# PREFACE

Surface engineering is getting popularity across the globe for engineering applications where surface interactions are involved. The surface of such components is either protected or modified in such a manner that suits the interaction at the surfaces. In this regard, several technologies have been developed. The research fraternity has participated in a revolution as far as the shaping of surface properties is concerned. The shaping of surface properties largely involves physical, chemical and solid-state mechanical treatments. However, challenges are there related to economic issues, environmental and energy aspects and material performance. Constraints are there to minimise production costs, to have low impacts on environmental emissions and minimized solid and liquid disposals along with low energy consumptions. There, green processes, efficient from an energy point of view are required.

Pure copper is inherited with superior electrical and thermal conductivity, high formability, good ductility and excellent oxidation and corrosion resistance. Due to those characteristic attributes, copper drew a lot of attention from several industries which were not limited to optical, thermal and electrical industries. However, copper is known to have low strength and hardness, poor wear resistance and inferior arcing resistance. Therefore, for the applications such as bearing bushes, nozzles, electrical connectors, railway overhead current collector etc. those properties require considerable improvement.

Conventionally, the surface of light metals such as aluminium, magnesium, copper etc. can be significantly improved by putting hard coating layer on the surface through techniques like physical vapour deposition, hard anodizing and ion beam enhanced deposition. However, the coating layer produced by these processes are too thin to sustain high load it gets break easily with deformation of the matrix. Moreover, these processes are costly, time-consuming and have a harsh effect on the environment due to expensive consumables, long processing time and toxic emissions. Surface properties of light metals can also be improved by reinforcing hard ceramic and intermetallic particles in the surface of the materials. So far, different methods such as laser cladding, plasma spraying and micro-arc oxidation have been used to produce surface composites. As laser cladding is a melt based process where melting of metals occur which leads to several defects such as porosity, cracking, anisotropic and dendritic grain coarsening and formation of some detrimental phases due to the interfacial reaction between particulate and matrix. Whereas, in the case of plasma spraying and micro-arc oxidation techniques, there is an obvious stratification between composite layer and substrate and interface strength is limited. In order to overcome the problems associated with these aforementioned techniques, more advanced technologies are still desirable.

Solid-state technologies, known from the middle of the twentieth century, were revisited to meet these new requirements. The development of the friction stir welding concept and its applications to surface modification opened up new possibilities to improve the surface properties of components produced by conventional technologies. Friction stir processing (FSP) has been intensively investigated in recent years as a solid-state process with an enormous potential to modify material surfaces.

Therefore, in order to improve the surface properties of pure copper, FSP was used to reinforce different particles. The investigation conducted in present research work has not been performed earlier. The composites Cu/FA, Cu/$ZrSiO_4$

and Cu/$ZiO_2$ has been fabricated first time by FSP. Sequential steps that involved in the fabrication of surface composites by FSP were machining a groove exactly at the centre of the work-piece viz. copper plate by CNC end mill cutter. Groove dimensions are usually cut according to the Vol% of reinforcements that has to be compacted within the slot. The volume fraction of the reinforcements (Fly ash, zircon sand and zirconia) had to be 18 Vol%, so accordingly groove dimension was selected. The dimensions of the grooves were 1.5 mm in width and 3.5 mm in depth. In the next continuous step, the particles were carefully filled in the slots created over copper plates. Then compaction of particulates into the slots was carried over followed by passing of a pinless tool made of double tempered H13 tool steel. This procedure was performed to avoid the scattering of particles anywhere outside the groove during the stirring process. The final step of processing involves passing of FSP tool made of double tempered H13 tool steel above the copper surface with a 6 mm diameter pin of length 4 mm possessing a shoulder diameter of 18 mm. Pin profile was cylindrical and it was threaded. The performance of the composites have been assessed in terms of microstructural features, mechanical, tribological and electrical behaviour.

**Chapter-1** presents a brief introduction about copper and its application along with the shortcomings faced by copper due to which its application is hindered in certain cases. It also presents the means to overcome the shortcomings faced by copper along with different processes including the potential of friction stir processing as a tool for surface modification.

**Chapter-2** deals with the current trends, various issues, and strategies used to fabricate surface composites by FSP in order to enhance the efficiency of the process. Various factors involved in the process of SCs fabrication are discussed and classified. Also, a variation of microstructural, mechanical, wear and electrical characteristics with these factors is reviewed. A summary of the literature on SC fabrication via FSP for different metals has also been tabulated with prominent results.

**Chapter-3** deals with the details of the materials used for the present investigation and experimental procedure of surface composite fabrication by friction stir processing. The characterisation details followed for the present study such as microstructure, mechanical properties, wear properties, electrical behaviour and leaching tests have been discussed in detail.

**Chapter-4** presents fabrication of Cu/$ZrSiO_4$ composite by friction stir processing and effect of zircon reinforcement on microstructure, mechanical, tribological and electrical behaviour. 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. XRD pattern revealed no peaks corresponding to intermetallics or interfacial reaction products. 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 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.

**Chapter-5** 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 boundary. The stir zone (SZ) was engulfed with particulate along with clean interface and excellent bonding. The XRD pattern revealed no intermetallics or in situ products except copper and particulate. Vickers microhardness tester machine adjudged significant improvement in hardness. The composite showed higher tensile strength and lower ductility as compared to copper. The decrement in electrical conductivity was observed as evaluated by four probe method. 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.

**Chapter-6** 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.

**Chapter-7** summarises the findings of the present investigation together with concluding remarks and scope for future work.

This chapter gives a general introduction on MMCs especially CMCs such as,

- Copper and its alloys along with problems and solutions
- Processing techniques involved to fabricate CMCs
- Role of wastes as reinforcements in CMCs
- Friction stir processing as a technique for grain refinement and composite fabrication