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Experimental Investigations on Friction Stir Processed Copper and Enhancement of Mechanical Properties of the Composite Material

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ABSTRACT

This paper investigates the parameters affecting the friction stir processed copper and enhancement of the mechanical properties of the composite material. The results showed that the grain size of fabricated composite reduce, also it is indicated that in comparison to base metal (copper) micro hardness of friction stir processed composites in stir zone (SZ) increase significantly. The results obtained also indicated that the selected FSP parameters significantly influence the area of surface composite by the distribution of material particles. Higher tool rotational speed and lower processing speed produce an excellent distribution of material particles and higher area of surface composite due to higher frictional heat, increased stirring and material transportation.

Keywords: *Surface Composites; Process Parameters; Mechanical Properties; Friction Stir Processing of Copper.*

1.0 Introduction

Friction stir processing (FSP) was developed for microstructural modification of metallic materials. In this review article, the current state of understanding and development of the FSW and FSP are discussed.

At this stage, the technology diffusion has significantly outpaced the fundamental understanding of microstructural evolution and microstructure–property relationships.

In FSP, a rotating tool is plunged into a material and high plastic deformation is produced. FSP is used to enhance ductility, induces super plasticity and improve corrosion resistance properties. Dynamic recrystallization of the deformed zone forms an ultrafine-grained structure. FSP has been successfully applied to various cast aluminium and magnesium and copper alloys to eliminate casting defects and thereby improve their mechanical properties.

Copper is a mostly used industrial and functional metal for various thermal, electrical and electronic applications, i.e. electronic packaging, electrical contacts and resistance welding electrodes. This is because of good thermal and electrical conductivity, high plasticity and excellent resistance to corrosion and oxidation. Nevertheless, low mechanical strength and poor wear resistance limit its applications.

Two modes of metal transfer during friction stir processing have been discussed [12]. The first mode of metal transfer is generated between the tool shoulder and the plate and takes place as layer-by-layer deposition of metal one over the other.

The second mode of metal transfer is generated by the extrusion of metal around the tool pin, when it reaches a state of sufficient plasticity.

Metal transfer, generated between the tool shoulder and the plate, plays an important role in influencing the mechanical properties during friction stir process. Modes of metal transfer are clearly visible in the microstructure characteristics, but they are not too distinct in macrostructure of most processed samples.

Friction stir processing can be applied as a single-pass for processing a small area.

For large engineering components in which the contact areas are relatively large, single pass FSP may not be adequate. Multi-pass FSP with a certain level of overlap between the successive passes is required for large contact areas.

For both single and multi-pass processes, it is important to assess the microstructural evolution and its influence on the mechanical properties.

This paper mainly focused on friction stir processing (FSP) used to produce copper–graphite surface composites. Two tools with different pin profile were employed in order to achieve a comprehensive dispersion. Results showed that the tool with H13 steel triangular and threaded pins give rise to a better dispersion of graphite particles. Furthermore, copper–graphite composites containing

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different graphite content were prepared using the tool through repeating the process passes.

2.0 Literature Review

Bahram A. Et.al [1] has produced copper reinforced metal matrix composite (MMC) using micron sized chromium particles via friction stir processing (FSP) in order to study effects of adding Cr particles to copper based matrix by FSP. Microstructures, micro hardness and wear properties were studied in order to evaluate the microstructures and mechanical properties of fabricated composites. The microstructure properties were evaluated by optical microscopy (OM) and field emission scanning electron microscopy (FESEM).

The mechanical behaviours of the samples were determined by micro hardness and wear tests. The results showed that the grain size of fabricated composite reduced. Also it was indicated that in comparison to base copper micro hardness of friction stir processed composites in stir zone (SZ) increased significantly. The results of wear test showed that in comparison with specimen with traverse speed of 80 mm/min, higher traverse speed of 160 mm/min increase wear rate of cylindrical pins.

Akramifard H.R.et.al, [3**]** had investigated pure Cu sheets were reinforced with 25µm SiC particles to fabricate a composite surface layer by friction stir processing (FSP). In order to improve distribution of reinforcing SiC particles, a net of holes were designed by drill on the 4 surface of pure Cu sheet. For evaluation of microstructure, Optical Microscope (OM) and Scanning Electron Microscope (SEM) were used. Microstructural observation confirmed fine and equiaxed grains in the stir zone (SZ) and showed that SiC particles act as heterogeneous nucleation sites in the dynamic recrystallization of Cu grains. Moreover, agglomeration of particles wasn't observed and fine particles had a good distribution in SZ. In the SEM micrographs, porosities were detected as microstructure defects.

