WEAR MECHANISMS OF BRONZE MATRIX COMPOSITES REINFORCED WITH CORE SHELL Ni COATED Al_2O_3 PARTICLES PRODUCED BY RAPID CURRENT SINTERING TECHNIQUE

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Abstract

In this study, bronze matrix was reinforced with particles using mechanical alloying and then subsequent rapid current sintering technique. The composites were cold compacted under constant pressure of 200 MPa. The compacted structures were sintered at atmospheric conditions almost to the full density using current sintering, in which the powders were heated by a low voltage and high amperage current and compressed simultaneously. The samples were sintered at 1000 A current to provide dense composites. Microstructural tribological behavior of the resultant composites were tested by a ball-on-disc method for determination the wear loss and friction coefficient features against a counterface alumina ball. Wear mechanisms were studied to determine the effect of particle content and applied load. Results proved that rapid sintering was also thought to be an advantage to eliminate conventional atmospheric sintering difficulties.

1. Introduction

Copper based materials are widely used as bearing material because they have high thermal and electrical conductivity, self-lubrication property, good corrosion and wear resistance. Cu-matrix composites are promising candidates for applications in electrical sliding contacts such as those in homopolar machine and railway overhead current collection system, where high thermal electrical thermal conductivity and good wear resistant properties are needed. Among various dispersoids, alumina particles are commonly used to reinforce copper. The Al_2O_3 dispersion strengthened copper have been reported to exhibit superior elevated temperature strength, increased hardness and improved creep resistance compared to pure copper[1-4].

Investigations on the bronze matrix Al_2O_3 particle reinforced composites are available; however, literature on tribological studies of bronze/Al_2O_3 composites produced by current sintering is scarce. Depending on the particle volume content, current assisted rapid sintering behavior has undergone evaluation in this paper and the wear properties of these composites were assessed with a ball-on-disk wear tester under dry sliding conditions at different applied loads. This work provides an authentic approximation to coat Al_2O_3 particle surfaces with a Ni core-shell structure and apply rapid sintering to evaluate tribological properties.

2. Experimental

The matrix material was a 10 wt. % Sn bronze alloy in the powder form and has an average particle size of 80 μm. The reinforcement materials used in this investigation were Al_2O_3 powders with 80 μm average particle size. The unreinforced bronze matrix and the composites with 10, 20 and 30 vol.% Al_2O_3 reinforcements were fabricated. 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 materials used in the present work were unreinforced bronze, and its composites reinforced with 10, 20 and 30 vol. % Al_2O_3 particles. Bronze matrix was reinforced with Al_2O_3 particles using mechanical alloying and then subsequent rapid current sintering was applied for consolidation of the powder mixtures. Proper proportions of the powders were placed in a planetary ball mill and mechanical alloying performed for 60 min. with 150 rpm, ball to powder ratio was chosen as 10:1. The blended and mechanically ball milled powders were then cold compacted in a steel die which has a 20 mm diameter and the compacts were obtained by applying an uniaxial pressing under a pressure of 200 MPa. The cold compacted composite mixture structures were then sintered with electrical current at atmospheric conditions to nearly their full density. The current activated sintering of the bronze/Al_2O_3 composites were carried out for 10 minutes under applied pressure of 10 MPa and the electric current of 1000 Amperes. The current activated sintering system and the details of the apparatus can be found in our previous work [5]. 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 (JEOL 6060LV) equipped with energy dispersive X-ray spectroscopy (EDS). X-ray diffraction (XRD) analysis 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” ball-on-disc tribometer machine. The tribological behavior of the resultant composites was tested at 0.5, 1.0 and 2.0 N applied loads with 0.3 m/s sliding speed for determination the wear loss and friction coefficient features against a counterface alumina ball.

3. Results and discussion

3.1. Microstructures

SEM micrographs of as-received Al_2O_3 powders and the Ni coated Al_2O_3 powders are presented in Fig. 1. The morphology seen in Fig. 1a is as-received Al_2O_3 powders with irregular shape and a particle size range of 80 μm. It can be seen clearly that the surfaces of Al_2O_3 powders have been coated by continuous and uniform Ni-P material with a core-shell structure Fig. 1b. Fig. 1c shows the EDS spectrum of the Al_2O_3 powder surface after the electroless coating.

