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Experimental Investigation of Alumina Reinforced Copper Metal Matrix Composite by Stir Casting Method

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ABSTRACT:

In the present study, alumina reinforced copper metal matrix composites were prepared by stir casting method. Three different specimens were prepared by changing the weight ratio of alumina to copper. The samples were prepared by adding 10%, 20% and 30% alumina to copper matrix. The three specimens were subjected to mechanical, thermal and corrosion testing, in order to find out the properties of the material. Various mechanical tests like hardness, impact and corrosion were performed including thermal conductivity to understand the behaviour of the specimens under combined loads. Specimen number 2 which was 80%-20% copper to alumina was found to be the best combination for such type of applications.

KEYWORDS:

Alumina; Metal matrix composite; Stir casting; Wear test

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1. Introduction

Lightweight metal matrix composites are prepared using stir casting method and a total of three samples are tested to check the suitability of the composition for particular properties. This study investigates the influence of alumina particles in the matrix of copper [1].The composite material is prepared by stir casting technology. In stir casting, both the matrix and the reinforcement are heated separately as they have different melting points. On attaining critical temperature, they are mixed together in a single holding unit by a stirrer rotating at 250rpm. After the mixture is turned thoroughly, the homogeneous mixture thus formed is poured to pre-formed mould in batches of required weights. Melt stirring process is used mainly for stirring particles in a light alloy melt only. The formation of agglomerates in the particles which are not a desired characteristic in MMCs can only be dissolved by intensely stirring the mixture. The presence of more amount of porosity in MMCs is not desired, thus incorporation of gases is avoided [2].

During the dispersion of reinforcement components, adequate attention should be paid in order to balance the reaction rate of the components with the temperature of the melt along with the duration of the stirring process. The dispersion phase is of great importance as the unwanted reaction of reinforcement component with the melt can lead to the dissolution of reinforcements [3-4]. The reaction rate is usually less critical with stirred particle reinforcements than with fibres because of the presence of lower surface to volume ratio of spherical particles. Materials that contain ceramic particles are characterised to have three times the wear resistance that than of the unreinforced Cu matrix [5]. The co-efficient of friction decreases with the increase in particle content of the copper based composite material. High volume fraction of Al_2O_3 particles in the composite material results in more intense grooves formation than the counter specimen material. Al_2O_3 nano-particles has pinning effects which results from dislocations that can further lead to the suppression of cross slip, thereby increasing the hardness of the composite [6].

The bending strength of the composites is found to increase with high ceramic fraction. Failure of composite occurred by ductile fracture of the metal followed by fracture of ceramic. The wear rates of composites were greatly lowered as compared to that of pure copper and decreased with increase in ceramic fractions [7]. Fine alumina particle distributes homogeneously within the matrix. Phase transition among these alumina particles occurs only above a particular temperature [8-9]. Due to the existence of alumina particles, the effect of strengthening is rather dramatic as compared with the pure copper. The strength of unreinforced copper decreased at elevated temperature. Reinforcing with fibres significantly inhibits this drop and improves the bending strength at high temperatures [10].

2. Experimental procedure

2.1. Processing

Preparation of the samples is done by stir casting method. In this method the matrix and the reinforcement are pre-heated and added to a container. A stirrer is used to stir the mixture at a certain speed. In our experiment, the alumina is heated to 150°C and added to molten copper. The stirrer is rotated at 250 rpm for 15 minutes at 1500°C [11-12]. This method was chosen in particular as we can obtain a homogeneous mixture and attain a uniform distribution of alumina particles over copper. Fig. 1 shows the flow chart for the preparation of copper-based metal matrix composite. Alumina nano particle with grain size of 200µm was selected as reinforcement. Using this method comes with an advantage of attaining long range order. All the three samples were prepared the same way and put to various listed tests [13].

