Chapter 5

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

The demand for energy is increasing day by day. Due to the shortage of natural gas and crude oil, it is becoming very difficult to fulfil even the primary energy requirements. So coal-based energy production methods have gained attention in mass-energy producing units. For rapid combustion of coal and to extract maximum energy, pulverized coal is used in power plants. Rapid combustion of coal produces FA. The FA production depends on the quality of coal used; for instance, Indian coal has high ash content (35-45%) and is of lower quality (Mathur et al., 2003).

The major portion of FA produced is disposed of in ash pond and landfill and a very small fraction of it is being utilised (Bhattacharjee and Kandpal, 2002). Due to its toxic contents and high salinity, disposal in landfill leads to soil pollution (Pandey and Singh, 2010). FA production and utilization in India from 2011 to the first half year of 2016-17 has been shown in Figs. 1 and 2 respectively.

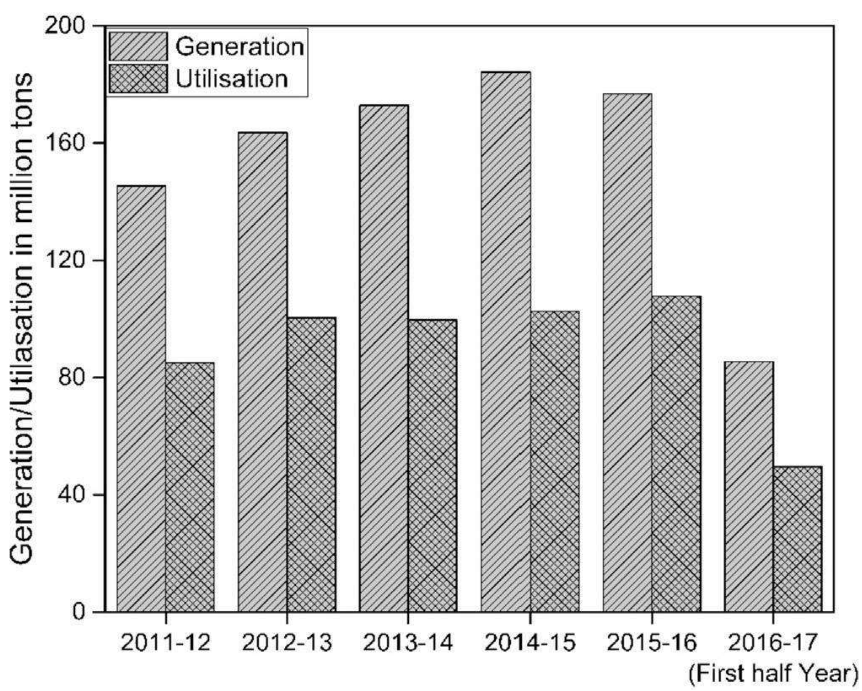

Fig. 1. Fly ash production/utilisation (millions tons per year) in India during 2011 to 2016-17 (first half year) (plots present data from the source: http://cbrienvis.nic.in)

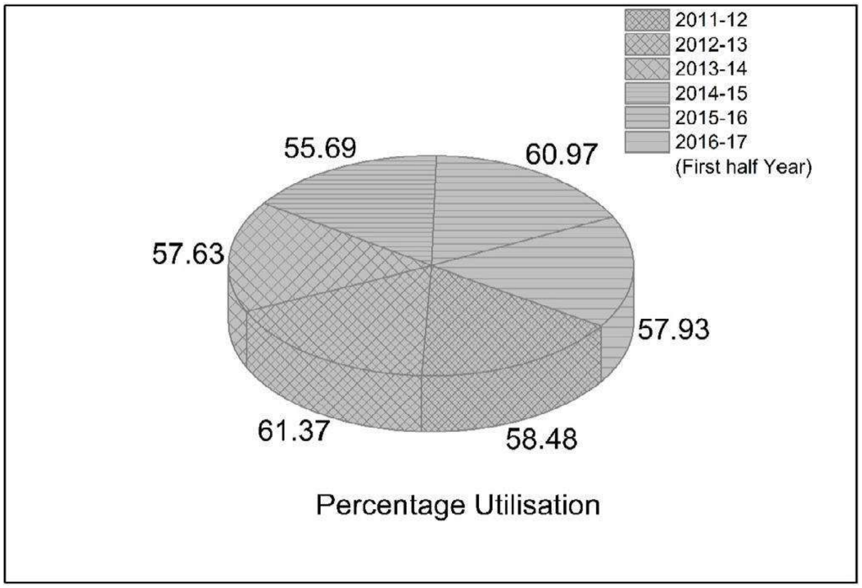

Fig. 2. Utilization (%) of Fly ash in India during 2011 to 2016-17 (first half year) (plots present data from the source: http://cbrienvis.nic.in)

The ministry of environment and forest (MoEF) in India issued Solid waste management (SWM) rules 2000 to ensure proper waste management and new updated draft rule has been published recently (MoEF, 2015). Because of negative impact on the environment and enormous generation all over the world, research is being conducted to utilise FA rather than dumping. Till now, it has been used making ceramics (Bhagat et al., 2011), cement and concrete additives (Arezoumandi et al., 2015, Hemalatha et al., 2016, Kovtun et al., 2016, Paris et al., 2016, Tang et al., 2013, Vargas and Halog, 2015, Zhao et al., 2015), water treatment (Wang et al., 2016b), agriculture application (Jain, 2016), Building materials (Yu and Shui, 2014), CO2 sequestration (Ukwattage et al., 2015), metal matrix composites (Balamurugan and Uthayakumar, 2015, Dinaharan et al., 2016a, Sai et al., 2008) etc. Although fly ash can be utilized for making ceramics, cement and concrete additives, water treatment, building materials etc. but it can also be used as a potential reinforcement for MMCs fabrication. It will not only reduce environment threats impose by FA but also reduce the fabrication cost of MMCs which is a major concern in MMC applications. Various reports have been reported in which fly ash has been used as reinforcement.

(Dinaharan et al., 2016a) reinforced FA in AA6061 aluminium matrix through FSP route in order to fabricate surface composite. The results showed improvement in mechanical and wear properties of the composite. The improvement in mechanical and tribological properties was almost comparable to the known ceramic reinforcement in an aluminium matrix. In a similar study, (Zahi and Daud, 2011) reinforced FA in Mg alloy and found to have significant improvement in mechanical and wear properties of the fabricated composite. As far as copper is concerned, no studies have been reported in which copper/FA composite was fabricated through FSP route.

This chapter deals with the manufacturing of Cu/FA surface composite using friction stir processing technique. The outcome of the fabricated composite has been investigated in form of microstructure, mechanical, tribological and electrical behaviour. The leach test was also performed for the FA particles and Cu/FA composite for environmental impact.