Al_2O_3 particles were added to a bronze matrix as 10, 20 and 30 vol. %. Unreinforced alloy was also produced under the same conditions with the composites for comparison. SEM microphotographs of bronze/Ni–P/Al_2O_3 composites with the different percentage of

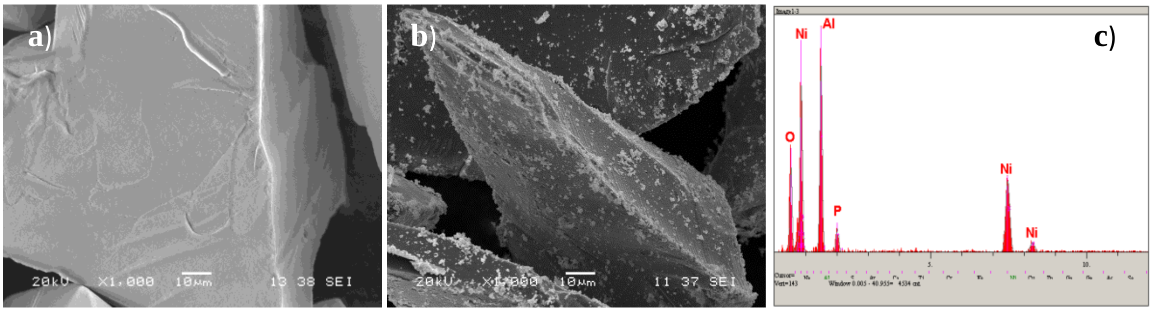

Fig.1. Surface morphology of a) uncoated, b) Ni-coated Al_2O_3 and, c) EDS of Ni-coated Al_2O_3

reinforcement are shown in Fig.2a–c. From the microphotographs it is observed that Ni-P coated alumina particles are distributed homogeneously throughout the matrix alloy and there is no significant agglomeration of the Al_2O_3 particles. This implies composites exhibit a good bond between matrix alloy and reinforced particles with minimum micro porosities. It is well known the uniform distribution, porosity free structure and interfacial bonding of ceramic particles with matrix caused from wettability [6]. In some studied composites, it was reported that ceramic particles are highly influenced by good wettability of Ni–P core-shell coated particles in the matrix during the preparation of composites [7]. In Fig. 3, two selected high magnification microphotographs are presented for the composites reinforced with 10 and 20 vol. % Ni-P/Al_2O_3 particles. It can be easily seen that the surface of the Al_2O_3 particle in Fig 3a is fully coated with a thin layer of Ni. This implies composites that thought to produce with these particles can possess good interfacial characteristics. Therefore, high magnification structures do not contain macro porosities and implies very attractive interface structure between matrix and the reinforcements.

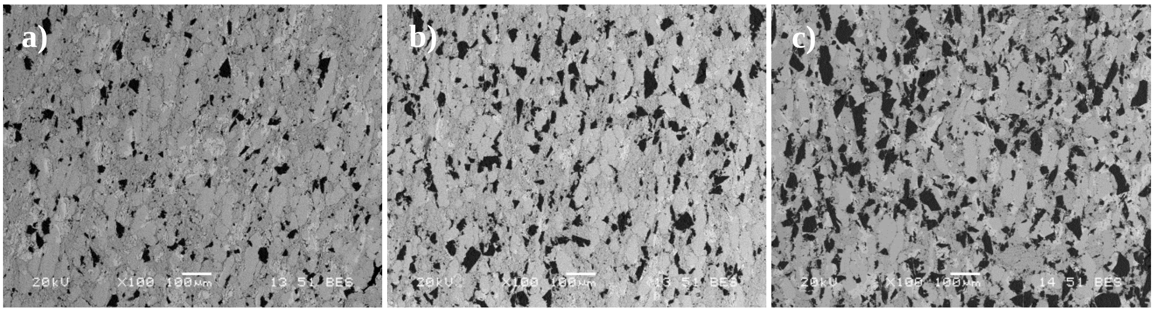

Fig. 2. Back scattered SEM micrographs of bronze matrix composites reinforced with Al_2O_3:a)10 vol. %, b) 20 vol. % and c) 30 vol. % Al_2O_3 content