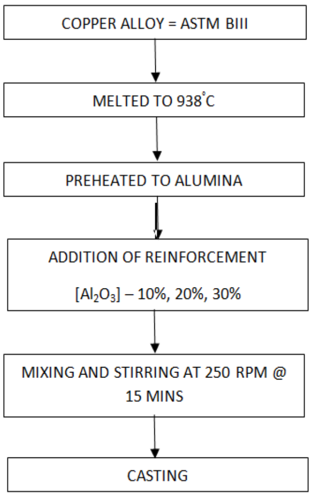

Fig. 1: Flow diagram for the preparation of copper-based metal matrix composite

2.2. *Hardness testing*

The Rockwell hardness testing machine in Fig. 2, is used for measuring the hardness of the material. Three specimens were tested with three different spots identified in each specimen. The results are shown in Table 1. 15% decrease in hardness was observed as the percentage of Al_2O_3 increased from 10% to 30% by weight. Hardness is measured as the resistance of the material to plastic deformation usually by indentation. Alumina particles have high strength values. When the alumina is introduced into the matrix of copper, they influence the mixture with their strength. As the percentage of alumina increases in the composite, an increasing trend of strength is observed.

Fig. 2: Rockwell hardness testing machine

Table 1: Result obtained from hardness test

Specimen	Trial-1	Trial-2	Trial-3	Mean
90%Cu-10%Al_2O_3	144.5	140.8	141.4	142.2
80%Cu-20%Al_2O_3	155.8	155.5	156.2	155.8
70%Cu-30%Al_2O_3	167.8	167.2	167.6	168.0

2.3. *Impact testing*

Fig. 3 shows the impact testing machine along with the specimen after testing. The impact test is conducted using Charpy Impact test. Table 2 shows the results obtained by the test. Cu-Al_2O_3 composite shows a decrease in toughness by about 44.46% as the content of Al_2O_3 is increased from 10% to 30% by weight. Toughness is measured as the resistance of a material to withstand a suddenly applied load. Copper provides the required toughness necessary to prevent sudden failure to the material when it undergoes catastrophic loads.

Fig. 3: Impact testing machine &specimen

Table 2: Result obtained from impact test

Specimen	Trial-1	Trial-2	Trial-3	Mean
90% Cu-10%Al_2O_3	26	34	30	30
80% Cu-20%Al_2O_3	20	18	20	19.33
70% Cu-30%Al_2O_3	16	18	16	16.66

2.4. *Corrosion test*

Fig. 4 shows the specimen image of after corrosion test. Corrosion is a gradual destruction of materials by chemical reaction with its environment. Salt spray test was done on the three specimens to test their resistance to corrosion. It consists of atomizing salt solution into uniform droplets on specimens suspended between 15°-30° from the vertical. A 5% NaCl solution was used and the exposure chamber was maintained at 35°C. At this stage, the pH of the salt solution was in the range of 6.5-7.2. A chamber consisting of a nozzle of 430 litres volume was used as per international standards This chamber maintains the temperature at a given value and sprays the neutral salt solution over the specimen hung inside at a certain vertical angle for 24 hrs. Table 3 indicates the result after 24 hours of the salt spray test. The 90% and 80% Cu specimens did not show any discoloration or rusting over the surface of the specimen while in the 70% Cu sample, discoloration was noticed after 12 hrs.

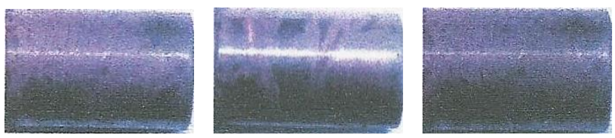

Fig. 4: Specimens after corrosion test - Left (1), Mid (2), Right (3)

Table 3: Result obtained from corrosion test

Specimen	Weight loss (%)	Abrasion loss (%)
90% Cu-10% Al_2O_3	0.04	0.95
80% Cu-20% Al_2O_3	0.06	1.02
70% Cu-30% Al_2O_3	0.07	1.18

2.5. Thermal conductivity

Thermal conductivity refers to the amount of heat transmitted through a material. Heat transfer occurs at different rates across the materials depending on their thermal conductivities. Thus, the composite material should have higher thermal conductivity to be used in the automobile application. Such as piston rings, the values obtained from the thermal conductivity test are shown in Table 4. It shows the increase in the thermal conductivity by 43.91% as the amount of Al_2O_3 is increased in the composite from 10% to 30%.

Table 4: Result obtained from thermal conductivity test

Sample	Thermal Conductivity (%)
Cu 90% + Al_2O_3 10%	15.2
Cu 80% + Al_2O_3 20%	21.5
Cu 70% + Al_2O_3 30%	27.1

2.6. Wear test

Wear test helps to predict the wear performance of the material and also to investigate its wear mechanism. In this test we take a disc of specified diameter. At a fixed rpm the material is made to rub the ground for 3 kilometres. The pin on disc apparatus and the specimens are shown in Fig. 5. The values obtained from the pin on disc test are given in Table 5. The wear in the material surface reduces as the amount of Al_2O_3 increases from 10% to 30% in the composite material.