Chapter 5

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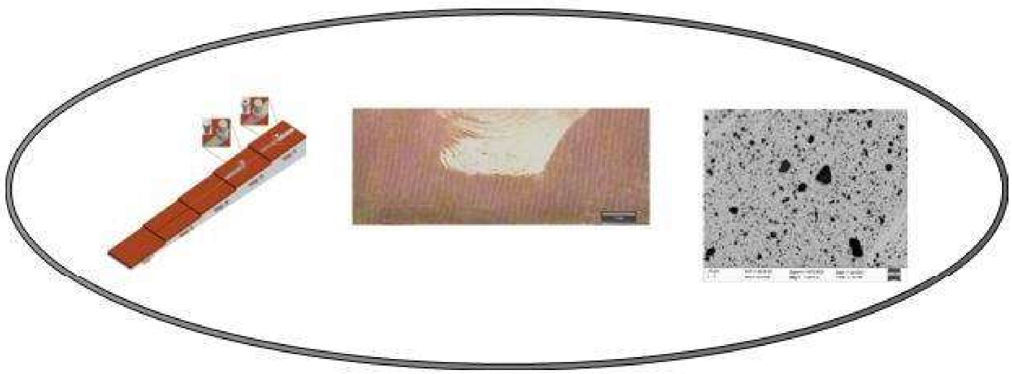

Results of this chapter have been published in

Kumar, H., Prasad, R., Srivastava, A., Yusufzai, M.Z.K. and Vashista, M. ‘Utilisation of Industrial waste (Fly ash) in the synthesis of copper-based surface composite through friction stir processing route for wear applications’, Journal of Cleaner Production (2018) 196:460-468.

5.1 Introduction

As mentioned previsiouly, although metal matrix composites exhibit superior properties in comparison of monolithic materials, due to higher processing cost their applications are limited. The processing cost of the MMCs can be reduced significantly by using industrial and agricultural wastes as reinforcement. Moreover, using these wastes as reinforcements will not only reduce the cost of MMCs but also reduce the ill environmental effects generated by them. Therefore, keeping that in mind present chapter studies focusses on the utilisation of FA particles as reinforcement in copper matrix in order to fabricate Cu/FA surface composite by friction stir processing. The performance of the composite was assessed in terms of microstructural features, mechanical, tribological and electrical behaviour. Microstructural features of prepared CMC revealed uniform and homogeneous dispersion of FA particles in the SZ. Defects such as porosity, segregation, clustering and variation in particle dispersion were not observed. No appreciable change in shape and size of reinforced FA particles were observed after FSP. FSP of the composite resulted into fine and equiaxed grain structure of the matrix. The incorporation of FA enhanced the mechanical and tribological properties of the composite. The electrical conductivity and ductility of the composite decreased as compared to base copper. Due to the negative environmental impact of FA, leaching test of the fabricated composite was also carried out.

5.2 Experimentation

5.2.1 Materials

Details of the materials (Copper and FA) used for present investigation are detailed in chapter 3, section 3.2.

5.2.2 Fabrication

The procedure followed for the preparation of Cu/FA surface composite by FSP is detailed in chapter 3, section 3.3.

5.2.3 Characterisation

Various characterization methods employed for the performance assessment of the fabricated composite were optical microscopy, scanning electron microscopy, electron back scattered diffraction, Vickers microhardness tester, XRD, tensile test, wear test and electrical conductivity measurement. The detailed procedures of all the characterizations are given in chapter 3, section 3.5.

5.3 Results and discussion

5.3.1 The macrostructure of the FSPed Cu/FA composite

Fig. 5.1 depicts the macroscopic top view of the fabricated Cu/FA surface composite.

Figure 5. 1 The surface appearance of FSPed Cu/FA surface composite

FSP of materials generally produces ring like textures on the surface of the FSPed plate. In the present case, various ring-like patterns are visible (Fig. 5.1) on the surface of the FSPed Cu/FA surface composite. It can also be observed that there are no depressions or discontinuities visible on the surface of the FSPed plate. The process parameters chosen for the investigation was optimized after various trial runs. The ring-like textures on the surface of the FSPed plate having no defects on the surface clearly justify the effectiveness of the chosen process parameters. The clean surface appearance with sound ring-like textures is necessary to produce defect-free composites by FSP. FSPed surface having defects on the surface accompanies corresponding defects in the SZ of the fabricated composites. In

FSP/FSW, tool rotates and travel against the workpiece and due to the relative motion between the tool and sample frictional heat generates. Material softens and deformed due to temperature rise and stirring action of the tool respectively. Hence the softened and plastically deformed copper moves from advancing side of the tool to retreating side of the tool. Due to the simultaneous motion of tool in linear and rotational direction ring-like surface pattern forms. The cross-sectional macrostructure of SZ of the Cu/FA composite is depicted in Fig. 5.2.

Figure 5. 2 The cross-sectional macrostructure of FSPed Cu/FA surface composite

The SZ area where composite formation has occurred is quite clearly visible from the macrograph. The initially machined groove for particle filling has completely disappeared which ascertain that the composite fabrication is completed and the severely plasticized copper flow was continuous. No macrostructure defects such as worm holes and tunnels were evident which further validate the chosen process parameters. The absence of defects can be ascribed to sufficient flow of plasticized copper from advancing side to retreating side, causes the grooves to collapse and mixes the packed FA particles with the plasticized copper finally leading to the formation of the defect-free SZ, namely the Cu/FA composite. The width at the top surface of the stir zone is larger than the width at the bottom of the stir zone. The reduction in width of the SZ from the top surface to bottom surface is believed to be because of material flow nature during FSP. Two modes of material flow exist during FSP of materials (Kumar and Kailas, 2008). The shoulder and pin of the tool affect the material flow differently which is commonly termed as shoulder driven and the pin is driven respectively. The resultant dimension of material flow changes from the top surface of SZ to the bottom of SZ. Shoulder driven material flow is more dominant up to a certain depth of the SZ and after that pin driven material flow comes in to picture. That's why the width of the stir zone is more at the top as compared to that at the bottom. Moreover, it can be also observed that the SZ is asymmetric about the rotational axis of the tool. It is believed that single pass FSP/FSW produce asymmetry material flow which leads to asymmetry in macrostructure of the SZ (Rao et al., 2013). Some researchers have reported that this asymmetry in macrostructure of SZ can be eliminated by multi-pass FSP by reversing the tool rotation after every pass (Liu et al., 2014). Similar studies on composite fabrication by FSP have been reported in which symmetry in macrostructure of SZ was observed in a single pass of FSP (Dinaharan et al., 2017a, Dinaharan et al., 2017c, Saravanakumar et al., 2017).

5.3.2 Microstructure of the FSPed Cu/FA composite

Fig.5.3 shows the SEM micrograph of the fabricated Cu/FA composite at different magnifications.

