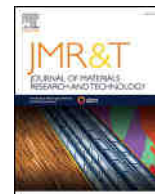




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Synergistic mechanisms of fly ash reinforcement on the mechanical characteristics, deformation behaviour, grain refinement, and grain boundary in friction stir processed copper matrix composites

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ABSTRACT

Fly ash is an attractive reinforcement for copper and its alloys. It is a by-product produced from the combustion of coal in thermal power plant. This solid waste produced massively across the globe is considered as a serious threat to the environment. Researchers across the globes are looking for its utilization. Copper matrix composites reinforced with fly ash instead of costly hard ceramics are one of those applications. However, it is technically challenging to incorporate fly ash in copper matrix uniformly and homogeneously via liquid-based processing techniques due to large density gradient. In the present study, efforts are being put to fabricate fly ash reinforced copper matrix composites by friction stir processing (FSP) and analyze its performance for microstructure and mechanical properties. Microstructural features were depicted by optical microscopy, scanning electron microscope and electron backscattered diffraction across cross-section. Hardness was observed across cross-section of the processed plate for plotting hardness profile. Tensile test was conducted on base and processed plate for strength. The composite exhibited uniform and homogeneous sputtering of fly ash particles in the copper matrix without agglomeration of particles irrespective of the position in stir zone which may be attributed to the solid state nature of the process. No disturbance in terms of voids or irregularities was detected at the interface which shows excellent integrity at the interface. Substantial grain refinement for the copper matrix along with fracture of the reinforced fly ash was observed. It was also observed that the hardness and tensile strength of the composite improved but ductility decreased. The mechanism responsible for hardness and strength improvement may be attributed to grain refinement and uniform dispersion of fly ash particles. Reduced ductility may be due to the presence of fly ash particles which brought brittleness to the composite.

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1. Introduction

Copper is a valuable metal that is commonly used in many different industrial applications and hence has been explored extensively [1–3]. It has better resistance to air corrosion [4], increased electrical and thermal conductivity, formability, and workability [5]. Its restricted use is caused by its low mechanical strength, hardness [6], wear resistance [7], and thermal stability, despite its extensive use [8]. To overcome these limitations, researchers reinforce copper with ceramic particles [9], which significantly improve its performance for mechanical [10] and wear properties [11]. These improvements establish copper metal matrix as a reliable material for use in a variety of applications, including water, marine [12], electrical, and thermal utilities [13]. Research has indicated that the incorporation of ceramic particles enhances some characteristics of copper; nevertheless, their dispersion may diminish the composite material's bulk properties [14]. Changes to the surface microstructure or composition may be taken into consideration in order to improve the surface-dependent qualities of hardness and wear resistance in copper. It has been discovered that hardness and wear resistance may be increased on the copper matrix's surface by adding ceramic particles, all without compromising bulk characteristics [15, 16]. Researchers employ a variety of techniques, such as thermal spraying, plasma arc melting, and laser beam melting, to modify surfaces substantially. Unfortunately, because these procedures frequently take place at high temperatures, the ceramic reinforcement particles and matrix material may react, which might lower the desired characteristics by causing harmful phases and intermetallic compounds to develop [17, 18]. A method that works below the matrix material's melting point must be taken into consideration in order to prevent these problems. For the development of surface composites and microstructure changes, Friction Stir Processing (FSP), a revolutionary solid surface modification technology based on the principles of Friction Stir Welding (FSW), is gaining popularity [19, 20]. Through the frictional heat produced by the revolving FSP tool, FSP works by plastically deforming the base material. Constant stirring causes the reinforcement particles to be mixed throughout the surface and undergo severe grain breakup.

Through the FSP process, researchers have successfully modified the surface of the copper matrix by using carbides, oxides, and borides. These efforts have produced positive results and encouraged the investigation of advanced ceramic particles [21–25]. While the increased expense of these ceramic particles has been a worry, they have proved beneficial in improving the characteristics of metal matrix composites. By using industrial and agricultural waste residues as reinforcement, such as fly ash, bagasse ash, egg shell ash, red mud, zircon sand ash, etc., the total processing cost of the composites can be decreased [26]. The total cost of the composites is significantly lowered by these leftovers from industry or agricultural. Furthermore, a significant portion of the negative effects caused by wastes, particularly fly ash, can be mitigated.

The need for energy is always growing. The scarcity of crude oil and natural gas has made it difficult to meet even the most basic energy needs. Large-scale energy-producing facilities have therefore begun to pay more attention to coal-based energy production techniques. Power plants employ pulverized coal to maximize energy extraction and achieve quick combustion of coal. FA is produced when coal burns quickly. The quality of the coal used determines how much FA is produced; Indian coal, for example, is of lower quality and has a high ash percentage (35–45 %) [27]. Only a small portion of the FA produced is used; the remainder is disposed of in landfills and ash ponds [28]. Soil pollution results from dumping in landfills because of the high salinity and harmful substances [29]. Due to its harmful effects on living things and massive global production, efforts are being made to use instead of dump. It has been utilized to make building materials, cement and concrete, ceramics, water treatment, and more. Additionally, not many findings on metal matrix composites have been published [30–33].

