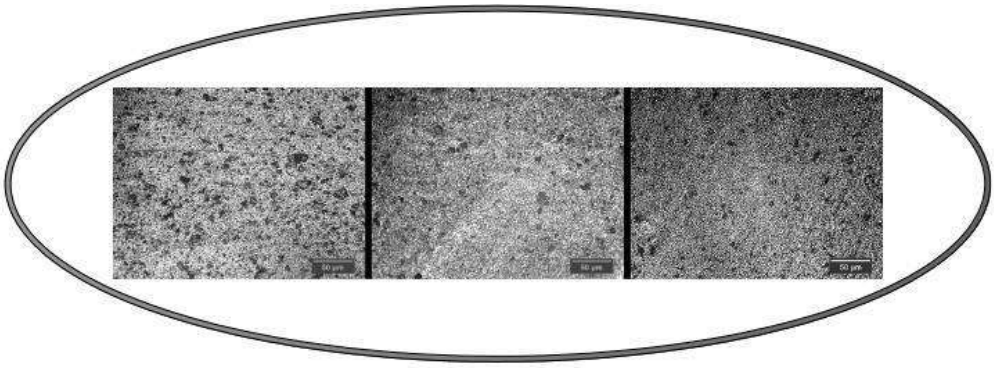
Chapter 7

Summary and Conclusions



This chapter summarizes the findings of the present investigation together with concluding remarks and scope for future work.

7.1 Summary and Conclusions

This research was aimed at developing cost-effective copper-based surface composites via friction stir processing by utilizing wastes as potential reinforcements and to investigate their performance through microstructural, mechanical, tribological and electrical behaviour. Covering these aspects, the work was divided into the following chapters:

i. Studies on Cu/$ZrSiO_4$ surface composite fabricated by friction stir processing
ii. Studies on Cu/FA surface composite fabricated by friction stir processing
iii. Studies on Cu/ZrO_2 surface composite fabricated by friction stir processing

The important observations made on different aspects are listed at the end of the respective chapters and the major findings are summarized below:

7.2 Studies on Cu/ZrSiO4 surface composite fabricated by friction stir processing

In this chapter, fabrication of Cu/$ZrSiO_4$ composite by friction stir processing and effect of zircon reinforcement on microstructure, mechanical, tribological and electrical behaviour was investigated. For microstructure analysis, XRD, microhardness, tensile strength, electrical and wear characterization, specimens were cut from the processed portion of the plate. The micrograph obtained by optical, electron back scattered diffraction and scanning electron microscope revealed equiaxed and fine grain structure in stir zone with no sign of concentration gradient, aggregation and segregation of particles. The absence of

defects in the stir zone of the composite was due to the proper selection of processing parameters and solid-state nature of FSP. The formation of fine and equiaxed grain structure in SZ was the result of dynamic recrystallization due to intense plastic deformation. XRD pattern revealed no peaks corresponding to intermetallics or interfacial reaction products which may be ascribed to a lower temperature during FSP which was insignificant for initiation of reaction between copper and zircon. The microhardness, tensile strength and wear resistance of fabricated surface composite improved significantly as compared to base copper whereas, ductility and electrical conductivity decreased. The improvement in mechanical properties of the composite was due to grain refinement, uniform dispersion of zircon in the copper matrix and the excellent interface between matrix and particulate. The decreased electrical conductivity of the composite was ascribed to more scattering of electrons due to increased grain boundaries and non-conductive nature of zircon sand. The micrograph of the worn surface was also analysed to investigate the predominant wear mechanisms. Adhesion and delamination wear was predominant wear mechanisms in pure copper whereas this wear mechanism was not significant in Cu/Zircon composite.

7.3 Studies on Cu/FA surface composite fabricated by friction stir processing

This chapter work emphasizes the utilisation of FA as reinforcement in copper-based surface composite fabricated by friction stir processing (FSP). The properties of fabricated composite and its environmental impact through leaching test have also been reported in the present study. The microstructural features of the fabricated composite were observed by optical, electron back scattered diffraction

and scanning electron microscope revealed equiaxed and fine grain structure with no concentration gradient, agglomeration and segregation along the grain boundaries. The grain refinement in the SZ of the composite is supposed to be due to dynamic recrystallization because of high stirring rate and frictional heating whereas, the absence of defects is the result of optimized process parameters. The stir zone (SZ) was engulfed with particulate along with clean interface and excellent bonding. The clean interface between copper and FA may be attributed to smaller size and smooth surfaces of FA which allowed resistance free movement of plasticized copper all over the particulate. The XRD pattern revealed no intermetallics or in situ products except copper and particulate. The absence of reactional products is due to insignificant heat generation during FSP. Vickers microhardness tester machine adjudged significant improvement in hardness. The composite showed higher tensile strength and lower ductility as compared to copper. A higher value of mechanical properties of the composite was due to the incorporation of hard phase in the copper matrix, grain refinement and the difference in expansion of thermal coefficient between copper and FA. Decrement in electrical conductivity was observed as evaluated by four probe method was due to the non-conductive nature of FA. The pin on plate unidirectional dry sliding wear test was performed to evaluate the wear loss. The wear resistance of the fabricated composite improved substantially. The worn surface was observed by scanning electron microscope to have a detailed understanding of wear mechanism. Further through leaching test, it was observed that concentration of leached out metals was far below as specified in Indian legislation.

7.4 Studies on Cu/ZrO_2 surface composite fabricated by friction stir processing

This chapter presents the effect of friction stir processing on Cu/ZrO_2 composite by adjudging microstructure, mechanical, electrical and tribological behaviour. The microstructural evaluation was carried by optical, scanning electron microscope (SEM) and electron back scattered diffraction technique. Observed micrograph confirmed uniform dispersion of zirconia in the copper matrix. The stir zone (SZ) of the fabricated composite displayed equiaxed and fine grain structure. Mechanical properties of the composite were assessed by microhardness and tensile test. The hardness and tensile strength of the fabricated composite in SZ improved significantly as compared to as received copper. Grain size reduction and uniform dispersion of zirconia contributed to the improvement in hardness and tensile strength. The ductility and electrical conductivity of the fabricated composite were found to be less as compared to as received copper. The decreased electrical conductivity of the composite was ascribed to more scattering of electrons due to increased grain boundaries and non-conductive nature of zirconia.

To summarize,

i. Three different copper-based surface composites ($Cu/ZrSiO_4$, Cu/FA and Cu/ZrO_2) were successfully fabricated through FSP.
ii. The fabricated composites showed improved mechanical and tribological behaviour whereas, ductility and electrical conductivity decreased in comparison of base copper and processed copper without reinforcements.
iii. $Cu/ZrSiO_4$ and Cu/FA composites showed almost comparable properties to Cu/ZrO_2 composite. Further, through leaching test, it

was observed that the concentration of leached out metals was far below as specified in Indian legislation.

7.5 Future perspectives

Based on the present results, the future perspectives of this research work are:

i. The present studies showed moderate mechanical properties. Further, the investigation can be extended on the improvement of their mechanical properties by carrying out multiple passes of FSP on fabricated SCs.

ii. The present study showed improved mechanical and wear properties by utilising FA and zircon sand in copper-based surface composite. Further, the investigation can be extended on the utilisation of industrial and agricultural wastes such as egg shell ash, coconut shell ash, bagasse shell ash, red mud etc. as reinforcements in the copper matrix.

iii. The investigation can be conducted on the manufacturing of hybrid copper-based surface composites by utilising wastes with known ceramic particles as reinforcements.