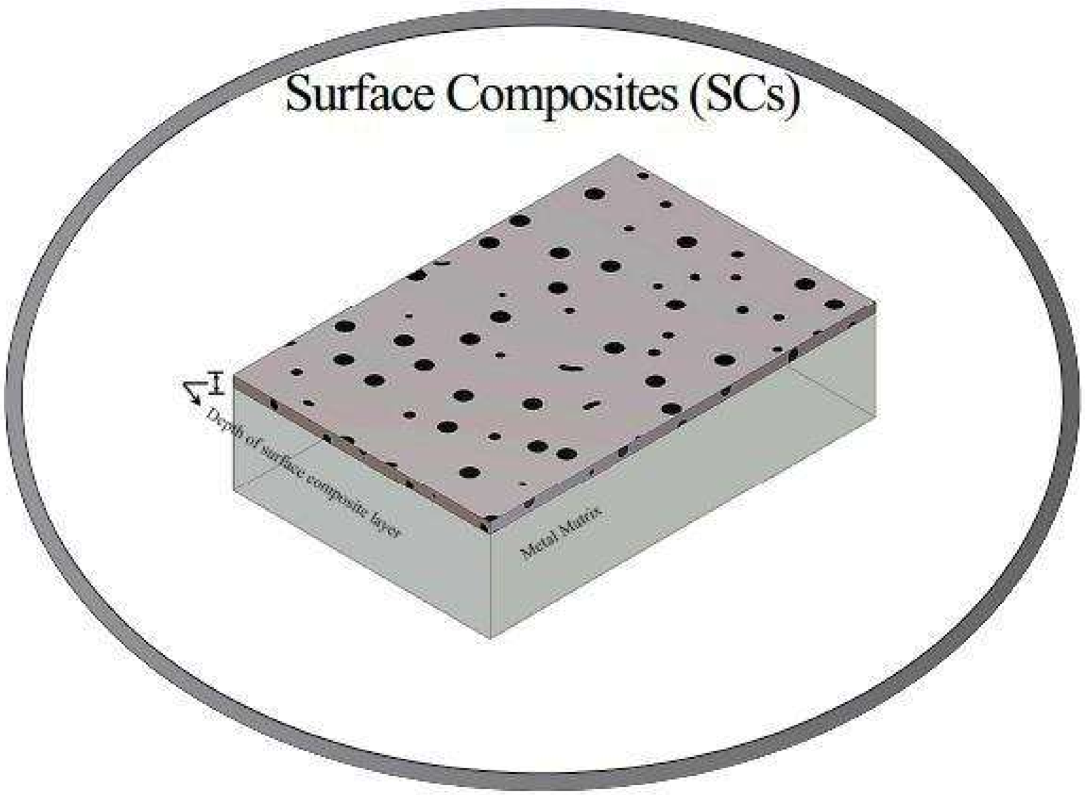
Chapter 1

Introduction



This chapter provides a general introduction on copper based surface composite such as,

- Need for surface composites
- Processing techniques involved to fabricate surface composites
- Role of fillers used as reinforcements in CMCs

The introductory chapter concludes with detailed investigation of friction stir processing as a surface modification technique

1.1 Introduction

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 has drawn a lot of attention from several industries which are not limited to optical, thermal and electrical industries (Das et al., 2016, Rathod et al., 2009, Vettivel et al., 2013). 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. these properties require considerable improvement. The techniques employed for the improvement of the desired properties include alloying (Champion et al., 2016), heat treatment (Diánez et al., 2016), severe plastic deformation (Uniwersał et al., 2016), and dispersion strengthening (Guo et al., 2016). Dispersion strengthening is getting attention among research fraternity and is widely accepted to improve the properties of copper by using various particulates due to ease of fabrication and low cost (Wang et al., 2009, Koksal et al., 2012, Ramesh et al., 2009b). When particulates are reinforced in copper to improveits such as hardness, corrosion and wear resistance and strength etc. it is generally termed as copper matrix composites (CMCs). CMCs are considered to be the most appropriate choice to improve above mentioned pproperties without degradation of electrical and thermal conductivity (Zheng et al., 2010).

Ceramic particles such as TiC (Fathy et al., 2017), WC (Zhao et al., 2004), SiC (Efe et al., 2012), Al_2O_3 (Fathy and Megahed, 2012), TiB_2 (Sharma et al., 2013) etc. are generally reinforced in copper to improve its wear resistance and mechanical properties. These ceramic particles are very costly which lead to increase in the cost of the CMCs. The end product cost of the CMC can be considerably reduced by the utilization of industrial and agricultural waste residues such as fly ash, zircon sand, bagasse ash, rice husk ash, egg shell ash, red mud, coconut shell ash as reinforcements in a copper matrix in place of costly ceramic particles (Bahrami et al., 2016). Some of the studies have been reported in which these wastes were used as reinforcements and found to have considerable improvement in wear resistance and strength of the fabricated composites (Dinaharan et al., 2017, Sharifitabar et al., 2016, Rahsepar and Jarahimoghadam, 2016).

