TRIBOLOGICAL STUDY OF COPPER ALLOY-BASED COMPOSITES REINFORCED WITH WC-W POWDERS PREPARED BY THE SPONTANEOUS INFILTRATION PROCESS OF THE LOOSE POWDER.

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Abstract: *Copper alloy-based metal matrix composite (MMCs) reinforced with different combination of WC-W powders were prepared using the spontaneous infiltration process of the loose powders. The density, microstructure, and hardness of the produced composites were characterized. Friction coefficient and wear rate of the samples under different conditions were carried out in order to determine the tribological properties of the copper based composites as a function of different combination of reinforcement mixtures (WC/WC-W). Wear surfaces of the composites were analysed by scanning electron microscopy (SEM). Results show that WC-W powders improve wear resistance of composites significantly. Wear mechanisms were characterized by delamination, micro cracking and abrasive wear.*

Keywords: INFILTRATION, METAL MATRIX COMPOSITES, REINFORCEMENT, WEAR BEHAVIOR, WC-W.

1. *Introduction*

Metal matrix composites (MMCs) are the combination of different materials in properties with a metal as matrix phase and particulates or fiber as reinforcement phase, the composites can exhibit news properties which each phase does not have. For The required properties and performance from matrix/reinforcement combinations, the objective might be to combine different combination as like as the ductility /stiffness combination, or high thermal conductivity/ low thermal expansion combination. [1-2] However, a great interesting for the MMCs combination of a good ductility and good wear resistance, where there is a widely use of these composites as highly wear-resistant materials. [2-5]

Copper or copper based-alloy composite reinforced with Tungsten or its carbide are one such type of these MMCs. The copper/copper alloy provide the a good ductility and high toughness, while the tungsten carbide used as reinforcement planned to be candidates due to their desirable properties of good wear resistance, high refractory , and excellent mechanical properties, however, their poor toughness limited there utilization into many applications [6]. The demand to produce a new materials with reductions in cost and improvements in performance, for these reasons, effort has been devoted to producing news copper metal matrix composites. In recent years, Several studies concerning the use of Tungsten or Tungsten carbide as reinforcement for copper or copper alloy-based composites for electrical contact applications [7], Thermal management, [8] and wear application [4-5]. Copper or cooper alloy reinforced with WC/W powders are also characterized by the good wettability and the lowest interfacial interaction between matrix / reinforcement led to provide a good compatibility between these combination [9].

The common MMCs fabrication methods including melt stirring, pressureless infiltration, pressure infiltration, and powder metallurgy. [10-12]. the spontaneous infiltration of loose powders is a promising method for manufacturing MMCs. The advantage of this process over conventional method is the process's ability of complex near net shape Components fabrication with lower cost. Spontaneous infiltration processing starts with a ceramic preform of the desired shape, when this preform subjected to elevated temperatures, the molten metal infiltrates spontaneously into the preform, the infiltration continues until the preform fills with molten metal [2-3]. This work presents a tribological study of a copper alloy-based composites reinforced with WC/WC-W powders manufactured by the spontaneous infiltration of loose powders, the effect of W as reinforcement with WC on microstructure and wear resistance of the Cu alloy-based composite was investigated.

2. *Experimental*

WC (99.7% purity, average particle size of 110 μm), and W powders (99.5% purity, average particle size of 90 μm) were used for the elaboration of Cu-alloy based composites reinforced with a mixture of WC-xW (x=0, 10, 20 and 30 wt.%). Copper-based alloy with the composition of 30 wt.% Mn and 1 wt.% P was used as binder. To obtain homogeneous distribution of the powders a Turbula mixer was used. The mixing time was kept constant as 30 min. After mixing, the loose powders were filled into à graphite mold with an internal diameter of 14 mm. To improve the wettability among powders and molten binder, a BORAX flux (sodium tetraborate decahydrate) was also added on the solid surface of the powders. The infiltration process was carried out in H_2 atmosphere protection at 1050° C with a heating rate of 5 °C/min and 30 min as holding time using a brand of NEW Borel furnace. After the infiltration, the sintered composites were cooled into furnace at 5°C/min to room temperature under H_2 atmosphere. Infiltrated composites were metallographically prepared using silicon carbide paper from 180 to 1200 grit then polished with 9, 3 and 1μm diamond solution.