P. Balamurgan et al. [30] fabricated copper based composite by reinforcing fly ash by powder metallurgy technique and analyzed the

effect of compact pressure, sintering temperature and sintering time on mechanical and wear properties. The results showed with increase in process parameters density, strength, wear resistance and hardness increased. I. Dinaharan et al. [31] reinforced fly ash in three different matrixes (copper, aluminum and magnesium) by friction stir processing and studied its effect on microstructure and strength of the composite. The results showed excellent bonding between particles and the matrixes along with uniform and homogeneous dispersion throughout the stir zone. They reported almost two fold increment in hardness and substantial growth in strength. N. Vijaya Sai et al. [32] investigated preparation and properties of sintered copper-Tin composites containing copper coated or uncoated fly ash. It was observed that the copper coated fly ash composite had higher wear resistance. Kumar et al. [33] fabricated copper based surface composites by friction stir processing for wear applications. They reported very encouraging results for hardness and wear resistance. The hardness and wear resistance of the composites were almost equivalent to ceramics reinforced composites. They also conducted leach test to ascertain about the leaching effect of the composites fabricated and presented positive results.

The ductility and toughness of the material are adversely affected when hard reinforcements are included into the copper matrix [34]. Because of this, a number of researchers have opted to use surface-only reinforcement for hard materials rather than bulk reinforcement; these materials are known as surface composites. This idea contributes to the development of a robust, rust- and wear-resistant surface without sacrificing the matrix body's volumetric characteristics. One surface composite production technology that happens considerably below the melting point of the constituent materials is the Friction Stir technique [35]. Researchers and industry have taken notice of FSP because it alters the microstructure of the material, increasing ductility without compromising strength [36]. Furthermore, FSP is a more dependable and cost-effective method for fabricating surface composites.

According to the assessment of the literature, copper composites have a lot of advantageous qualities, with the exception of a higher total cost due to the expensive ceramic reinforcements. Thus, the goal of the current study is to create a new, highly strong copper composite using fly ash as a suitable substitute for other reinforcement materials. The strength of fly ash-incorporated copper composites has not been thoroughly examined in the limited studies that have been done on the subject. Because the addition of hard particles decreases ductility, the FSP technique will only allow reinforcement to be applied to the surface of copper. Applying the FSP technique improves copper's surface qualities without changing its bulk properties. Therefore, the goal of the proposed research is to use the FSP technique to create a high strength Cu-fly ash composite and to thoroughly analyze its properties.

2. Experimentation: materials and methods

The industrial waste fly ash in particle form of average size range $2.65 \mu\text{m}$ was used as reinforcement for the current study (mentioned in Table 1). The grain size of the reinforcement and copper base was estimated by ImageJ software. Copper in rolled plate form was for matrix. The SEM image of the fly ash particle along with particle size distribution is given in Fig. 1.

Samples of dimension $200 \text{ mm} \times 100 \text{ mm} \times 6 \text{ mm}$ were machined from copper plate for experimental requirement. A known dimension groove (3.5 mm deep and 1.5 mm wide) was machine in the centre along the length of the plate. The groove cross-section was rectangular and its dimension was for 18 vol% of reinforcement. The groove was filled with particles and to ensure that it is tightly filled; plates were being shaken multiple times. The groove opening was closed with tool (pin-less), so that sputtering of particles during processing and hence wastage can be avoided during processing. Tool used in present experimentation is given Fig. 2.

$$\text{Volume fraction} = \frac{\text{Area of groove}}{\text{Projected area of tool pin}} \times 100 \quad (1)$$

$$\text{Area of groove} = \text{Groove width} \times \text{Groove depth} \quad (2)$$

$$\text{The projected area of tool pin} = \text{pin diameter} \times \text{pin length} \quad (3)$$

Finally it was processed for the composite fabrication. In current experimentation, FSW set-up used is presented in Fig. 3.

An axial load of 10 kN, traverse speed of 35 mm/min and 1150 RPM rotational speed was used. Tool was also tilted from the vertical by 2.5°. The process parameters were decided on the basis of literature and authors past experience [37–40]. The tool used for processing was super alloy IN718 in peak aged form [41]. Tool pin diameter was kept 6 mm and its length 4 mm keeping groove depth in mind. Tool shoulder was flat with 18 mm of diameter. The environmental conditions were kept normal during processing of the composite. The complete process of composite fabrication is schematized and is depicted in Fig. 4.

The specimens were machined according to different ASTM standards for the characterization. For microstructure, machined specimens were molded to hold it properly during disc and cloth polishing. Specimens were polished following ASTM standard E3-11 before etching with 40 g of chromic acid, 4 g of sodium sulphate, 3.4 ml HCL in 200 ml distilled water solution. Mitutoyo microhardness tester was used for hardness estimation of the samples. Processed plates were machined from top by 1 mm and then were polished properly before indentation. The indentation was captured along transverse section of the processed plate. Fair distance between the indentations was maintained. At every place three indentations were averaged to plot the hardness profile. The load and dwell time was kept 100 g and 15 s respectively. Hardness measurement was performed according to ASTM E–384 standard. Microstructural features were captured using optical microscopy (OM), scanning electron microscopy (SEM) and electron backscattered diffraction technique (EBSD). The SEM equipped with EDX was used for compositional analysis of the composites. Also, X-ray diffraction was employed for chemical validation of the reinforcement. The composite performance was assessed in terms of tensile test. The uni-axial tensile tests were performed at room temperature at a strain rate of $1 \times 10^{-3} \text{ s}^{-1}$. The tensile tested specimens were observed under SEM for fractography. The schematic of the tensile sample used is presented in Fig. 5. All the dimensions in the schematic is in mm.