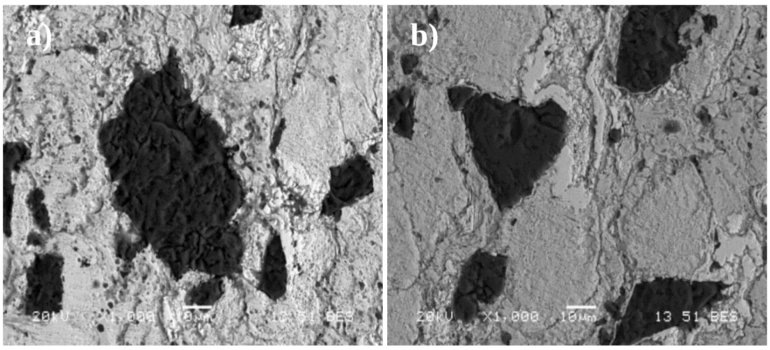

Fig 3. High magnification SEM micrographs of bronze matrix composites reinforced with Al_2O_3: a)10 vol. %, b) 20 vol. %

3.2 Microhardness

The variations of hardness of the composites are shown in Fig. 4. The hardness of the MMCs increased more or less linearly with the volume fraction of particles in the alloy matrix due to the increasing ceramic phase of the matrix alloy. It shows that the addition of reinforcement increases hardness of the matrix. The improvement in the hardness of the composites with increased content of reinforcement can be mainly attributed to the higher hardness of the reinforcements. Further, it can also be explained in terms of dislocation densities. Increased content of reinforcement in the matrix alloy leads to increased dislocation densities during thermal treatment due to the thermal mismatch between the matrix alloy and the reinforcement [8]. The mismatch of the thermal expansion between matrix and reinforcement due to temperature change results in large internal stresses and mismatch strain that affects the microstructure and mechanical properties of the composites.

3.3. Wear of Composites and Friction coefficient

The effect of percentage of Al_2O_3 on the current sintered bronze matrix composite wear rates and friction coefficient was tested with the ball-on disc technique. Fig. 5a shows the variation of the friction coefficient of the unreinforced alloy and composites with increased content of Ni–P coated alumina particles and applied load. It is observed that friction coefficient of composites increased with increased content of Ni–P coated alumina particles. This increment in the friction coefficient of bronze with the increment in the volume of Ni–P coated Al_2O_3 can be attributed to the decreasing lubricity of the bronze matrix. Bronze is a well-known load bearing alloy which both provide load carrying and low friction coefficient. Increasing ceramic particle content reduces lubrication effect of second alloying element of tin. Another possible effect of decreasing friction coefficient is the small amount of porosity between particles and matrix. Porosity measurement carried out according to the Archimedes' law yielded 3,1 %, 3,4 % and 4,1 % vol. porosities for 10, 20 and 30 vol. % Al_2O_3 reinforced composites, respectively. However, the porosity of the unreinforced alloy is only 2,2 %. Increasing porosity is known to cause decreasing interfacial bond and leading three body abrasion and therefore, high friction coefficient [9].

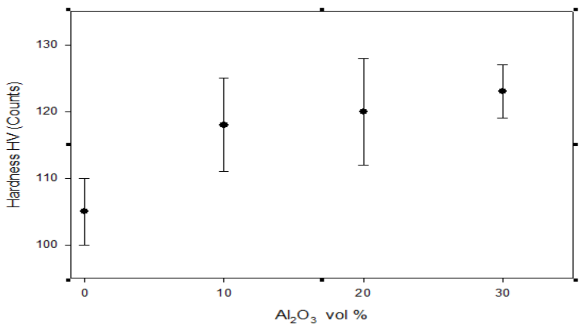

Fig. 4. Variation microhardness of the bronze composites as a function of Al_2O_3 particles

