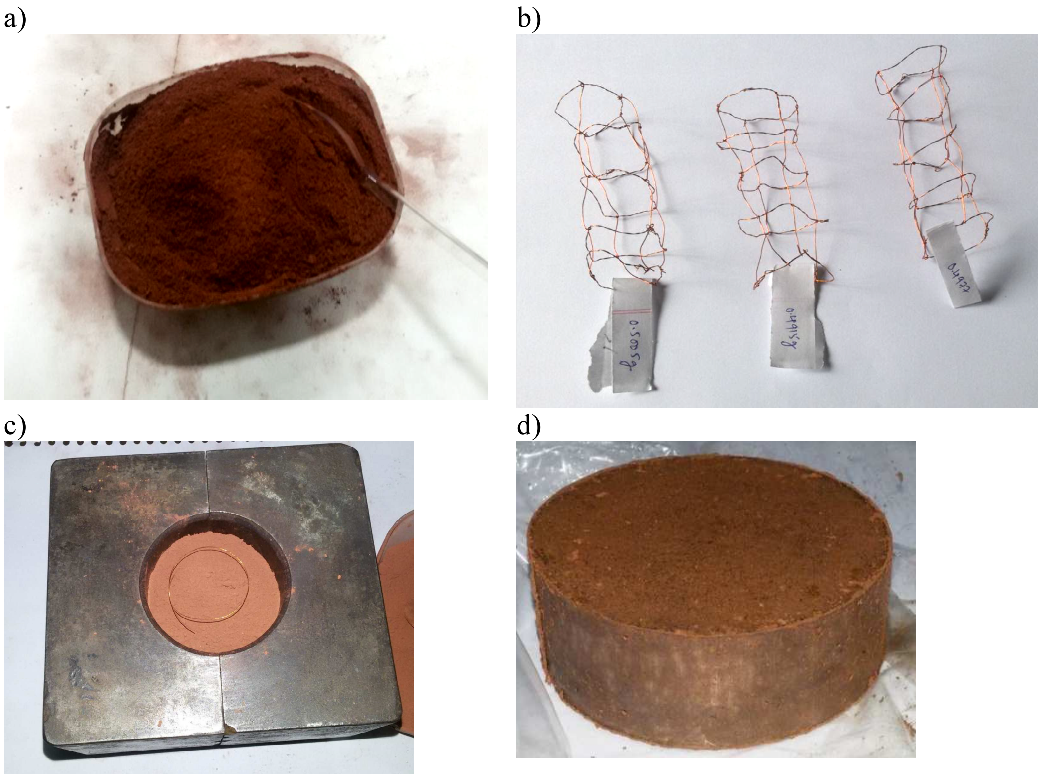


Fig. 1. Copper powder and SiC particle mixture with binder (a), copper wireframe structure (b), prepared mixture with wireframe structure in die before cold compaction (c), sample after sintering (d)

b) Preparation of wireframe structure

The wireframe structure was fabricated with copper wire of different dimensions in the required percentage (by weight). Copper wire 0.2 and 0.3 mm in diameter was used to make the wireframe structure. The 0.2 mm wire was chosen for radial part, while the 0.3 mm wire was for longitudinal part. The fabricated wireframe structure is shown in Figure 1b.

c) Cold compaction of the mixture

A universal testing machine (UTM) was utilized for cold compaction (forging) of the composite material. The prepared powder mixture was poured into a stainless steel die 52 mm in diameter, and subsequently the wireframe structure was also placed inside powder volume. Afterwards, the powder was compacted with a load of 250 kN (118 MPa). The powder mixture in the die and the position of the wireframe structure before cold compaction is shown in Figure 1c.

d) Sintering

After cold compaction, the mixture was put in an air-tight vessel and kept in sunlight for more than 2 hours. This was done to remove any moisture content from the compact as the presence of moisture may result in the formation of oxides during the sintering procedure. Afterwards, the composite material was sintered in muffle furnace at 700°C for 2 hours. The sintering process was performed with the composite material embedded in graphite powder to prevent any oxidation. The final product after the sintering process is shown in Figure 1d.

