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# Characteristics Bronze/$Al_2O_3$(Ni) Reinforcement Metal Matrix Composite Produced by Current Activated Sintering

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In this study, a bronze matrix (90 wt% Cu + 10 wt% Sn) was reinforced with $Al_2O_3$ particles using mechanical alloying and then produced by a subsequent rapid current sintering technique. The mechanically ball milled bronze powders were reinforced with electroless Ni coated 20 vol.% $Al_2O_3$ particles with three different particle sizes of 90, 70, and 50 μm. Microhardness testing, and scanning electron microscopy were used for the structural characterization of the composites. The tribological behavior of the resultant composites was tested by the ball-on-disk method at 1.0 N applied load with 0.3 m/s sliding speed for determination the wear loss and friction coefficient features against a counterface steel ball.

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## 1. Introduction

In recent years copper-based composites have gained widespread importance for several technological applications. Due to low mechanical strength, a highly conductive copper matrix needs to be dispersion strengthened, and new composite materials with superior characteristics have been developed. Dispersoid particles such as oxides, carbides, and borides, which are insoluble in the copper matrix and thermally stable at the high temperature, are being increasingly used as the reinforcement phase [1]. Particulates strengthened copper matrix composites can offer desirable improvements in mechanical properties, particularly at the high temperatures, such as stiffness, tensile properties and wear resistance [2–5].

## 2. Experimental

The matrix material was a 10 wt% Sn bronze alloy in powder form and has an average particle size of 80 μm. The reinforcement materials used in this investigation were $Al_2O_3$ powders. Different $Al_2O_3$ particle sizes 90, 70 and 50 μm and a constant volume percent of $Al_2O_3$ (20 vol.%) were used for reinforcing the bronze matrix. $Al_2O_3$ particles were previously coated with Ni to promote wetting. The experimental Ni deposition parameters on $Al_2O_3$ surfaces were optimized in such a way that both coating thickness and deposited particle size of Ni were equal to produce a core-shell structure of $Al_2O_3$–Ni. The bronze matrix and $Al_2O_3$ reinforcing particles were ball-milled for 60 min with 150 rpm, and then subsequent rapid current sintering was used for consolidation of the powder mixtures. The ball to powder ratio was chosen to be 10:1. The mechanically ball milled powders were then cold compacted in a steel die, and the compacts were obtained by applying a uniaxial pressure of 300 MPa. The cold compacted composite mixtures was then sintered with electrical current at atmospheric conditions to nearly a full density. The current activated sintering of the bronze/$Al_2O_3$ composites was applied for 10 min under an applied pressure of 10 MPa and under electric current of 1000 A. The matrix microhardness measurements were conducted on a Vickers hardness tester using a 300 g load for 15 s.

The microstructures were examined using scanning electron microscopy (SEM) (JEOL 6060LV) equipped with energy dispersive X-ray spectroscopy (EDS). X-ray diffraction (XRD) analysis was performed on the coated $Al_2O_3$ particles to determine the Ni deposition. A complete wear microstructural characterization of the worn surfaces was carried out via SEM after the tests. Dry sliding wear tests were carried out by a "CSM Tribometer" pin-on-disc tribometer machine. Wear loss and friction coefficient behaviors against a steel ball ($\phi$ 10 mm) suitable for DIN 50 324 and ASTM G 99-95a were measured. The tests were performed against a counterpart M50 steel ball at room temperature and in laboratory air conditions with a relative humidity of 40–60%. The sliding distance was chosen to be 500 m with applied normal loads of 1.0 N and a sliding velocity of 0.3 m/s.

## 3. Results and discussion

### *3.1. Ni coating on $Al_2O_3$ powders*

Typical surface morphologies of uncoated and Ni coated $Al_2O_3$ powders are shown in Fig. 1. While the as-received powders show a clean, deposit-free surface (Fig. 1a), the plated powders show a uniformly distributed nickel coating (Fig. 1b). At high magnification, a continuous nickel film is observed over the whole surface (Fig. 1b). The results of XRD analysis on $Al_2O_3$ coated with Ni film are shown in Fig. 1c, and both nickel and $Al_2O_3$ were detected.

