Friction Stir Processing (FSP) of Copper and Enhancement of Its Mechanical Properties Using Graphite Powder (C)

Md. Noorul Hoda[a], Dr. Ranganath M.Singari[b], V. Jeganathan Arulmoni[b]

[a]*M.Tech, Department of Mechanical Engineering DTU, Delhi-110042, India*

[b]*Associate Professor, Department of Mechanical Engineering DTU Delhi-110042, India*

Abstract: **This project investigates change in micro structure; hardness and wear resistance of friction stir processed copper in multiple passes with the help graphite powder. The behavior of copper with graphite powder has been studied with single pass, double pass, triple passé and four passes. A 6 mm triangular pin and 19.95 mm diameter shoulder tool has been used for processing. The optical microscopy (OM) results are also presented for each case. The objective of this project is to investigate change in micro structure, hardness and wear resistance of friction stir processed copper in multiple passes with the help graphite powder. Friction stir processing has the advantage of reducing distortion and defects in the materials. The hardness test, wear test and microstructure test has been successfully examined and results are analyzed.**

Keywords **- Multipass; Friction stir processing; copper and graphite; mechanical properties, Testing.**

I. INTRODUCTION

In today's Engineering era, there is high demand and necessity of high strength materials in manufacturing. So, Friction stir processing was developed for micro structural change of metallic materials.[1] Processing/welding parameters, tool geometry and joint design apply significant effect on the material flow pattern and temperature distribution, thereby influencing the micro structural advancement of the material.[2] In FSP, a rotating tool is inserted into an objects and high plastic deformation is produced. FSP is used to improve ductility, induce super plasticity and improve corrosion resistance properties of the material. FSP has been effectively applied to various cast aluminum, magnesium and copper alloys to reduce casting defects and thereby improve mechanical properties of the material. Mixing of metal between the tool shoulder and the plate plays a significant role in influencing the mechanical properties during friction stir process.[3] Modes of metal transfer are visible in the microstructure characteristics, in macrostructure of most processed samples. Tool geometry is the most important aspects of process development. The tool geometry plays a vital role in material flow.

FSP tool consist of a shoulder and a pin. The tool has two primarily purpose: localized heating and material flow.[4] In the early stage of tool plunge, the heating results mainly from the friction between pin and work piece. Some further heating results from deformation of the composite material. The tool is plunged into the work piece till the shoulder touches the surface of processing work material. The friction between the shoulder and work material results in the major component of heating. From the heating aspects, the comparative size of pin and shoulder is very important, and the other design characteristics are not critical.[5-7] The shoulder of the tool also provides confinement for the heated volume of material. The 2nd purpose of the tool is to 'stir' and 'move' the work material. The uniformity of micro structure and properties is governed by the tool design.[8] Usually a concave shoulder and threaded cylindrical pins are used. Tool rotational speed depends upon the hardness of the work piece.[9] Further if the rotational speed of the tool is very low and traverse speed is low the grain size can be larger in the material which might affect the microstructure, hardness, tensile strength and wear resistance of the composite material. Hence one should go for best possible tool rotational speed and traverse speed in processing. Processing speed is nothing but traverse speed. An increase in traverse speed and decrease in rotational speed may cause reduction in the grain size of the material in stir zone. Generally traverse speed has been used as the processing variable on microstructure and micro hardness. Higher traverse speed influence micro hardness. Axial load is the force acting upon the Friction stir processing tool. It helps the tool pin to plunge into the material and the pressure generated upon the work material by shoulder of the tool. Groove thickness and depth depends upon the amount of powder to be used to make metal matrix

II. EXPERIMENTAL SETUP AND PROCEDURE

Friction stir processing (FSP) machine from the central workshop of DTU Delhi has been utilized for conducting the process. This machine can be used for the work piece dimension of 200*80*5 mm. For the formation of the work piece, copper is used as a material. So, the sample is cut from the given plate manually using hacksaw. After that, the sharp corner of the samples is rounded by filing for safety purpose.

Since, for processing purpose and for filling the filler powder groove is cut on the work piece with the help of the Milling machine in the project lab, DTU. 1 mm thick milling cutter has been used for cutting the groove in the middle of the plate along longitudinal axis. the work piece dimension has been taken as 200*75*6 mm and groove dimension has been taken as 200 mm length, 2.5 mm depth and 1 mm width. The Tool used for friction stir processing is consisting of shoulder and pin. The Tool is made up of High Speed Steel (HSS) with 5% cobalt. 1st design is prepared on the solid work software and then fabricated on the lathe and milling machine. After that heat treated by "Vacuum Hardened" to gain hot hardness of the tool. In my case I have used a triangular pin tool of 6 mm each side without thread.

Table 1. Tool Dimension

Length of tool	120 mm
Diameter of the shoulder	19.95 mm
Width of the pin	3 mm
Diameter of the pin	7 mm
Pin type	Triangular