Fig. 5a also shows the variation of the friction coefficient of bronze/Ni–P/Al_2O_3 composite depending on the applied load. It is observed that for unreinforced alloy and composites, a continuous reduction in the friction coefficient is observed with the load increment. Increasing applied load causes more work hardening and oxidation on the worn surfaces, which causes a decrease in adhesion between the bronze matrix and steel ball. Similar results and comments were performed for different materials. For instance, Ramesh et al. [10] have proven that a reduction in the friction coefficient was observed with the increase in load in the Al6061 matrix composite reinforced with nickel coated silicon nitride particles were manufactured by liquid metallurgy route. In addition to this, reduced friction coefficient of composites can also be attributed to improved dispersion of silicon carbide particles, excellent bond and clean interface between matrix alloy and reinforcement. Fig.5b shows the variation of wear rate with the increased percentage of Ni–P coated Al_2O_3 particles in matrix alloy.

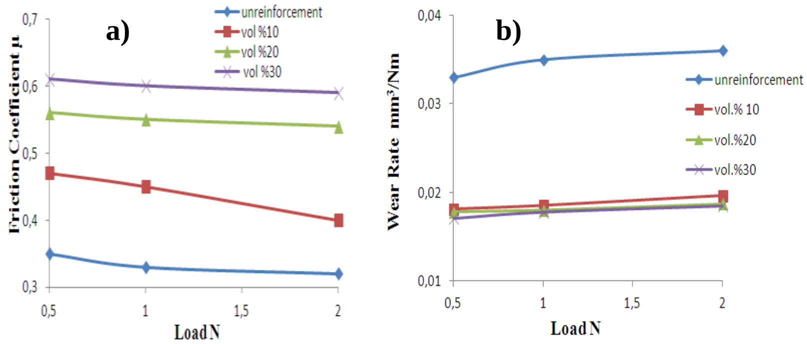

Fig. 5. Variation of tribological properties of bronze/Al_2O_3 composites depending on Al_2O_3 content and applied load; a) Friction coefficient and b) applied load.

This considerable improvement in wear resistance is due to presence of hard alumina particles. Further, excellent wear resistance of bronze/Ni–P/Al_2O_3 composites can also be attributed to improved surface hardness and high load bearing capacity of alumina particles with the increase in the percentage of reinforcement. Increase in hardness results in improvement of wear and seizure resistance of materials [11]. Further, the experimental supports and evidence suggest that the onset of the adhesive process such as scuffing and seizure are retarded by the in the hardness of matrix materials. Existence of good bond between the matrix and the Al_2O_3 particles is another reason for improved wear resistance for the materials studied. The interfacial bond between the matrix and the particle reinforcement plays a significant role in wear process. Saka and Karalekas [12] have found that wear resistance decreased with increased reinforcement content for Cu based composites. The detrimental effect of ceramic particles on the wear resistance of the composites has been attributed to poor interfacial bond between copper and ceramic reinforcement like Al_2O_3. Fig. 5b also shows the variation of the wear rate of the bronze/Al_2O_3 composites with normal loads. An increase in the normal load increases the wear rate of all the composites tested. It is observed that the wear rate of soft bronze/Al_2O_3 composites increases steadily with increases in load. Increased wear rates with increased load can be attributed to the fact that, at higher loads, there is a tendency for plastic deformation, which promotes the extent of wear debris formation. Further increased loads will result in onset of delamination leading to higher wear volume for both the matrix and alloy composites as observed by several workers. When the normal load was increased, considerable deformation of copper occurred, and transfer of copper to counter surface was also observed on the steel ball. Deformation of copper increases the amount of transferred copper. Though it is known that Al_2O_3 carries a majority of the load applied to the specimen during wear, an increase in load may reduce the wear resistance of the Al_2O_3. This phenomenon was reported in several works in the open literature [13, 14].