3. Results and discussion

3.1. Macrostructure and microstructure

Fig. 6a presents macro top view of the processed plate captured via optical microscope. Ring like appearance without depression or discontinuity can be observed from the surface of the processed plate (Fig. 6a). Ring like feature on the surface of processed plate is characteristic feature of FSP and reflects the sound processing and is essential for defect free composite fabrication. The formation of ring like texture on the surface of the plate is because of simultaneous motion (linear and rotational) of the tool. During FSP, materials experience severe plastic deformation and stirring from advancing side of the tool pin to retreating side of tool pin which finally results in form of ring. Any discontinuity on the surface will reflect in the form of defects. Moreover, smooth surface without defects reflects the appropriate selection of process parameters during the process which could sufficiently plasticize the material for its easy movement from advancing side to

retreating side.

Fig. 6b is for cross-sectional macrostructure of the composite. As mentioned, particles were pre-placed in the groove initially for composite fabrication which is completely vanished. The groove prepared for compaction of particles are filled and mixed with the reinforcement is evident from the cross-section of the processed plate also (Fig. 6c). Furthermore, the macrostructure defects such as worm holes or tunnels are also not visible. This we can assume as the consequence of appropriate selection of process parameters. Material flow during processing depends on the plastic state of the materials. Here in the present case as there is no visible defect in the macrostructure and hence indicates the sufficient plasticization and stirring of material during processing which could promote smooth flow of material from advancing to retreating side and completed composite fabrication. The shape of the stir zone is basin like (Fig. 6b). The shape of stir zone is largely affected by tool shoulder and pin. Tool shoulder had higher diameter (18 mm) which affected the material largely at the top whereas, pin being less in diameter (6 mm) could affect only little and hence the shape is like basin wider at the top and narrow at the bottom. This is also characteristic features of the processed plate by FSP and validates the appropriateness of the variable chosen during the process. The shape of stir zone is almost symmetrical about the vertical rotational axis. It is not inherent to FSP but depends on the stirring and material transportation from advancing side to retreating side during the process. Symmetric shape indicates material deformation, stirring and transportation was sufficient during the process which further validates the correctness of the chosen variable.

Microstructural characterization of base copper and processed copper without reinforcement with the aid of optical microscopy is provided in Fig. 7.

As can be observed from the micrograph (Fig. 7a), grain is coarse and elongated at some places. The average size of the grains is larger. Elongation of grain may due to rolling process used during manufacturing of the plate. However, in processed plate, grain is fine and equiaxed. Also, the size of the grain has reduced drastically (Fig. 7b). The rolled copper plates used for experimentation had average grain size 34 μm and after processing it reduced to 2.7 μm which is huge in a single pass of processing. No other processes except FSP are capable of producing such drastic change in grain structure in a single pass. During FSP, mechanical deformation and temperature rise due to friction are bound to happen simultaneously. This synergetic effect of deformation and heat generation causes dynamic recrystallization and hence grain refinement. It is important to note that annealing effect should not dominate during the processing or else coarse grain is bound to happen and therefore selection of variables during the process becomes vital.

Fig. 8 depicts microstructural features of developed Cu surface composites developed by reinforcement of fly ash and captured through optical microscope.

It is evident from the microstructure; the fly ash particles are distributed throughout the copper metal matrix. The image was captured at the various sections of the processed plate to justify the fact that particles are everywhere. Moreover, the particles are almost placed equidistant from each-other i. e the particle free space is not visible in the micrograph. Processes where solidification involves, generally the scenario get reversed i.e. particle segregation along the grain boundaries are hard to control [42]. Segregation of particles in phenomena like stir casting is because of the difference in densities of the reinforcements and the matrix. In the present study, nothing like that was observed which is solely because the process is having solid state nature where

Table 1

The chemical composition of the fly ash particle.

Elements	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	K ₂ O	TiO ₂	CaO	P ₂ O ₅	MgO	SO ₃	Na ₂ O
wt.%	52.53	30.01	7.53	1.98	1.79	1.15	0.45	0.32	0.02	0.02

solidification did not occur. The process (FSP) involves severe plastic deformation of the matrix without melting. As matrix is not in molten phase, reinforcements are not free to move freely either on the top or in the bottom due to density difference. Hence, the developed composite is free from segregation or clustering of fly ash particles. Additionally, the particles are dispersed homogeneously in the copper matrix. Also, the complete stir zone is engulfed with the particles. Agglomeration of particles or area where particle is not present is rare in the microstructure. The processing parameters such as bed speed, tool rotational speed, tilt angle, axial load etc. play vital role in the dispersion of particles in the matrix [43]. So, safely it can be assumed that the chosen parameters for the present experimentation were appropriate. Homogeneous sputtering of particles in the matrix is essential for better performance of the composite including isotropic properties. Microstructural features of the composites were captured through SEM also (Fig. 9).