Microhardness measurements showed that surface hardness was two times as high as that of substrate. The rotational wear tests demonstrated that use of SiC particles enhanced wear resistance and increased average friction coefficient of pure Cu. No intermetallic compound was found in Cu/SiC composite as revealed by XRD analysis**.**. Sarmadi H**,**et.al[4**]** mainly focused on friction stir processing (FSP) used to produce copper–graphite surface composites.

Five tools with different pin profile were employed in order to achieve a comprehensive dispersion. Results showed that the tool with triangular pin give rise to a better dispersion of graphite particles. Furthermore, four copper–graphite composites containing different graphite content were prepared using triangular tool through repeating the process passes. Friction and wear performance of the composites were also studied using a pin-on-disctribometer.

It was indicated that the friction coefficients of composites were lower than pure annealed copper and decreased with increase in graphite content. The reduction in friction coefficient is due to decrease in metal–metal contact points, originated from the presence of graphite particles as a solid lubricant.

Wear loss of the composites was also decreased with increase in graphite content which was related to change in wear mechanism from adhesive to delamination wear and reduction of friction coefficient.

Their work was concluded as mentioned below. Fabrication of copper–graphite composites by friction stir processing (FSP) is possible. Using this technique leads to more homogenous distribution of particles in surface of composite and prevents particle changing into clusters which was the most important problem in prior techniques such as powder metallurgy and centrifugal casting.

It was also noted that in order to produce more heat and avoid wasting produced heat, rotating speed and transverse speed should be chosen high and low respectively and specimens should be isolated. Using tool with triangular pin leads to better distribution of particle rather than other tools which were because of flow pattern of materials against this tool. The area of composite produced with this tool was larger in comparison with compo- sites produced by other tools.

Friction coefficient was decreased with increase in graphite content so that friction coefficient of Cu-4G composite containing about 22vol% graphite is79% lower than pure annealed copper. This was due to presence of graphite as a solid lubricant and decrease in number of metal to metal contact point. It was also observed that friction coefficient decreases to some extent as graphite con- tent increases and after a threshold value of graphite content, it remains constant.

The threshold graphite content in their study was about 25vol%. Wear loss of specimens was decreased with increase in graphite content. Adding about 22vol% graphite to copper increases wear resistance of the composite by 65%. This was due to presence of graphite as a solid lubricant. Increase in graphite content results in increase in delamination wear and decrease in adhesive wear. Galvao I.et.al [5] in their work, 1 and 3 mm-thick copper-DHP plates were processed with the aim of simulating surface (SFSP) and bulk (VFSP) processing. The influence of the processing conditions on the microstructure and mechanical properties of the processed materials was analyzed. It was found that the tool geometry, which has a close relation with the plastic deformation and dynamic recrystallization kinetics inside the stirred volume, the processing parameters and the heat exchange conditions,

which determine the extent of dynamic recrystallization and annealing phenomenon, are determinant in FSP.

Kudzanayi Chiteka**[6]** conducted studied making a choice in selection of friction stir welding/processing (FSW/P) tool material which has become an important task in determining the quality of the weld produced.

The tool material selection depends on the operational characteristics such as temperature, wear resistance and fracture toughness that determine the type of materials to be joined.

Soft materials can be easily welded using tool steels while harder materials need harder tool materials such as carbide based materials and polycrystalline cubic boron nitride (PCBN).

K. Surekha, A. Et.al. [7] Considered the objective of their study was to obtain a high strength, high conductivity copper by friction stir processing.

Three milli meter thick pure copper plate was friction stir processed to a depth of 2.8 mm at low-heat input conditions by varying the travel speed from 50 to 250 mm/min at a constant rotation speed (300 rpm) to obtain fine grains.

Grain size of the nugget decreased from 9 to 3 μm and the hardness increased from 102 to 114 HV by increasing the traverse speed from 50 to 250 mm/min.

Yield strength, microhardness and ultimate tensile strength increased with decrease in grain size in the nugget region and the yield strength obeyed $\sigma s = 223.8 + 0.07d-1/2$ Hall–Petch relationship, where d is the grain size in m.