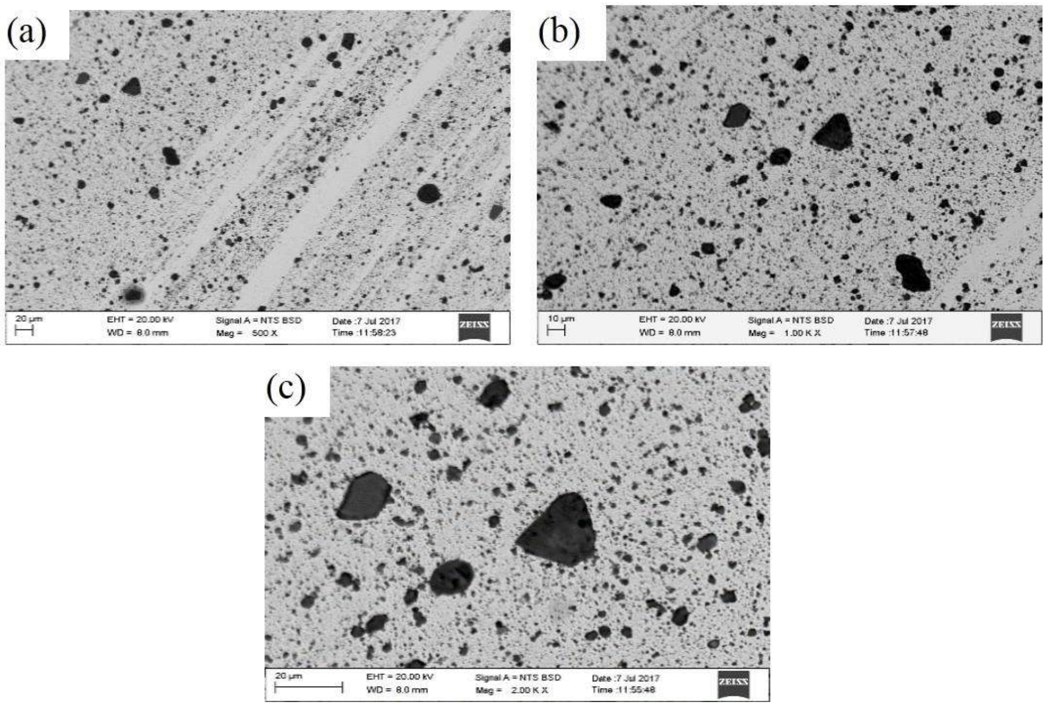

Figure 5. 3 SEM micrograph of SZ of the composite at different magnifications

The micrographs clearly display the characteristics and nature of dispersion of the reinforced FA particles. FA particles are dispersed all over the SZ area. The particles are fairly separated from each other i. e. with inter-particle distance. No regions are visible which is unreinforced or crowded with particles. Therefore, we can say that the FA particles have been dispersed homogeneously in the SZ of the fabricated Cu/FA composite. The frictional heat developed during FSP plasticize the copper. Because of the rotatory motion of the tool, compacted FA particles in the grooves were dispersed in plasticized copper. The extent of rotation decides stirring action of the tool which mainly depends on the process parameters. In FSP, there are many process parameters like rotational speed, welding speed, tool tilt angle, plunge depth etc. which influence the particle distribution. Out of all mentioned parameters, rotational and welding speed is most influencing processing parameters. An increase in rotation speed leads to better dispersion of particles in the matrix whereas, an increase in traverse speed reduces the stirring action of the tool and hence improper particle dispersion and clustering is observed (Sathiskumar et al., 2014). So in the present investigation, uniform and homogeneous distribution of FA particles are because of proper selection of rotational speed and traverse speed. In melt based processes, particles tend to arrange themselves along the grain boundaries which is known as segregation, which can deteriorate the mechanical properties of the composites. Segregation is generally encountered in case of melt-based processes because of solidification induced factors. Since FSP is a solid state based process so solidification induced factors did not play any role here. In FSP particles are not free to move like melt based processes. Particles movement in case of FSP is controlled by the mechanical action of the tool only. Hence particles are unable to arrange themselves constantly with zero or little interspacing. In addition to particle distribution, particle-matrix interface plays important role in determining the physical and mechanical properties of the fabricated composite. So to have the clear microstructure of the FA/Cu interface SEM micrograph of the fabricated Cu/FA composite of SZ at higher magnification was observed. It can be observed that the interface between FA and Cu has no interruption. The bonding is excellent with no pores at the interface. The absence of any defects at the interface is due to a smaller size and smooth surface of the reinforced FA particles which allowed smooth flow of plasticized copper all over the FA particles and resulted into defect-free interface. This result contradicts the results reported by previous researchers where they observed pores around reinforcements. For Example, (Akramifard et al., 2014) and (Sabbaghian et al., 2014) observed pores around SiC and TiC particles respectively in copper matrix composite fabricated through FSP. FSP of composite lead to change in shape and size of the reinforcements observed by various researchers (Sharma et al., 2015, Salih et al., 2015, Avettand-Fènoël and Simar, 2016). Due to FSP, materials experienced high strain rate because of the collective impact of frictional heat and rotating tool. Ceramic particles being brittle in nature could not deform plastically compared to metallic materials. So they undergo fragmentation during FSP. In the present work, there is no major change in the size and shape of FA particles before (Fig. 3.2 b) and after FSP (Fig.5.3 b). This can be explained as follows:

The initial size of the FA particles was small. A smaller particle does not offer high resistance to the flow of plasticized copper compared to a bigger ceramic particle. Secondly, there are no sharp corners in the FA particles. Sharp cornered portion of ceramic particles breaks away easily due to stress concentration. Further, most of the FA particles exhibit a smooth contoured spherical shape. This feature allows easy flow of plasticized copper without impingement on FA particles avoiding fracture.

Fig. 5.4 shows the optical micrograph of fabricated Cu/FA surface composite at various locations of stir zone.