The nature of the particle's distribution is clear from SEM micrograph. Here also it can see that the particles are uniformly and homogeneously scattered throughout the matrix. There is no sign of segregation and clustering of particles in the matrix. Further, particle gradient is not in the micrograph. Although, the grain boundaries are not even clearly visible in SEM micrograph but due to absence of segregation the particle distribution may be assumed in-triangular. Possibility of some particles on the grain boundaries cannot be denied. FSP comes under the category of severe plastic deformation processes. During processing of the composites, matrix experiences severe plastic deformation and hence high strain field develops in the materials. Matrix being elastic in nature is capable of absorbing the stress but reinforcements suffer fracture due to their brittleness. It happened with fly ash particles also in the present investigation which can be observed by comparing Figs. 1 and 8. Owing to high strain field developed and stirring action of the tool particles which had irregular shape suffered fracture during processing. After closely observing the SEM micrograph of fly ash Fig. 1, it can be inferred that some of the particles are not having regular shape. During processing as material flow from advancing side to retreating side, the particles with irregular shape will resist the motion more and hence stress development will be more at those particles. Due to their brittle nature, they would not absorb the stress and got fractured. Another reason for fracture may be cited as high RPM of the tool during processing. The particles which came in contact with the tool get fractured. It is important to note that the fractured particles will have smaller size which is difficult to reinforce uniformly in the matrix by single pass of FSP. Still, particles agglomeration was not observed in the composite. Further, for the assessment of interface between the reinforcement and the copper matrix, SEM image at high magnification was captured (Fig. 9b). From the image it can be infer that the bonding between the matrix and the reinforcement is excellent

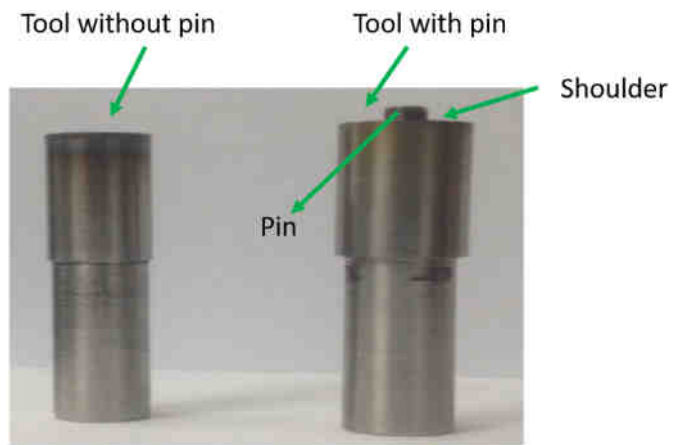


Fig. 2. Tool used during capping and processing.



Fig. 3. FSW Set-up used for experimentation.

because there are no irregularities or micro-pores at the interface. The interface is clean and no voids are there which further justify the strong integrity between fly ash and copper material. It may be attributed to

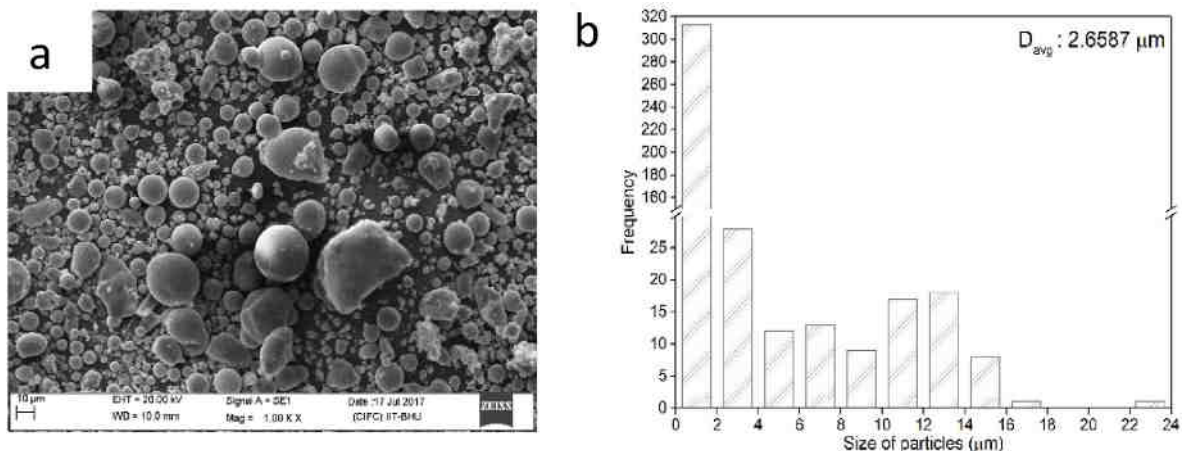


Fig. 1. SEM image of fly ash particles and its particle size distribution.

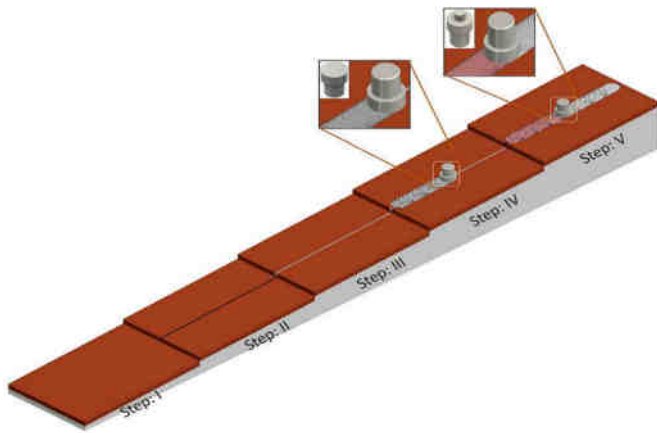


Fig. 4. Schematic of the process of composite fabrication.