3.0 Experimental Set Up

The machine used for Friction stir processing was a vertical milling machine in which necessary adjustments were made to make it suitable for use in friction stir processing.

The collect chuck was used to hold the tool.Proper job holding fixture was used which could hold a 150 X 74 x 5 mm plate.

Toe clamps were used to hold the job firmly.

Collet used for holding the tool could hold a cylindrical (tapered/ untapered) tool of diameter 15-16 mm. Two 150 x 37 x 5 mm 99% pure Copper Plates mounted on the fixture used for job holding one by one on Milling Machine for groove cutting.

Two grooves of 1mm deep was made on 2 plates using a 1mm (width) saw cutter at equal linear distances. First plate (without grooves) was clamped firmly by using the toe clamps.

Then H13 tool steel with shoulder dia 15mm and pin dia 5 mm and pin length 1.5mm was inserted in to the collet and tightened.

The pin of the tool was brought just above the plate in such a way such that the centre of the pin lies just above the centre of the groove cut. First Pass, than a full pass is made along the length of the job.

Second Pass, after cooling the plate for 5-10 minutes than a full pass is made along the length of the job.

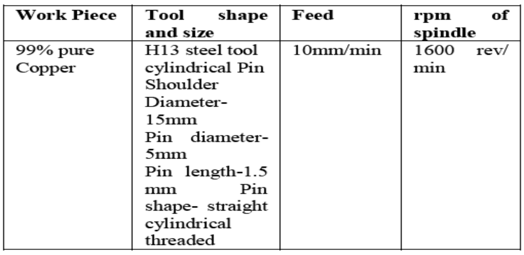
The job was allowed to cool for some time and then taken out from the fixtures.

Graphite powder was filled into the grooves of second and third plate using a Shoulder tool of diameter 15mm.

Fig 1: Graphite Powder Filled in the Grooves of Copper Plate

Fig 2: Tensile Specimens

The Graphite powder was filled into the grooves of second and third plate and process is repeated as per the following table. Process Parameters for first, second, third plate are mentioned in the table



Work Piece	**Tool shape and size**	**Feed**	**rpm of spindle**
99% pure Copper	H13 steel tool cylindrical Pin Shoulder Diameter-15mm Pin diameter-5mm Pin length-1.5 mm Pin shape- straight cylindrical threaded	10mm/min	1600 rev/ min

Specimen 1-- No. of Passes = 1
Specimen 2--Ist Groove, No. of Passes = 2
Specimen 3--IInd Groove, No. of Passes = 3
Specimen 4 --Ist Groove No. of Passes = 2
Specimen 5--IInd Groove,No. of Passes = 4

The processed pieces are now taken for the following tests:
Tensile Strength Test
Brinell hardness test
Microstructure test

3.1 Tensile strength test

After the FSP the specimen for tensile testing were cut from the job. The specimens are as shown in figure. The specification of specimen is as following:

1. Length of specimen- 101.6 mm
2. Gauge Length – 25.4 mm
3. Gauge width- 6mm
4. Gauge thickness- 5mm

Five specimens were chosen marked with marker on their ends. Care was taken to ensure that the specimens did not have any notching or cracks from manufacturing or any surface defects that would adversely affect the tensile tests. Before loading the specimens in the Instron machine, the computer system connected to the machine was given inputs such as gauge length and width of the specimen. The computer system was then prepared to record data and output necessary load-deflection graphs. The specimens were loaded into the Instron machine, and a tensile test was performed. The data was recorded electronically in text files and the load-deflection curve was shown on the computer screen as a visual representation. The average of different values of 3 specimens each from 2 jobs and parallel material was taken as the final values. The stress strain graphs and load elongations graph are shown for the ultimate strength of the specimen. The ultimate tensile strength of the processed material comes out to be lesser than the parallel material