TESTING OF PROPERTIES

In the present work, the investigated metal matrix composites were based on pure copper reinforced with 5 and 7 wt.% SiC particles and a 0.1 and 0.2 wt.% copper wireframe structure. A total of six samples was fabricated and they are presented in Table 1 with their constituent elements. Each sample was used to determine the various properties.

TABLE 1. **Specifications of composite samples**

Sample	Copper powder [wt.%]	SiC [wt.%]	Copper wire [wt.%]
A	94.9	5	0.1
B	94.8	5	0.2
C	92.9	7	0.1
D	92.8	7	0.2
E	95	5	-
F	93	7	-

The microstructure analysis of each sample was done by a ZEISS EVO MA 15 scanning electron microscope (SEM). The SEM micrographs were made at the magnification of 500X. The hardness test was performed on a Vickers hardness testing machine with a load of 100 kgf. The compression test was conducted at the strain rate of 0.05 mm/min on a UTM machine. The standard used for the compression test is ASTM E9 [17]. According to this standard, the L/D ratio for the compression test specimen is taken as 0.8. Table 1 shows the specifications of the composite samples prepared by the powder metallurgy (PM) route.

RESULTS AND DISCUSSION

The results obtained from the property measurements were compared and analysed.

Microstructure

SEM micrographs of the Cu-SiC composites with and without the wireframe structure are shown in Figure 2a to Figure 2f. It was observed from the SEM micrographs that the Cu-SiC composites with and without the wireframe structure have a dense and homogenous structure. Moreover, the SiC particles are uniformly distributed around the copper particles. Additionally, the copper wireframe structure is not very visible due to the very low content of the copper wireframe structure (0.1-0.2%). In the following SEM micrographs, Circle 1 depicts oxides in the composite, which were formed at the time of sintering due to porosity present in the composite. Circle 2 indicates the defused SiC particles present in the composite. They were formed due to the combined effect of compression and sintering. Circle 3 in the micrographs in Figure 2c, d and f shows some amount of porosity in the composite. The effects indicated above result in decreases in the hardness as well as the compressive strength of the composite.

Hardness

The hardness range for the different composites is tabulated in Table 2. It is observed that the composite containing 5 wt.% SiC particles has hardness ranging from 125.97 to 132.88 HV for both composites (with and without the wireframe structure). For the composite having 7 wt.% SiC particles the hardness varies from 148.5 to 157.36 HV for both composites. It is interesting to note that the addition of the copper wireframe structure to the composite has a negligible effect on the hardness of the composite. This may be attributed to the very low percentage of copper wireframe structure in the composite. The copper wireframe structure has a significant effect on the compressive strength of the composite but has a negligible influence on surface properties like hardness. The hardness of the composite mainly depends on the SiC weight percentage in the composite. With an increase in SiC content, the hardness of composite also increases. This may be attributed to the harder strength of the SiC particles than compared to the copper particles.

