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Constrained sintering and wear properties of Cu−WC composite coatings

J. L. CABEZAS-VILLA[1], L. OLMOS[2], H. J. VERGARA-HERNÁNDEZ[1],
O. JIMÉNEZ[3], P. GARNICA[1], D. BOUVARD[4], M. FLORES[3]

1. División de Estudios de Posgrado e Investigación, TecNM/Instituto Tecnológico de Morelia,
Av. Tecnológico #1500, Colonia Lomas de Santiaguito, Morelia, Michoacán, C. P. 58120, México;
2. INICIT, Universidad Michoacana de San Nicolás de Hidalgo,
Fco. J. Mujica S/N, Morelia, Michoacán, C. P. 58060, México;
3. Universidad de Guadalajara, Departamento de Ingeniería de Proyectos,
José Guadalupe Zuno # 48, Los Belenes, Zapopan, Jalisco, C. P. 45100, México;
4. Univ. Grenoble Alpes, CNRS, SIMaP, 38000 Grenoble, France

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Abstract: Coatings of metal matrix composites (Cu−WC) were fabricated by solid-state sintering. WC reinforcing particles in different quantities from 5% up to 30% (volume fraction) were mixed with Cu particles. After mixing, the powders were poured onto the surface of copper substrates. Sintering was carried out at 1000 °C under a reducing atmosphere in a vertical dilatometer. Sintering kinetics was affected by both rigid substrates and WC particles which retarded the radial and axial densification of powders. However, the coatings were strongly attached to the substrate, and WC particles were randomly distributed within the matrix. The addition of the reinforcing particles enhanced the microhardness and reduced the volume loss in wear tests to 1/17 compared to the unreinforced sample. The predominant wear mechanism was identified as abrasion at a load of 5 N. 20% WC (volume fraction) reinforcing particles led to the maximum values of properties for the composite coating.

Key words: constrained sintering; dilatometry; dry sliding wear; microhardness; metal matrix composites; coating

1 Introduction

Copper and its alloys have several automotive applications since they are efficient by combining multiple electrical, thermal and corrosion components. Nevertheless, the applications of copper alloys are often limited because of their low mechanical properties when compared to steel, aluminum or nickel. In particular, copper alloys are used to produce bearings in which a coating of powders is sintered onto a rigid substrate. In order to obtain a continuous process, the powders are poured onto the surface of the substrate; then, free sintering is achieved by introducing the products into an industrial furnace under a reducing atmosphere. Different problems are present during the process (e.g., delamination, large porosities, cracks), which are generated by the constrained sintering. Those problems reduce the life of bearings as well as the wear properties of the copper alloys. A few works have studied constrained sintering to fabricate coatings composed of powders on solid substrates [1−5]. Most of those works studied the sintering process and pointed out defects like pores and grain anisotropy [6] and delamination during sintering [7]. However, none of those works investigated the wear properties of the films. On the other hand, metal matrix composites reinforced with ceramic particles [8−11], whiskers [12] and nanoparticles [13,14] have been developed in order to improve the wear resistance and mechanical properties of different alloys. With respect to Cu alloys, DESHPANDE et al [15,16] observed that the pore volume and pore geometry increased the wear rate in composites of Cu−WC made by the infiltration process. HONG et al [17] found that small quantities of indium can improve the hardness and wear properties of the Cu−WC composites. LARIONOVA et al [18] introduced carbon nanofibers into a Cu matrix and reported that the coefficient of friction (CoF) was reduced up to 1/8 compared to that of the matrix. KHOSRAVI et al [19] used the stir process to

Corresponding author: L. OLMOS; E-mail: luisra24@gmail.com
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fabricate layers of Cu−WC composites on solid substrates of copper; they found that the hardness was improved up to two times with respect to that of the pure copper, which was attributed to the reduction of the grain size. MIRAZIMI et al [20] fabricated composites of Cu−YSZ by SPS and obtained relative densities close to 95%, thus, microhardness and wear properties were improved. Nonetheless, the coefficient of friction was reported to be around the same values. PAK et al [21] produced Cu matrix composites reinforced with carbon nanotubes by extrusion process, improving the hardness of composites 4 times by adding 10% of nanotubes.