Fig 3(a) : Stress-Strain Curve for Specimen 1

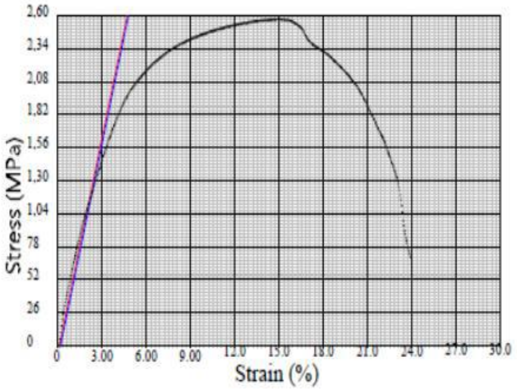


Fig 3(b) : Force-Displacement Curve Specimen 1

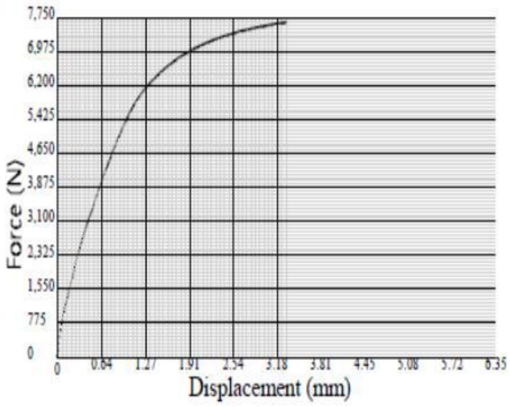
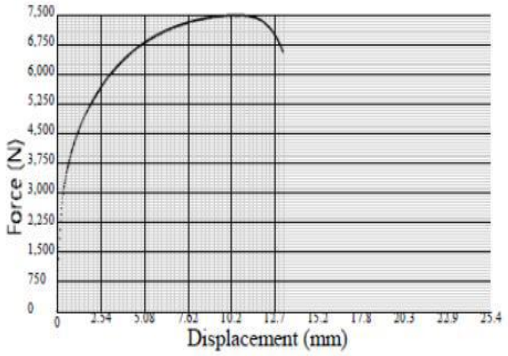
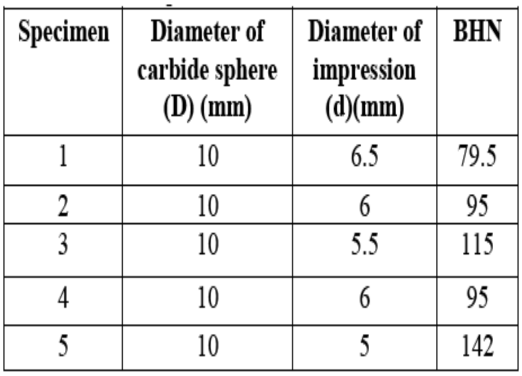


Fig 3(c) : Stress-Strain Curve for Specimen 3



3.2 Brinell hardness test

The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece. It is one of several definitions of hardness in materials science. The brinell hardness was conducted on all 5 specimens each from 3 plates. The table below shows the BHN for different specimen:-



Specimen	Diameter of carbide sphere (D) (mm)	Diameter of impression (d)(mm)	BHN
1	10	6.5	79.5
2	10	6	95
3	10	5.5	115
4	10	6	95
5	10	5	142

As we can see the brinell hardness of the processed specimen increases as the number of passes are increased due to the more compact microstructure. The brinell hardness number comes out to be highest for specimen no. 5

4.0 Microstructure Ananlyis

The optical microscope is the principal tool used to characterize the internal grain structure of steel. Traditionally, the structure revealed by the microscope is called the **microstructure**. The mechanical properties of given steel are strongly influenced by its microstructure. An optical microscope uses reflected light to generate an image. A beam of light is directed down onto the surface and the image is generated either on film or the eye by light reflected along the same direction. This is performed on specimens either cut to size or mounted in a resin mold. The samples are polished to a fine finish, normally one micron diamond paste, and usually etched in an appropriate chemical solution prior to examination on a metallurgical microscope. For microstructure test we had 4 specimens. There are two examination methods in metallography:

1) Macroscopy
2) Microscopy

In macroscopy the examination of the structural characteristics or chemical characteristics of a metal or an alloy is done by the unaided eye or with the aid of a low-power microscope or binocular, usually under l0x. In microscopy similar examination is done with the prepared metal specimens, employing magnifications with the optical microscope of from 100x to as high as 2000x.