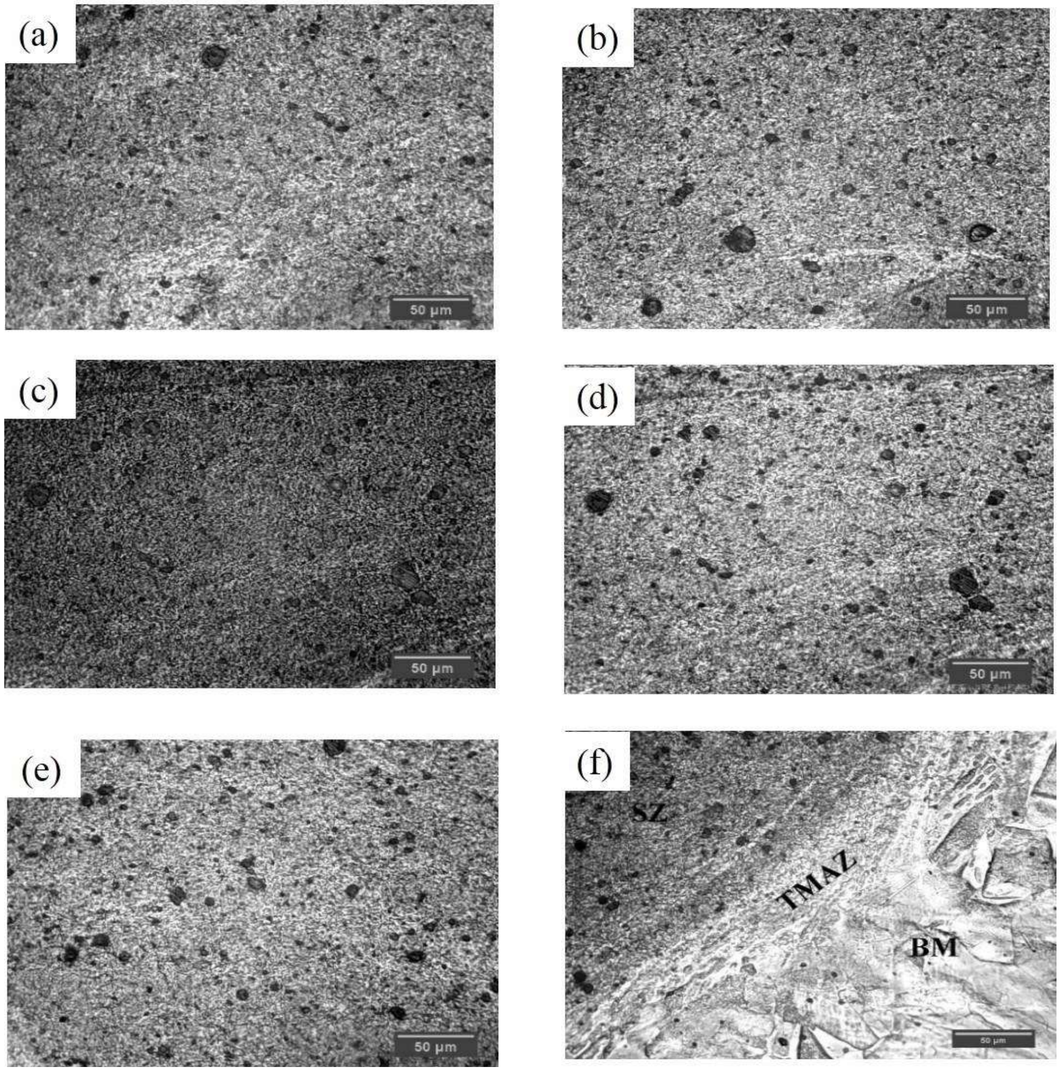

Figure 5. 4 Optical micrograph at various locations within SZ of the composite (a) towards advancing side at the top (b) towards retreating side on the top (a) at the centre towards advancing side (d) at the centre towards retreating side (e) towards advancing side at the bottom (f) Interface

In Fig. 5.4 (f), the base metal (BM), thermally mechanically affected zone (TMAZ) and stir zone (SZ) can be clearly seen. The base metal is recognized as the area unaffected by the frictional heat and plastic deformation suffered by the processed plate during FSP. The interface between BM and TMAZ can be observed in Fig. 5.4 (f). Thermally mechanically affected zone is recognized by the region having elongated grain structure in the direction of material flow. The region adjacent to the stir zone is the TMAZ, can be seen in Fig. 5.4 (f). The SZ is characterized by a region having equiaxed and fine grain, as evident from Fig. 5.4 (a)-(e). The heat energy produced during FSP due to frictional heating and plastic deformation was sufficient for the recovery of the grains but due to insufficient strain rate dynamic recrystallization did not happen (Mishra and Ma, 2005). So, grains remain elongated in TMAZ which is evident from Fig. 5.4 (f). The heat affected (HAZ) zone was not observed in the micrograph as can be seen in Fig. 5.4 (f). The HAZ is observed in FSP due to heat transfer in the lateral direction. Since the heat transfer rate varies directly with the cross-sectional area, materials having higher thermal conductivity and relatively lower thickness suffers from HAZ during FSP. Since in this investigation copper plate used was relatively thick (6 mm) and the backing plate used was of copper, the heat transfer rate along depth was higher as compared to the heat transfer in lateral directions. Therefore HAZ was not observed in this investigation. The onion rings formed during processing of Cu/FA can be observed from the macrograph (Fig. 5.2). This can be attributed to inadequate mixing of plasticized copper in vertical and rotatory direction.

The variation in the distribution of reinforced particles is not evident from the micrograph as can be observed from Fig. 5.4 (a)-(e). This can be attributed to proper selection of process parameters which caused sufficient plasticization of copper so that mechanical action of tool could occur. Some studies have been reported on variation in distribution due to improper selection of process parameters (Sathiskumar et al., 2014). Liquid metallurgy based processes suffer from variation in distribution due to the density difference between matrix and particulate. The density difference forces the particulates to either float on the top or sinks in the bottom and results into variation in the dispersion.

The grain structure of the fabricated Cu/FA composite was investigated by EBSD analysis. The EBSD micrograph of the composite has been shown in Fig. 5.5.

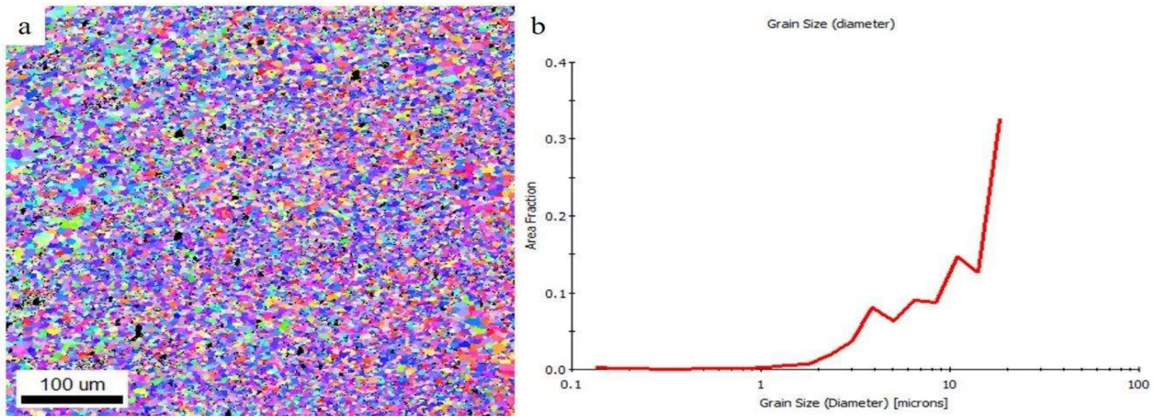

Figure 5. 5 (a) EBSD map and corresponding grain size distribution of particles (b)

The microstructure of the composite is characterized by fine and equiaxed grains. The average grain size was estimated to be 7 µm whereas, it was 108 µm in case of base copper. The grain refinement during FSP occurs due to high strain rate, frictional heating and pinning effect (Sharma et al., 2015). Dynamic recrystallization caused by high strain rate and frictional heating resulted in equiaxed fine grains. Severe plastic deformation generates a large number of nucleating sites for new grains to develop and reduce grain growth. Due to the pinning effect, the movement of grain boundaries is pinned by the particles reinforced which reduce the grain growth rate caused by dynamic recrystallization.

5.3.3 Quantification of particle distribution of Cu/FA composite

The quantification of dispersion uniformity was done using the Lorenz Curve. The position and area of each particle were considered. SEM micrograph was binarized by Image J. The data were acquired by quadrant method by dividing the image into 20 equal sized quadrants having an area approximately 3162.54 μm^2 (Fig. 5.6 b).