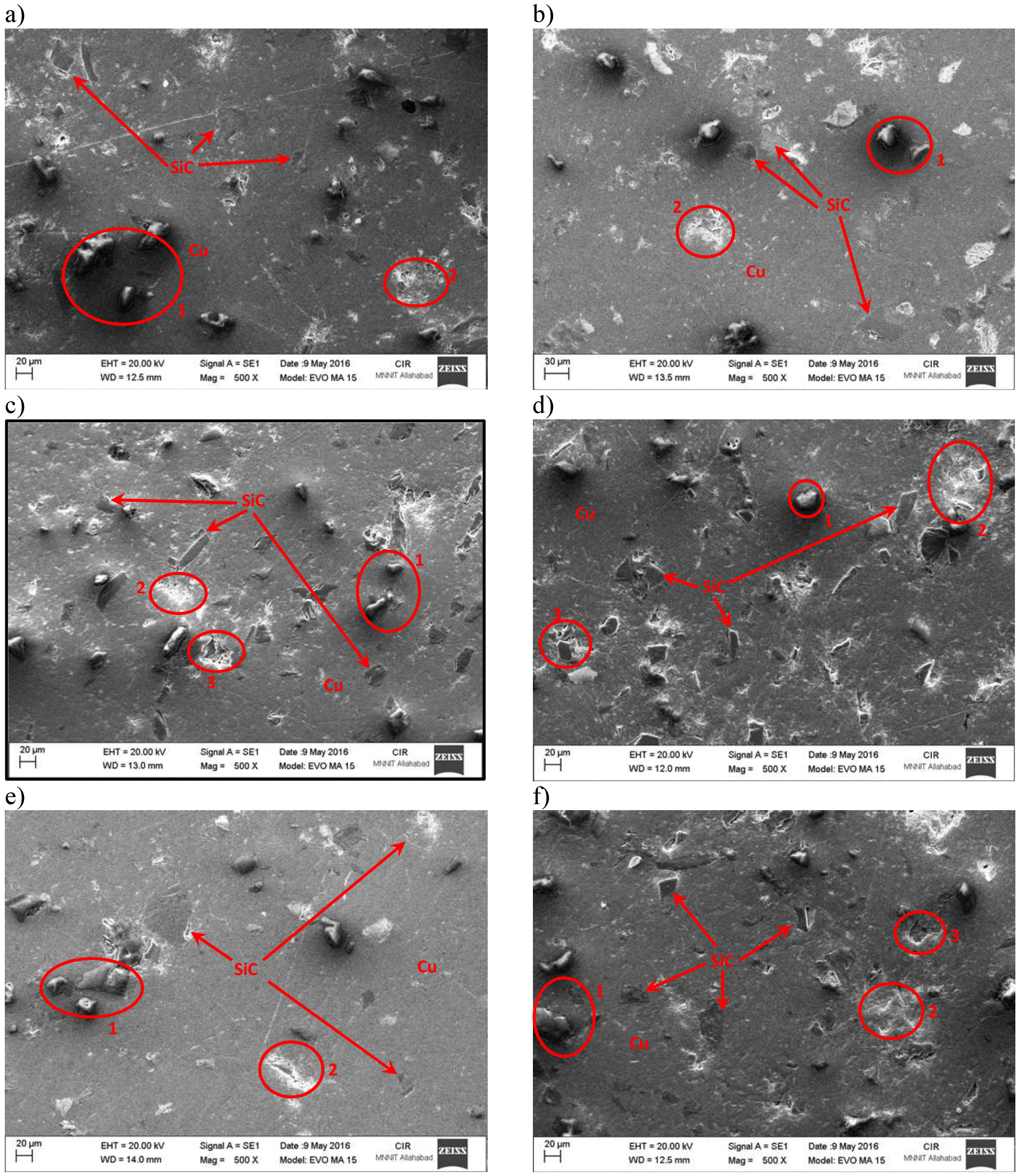


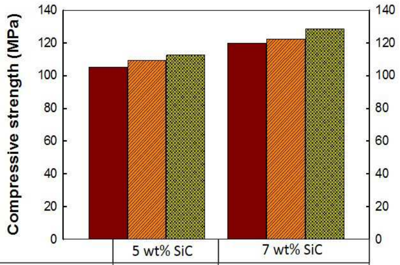
Fig. 2. SEM micrographs of (a) Cu-94.9 wt.%, SiC-5 wt.% and Cu wireframe structure 0.1 wt.% (b) Cu-94.8 wt.%, SiC-5 wt.% and Cu wireframe structure 0.2 wt.% (c) Cu-92.9 wt.%, SiC-7 wt.% and Cu wireframe structure 0.1 wt.% (d) Cu-92.8 wt.%, SiC-7 wt.% and Cu wireframe structure 0.2 wt.% (e) Cu-95 wt.% and SiC-5 wt.%. (f) Cu-93 wt.% and SiC-7 wt.%