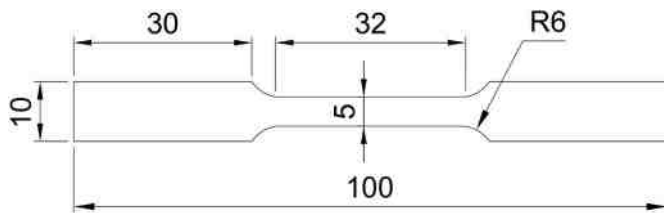


Fig. 5. Schematic of the tensile samples used for testing (All the dimensions in the schematic is in mm).

decent deformation of copper materials and its flow all over the fly ash particles and avoiding the formation of micro-pores at the interface.

The grain boundary maps of the copper matrix and produced composite Cu/fly ash is presented in Fig. 10.

The micrograph shows copper matrix experienced drastic grain refinement during composite fabrication. Also, the grains are fine and equiaxed. The estimated average grain size of the base copper was $34\ \mu\text{m}$ before processing which reduced to $1.7\ \mu\text{m}$ after fabrication. It clearly shows that the reinforcement of particles has further reduced the grain size of the matrix. The materials around the pin experience the highest deformation and heat exposure during processing. The high temperature and deformation at high rate lead to dynamic recrystallization and hence grain refinement. The reason for further grain refinement after

reinforcement may be firstly because the difference in thermal coefficient of fly ash and copper generated additional dislocations. These additional dislocations could provide more stored energy for ignition of dynamic recrystallization. Also, suppression of grain growth due to the presence of reinforcement may be seen as another reason for grain refinement. The fractured small particles of fly ash and its uniform dispersion in the matrix further encouraged the Zener pinning effect.

3.2. Compositional analysis

The compositional mapping of the composite was done through EDS mapping which is depicted in Fig. 11.

The EDS analysis conducted for the composite clearly shows that the fly ash particles are there in composite. Moreover, it is also obvious from the analysis that except matrix and reinforcement nothing is there. Absence of peaks of any discernible products from the analysis indicates that there was no initiation of interfacial reaction between the matrix and the reinforcement. This may be attributed to following two reasons: firstly, the arising heat was insufficient to initiate reaction between the reinforcement and the matrix due to low temperature rise and short processing time of the process (FSP). Secondly, the reinforcement is having high melting temperature far more than the maximum temperature reached in stir zone of copper during processing. These two factors strongly opposed the formation of any discernible reaction product.

4. Mechanical properties

4.1. Hardness

Fig. 12 shows the micro-hardness values obtained after indentation across the processed length of the plate.

The average hardness value for the base copper was estimated to be 66 HV whereas, the fabricated composite was found to exhibited higher hardness (114 HV). The hardness value has decreased slightly in the side region of stir zone. The reason for this may be annealing effect gone through by the plate after processing and also loss in dislocation density due to higher temperature. During processing of materials by FSP, grain refinement due to dynamic recrystallization and annealing effect both happens simultaneously. Depending upon the dominance either hardness will increase or decrease. The results showed that the hardness value in the composite is around 72 % higher than that of the base copper. The higher hardness due to the presence of hard fly ash particles brings various strengthening mechanism in to picture which will be discussed in next section. The variation in hardness in stir zone is

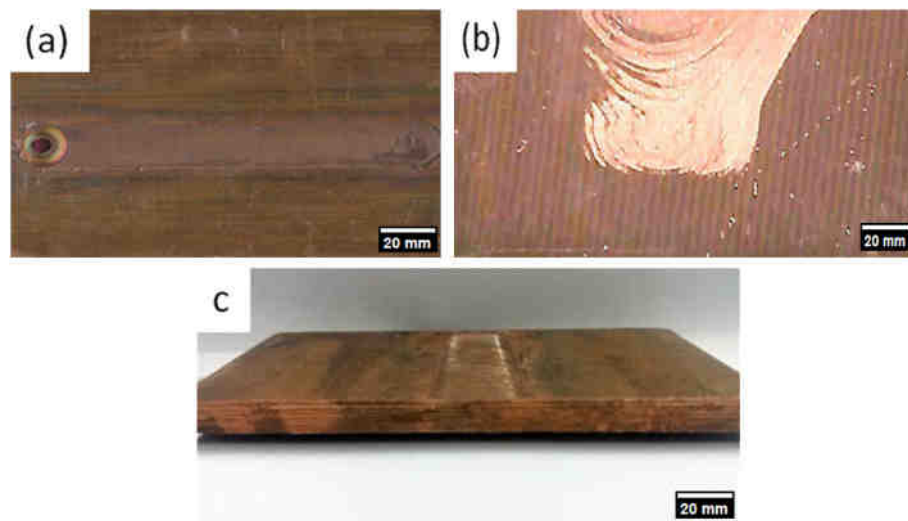


Fig. 6. (a) Top view of the processed plate (b) Cross-sectional macrostructure and (c) Cross-section of the processed plate.

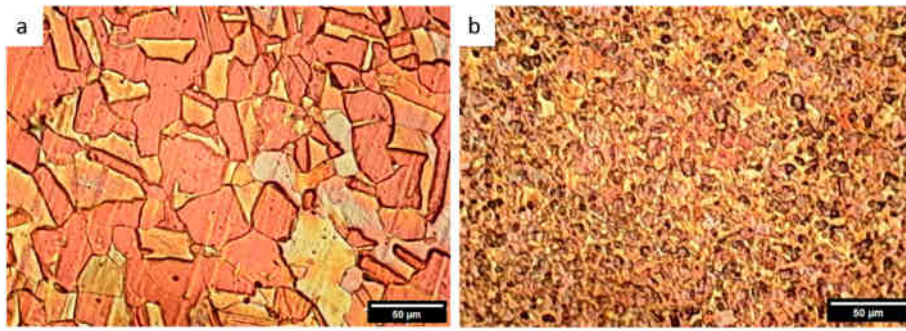


Fig. 7. Optical micrograph of (a) base copper (b) processed plate without reinforcement.