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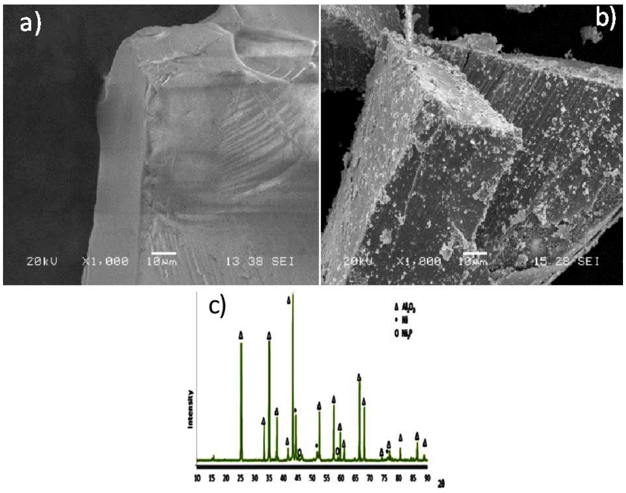


Fig. 1. Surface morphology of (a) uncoated, (b) Ni--coated 70 $\mu$m $Al_2O_3$, and (c) XRD pattern of Ni-coated $Al_2O_3$.

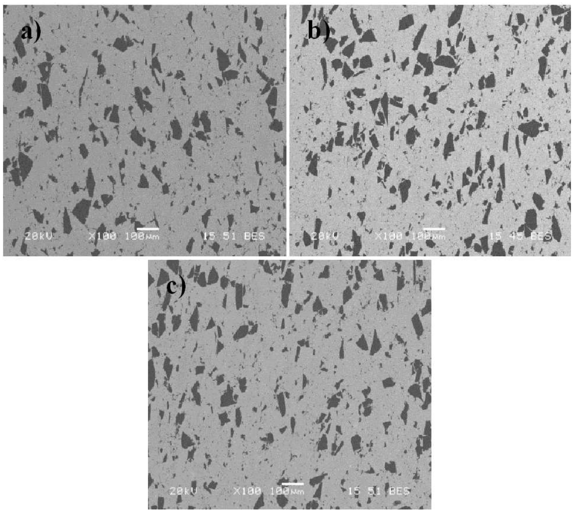


Fig. 2. Backscattered SEM micrographs of bronze matrix composites reinforced with different particle size of $Al_2O_3$: (a) 90 $\mu$m, (b) 70 $\mu$m, (c) 50 $\mu$m.

### 3.2. Microstructure of composites

The backscattered SEM micrographs in Fig. 2 show the microstructure of the bronze matrix composites reinforced with the different sizes of $Al_2O_3$. From the micrographs, it is observed that Ni–P coated alumina particles are distributed homogeneously throughout the matrix alloy and there exists a good bond between matrix alloy and reinforced particles with minimum micro porosities.

### 3.3. Microhardness of composites

The Vickers hardness of the composites was determined on the polished surfaces of the current sintered composites, and the results are given in Fig. 3, which shows that the hardness of the composites increases with decreasing particle size. It is well known that decreasing the second phase grain size leads to increasing hardness and strength of the metallic materials. Basically, this increment is attributed to the increased surface area between the matrix and $Al_2O_3$. Several studies have demonstrated this phenomenon and revealed that a greater interfacial area between the matrix and reinforcement leads to strengthening of the matrix [6].

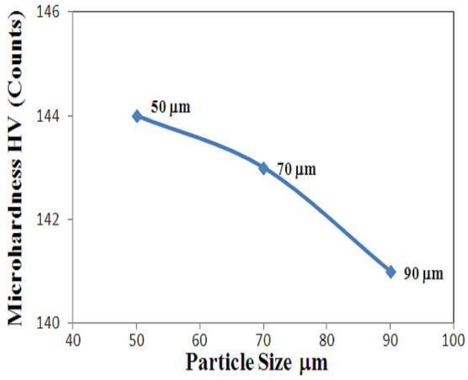


Fig. 3. Variation microhardness of the bronze composites as a function of $Al_2O_3$ particle size.