The microstructural characterization of the MMCs was investigated by a JEOL JSM 6060 scanning electron microscope (SEM), equipped with an Energy Dispersive Spectroscopy (EDS). Vicker's hardness (HV30) of each composites was meseared with indentation loads of 30 kg for 10s (Model FV-700, Future-Tech Corp., Tokyo, Japan), 5 five hardness measurements were performed and the results were given with standard deviations. The densities of composites were measured by the Archimedes method.

Tribological tests were performed using a Nanovea MT/60/NI-type pin-on-disc Tribometer, using an Al_2O_3 ball (6 mm in diameter). The linear speed was set to 0.135 cm/s with a sliding distance of 500 m at room temperature. The normal loads of 20 N and 40 N were applied, respectively. Friction coefficient was continually measured and recorded. Weight loss the samples before and after wear tests using an AND GR200-type microbalance with an accuracy of 10^{-4} g. The following equation was used to obtain the specific wear rate of the composites:

$$W = \frac{M}{\rho.D.L} \quad (1)$$

Where W is the wear rate (mm^3/m.N), M is the weight loss (g), ρ (g/mm^3) is the density of MMC, D (m) and L (N) are and sliding distance and applied load respectively. Worn surfaces characterization of composites after wear test was examined by a scanning electron microscope (SEM) equipped with (EDS).

3. *Results and discussion*

3.1. *Microstructure characterizations*

Fig. 1 shows the representative SEM images of the infiltrated composites reinforced with WC-xW powders. It can be clearly seen from the SEM images that all composites have a uniform distribution of the reinforcement powders. The composites showed enhanced densification without any visible porosity indicating that the success of the infiltration process. Fig .1 (E) present a height magnification micrograph of MMC reinforced with WC-30W, it can be seen that there is a good bending at the interface between the reinforced phase and the matrix phase. No change on the initial shape and surface morphology of the reinforced particles was observed, which implies the lowest dissolution of WC and W particles into matrix phase.

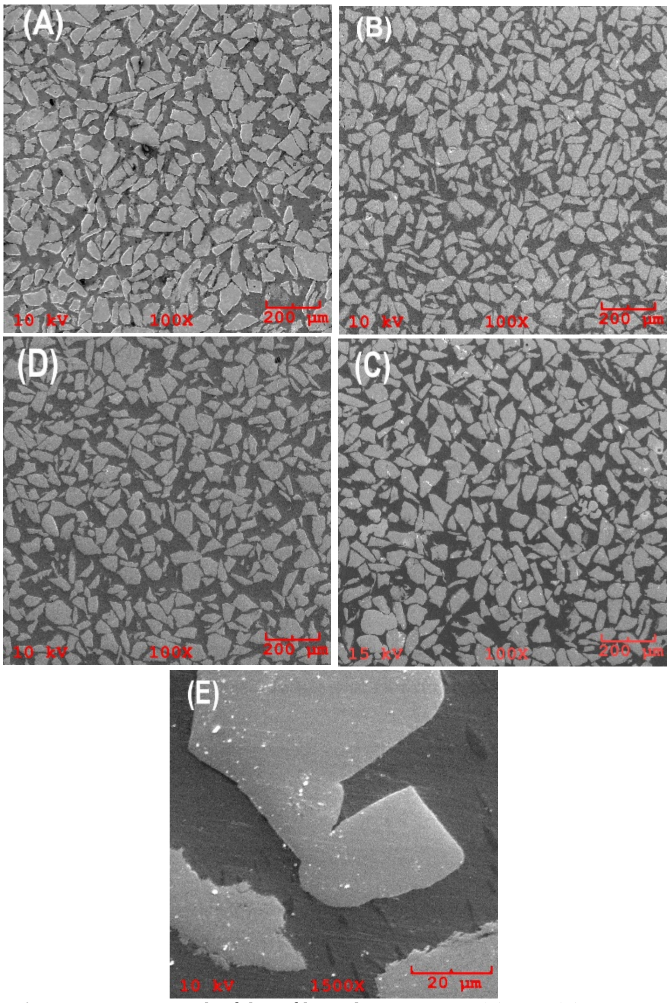


Fig. 1 *SEM micrograph of the infiltrated composites : (A) WC, (B) WC-10W, (C) WC-20W, (D) WC-30W and (E) height magnification of WC-30W.*

3.2. *Density and hardness*

The density and hardness of the infiltrated composites reinforced with WC/WC-W powders is represented in Fig. 2. It can be seen that the density of the composites increased with increasing W content. The highest values of density was observed for the composite reinforced with of WC-30W, while MMC reinforced with WC particles present the lowest one. At the same infiltrated condition, also, since the wettability behavior of WC and W powders is almost the same, the density change can be explained by the highest W powders density (19.25 g/cm^3), which can significantly influenced the final density of the infiltrated composites.