Fig 4: Specimen 1--10x

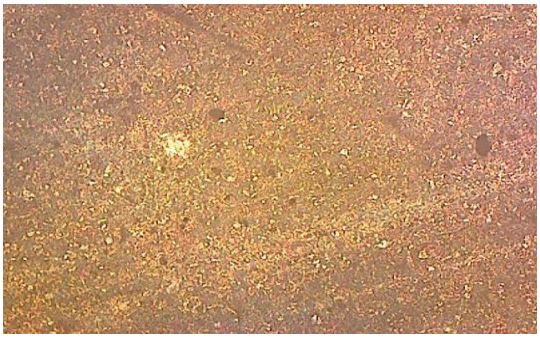


Fig 5: Specimen 1--20x

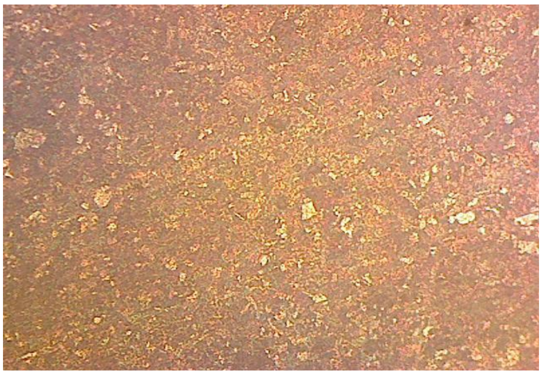


Fig 6: Specimen 1--50x

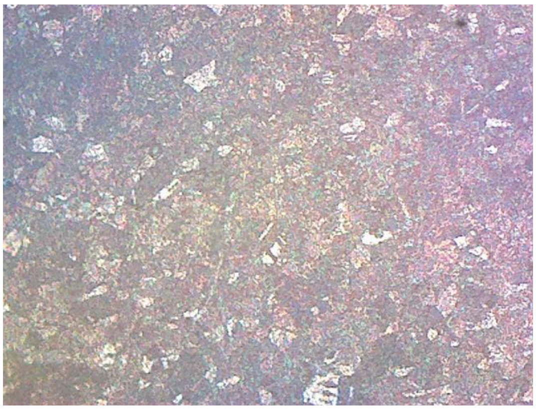


Fig 7: Specimen 1--100x

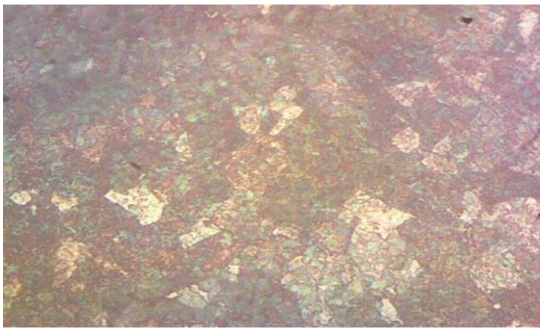


Fig 8: Specimen 2--10x

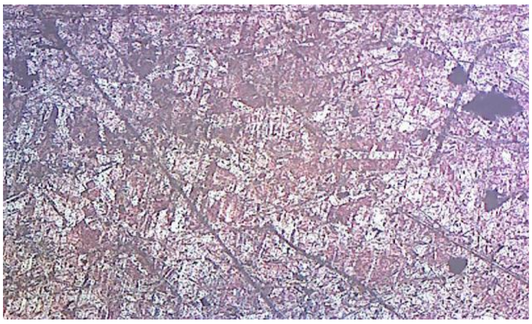


Fig 9: Specimen 2--20x

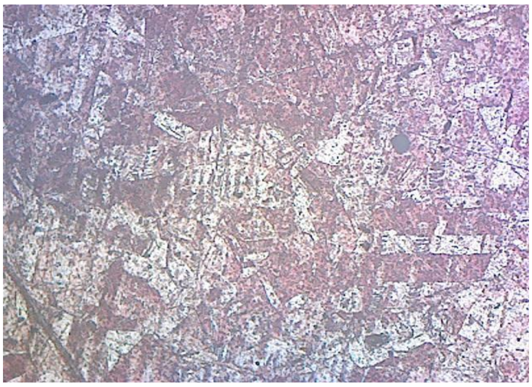


Fig 10: Specimen 2--50x

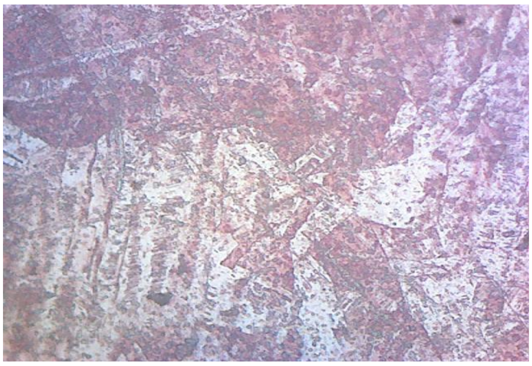


Fig 11: Specimen 2--100x

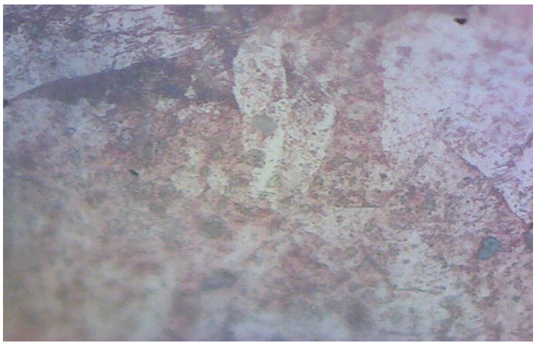


Fig 12: Specimen 3--10x

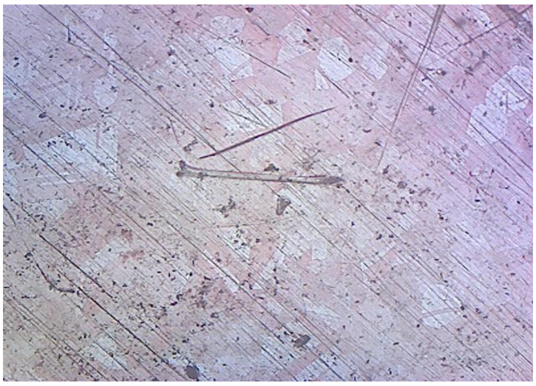


Fig 13: Specimen 3--20x

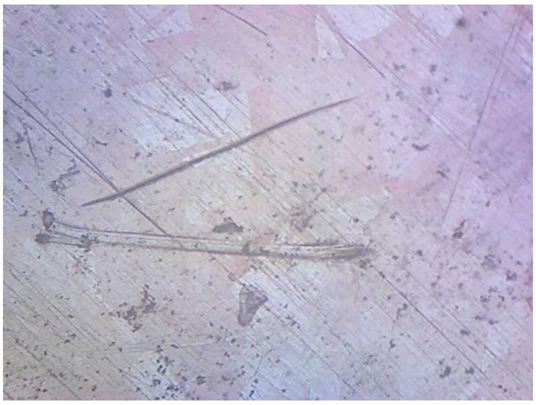


Fig 14: Specimen 3--50x

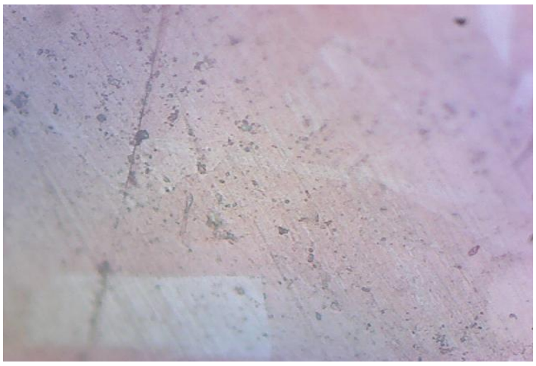


Fig 15: Specimen 3--100x

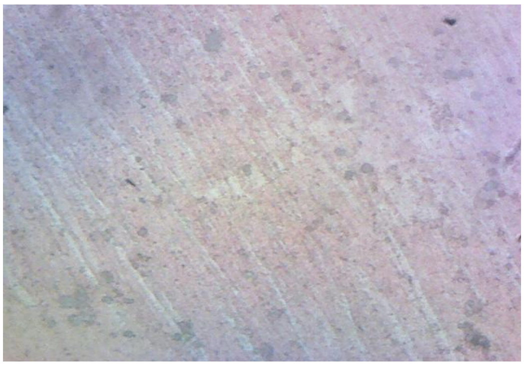


Fig 16: Specimen 4--10x

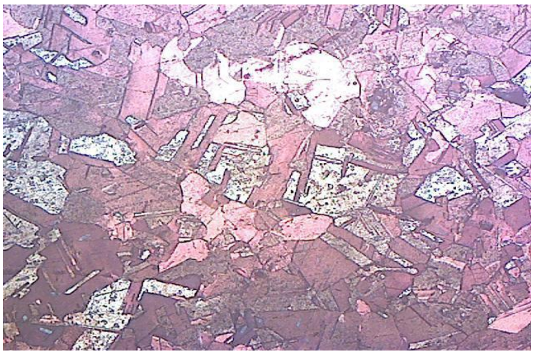


Fig 17: Specimen 4--20x

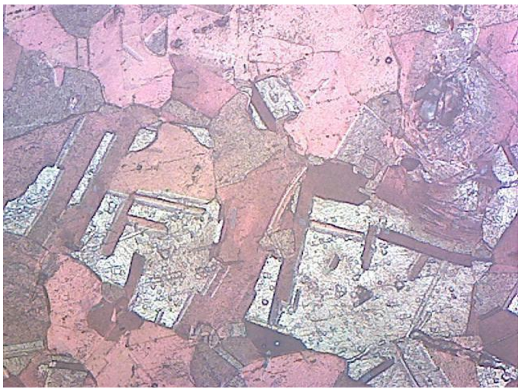


Fig 18: Specimen 4--50x

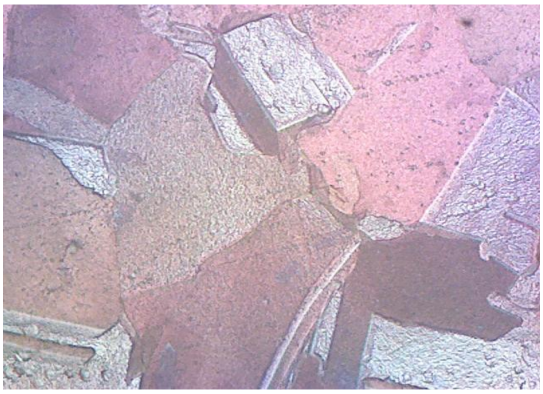
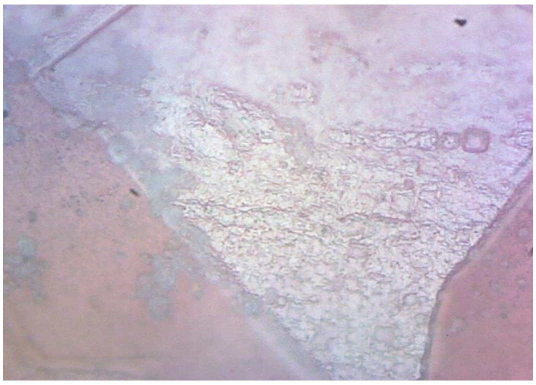


Fig 19: Specimen 4--100x