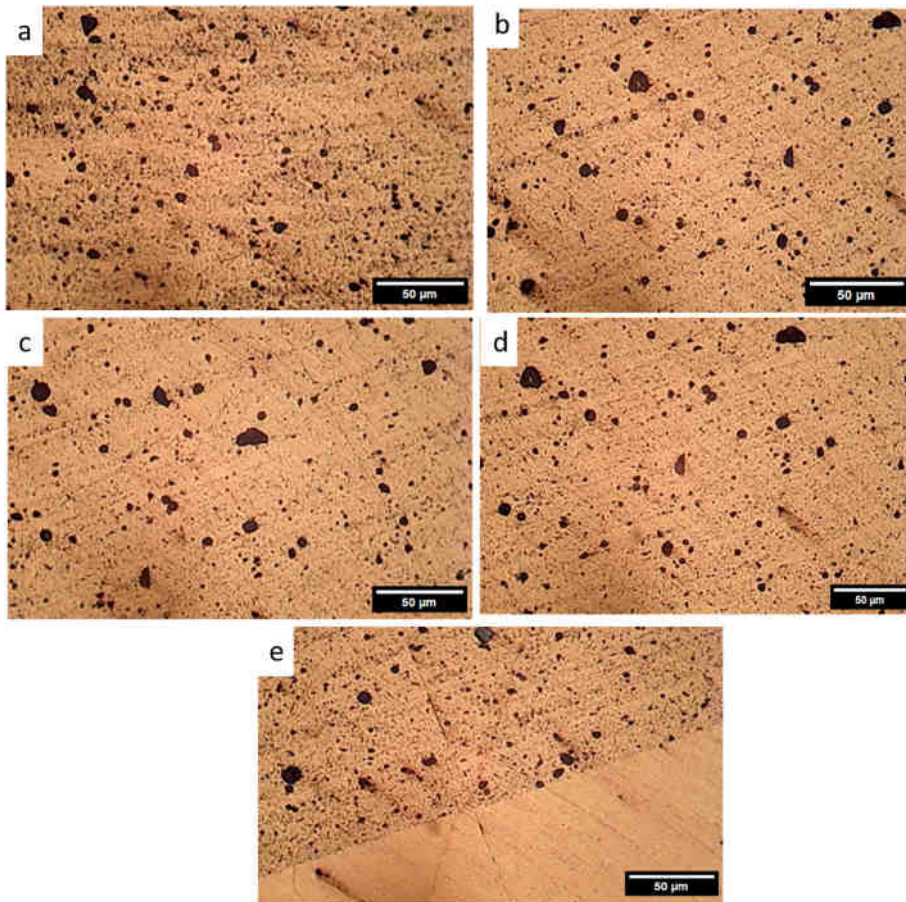


Fig. 8. Optical micrograph of SZ of the composite (a) At top (b) At bottom (c) At centre (d) towards retreating side (e) At interface.

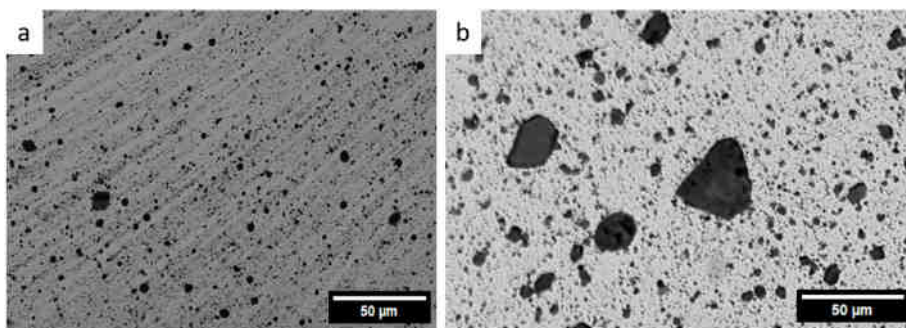


Fig. 9. SEM micrograph of SZ of the composite at different magnifications.

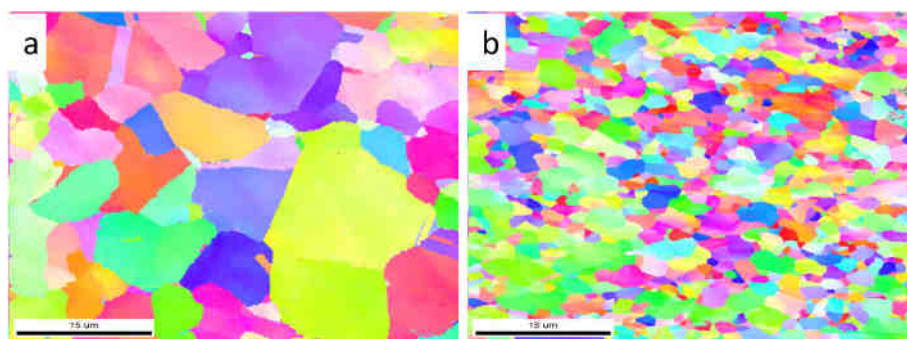


Fig. 10. EBSD grain boundary maps of (a) base copper and (b) composite.