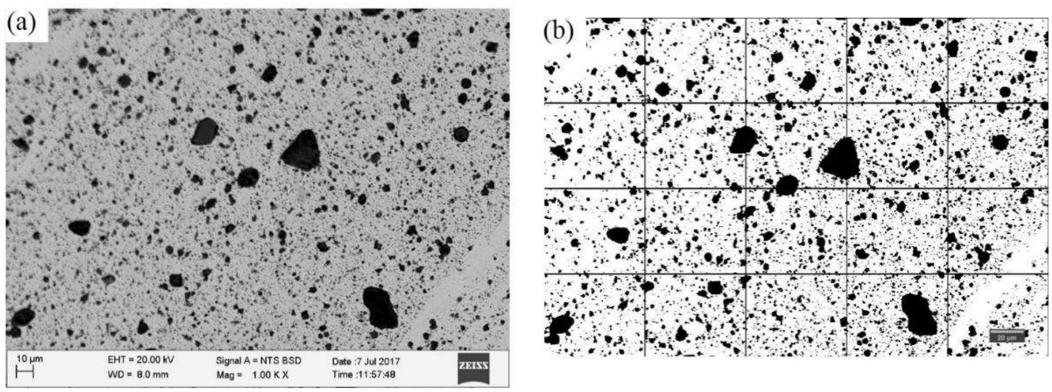

Figure 5. 6 SEM micrograph of fabricated composite Cu/FA and its binarized image (b). The dark spots are FA particles and white spots are a matrix

Further, the arithmetic mean of the area occupied by each particle was also calculated. The relation between equality line and a Lorentz curve representing partial homogeneity was used to find quantification of the degree of distribution and homogeneity (Ceriani and Verme, 2012) shown in Fig. 5.7.

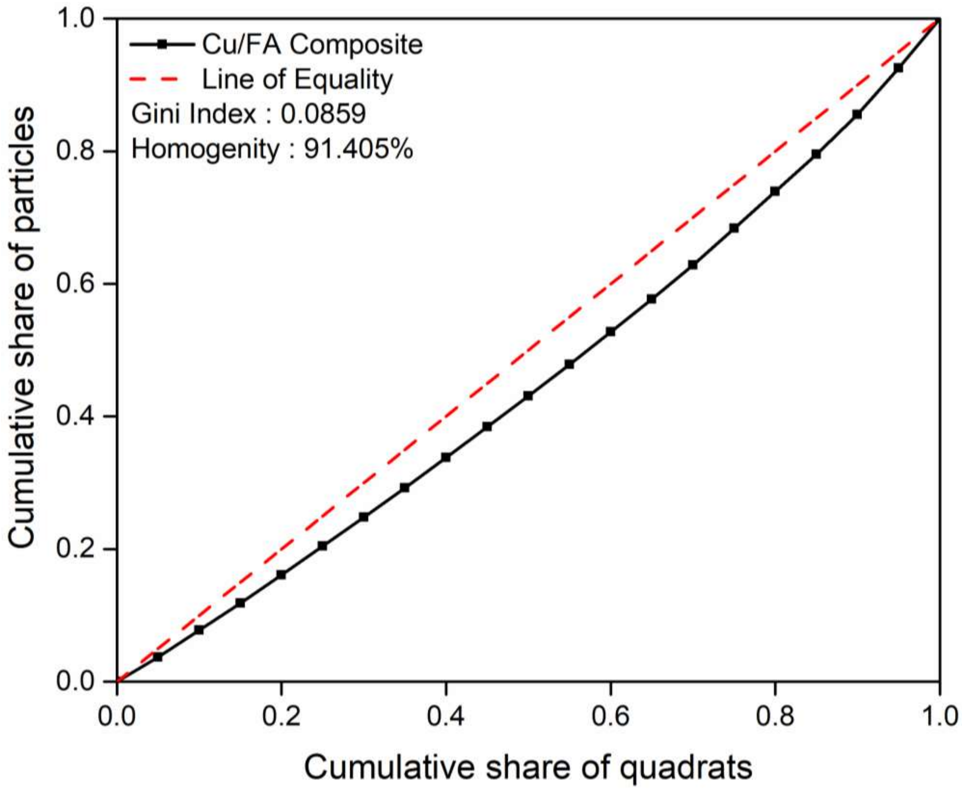

Figure 5. 7 Homogeneity curve for FA particles

The homogeneity was calculated using the following equation

$$H = 1 - G$$

Where H is homogeneity and G is Gini Index (Ceriani and Verme, 2012, Rossi et al., 2014). The Gini Index was chosen for the calculations since it was conceived as a measurement of the distribution inequality of a given attribute. Since the value of the 'G' is related to the area below the Lorentz curve (A_L) by G = 1-2A_L, the homogeneity value is thus determined by H = 2A_L. Homogeneity curve for particle distribution is very close to the Line of equality. The Gini Index and homogeneity value were estimated to be 0.0859 and 91.405% respectively. It clearly indicates that FA particles were uniformly dispersed in the copper matrix.

Fig. 5.8 shows the XRD pattern of the fabricated Cu/FA composite.

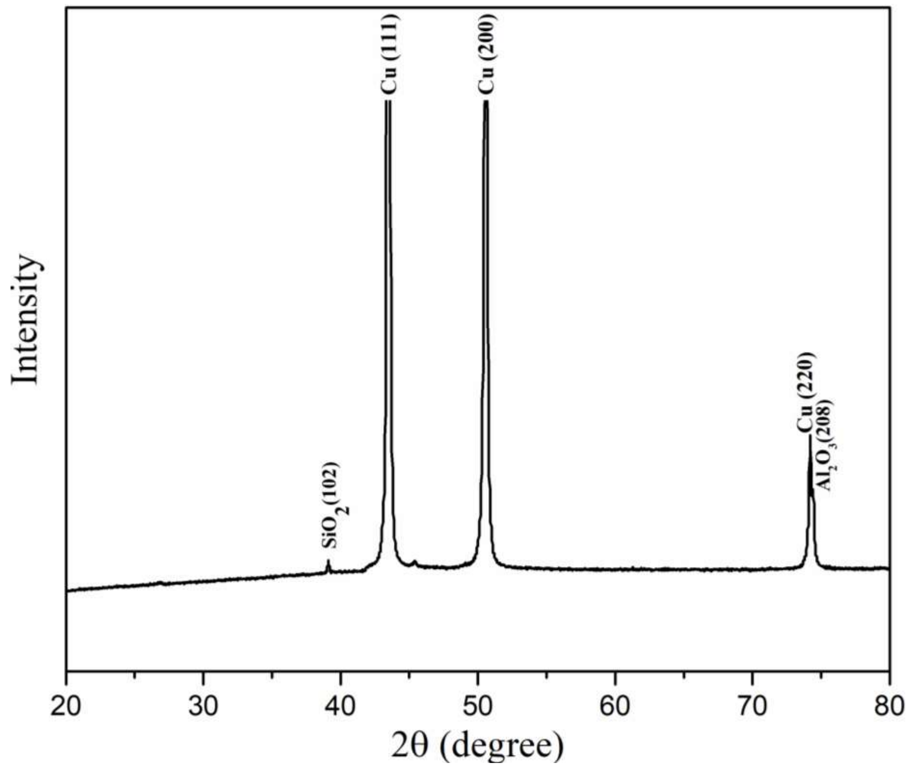

Figure 5. 8 XRD pattern of fabricated Cu/FA surface composite

The Cu, SiO_2 and Al_2O_3 peaks are observed from the graph. No other peaks corresponding to intermetallics or reaction products were present. The intermetallic or reaction products were not found in the XRD pattern, this can be attributed to insignificant heat generation during FSP for interfacial reactions to occur.

5.3.4 Mechanical properties of FSPed Cu/FA composite

The mechanical properties (microhardness and tensile strength) of the fabricated Cu/FA composite was evaluated by Vickers microhardness tester and tensile strength testing machine respectively. Further, the fractured samples resulting from tensile testing were observed by SEM to have a detailed understanding of the mechanism involved during fracture.