### 3.4. Wear and friction of the composite

The wear rate of the different sizes of $Al_2O_3$ particle reinforced bronze matrix composites are shown in Fig. 4a. It can be concluded from the experimental results and Fig. 4a that the composite reinforced with the largest $Al_2O_3$ particles (90 $\mu$m) showed the best wear resistance compared to the composites containing smaller particles (50 $\mu$m and/or 70 $\mu$m). That is, for the same fraction of $Al_2O_3$ particles of different sizes, the composites with smaller $Al_2O_3$ size exhibited lower resistance. For materials characterized by particles dispersed in a soft matrix, a decrease in the particle average distance by reducing the particulate size increased the hardness and also led to a decrease in the wear rate. Friction coefficient of the composites showed a gradual decrease with increasing $Al_2O_3$ particle size at a 1.0 N normal load. The adhesive nature of tribo-contact at these loads leads to the transfer of the soft bronze matrix to the harder counter surface. The higher wear rate for composites with small particle size is attributed to the particle-matrix interfacial area. The interfacial area in the case of a smaller particle size (50 $\mu$m) is larger, which increases the possibility for the small $Al_2O_3$ particulates to escape from the matrix. The composite with larger particles (90 $\mu$m) showed a resistance to particle separation from the matrix.

Figure 5 shows the SEM images of wear tracks on the bronze and bronze $Al_2O_3$ composite disks after the tests at 1 N applied load. The worn surfaces of composites are much smoother compared with unreinforced bronze. Worn matrix particles are clearly smeared in the form of fine particles on the bronze surface. Therefore, the

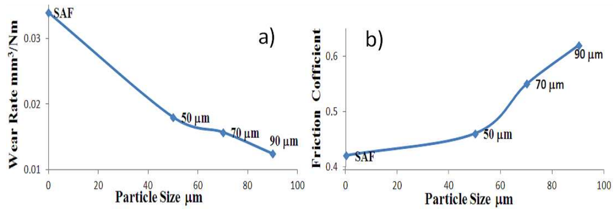


Fig. 4. The variation of (a) wear rate and (b) friction coefficient for different particle size $Al_2O_3$.

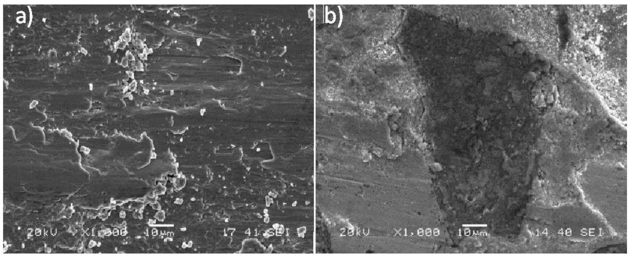


Fig. 5. Worn surface micrographs at 1 N load: (a) unreinforced alloy, (b) 20 vol.% $Al_2O_3$ (90 $\mu$m particle size) composite.

worn surface of unreinforced bronze at 1 N applied load exhibits a surface layer apparently formed by smearing and compaction of particles. Smearing is less pronounced on the bronze matrix $Al_2O_3$ composite surfaces as seen from Fig. 5b. The worn-out surface of the composites appears smooth, and no debonding or pulls out of the $Al_2O_3$ were observed as shown in Fig. 5.

## 4. Conclusions

Bronze/20 vol.% electroless nickel coated $Al_2O_3$ particle composites with three particle sizes were successfully produced using rapid current activated sintering, and their microstructural and tribological properties were studied. The addition of $Al_2O_3$ increases the performance of the bronze matrix with respect to the micro-hardness and sliding wear.

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