The objective of the present work is to investigate the sintering kinetics of the Cu−WC_p composite coatings fabricated by the powder metallurgy route and their mechanical properties and wear resistance. The effect of the volume fraction of the reinforcing particles, the pore volume and the sintering defects were evaluated and linked to the wear properties of the coating.

2 Experimental

In order to fabricate 1 mm-thick metal matrix composites (MMC) coatings, spherical copper powders with an average particle size of 23 μm (Fig. 1(a)) and tungsten carbide (WC) powders with an average particle size of 70 μm (Fig. 1(b)) were used as a matrix and the reinforcing particles, respectively. The reinforcing particles were added from 5% to 30% (volume fraction) into the Cu matrix. With the aim to obtain a random distribution of the WC particles, the powder mixture was poured into a plastic container; then, it was shaken for 30 min using a turbula. Two solid substrates of Cu were used: the first one consisted of cylinders with diameters of 8 mm and height of 14 mm were used to evaluate the sintering kinetics; the second one was a rectangular plate of 20 mm × 10 mm × 3 mm that was used for the wear tests. In the interest of fabricating the coating, substrates were placed inside a container with the same surface of the substrate. However, the thickness of the container was 1 mm larger than that of the substrate. The surface of the substrates was polished to eliminate external oxidation to avoid any interface problem during sintering. This space was filled with the powders that were poured onto the substrate. The powders were tapped in order to obtain a uniform distribution and to increase the green density of the coating. Finally, the outer surface was swept with a metallic plate to obtain a flatter surface. More details of the experimental set-up can be found elsewhere [5]. Immediately after the samples inside of the containers were introduced into a horizontal electrical furnace, they were heated at 450 °C for 30 min and a heating rate of 20 °C/min (under a reducing atmosphere of 10% H_2 and 90% N_2) to achieve adhesion between the particles and the solid substrate. Then, the samples were taken out of the containers with the coatings of powders attached to the surface of the substrate. Finally, sintering was carried out at 1000 °C with a heating rate of 25 °C/min for 1 h under a reducing atmosphere in two different instruments: a vertical dilatometer LINSEIS L75 to obtain the sintering kinetics and a horizontal furnace to produce larger samples used during the wear tests. The microstructure of the sintered coatings was analyzed by means of a Tescan Mira3 field emission scanning electron microscope (FESEM) using polished cross-sectional samples.

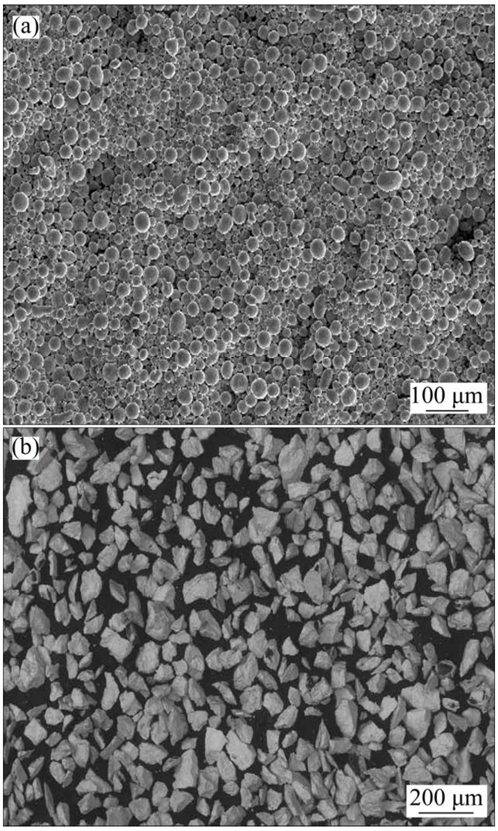

Fig. 1 FESEM images of initial powders: (a) Copper matrix; (b) WC used as inert inclusions

The microhardness evaluation was performed on cross-sectional polished surfaces by using a microhardness tester Mitutoyo MVK-HVL with a load of 0.5 N and a dwell time of 15 s. With the aim to obtain a map distribution of the microhardness, we indented in different locations on the coating surface from the interface with the substrate to the edge of the coating. A total of 49 points were measured and a 2D grid of 7×7 points was built; then, interpolation was performed using the Matlab software to obtain pseudo-continuous representations. Wear tests were performed at room temperature using a CETR UMT2 tribometer in a ball on flat, reciprocating sliding configurations under dry conditions and a relative humidity of 40%−45%. A