5.3.4.1 Microhardness

Fig. 5.9 represents the microhardness of the fabricated Cu/FA composite. As can be seen, the hardness of the composite improved significantly.

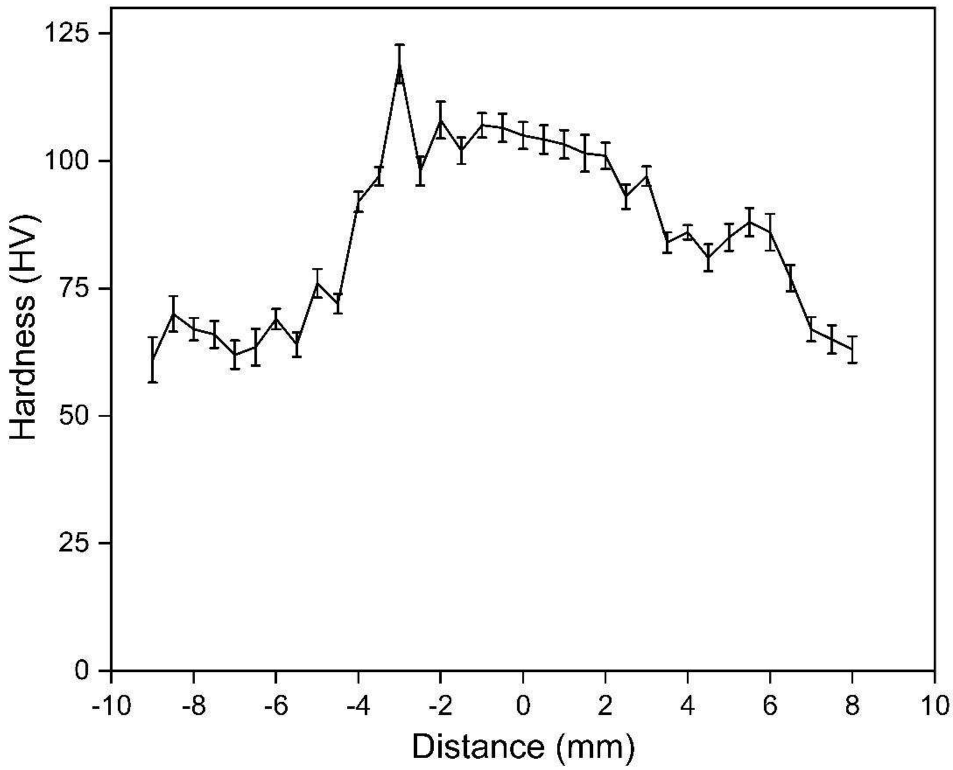

Figure 5. 9 Microhardness profile of FSPed Cu/FA surface composite

The average hardness value of the composite was observed to be 105±2.9 HV whereas, for Cu, it was 67±1.8 HV. According to the hall-pitch relation, strength and hardness are inversely proportional to grain size. The fabricated surface composite displayed equiaxed and fine grains as can be observed from Fig. 5.4 (a)-(e). The reinforced particles were dispersed uniformly in the stir zone as can be observed from Fig. 5.4 (a)-(e). The uniform and homogeneous distribution led to Orowan strengthening. Therefore the microhardness of the fabricated surface composite increased. The thermal mismatch and varied nature of deformation behaviour of matrix and particulate generated additional dislocations (Bauri et al., 2015). The higher dislocation density created further hindrance to dislocation movement and resulted in increased hardness.

5.3.4.2 Tensile Properties

The stress-strain curve for Cu/FA surface composite and base copper have been shown in Fig. 5.10.

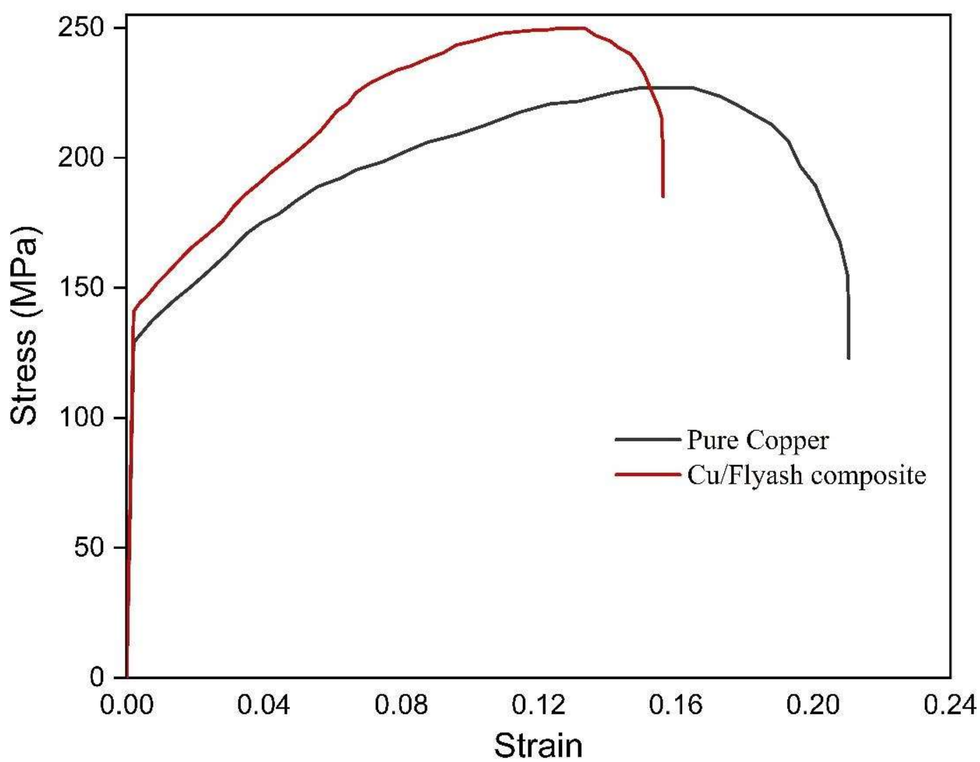

Figure 5. 10 Stress-strain curve of base copper FSPed Cu/FA surface composite

It can be observed that the ultimate tensile and yield strength of the composite has improved with respect to base copper. The UTS and YS for the composite were estimated to be 249±5.8 MPa and 141±4.9 MPa respectively whereas, the value for the same was 227±2.8 MPa and 129±2.6 MPa in the case of base copper. The improvement in strength of the fabricated composite may be attributed to grain refinement, uniform distribution of FA particles in copper matrix along with excellent bonding and generation of additional dislocations due to thermal mismatch between FA particles and copper matrix. The FSP of composite led to drastic grain refinement due to dynamic recrystallization which improves strength according to Hall-Petch relation. As mentioned earlier, FA particles dispersed uniformly in the copper matrix and there was no interruption at the interface that means interfacial bonding was excellent. The tensile load applied were transferred effectively from the matrix to strong FA particles by interfacial shear strength and improved strength of the composite. The large difference in coefficient of thermal expansion between copper and FA generates additional dislocations which create a hindrance for dislocation movement led to improvement in strength.