The hardness of the MMC has been measured using Vicker's method. Compared to the hardness of the binder (copper alloy) with an average hardness value of 154 HV, the hardness of the copper alloy was improved with addition of WC/WC-W reinforcements. Composites reinforced with WC powders present the highest value of hardness compared to other composites with both WC and W powders, with increasing W content, the hardness of MMCs decreased with a highest fluctuation on hardness values as represented by standard deviation. This is probably due to the difference between the hardness of WC (1954 HV) and W (504 HV) powders [13], the higher W content the lowest WC hard particles fraction for the same matrix fraction, therefore, the hardness of the composites decreased.

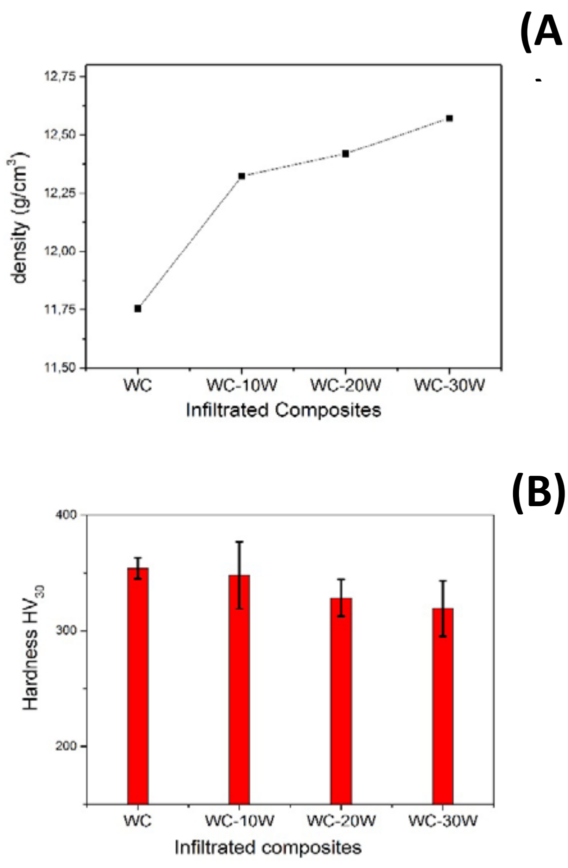
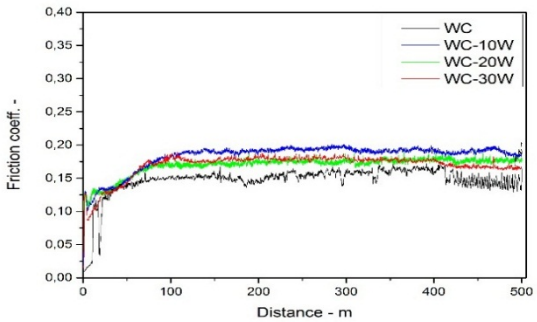


Fig. 2 *Density and hardness of the infiltrated composites reinforced with WC/WC-W powders: (A) density and (B) hardness.*

3.3. *Wear behavior*

3.3.1. *Friction coefficient and wear rate*

Fig. 3 shows the friction coefficient curves of composites against Al_2O_3 ball at the normal load of 20 N, after 500 m as sliding distance and sliding speed of 0.135 m/s. All the composites can reaches steady state when sliding distances exceeded ~100 m, during this state the average friction coefficient value was lower for the composites reinforced with WC powders than for the composites reinforced with WC-W. The friction coefficients of composites were in the range of 0.15–0.19. The composite reinforced with WC-10W presented the highest friction coefficient



despite its hardness was not the highest.

