CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE

The present investigation is an approach to develop copper-based hybrid composites and its characterizations. Two different categories of copper-based hybrid composites are developed, 1-binary reinforced copper hybrid composites, 2- tertiary reinforced copper hybrid composites. Total eight copper-based hybrid composites are developed, four from first category and designated as Cu-2Cr-1WC-1ZrO_2 (Hybrid composite-1 (HC-1)), Cu-2Cr-1WC-1Al_2O_3 (HC-2), Cu-2Cr-1WC-2ZrO_2 (HC-3) and Cu-2Cr-1WC-2Al_2O_3 (HC-4). Whereas, four from second category and designated as Cu-2Cr-1.5WC-1BN-0B_4C (HC-5), Cu-2Cr-1.5WC-1BN-0.5B_4C (HC-6), Cu-2Cr-1.5WC-1BN-1B_4C (HC-7) and Cu-2Cr-1.5WC-1BN-1.5B_4C (HC-8), respectively.

The chemical composition and the reinforcing particle content of the hybrid composites have been determined to characterize the hybrid composites and the effect of particle content on the physical properties like- electrical and mechanical properties have been investigated apart from dry sliding friction and wear behavior. The major conclusions of the present study are as follows.

1. The binary and tertiary reinforced copper-based hybrid composites were successfully synthesized by stir-casting technique. Fairly uniform distribution of the both binary and tertiary reinforcement particles are observed in their respective metallographic investigation.

2. Energy dispersive analysis of X-ray (EDAX) confirmed that no contamination takes place in both the developed binary and tertiary reinforced copper hybrid composites and reinforcing particles. Similarly, XRD analysis indicates that no intermetallics compounds are developed during the stir-casting of the copper hybrid composites.

3. Full width at half maxima (FWHM), crystallite size and lattice strain of the powders were evaluated from the XRD analysis as a function of reinforcements. The FWHM and lattice strain in binary and tertiary reinforced copper hybrid composites are significantly higher as compared with CC however, the crystallite is lower.

4. The lattice strain and FWHM of the hybrid composites increases with increasing content of reinforcement particles. Minimum crystallite size of 35.9 nm is obtained for 1.0 wt. % B_4C reinforced hybrid composite i.e. HC-7.

5. From the current study, it was observed that the density of the both binary and tertiary reinforced copper-based hybrid composites is lower as compared with CC. Moreover, the decreasing tendency in density of hybrid composites observed with increase in content of reinforcing particles. HC-3 and HC-8 display the least density in binary and tertiary reinforced hybrid composites, respectively.

6. Mechanical properties such as Brinell hardness, compressive strength and ultimate tensile strength of the both binary and tertiary reinforced copper based hybrid composites are significantly higher as compared with CC. These mechanical properties increase with increase in content of the reinforcing particles in cases of both binary and tertiary reinforced copper based hybrid composites.

7. Tertiary reinforced hybrid composites display better result of hardness, compressive strength and ultimate tensile strength as compared with binary reinforced and CC. In particularly, HC-4 shows the best mechanical properties among binary reinforced hybrid composites however, HC-7 displays the highest mechanical properties among tertiary reinforced hybrid composites.

8. The binary and tertiary reinforced copper hybrid composites exhibit the lower electrical conductivity as compared with CC due to addition of the non conducting nature of the reinforcing particles in the copper matrix. Whereas, electrical conductivity of hybrid composites decreases with increasing content of ceramic reinforcements like-ZrO_2, Al_2O_3 and B_4C.

9. The coefficient of friction of both binary and tertiary reinforced copper hybrid composites is observed to fluctuate with respect to sliding distance and no certain trend is observed. The fluctuating behavior has been attributed to the disparity in contact that occurs when the sample and the counter face are evolving to develop a better surface conformity.

10. The coefficient of friction with sliding distance of binary reinforced hybrid composites is higher as compare with CC and coefficient of friction of tertiary reinforced hybrid composites is lower than CC at almost all normal applied.

11. An opposite results of average coefficient of friction of binary and tertiary reinforced copper hybrid composites with normal load is observed. The average friction coefficient of binary reinforced hybrid composites increases with increasing load and have a higher value of average coefficient of friction in comparison to the CC.

12. The average friction coefficient of tertiary hybrid composites decreases with increasing load and have a lower value of average coefficient of friction as compared with CC.

13. For a particular load, average coefficient of friction of tertiary reinforced copper hybrid composites decreases with increase in B_4C content.

14. In the present investigation, the cumulative volume loss of both binary and tertiary reinforced hybrid composites increases almost linearly with increasing sliding distance at all the normal load applied. Therefore, the wear volume-distance relationship has been represented by linear segments in order to remain within the framework of Archard's law.

15. However, cumulative volume loss for both binary and tertiary reinforced hybrid composites is much lower as compared with CC. It is also observed that the cumulative volume loss of tertiary reinforced hybrid composites with sliding distance is highest among all the materials investigated.

16. The wear rate of both binary and tertiary hybrid composites increases almost linearly with increasing normal load. However, the wear rate of the both hybrid composites is lower than that of the CC.

17. Tertiary hybrid composites, it may be attributed to the lubrication provided by the B_4C and BN reinforcing particles including the credit of its higher hardness compared with CC. tertiary reinforced hybrid composites exhibit the lowest wear rate with normal load among all the materials investigated.

18. For the entire normal load, the wear rate in the tertiary reinforced hybrid composites decreases linearly with increasing B_4C content till 1.0 wt. % beyond which it increases for 1.5 wt. % of B_4C. The lowest wear rate is observed for HC-7.

19. The mechanism of wear is a mix of oxidative and adhesive wear in the range of loads used in the present investigation for CC, as evident from the severe morphology of worn surface and presence of oxygen in the EDAX spectrum.

20. It is a mix of oxidative and abrasive wear mechanism for both binary and tertiary reinforced hybrid composites.

21. The arithmetical mean deviation of profile (R_a) and root-mean-square deviation of profile (R_q) of worn surfaces of both binary and tertiary reinforced hybrid composites are much lower as compared with CC. It is observed very clearly that the R_a (0.225 μm) and R_q (0.238 μm) value of worn surface of CC is much higher than the R_a and R_q value of worn surfaces of binary reinforced hybrid composites.

22. Among all the worn surfaces of binary hybrid composites, HC-4 exhibits the least value of R_a (0.024 μm) and R_q (0.031 μm) due to its low wear among all. However, it is observed that among all the worn surfaces of tertiary hybrid materials, HC-7 exhibits the least value of R_a (0.012 μm) and R_q (0.018 μm). Overall, tertiary reinforced hybrid composites displays a better surface roughness and least values is observed in HC-7 among all the materials investigated in the current study.

23. These developed binary and tertiary hybrid composites can be used in the various engineering applications such as shipping hulls, resistance welding electrode, high bush-bars, railways electrical contacts, water/fire sprinklers and underground water pipes etc.

Future scope

1. The binary and tertiary hybrid composites can be developed using powder metallurgy technique (using normal and microwave sintering). An exhaustive comparative study of physical, microstructural, mechanical and tribological properties of both hybrid composites developed by both techniques can be made.
2. Corrosion properties of these developed hybrid composites can be examined under different acidic medium in the future.
3. Tribo-corrosion behavior of both binary and tertiary hybrid composites can be analyzed in the future.
4. An exhaustive study of crystallographic structure of these developed hybrid composites can be done.
5. Other engineering applications of these developed hybrid composites can be specifically examined thoroughly.