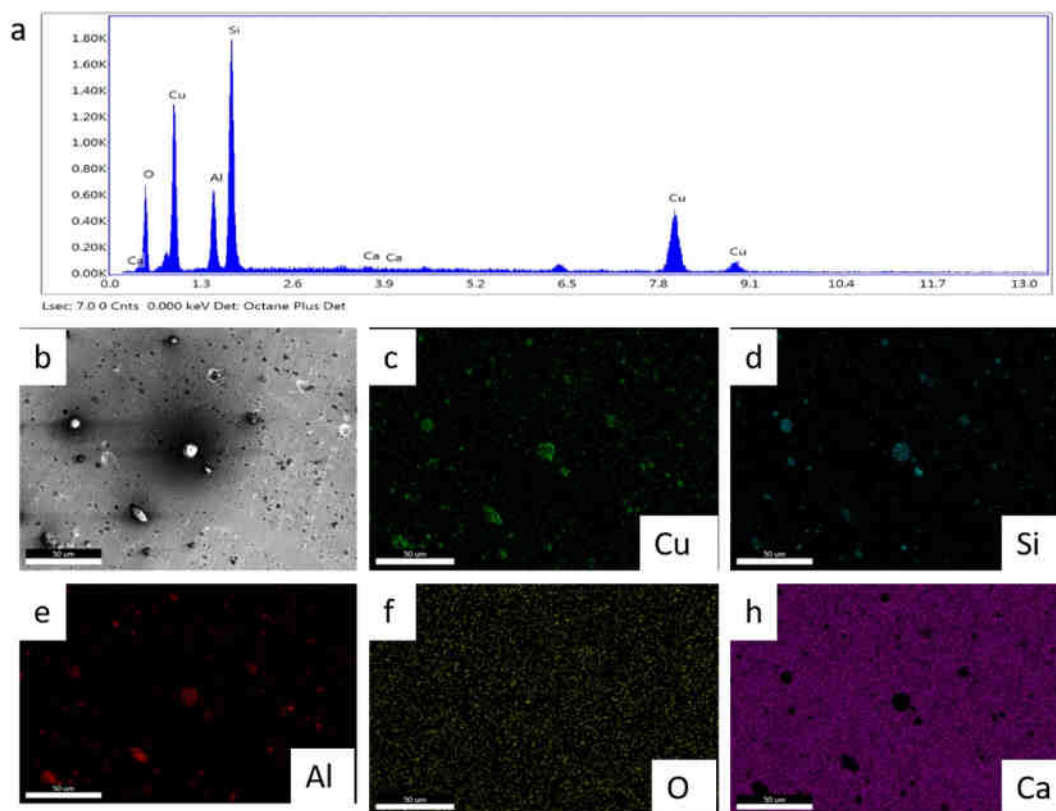


Fig. 11. (b) SEM micrograph of SZ of the composite (c)–(h) EDS map of the elements and their distribution.

minimal can be observed from the hardness profile. This shows that in the stir zone fly ash particles were dispersed uniformly and homogeneously which already we have seen in microstructure features.

4.2. Tensile properties

Stress-strain curve of the base copper and the processed composite is depicted in Fig. 13.

Obviously, the strength of the tensile tested composite samples has higher value than the base copper. But, percentage elongation for the composite has decreased as compared to the base copper. Also, the increment in yield strength is not substantial if compared with ultimate tensile strength. Grain refinement plays their role in enhancement of mechanical properties. Whenever, there will be reduction in grain size of the materials, number of grain boundaries will increase. Grain boundaries behave as barrier for dislocation during deformation of the material. Moreover, the reinforcement brought various strengthening mechanism in to picture which also contributed in strength increment of

the composite. The following strengthening mechanism may be thought of the reason behind hardness and strength growth. First, the Hall-Petch relation-based mechanism of grain refinement strengthening contributed to an increase in tensile strength [44]. Second, the reinforced particles were in micro scale but after fracture many of them came in nano scale and were uniformly distributed which prevented or stopped the movement of dislocation known as pinning effect. Third, as confirmed from compositional analysis of the composite (Fig. 11), there was nothing except fly ash and copper. Also, the interfacial integrity was excellent and hence loads during tensile test could easily transfer from soft matrix to the hard fly ash particles. Therefore, the composite showed higher mechanical properties. Fourth and the last reason may be the additional generated dislocations due to the difference in thermal coefficient of copper and fly ash. It acts as nothing sort of blockage for the free movement of dislocations during tensile testing and thus resulted in higher strength. Besides, the strength improvement Fig. 13 also shows that percentage elongation has reduced in case of composite with respect to the base copper. At the interface of the copper and fly ash

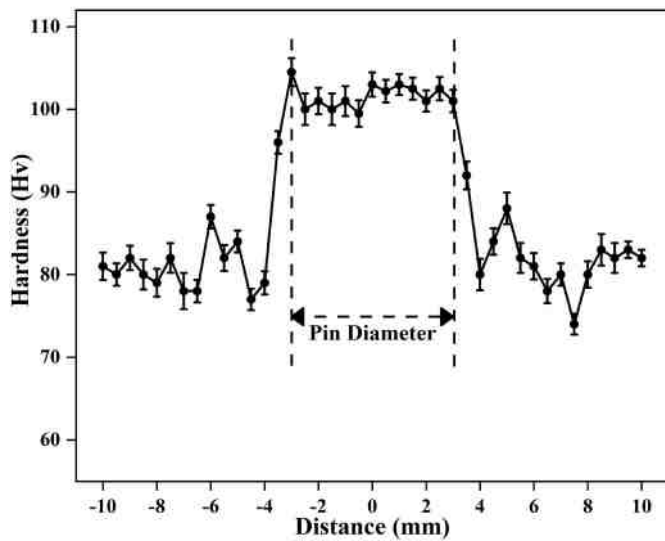


Fig. 12. Micro-hardness profile for the composite.