The percentage elongation in case of Cu/FA composite has decreased with respect to base copper. The reduction in ductility of the fabricated composite may be associated to improved hardness and strength. The reinforced FA particles resist the passage of dislocations by either creating stress field in the matrix or by inducing large differences in the elastic behaviour between the matrix and particulate (Barmouz et al., 2011a) and thereby decrement in ductility.

5.3.4.2.1 Fractography

Fig. 5.11 shows the fractured surface of the tensile tested Cu/FA composite.

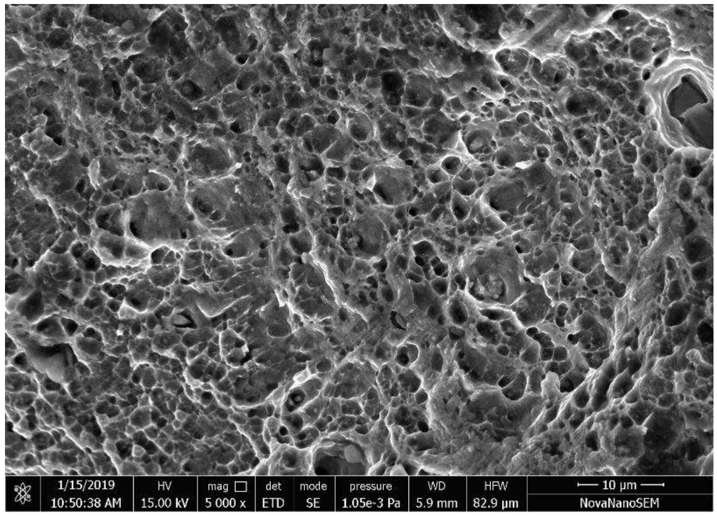

Figure 5. 11 Tensile fractograph of FSPed Cu/FA surface composite

It can be observed that the dimples are narrow and shallow and getting flattened. That means the ductility of the fabricated composite has decreased as compared to pure copper. This is in good agreement with the result obtained analytically through tensile testing. The reduction in ductility in the case of Cu/FA composite can be attributed to their higher hardness and strength which deprived their ability to be deformed plastically.

5.3.5 Tribological behaviour

Fig. 5.12 shows the variation in wear loss of the fabricated Cu/FA surface composite and as received commercially pure copper.

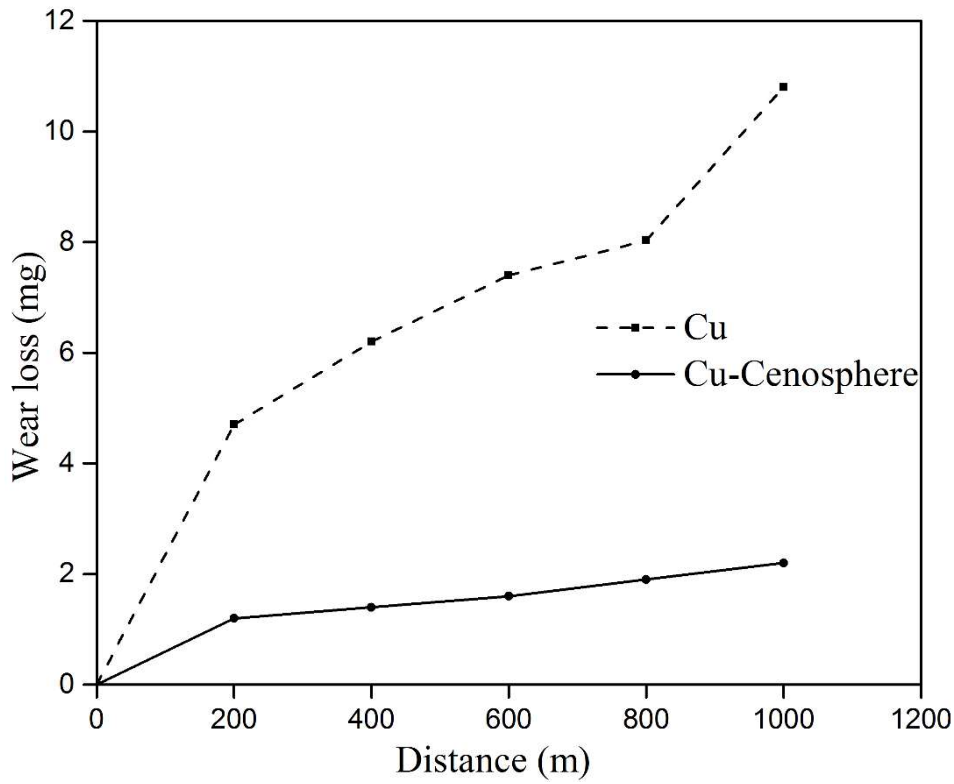

Figure 5. 12 Wear loss v/s distance profile of base copper and FSPed Cu/FA composite

It can be observed that the composite exhibited less wear loss as compared to the unprocessed copper. The wear rates were observed to be 0.22×10^{-5} g/m and 1.08×10^{-5} g/m for the composite and pure copper respectively. It was observed that there were almost 2-6 folds decrease in wear loss of Cu/FA composite as compared to unprocessed copper. The increase in wear loss showed an almost linear relationship with time in case of Cu/FA composite. Fig. 5.13 shows the variation of the friction coefficient of pure copper and fabricated composite.

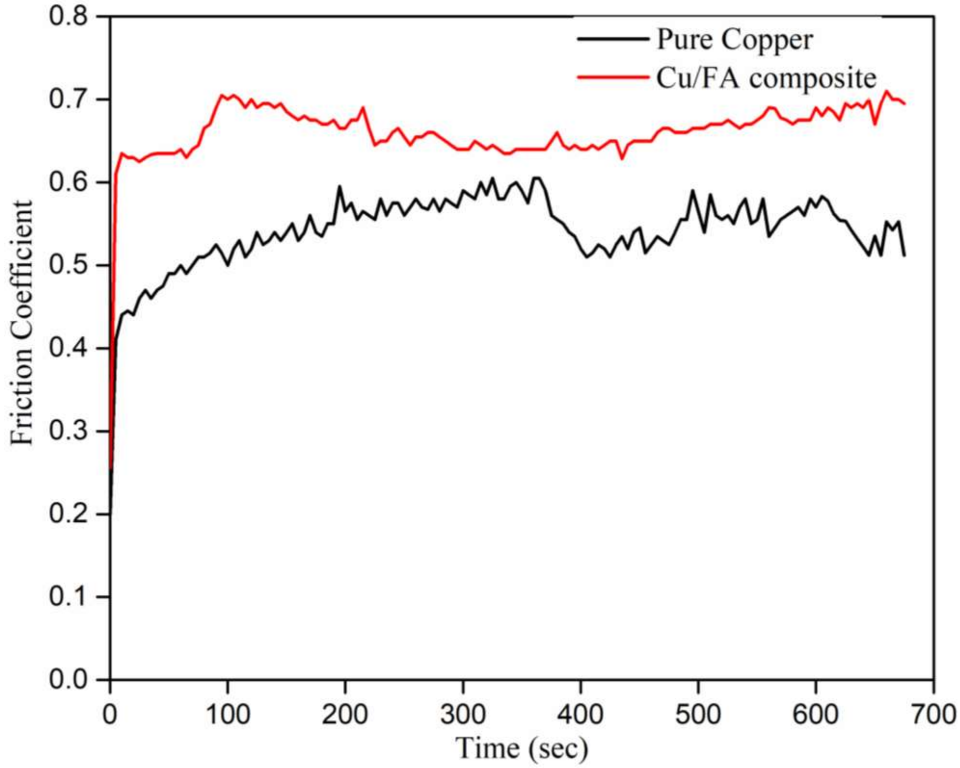

Figure 5. 13 Friction coefficient variation with time

It was observed that Cu/FA composite showed a high friction coefficient as compared to unprocessed copper. The fluctuations in case of pure copper were also more as compared to composite. The friction coefficient of Cu/FA composite didn't change much with time but for pure copper, it initially increased and after some time it decreased.

