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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.

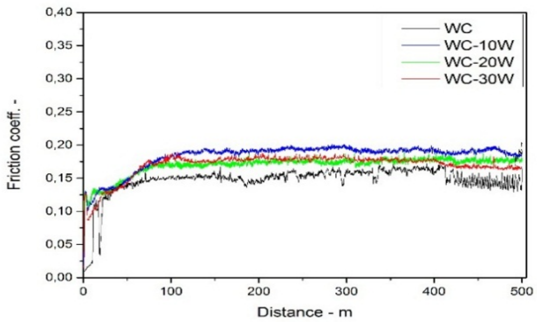

Fig. 3 *Friction coefficient of composites reinforced with WC/WC-W powders.*

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].

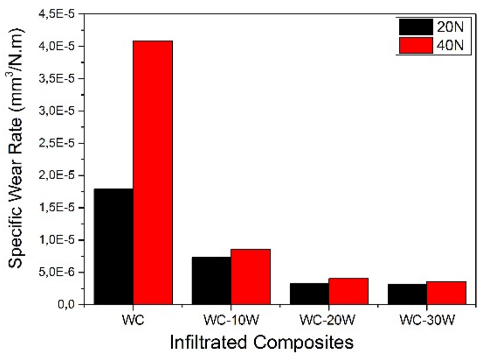

Fig. 4 *wear rate of composites reinforced with WC/WC-W powders.*

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].

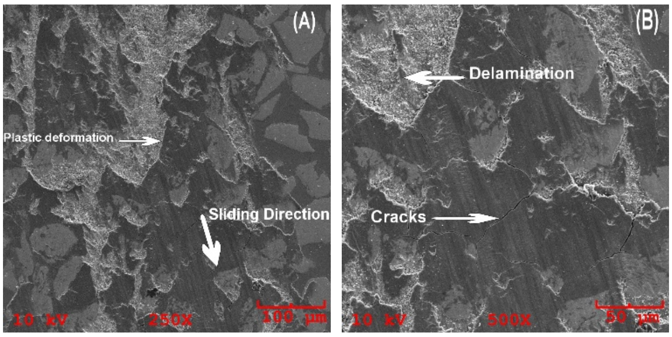

Fig .5 *SEM micrographs of worn surfaces of composites reinforced with WC-W powders at 20N after 500m sliding distance: (a) WC-20W, (b) height magnification of WC-20W.*

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

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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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