Fig. 5: Pin on disc apparatus and wear test specimens

Table 5: Result obtained from thermal wear test

Sample	Wear (in 3 km)
Cu 90% + Al_2O_3 10%	0.69
Cu 80% + Al_2O_3 20%	0.57
Cu 70% + Al_2O_3 30%	0.55

2.7. Microstructure

Scanning Electron Microscopy (SEM) is a method that is used for phase identification and failure analysis of any inorganic material. Information on unit cell dimensions is obtained through this rapid analytical technique. The results obtained in SEM test are shown from Fig. 6 to Fig. 8. Through this test we conclude that long order randomness is achieved in the microstructure of the composite. Thus, the material is evenly distributed.

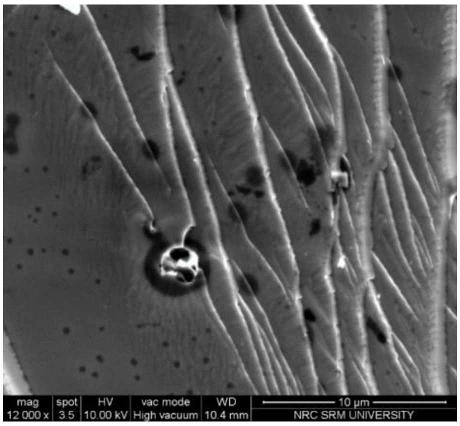

Fig. 6: SEM for Cu-Al composite of 90-10 composition

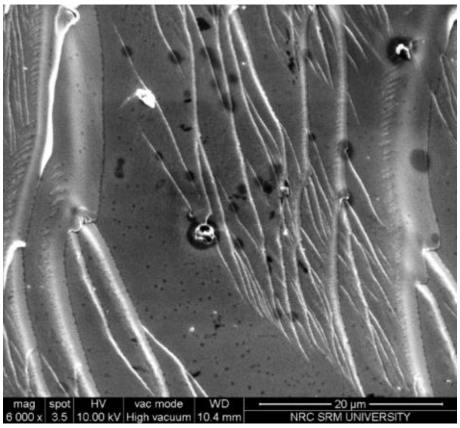

Fig. 7: SEM for Cu-Al composite of 80-20 composition

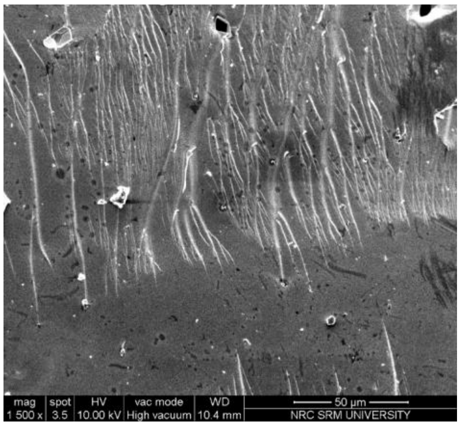

Fig. 8: SEM for Cu-Al composite of 70-30 composition

3. Conclusion

The samples were prepared by using stir casting method where alumina is added to the copper and the stirrer rotates at 250 rpm to evenly distribute the alumina particles in the matrix. The material is visualized using SEM to know the homogeneity of the material. The samples were then put through a series of tests to determine their mechanical and thermal properties. The three samples were tested and compared with each other to find the best combination for use in mechanical as well as thermal applications. The value of hardness was decreased by 15.15% and the value of toughness was also decreased by 44.46% as the amount of Al_2O_3 was increased from 10 to 30% in the mixture by weight.

The wear test also showed a reduction in the value of wear. Thermal conductivity of the material was increased by 43.91% as the amount of Al_2O_3 was increased from 10 to 30% in the sample. It was observed that sample 1 was very good for thermal applications whereas sample 3 was very good for electrical applications. But sample 2 was found out to be the best suited composition for both thermal and mechanical properties. All the three samples of various composition of Al_2O_3 showed good corrosion resistance.

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