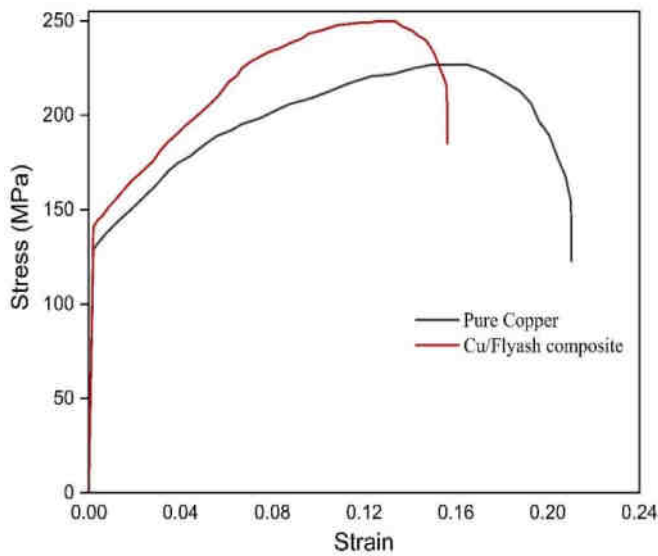


Fig. 13. Stress-strain curve for base copper and the composite.

dislocations initiate and micro-voids are formed. These micro-voids act as site for crack initiation during tensile testing and therefore composite displayed reduced ductility.

The fractured surfaces of base copper and the composite after tensile test is depicted in Fig. 14.

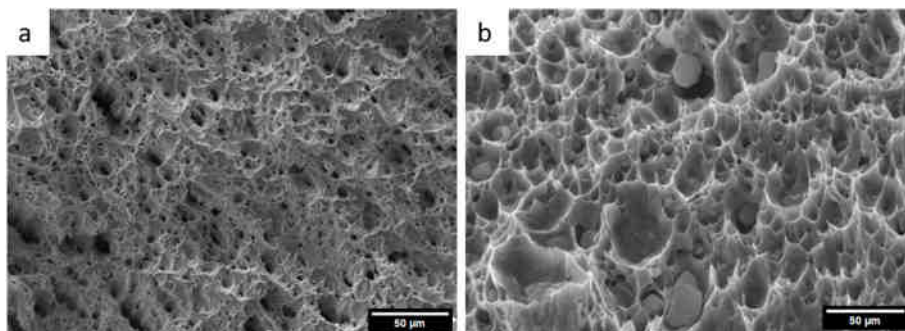


Fig. 14. Fractured surfaces of (a) base copper and (b) composite.

Fig. 14a is fractured surface of soft base copper. The characteristic features of ductile failure i.e. large dimples can be observed. However, for the composite (Fig. 14b) the dimples are shallower and smaller and also flat comparatively. This shows that the composite tensile samples could not delay the fracture much. Moreover, in the composite fracture surfaces there is no sign of debonding and pull out although the particles have fractured. Because of particle fracture, the surfaces are relatively rough with sign of brittle fracture. The quantitative data for tensile test also indicated the same. Lower ductility of the composite may be attributed to its higher hardness and strength.

5. Conclusions

In the current manuscript, FSP was employed for the fabrication of copper based low cost surface composite with fly ash as reinforcement. Also, this article concentrates on assessing the effect of fly ash incorporation on the performance of composite including microstructure, hardness and tensile strength. The core outcomes of the investigation are outlined below.

- i. The surface composite (Cu/Fly ash) was successfully developed by FSP without any defects
- ii. Fly ash was sputtered uniformly in copper matrix all over the stir zone. The interface was clean having excellent integrity between reinforcement and matrix. This may be attributed to proper process parameters which plasticized the copper sufficiently and forced it to adhere all over the reinforcement.
- iii. EDS analysis confirmed the absence of any discernible reaction products. The temperature developed during the process is well below at which reaction generally initiates and hence nothing harmful formed.
- iv. The hardness of the composite improved almost 70 % with respect to base copper. This was supposed to be because of uniform dispersion of fly ash and grain refinement of the copper matrix.
- v. The strength of the composite increased by 38 % although ductility was found to be less in comparison to base copper. Increment in strength may be due to combined effect of grain refinement, shear lag mechanism, Orowan mechanism and difference in thermal coefficient strengthening mechanism.

Consent to participate

Not applicable.

Consent to publish

All authors have read and approved this manuscript.

Ethical approval

Not applicable.

Author Contributions

Conceptualization, HK, RP, PK, ISPS, BY, AII, JL; methodology, SW, HK, RP, PK, ISPS, BY, AII, JL; formal analysis, HK, RP, PK, ISPS, BY, SHUBHAM SHARMA (SS), AII, JL; investigation, HK, RP, PK, ISPS, BY, AII, JL; writing—original draft preparation, HK, RP, PK, ISPS, BY, AII, JL; writing—review and editing, SHUBHAM SHARMA (SS), AII, JL, AII; supervision, AII, JL, AII; project administration, AII, JL, AII; funding acquisition, AII, JL, AII. All authors have read and agreed to the published version of the manuscript.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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