TABLE 2. **Hardness range of composites with different compositions**

S. No.	Cu [wt.%]	SiC [wt.%]	Cu wireframe structure [wt.%]	Hardness range [HV]
1	94.9	5	0.1	125.97 to 132.88
2	94.8	5	0.2	
3	95	5	-	
4	92.9	7	0.1	148.5 to 157.36
5	92.8	7	0.2	
6	93	7	-	

Compression test

The compression test results of the copper based SiC reinforced metal matrix composite with and without the copper wireframe structure are given in Figure 3. The compression test results of all the Cu-SiC composites are in good agreement with literature [13]. It is clear from Figure 3 that with the addition of the copper wireframe structure, there is an increase in the compressive strength of the composite. This may be due to the increased bonding strength of the composite owing to the copper wireframe structure. Figure 4 shows the stress strain curve of the composites with different compositions. The curve shows the energy absorbed by the composite up to the fracture point.



	5 wt% SiC	7 wt% SiC
Without Cu wireframe structure	105.29	119.9
With 0.1 wt% Cu wireframe structure	109.17	122.45
With 0.2 wt% Cu wireframe structure	112.55	128.71

Fig. 3. Comparison of compressive strength [MPa] of composites with different compositions

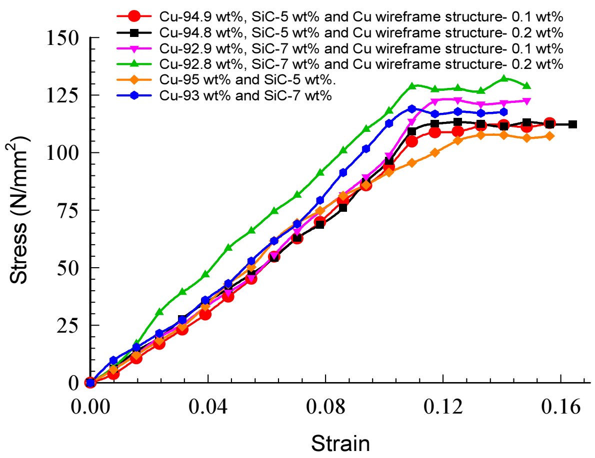


Fig. 4. Stress-strain curve of composites with different composition

Future work that can be done in this area is that the wt.% of SiC and copper wireframe structure in the Cu-SiC composite can be increased. Furthermore, some more physical properties of the composite like relative density, electrical conductivity etc. can also be investigated. This work can also be preceded by variation in other parameters like the grain size of the reinforcement particles, compression pressure, sintering temperature etc.

CONCLUSIONS

In the present work, the effect of the SiC content and copper wireframe structure weight percentage on the physical properties of a copper metal matrix composite was examined. In order to achieve that aim, six different samples were fabricated by the powder metallurgy method and different properties of the sinters were investigated. Copper matrix composites having 5 wt.% and 7 wt.% SiC, without a wireframe structure and with 0.1 wt.% and 0.2 wt.% copper wireframe structures were fabricated. The following conclusions can be drawn from the present work:

1. SEM studies of the composites reveal that the SiC particles were homogeneously distributed and dominantly located around the copper grains. The main components of the Cu-SiC composites were copper powder, SiC powder, the copper wire structure; in addition a small amount of oxide and porosity were found in the composite.
2. The hardness of the Cu-SiC composite increases with the increase in the wt.% of the reinforcement and the addition of the copper wireframe structure to the composite has a negligible effect on the hardness of the composite. The reason behind is that the copper wireframe structure is inside the composite material and not on the surface of the composite. Thus, it affects the compressive strength of the composite and does not have so much of an effect on surface properties like hardness.
3. The compression test shows that the compressive strength of the material increases with the addition of the copper wireframe structure in the Cu-SiC composite.

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