Copper matrix composites can be fabricated by different solid and liquid based processing techniques. These includes powder metallurgy (Efe et al., 2012), mechanical alloying (Sheibani et al., 2010), hot pressing (Tjong and Wang, 2006), spark plasma sintering (Sharma et al., 2013), laser melting (Gu et al., 2007), stir casting (Ramesh et al., 2009a), in situ reaction (Fathy and Megahed, 2012), squeeze casting (Xing et al., 2005), pressureless infiltration (Zhang et al., 2008), combustion synthesis (Lu et al., 2012) and spray forming (Lee et al., 1998). It becomes very challenging to produce CMCs having no defects such as porosity (Zhao et al., 2004), non-uniform dispersion (Lu et al., 2012), cluster formation (Sharma et al., 2013), segregation along grain boundaries (Fathy and Megahed, 2012) and interfacial reactions (Salehi et al., 2012) by these techniques. These defects limit the performance of CMCs during operation. Poor wettability between the surface of ceramic particles and the molten copper is faced in liquid metallurgy methods. The techniques followed to improve wettability add to the production cost. Therefore, the solution to produce sound CMCs lies either in the modification of traditional methods or in the application of new production methods.

Although reinforcement of ceramic particles in the copper matrix leads to improvement in wear resistance and strength. It reduces the ductility and toughness of the CMC which limits its applications to a greater extent. In the applications, where there is sliding motion between the surfaces, only surface properties need to be improved, so it will be sufficient to reinforce hard particles only in the surface in order to convert it in to surface composite layer. In this way surface composites will fulfil both requirements simultaneously i. e. improving the surface properties and retaining the ductility and toughness (Meng et al., 2013, Maharana and Basu, 2016).

In the past decades, intensive research has been devoted to modify the surface properties in order to improve component performance and life. In this regard, several technologies have been developed. The research fraternity has participated in a revolution as far as the tailoring of surface properties is concerned. The tailoring of surface properties largely involve physical, chemical and solid-state mechanical treatments. However, challenges are there which are related to economic issues, environmental and energy aspects and material performance. Constraints are there to minimize production costs, to have low impact on environmental emissions and minimized solid and liquid disposals along with low energy consumptions. Therefore, green processes, efficient from an energy point of view are required.

Conventionally, the surface of light metals such as aluminium, magnesium, copper etc. can be significantly improved by putting hard depositing 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. 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.

Friction stir processing is one of the variants of friction stir welding and its working principle is same as that of friction stir welding (Mishra et al., 2003). It consists of a specially designed tool of non-consumable nature having two major parts namely shoulder and pin. The tool is mounted with the spindle of the machine and is capable of rotating at high revolution. The tool pin presses against the plate under applied load up to the depth when the shoulder comes in contact with the plate. A schematic of the process is shown in Fig. 1.