3.4. Worn surface analysis

Fig. 6 shows the low magnification SEM worn surfaces, indicating the effect of the volume fractions for a 0.5 N applied load. Fig. 6 demonstrates that the amount of wear is increased when volume fractions is decreased for the composites tested at 0.5 N. The effect of volume fractions on the amount of wear can be easily understood from the wear track width, which is increased with decreasing Al_2O_3volume fractions. From the low magnification micrographs, the high surface plastic deformation level for the bronze matrix composites, increased with decreasing Al_2O_3 volume fractions. The increasing Al_2O_3 volume fractions are important for effectively reducing the plastic deformation. The increase of plastic deformation severity can be clearly seen on the worn surface of the bronze matrix with decreasing Al_2O_3 volume fractions. From the low magnification worn surface micrographs in Fig. 6, in the composites, adhesive wear is the predominant mode of wear. The worn surfaces of unreinforced alloy and Al_2O_3 reinforced composites are presented in Figs. 7 for 2.0 N applied loads. From the SEM images, the following wear mechanisms were identified: the bronze copper samples showed adhesive wear with extensive plastic deformation, evidenced by smearing wear track (Fig. 7a). There are smooth and rough areas to be seen for the composites produced with 10 vol. Al_2O_3 (Figs. 7b). The smooth areas are due to the polishing effect at the start of the wear test.

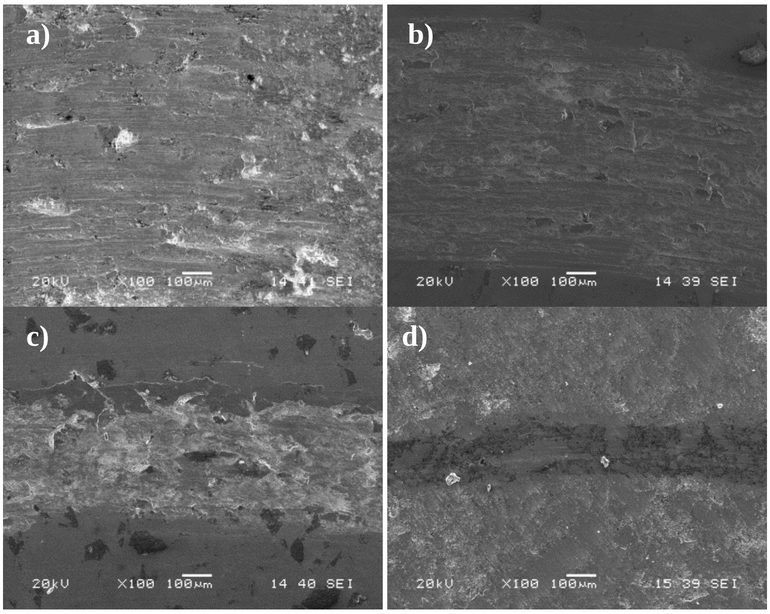

Fig.6 Wear tracks Al_2O_3 reinforced composites at the applied load of 0,5 N ; a)unreinforced bronze b)10 vol. % c) 20 vol. % d) 30 vol. % Al_2O_3content