In case of pure copper, asperities from the counter surface penetrated easily due to its low hardness and resistance to sliding was less due to the soft and ductile nature of copper. The hardness of Cu/FA was more as compared to pure copper. Thus, the resistance to shearing increased. Hard FA particles penetrated the counter surface and increased the friction coefficient. Adhesion, although observed in both pure copper and Cu/FA composite, was predominant in pure copper. The stick-slip phenomenon caused by adhesion led to fluctuations in the friction coefficient of pure copper. Fig. 5.14 (a) and (b) shows the SEM images of worn surfaces of pure copper and Cu/FA composite respectively. Abrasion marks can be observed in Fig. 5.14 (a). Due to adhesion, some material from the copper was transferred to the counter surface as can be observed from Fig. 5.14 (a). FA particles on the surface of Cu/FA composite can be observed from Fig. 5.14 (b). A discontinuous thin film at the surface of the composite can be observed. Due to its discontinuity, it increased the friction coefficient. The wear loss of Cu/FA composite was less as compared to pure copper due to its more resistance to abrasion. Due to the high hardness of Cu/FA composite, the surface was hard to cut or abrade. However, the abrasion resistance of pure copper is low. Thus wear loss of pure copper was more as compared to Cu/FA composite. It was observed that wear loss of Cu/FA composite didn't increase much with sliding distance. However, wear loss of pure copper increased with sliding distance. In the case of pure copper, adhesive wear was prominent due to which material from the surface wore out in the form of lumps as the sliding distance increased. The lump material ejection can be observed in Fig. 5.14 (a).

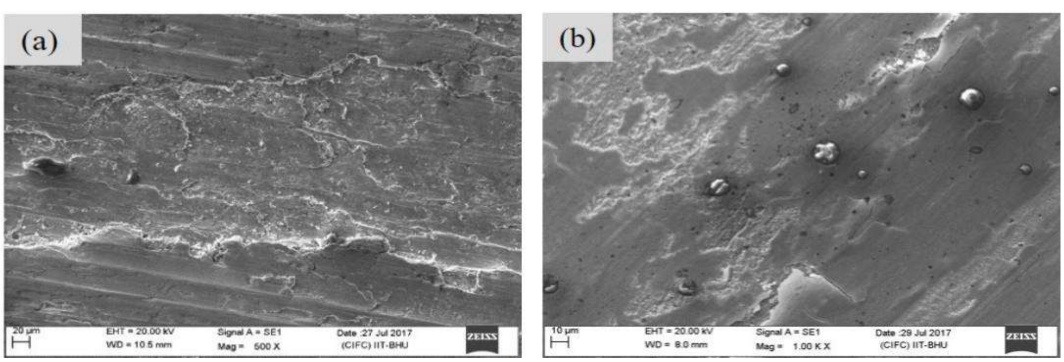

Figure 5. 14 SEM micrograph of the worn surface (a) Pure Copper (b) Fabricated Composites

5.3.6 Electrical conductivity

The electrical conductivity of pure copper and Cu/FA composite were estimated to be 99.93% IACS and 77.48% IACS respectively. The drop in electrical conductivity of the fabricated composite is approximately 23 %. The depreciation in electrical conductivity may be attributed to the non-conductive nature of the reinforced FA particles. Further, the more scattering of conduction electrons due to the surface, grain boundaries, point defects and dislocations contributed in a decrement of electrical conductivity of the composite. The FSP of Cu/FA composite produce fine grains which increased grain boundaries led to decreased electrical conductivity. Reinforced FA particles act as impurities in the composite. The additionally generated dislocations due to thermal mismatch between FA and copper affect electrical conductivity. The electrical conductivity exhibited by Cu/FA in the present investigation is comparable to the previous studies (Jeong et al., 2009, Sun et al., 2015, Wang et al., 2016a). Therefore its application will not be affected by the decrease in electrical conductivity.

5.3.7 Leaching test

Results of leaching test for FA and fabricated composite has been shown in Table 5.1.

Table 5.1: Results of leaching test by the standard shake method for extraction of solid waste with water (ASTM-D3987) in ppm

Sample	Al	Cu	Zn	Mn	Si	Cr
Fly ash	12.549	0.2372	0.2091	0.4169	4.425	0.0068
Cu/FA composite	0.1291	48.8396	0.1083	0.1048	0.1012	0.0008

It can be observed that the concentration of leached out metals from the fabricated composite is far less as compared to the concentration of metals leached out from the FA.

5.4 Conclusions

In this investigation, an industrial waste (FA) was reinforced in commercially pure copper by friction stir processing route to fabricate copper-based surface composite. The effect of FA reinforcement on microstructure, microhardness, tensile strength, workability, oxidation and corrosion resistance, electrical resistance and wear properties were studied in detail. The composite was also studied for its environmental impact through leach test. The results obtained by the characterization indicate that FA is the potential reinforcement for the fabrication of copper-based surface composite in place of other costly ceramic particulates. This not only reduces the cost of the final product but also reduces the environmental impact compared to the related composites. The process (FSP) which is a green technology is suitable for fabrication of copper-based surface composites. The results obtained can be summarized as:

- Uniform dispersion of FA particles was obtained using FSP to fabricate copper-based surface composite.
- The coarse and elongated grains of pure copper with a lot of twins were refined and become equiaxed as result of FSP. The combined effect of grain refinement and reinforcement of hard FA particles increased surface hardness (67 H V to 105 H V) which in turn increased the resistance to abrasion.

- Filler/Matrix interface was clean with excellent bonding. No interfacial products or intermetallics were observed in the XRD pattern.
- The friction coefficient of Cu/FA composites was more as compared to pure copper due to its increased resistance to abrasion and adhesion.
- The wear loss observed was higher in case of as received commercially pure copper as compared to Cu/FA composite.
- The fabricated composite showed improved oxidation and corrosion resistance along with an increase in tensile strength.
- The workability and electrical conductivity of the fabricated composite decreased as compared to pure copper. The reduction was almost 6% for workability and almost 23% for electrical conductivity.
- The leached out metals showed that the fabricated composite will not much affect the environment.

Therefore FA can be used as an effective reinforcement in copper for wear applications. So on the basis of result obtained in present case we can conclude that FA may be used as potential reinforcement in light metals such as aluminium, copper, magnesium and titanium for properties enhancement. It will not only reduce the cost of MMCs but will increase the options for utilization of FA and also reduce the environmental threats imposed by FA.