Base metal microstructure (b) Boundary between NZ and HAZ in sample processed in adequate heat input (c) Cavities and cracks in samples processed at tool speed of 300 rpm, (d-f) Microstructure of NZ in sample processed at tool speed of 600 rpm and traverse speed of (d) 40 mm/min (f) 100 mm/min [16]

5.0 Conclusions

The effect of FSP parameters on copper material with graphite powder as composite material studied. Tensile strength, microstructure and micro hardness tests were conducted on the specimens prepared. The following conclusions have been made. Fabrication of copper–graphite composites by friction stir processing (FSP) is possible. Using this technique leads to more homogenous distribution of particles in surface of composite and prevents particle changing into clusters which was the most important problem in prior techniques such as powder metallurgy and centrifugal casting. It was also noted that in order to produce more heat and avoid wasting produced heat, rotating speed and transverse speed should be chosen high and low respectively and specimens should be isolated.

Using tool with threaded pin leads to better distribution of particle rather than other tools which were because of flow pattern of materials against this tool. The area of composite produced with this tool was larger in comparison with compo- sites produced by other tools. The microstructure for different specimens showed that as the no. of passes are increased microstructure gets more compact and no defects after processing. The ultimate tensile strength of the processed pieces were more than the ultimate tensile strength of the unprocessed material. Also the processed surface formed by friction stir processing of 99% pure Copper by H13 steel tool has higher tensile strength than the base material. The processed plate specimen had higher brinell hardness number as compared to base material. Also as the number of passes are increased BHN number increases. This means friction stir processing of 99% pure copper by H 13 cylindrical threaded Pin provides a joint of hardness greater than the base material.

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