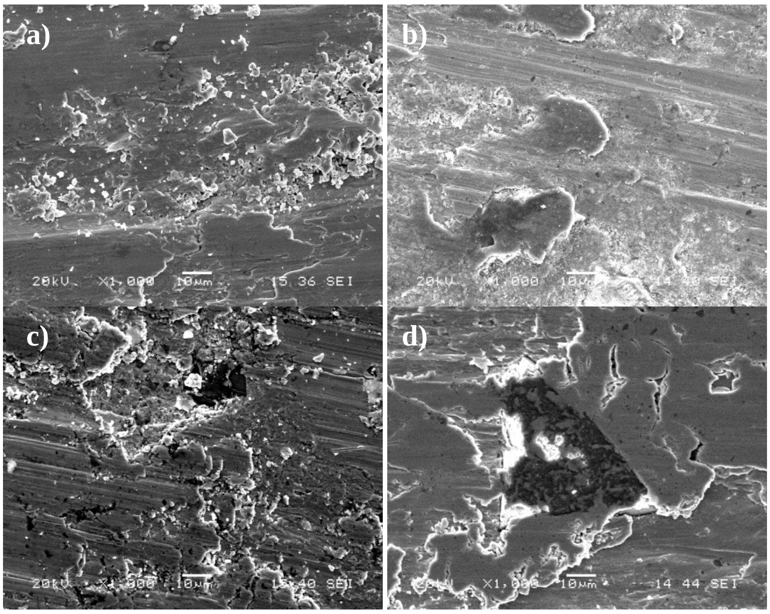

Fig.7. Worn surface micrographs after 2 N applied load of the composites with different Al_2O_3 particles; a)unreinforced bronze, b)10 vol. %, c) 20 vol. %, and d) 30 vol. % Al_2O_3 content.

The damaged layer formed during this polishing stage is fatigued with further sliding distance. Microcracks form and parts of the damaged layer spall, revealing small wear debris on the fracture surface. Increasing the particle volume resulted in revealing more smooth areas as can be seen from the Figs 7c. Increasing the amount of smoother areas and decreasing surface plastic deformation is believed to be caused by the effect of increasing load bearing capacity by increasing particle volume in the bronze matrix.

The worn surfaces were investigated by 3D profilometry and for brevity, only unreinforced alloy and 20 vol. Al_2O_3 particle reinforced composite surfaces are presented in Fig 8. Fig. 8a shows the 3D image of unreinforced alloy and illustrates many of protruded areas together with valleys. The high roughness is attributed to extensive plastic deformation and associated with microcracking which causes high surface roughness. When Fig. 8b is seen, it can be easily concluded that the amount of plastic deformation is reduced, and the surface contained several peaks, which are Al_2O_3 particles that protruded on the worn surfaces. As stated in wear mechanisms the wear of composite surface is governed by a smaller amount of plastic deformations since the ceramic particles behave as load bearing agents. 3D worn surface structure of the composite shown in Fig 8b is a great evidence that Al2O3 particles behave as perfect load carrying components in the produced composites, using current activated sintering technique.

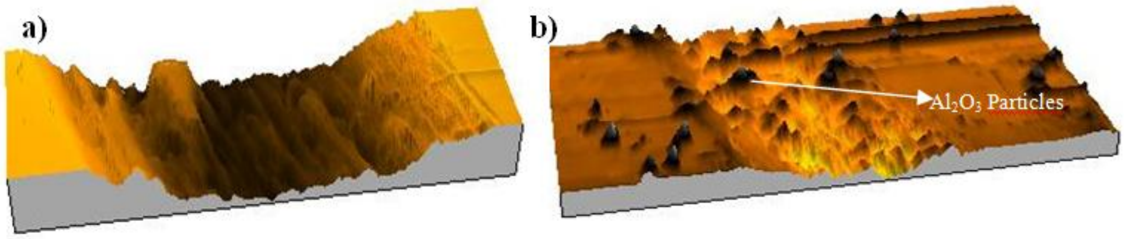

Fig. 8. Selected 3D profolimetre results for a) unreinforced alloy and b) 20 vol. % Al_2O_3 reinforced composite.

4. Conclusions

Bronze, electroless nickel coated Al_2O_3 particle composites with the different volume fractions 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 microhardness and sliding wear. In this research work, the following results can be drawn:

1. Bronze matrix/Al_2O_3 particle reinforced composites were effectively sintered using current sintering.
2. Microstructural and worn surface studies clearly reveal uniformity in the distribution of reinforcements and sufficient bonding between the matrix and the reinforcement due to the effective core-shell like Ni coating on the Al_2O_3 particles before composite sintering.
3. The microhardness of bronze matrix composites was increased with the increased in Al_2O_3 particle volume fraction.
4. The wear rate of the bronze matrix composites was decreased with increasing Al_2O_3 particle volume fraction.
5. The wear rate of the composites was increased with increases in the normal force due to the increased amount of plastic deformation and subsequent microcracking.

6. It can be concluded that rapid electric current sintering is a practical and low-cost technique for producing bronze matrix/ Al_2O_3 composites for load-bearing applications.

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