Fig. 3 *Friction coefficient of composites reinforced with WC/WC-W powders.*

The wear rate of composites reinforced with WC/WC-W powders at loads of 20 and 40N after a sliding distance of 500m and sliding speed of 0.135 m/s is presented in Fig. 4. The wear rate of composites at loads of 20 and 40N decreased linearly with increasing W content from 0 to 30 wt.%. The wear rate of the WC–30W composite was up to five times lower than that of composite reinforced with just WC powders. All composites present a lower wear rate above $10^{-5}mm^3.N^{-1}.m^{-1}$ and decreased with increase in W wt.% in the reinforcement phase. Fig. 4 shows also that the wear rate of all composites appears to increase with increasing applied loads for the same sliding distance. The reduction in wear rate with increasing the amount of W powders appears to be due to wear debris and plastic deformation of the matrix phase, which help to reduce wear rate. Similar results were reported by Fuzeng Ren et al [14] between Cu-Ag and Cu-W composites, they founded that the wear rate of Cu-Ag is much lower than that of Cu-W due to the plastic deformation during wear. In other hand, the W particle size used in this composite (90µm) compared to WC particle size (110µm) despite the low hardness of W powders (504 HV) influenced the wear rate, decreasing in particles size led to increase the surface area between the reinforcement particles and the matrix phase which can make the particles–matrix interface more strength for the composites reinforced with WC-W particles. However, as describe by Archard's law [15], there is an inverse relationship between the hardness (H) and the wear volume loss, which is in contradiction with the composites presents in this work, the harder composites exhibiting a much higher wear rate. P.K. Deshpande et al had studied the wear behavior of Cu/W and Cu/WC composites. They found that the Cu reinforced with WC particles display a good wear resistance than those of Cu reinforced with W particles, in addition the wear rate of this kind of composites can be influenced by several parameters such as the reinforcements phase ratio and its mechanical properties, the porosity, the reinforcement particle size and the reinforcements-matrix interface bonding strength [7].

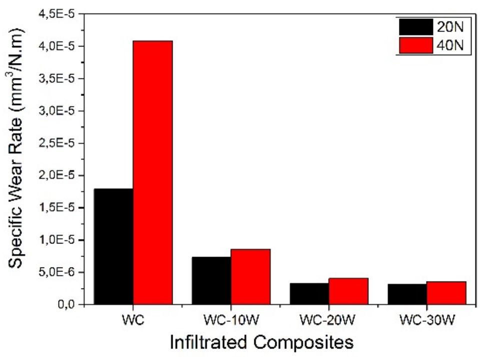
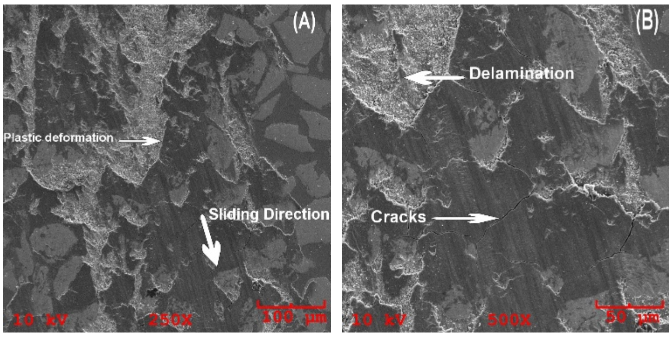


Fig. 4 *wear rate of composites reinforced with WC/WC-W powders.*

3.3.2. Worn surfaces

Fig. 5 shows the worn surface of the composites reinforced with WC-30W at a load of 20 N after a sliding distance of 500m. As revealed from the worn surface, the global mechanism dominant for all the composites was a combination of a plastic deformation of the matrix phase and reinforced particles delamination as shown in Fig. 5. The copper alloy were ploughing between the reinforced particles and can form a thin layer on the sliding direction, also some cracks were observed on matrix surface. On the other hand, reinforced phase were characterized by the delamination mechanism, where, the brittle reinforced particles can cracked, fragmentized, and removed partially or totally from the matrix phase under wear conditions. Generally, wear mechanisms for the metal matrix composites reinforced with ceramic particles can



varied from the abrasive wear, delamination and plastic deformation [4-5, 16-18].

Fig .5 *SEM micrographs of worn surfaces of composites reinforced with WC-W powders at 20N after 500m sliding distance: (a) WC-20W, (b) height magnification of WC-20W.*

4. Conclusion

Copper alloy-based metal matrix composites reinforced with WC/WC-W with different content of W were fabricated using the spontaneous infiltration. The following conclusions can be drawn from this work:

- All the composites present a uniform distribution of the reinforced phase through the matrix phase with a good densification of the final composites.
- The addition of W powders led to an increase in the density of the composites, however, hardness results showed that the

addition of W to WC particle reinforcement reduced the hardness of the infiltrated composites.

- The results of dry sliding tests showed that the addition of W improve the wear resistance of the composites, further the wear rate decrease as the W content increased.
- Composite reinforced with WC-30W showed the bests wear resistance among all the infiltrated composites.
- Wear mechanism varied between abrasive wear, delamination and plastic deformation.

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