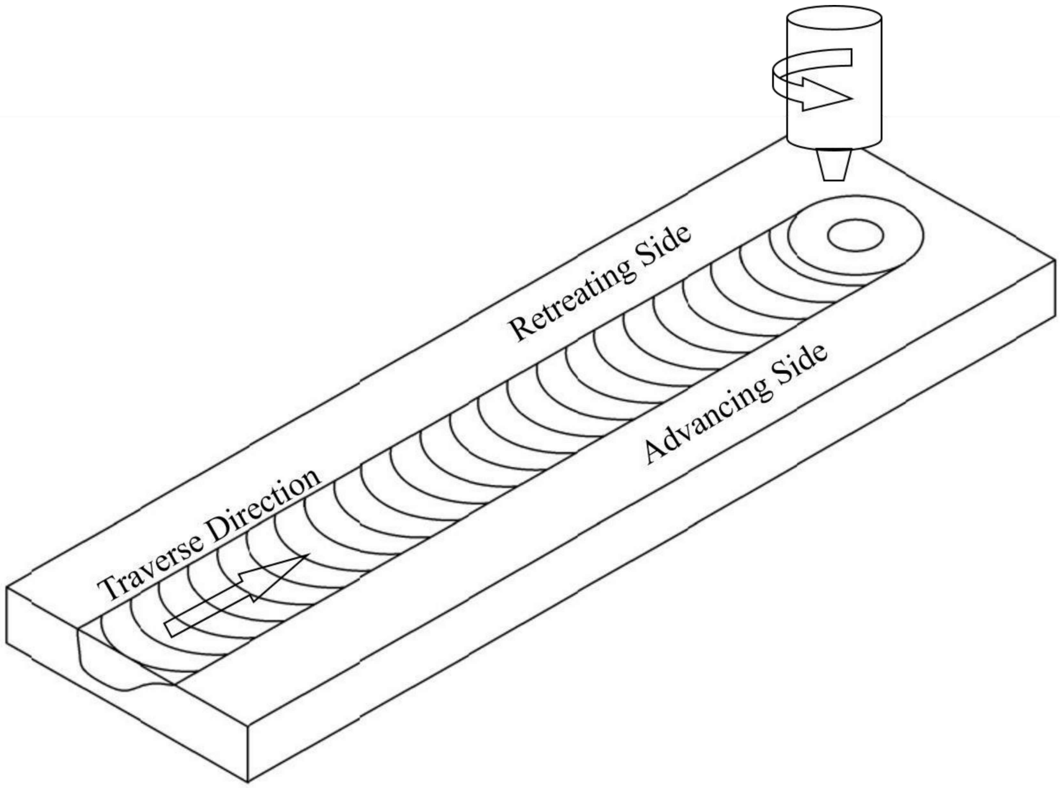


Figure 1.1 Schematic of friction stir processing process

As the tool rotates, there will be relative motion between tool and work piece and due to a frictional heating temperature of the plate will rise and get plasticized beneath the shoulder. After sufficient plasticization, tool traverses in the desired direction and material flow occurs around the tool pin and get forged at the back side of the shoulder leaving behind the processed zone. The material flow during the FSP is complicated due to the simultaneous rotatory and linear motions. The side in which the tangential velocity of the tool surface is parallel to the transverse direction is defined as advancing side and another side is defined as a retreating side as marked in Fig. 1.1. In principle, FSP is a thermomechanical process in which severe plastic deformation and frictional heating occur simultaneously. The temperature during FSP is generally above $0.5T_m$. The maximum temperature during FSP encountered was $0.9T_m$ and as no evidence of material melting during FSP has been observed so it is termed as a solid state process (Mishra and Ma, 2005).

Friction stir processing was initially used for aluminium and magnesium alloys. However, recently it is being used for a variety of materials such as copper, titanium, steels, and high entropy alloys (Lee and Jung, 2004, Moghaddam et al., 2011, Mironov et al., 2008, Chen et al., 2009, Kumar et al., 2015). As temperature elevates during FSP, so it can be used for hard to deform hexagonal closed packed metals and low ductility alloys. Friction stir processing finds their prime application for material processing, material fabrication and in a variety of microstructural modifications. Due to its thermomechanical behaviour, dynamic recrystallization occurs during processing which leads to grain refinement and so it is used to refine the grain size in various metals and alloys. Starting with the coarse grain structure of various materials, the grains have been refined into the fine and ultrafine structure through this technique (Su et al., 2006, Chang et al., 2007). Even studies on nanostructured material have also been reported by cooling the plate behind the tool to prevent the growth of dynamically recrystallized grains (Chang et al., 2008).

Besides grain refinement, FSP is found to have applications such as modification of cast alloy microstructure, elimination of casting defects and fabrication of composites like nano, surface and in situ ones. The stirring action of the tool makes it enable to homogenize the as-cast microstructure and eliminate the casting defects. The cast alloys suffer from defects like microporosity, dendritic microstructure, elemental segregation in the interdendritic region and non-uniform distribution of second phase particles which limit the mechanical properties of cast alloys especially ductility, toughness, and fatigue life. Friction stir processing of cast alloys results in breakage of dendritic microstructure and leads to homogeneous microstructure. Processing of cast products results in removal of casting defects which are mentioned above and leads to improvement in strength and ductility (Santella et al., 2005, Yuan et al., 2013). This process has got attention globally because of its uniqueness such as it does not affect the shape and size of the base material and can be carried out on a selective part of an engineering component for properties enhancement without affecting the properties of the rest of the material. Incorporation of second phase particles can be also achieved using friction stir processing (Mishra et al., 2003). A variety of surface composites such as nano-composites, intermetallic reinforced composites and hybrid composites have been fabricated by this process. Besides composite fabrication it is also used for solving the problem of in situ composite i. e. segregation along grain boundaries (Bauri et al., 2011).

Although FSP is an advanced technique used for the fabrication of surface composites but still it possess some limitations which need to be rectified for its full commercialization. To rectify all its problems, its basic understanding and main drawbacks need to be understood at microscopic level. The next chapter explore the usage of FSP for various purposes and basic fundamentals associated with it.