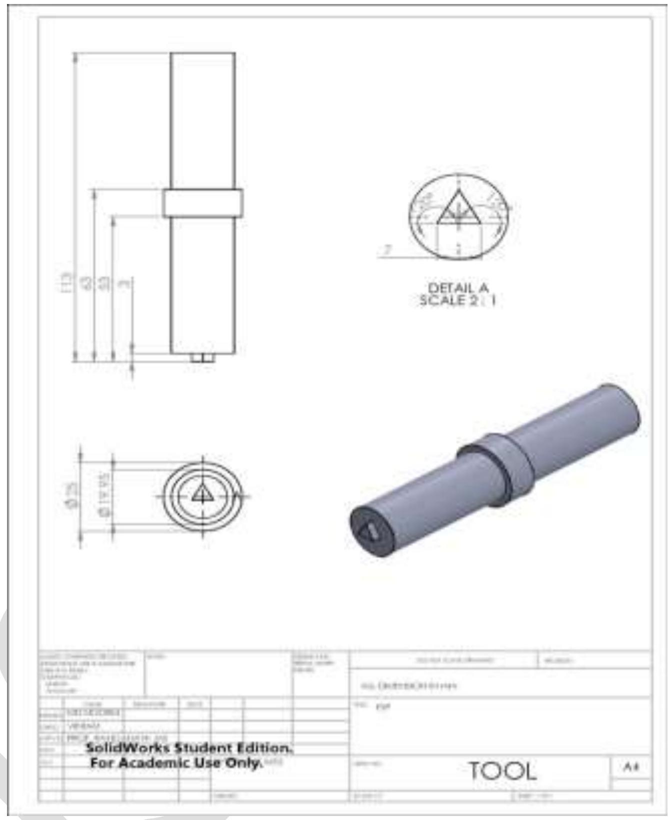

Fig. 2. Tool Drawing at Solid Works.

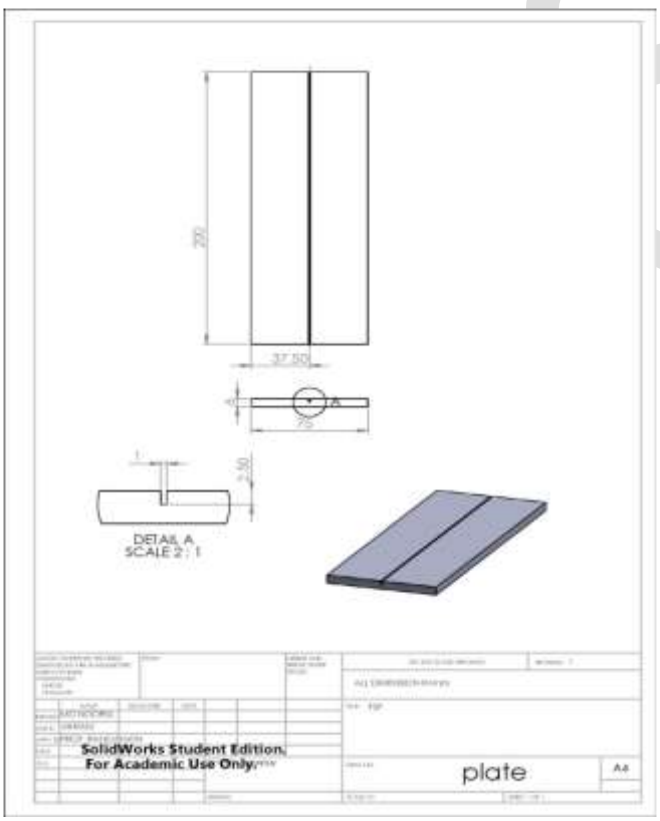

Fig. 1. Copper Plate Drawing at Solid Work

Filler powder used in the processing is the "graphite powder". The filler material should be filled in the Groove Area so that during processing it thoroughly mixed within the processing area and so that better result can be obtained. While filling the filler powder, a paste can be made by mixing Acetone in the powder so that the powder reaches every corner of the groove. The processing is performed on a special bench-top type friction processing machine. The machine is fully automatic and has a control panel to change the welding parameter accordingly to the requirement.

Before doing the processing, covering of filler powder in the groove should be done so that the filler powder thoroughly mixed within processed area and not spilled out during the processing. So, making a layer for covering the groove portion of work piece, a Flat tool is used. The tool is mounted on the tool holder of the machine such that the triangular probe part of the tool is up-side down and directs towards the area to be processed. The tool has little impression on its previous side for easy mounting on the machine. The tool is mounted on the tip and then the work piece is clamped in its place automatically. After that, the feed of the machine is recorded. The rotation of tool is set to a particular rpm Control Panel helps in the movement of tools along all x, y and z axis.Different values of load are measured during the contact of tool and the work piece. the following processing parameter has been taken for FSP. load- 1000kg, feed- 20 mm/min and rotational speed 1100 rpm. These parameters are kept constant during the processing. For Analysis of the micro structure and mechanical properties, the processing is done at single pass without powder, single pass with powder, double pass with powder, triple pass with powder and four pass with powder on the work pieces. Test samples are cut from the bead portion by the help of a "Wire Cut Electric Discharge Machine". Several samples are cut for different testing purposes. Wire cut EDM is used for cutting the test specimens since, EDM wire cut has more metal cutting capabilities and cut more delicate shapes. EDM wire machine cut to very high Tolerance +/- .0001"(.0025mm). as per ASME standard dimension has been taken for cutting of the specimen. the specimen is cut for the testing of hardness test, wear and microstructure test.

III. RESULT AND DISCUSSION

3.1 Hardness Test

Hardness is a characteristic of a material. It is defined as the resistance to indentation, and it is obtained by measuring the permanent depth of the indentation. We have performed the hardness test on Rockwell Hardness Testing Machine. Rockwell hardness test method is the most commonly used hardness test method.[10] The Rockwell test is generally easier to carry out, and it is more accurate than other types of hardness testing methods. In Rockwell hardness test method firstly, a preliminary test force is applied to a sample using a diamond indenter. This load represents the zero position that break the surface to decrease the effects of surface finish. After preload, an additional load is given to reach the total required test load.[11] This load is kept for a predetermined amount of time to allow for elastic recovery. The major force is then released and the final position is measured against the position obtained from preload, the indentation depth variance between the preload value and major load value. This position distance is converted to the Hardness number.

Table 2. Rockwell hardness number of specimen

	Specimen	Rockwell hardness number (HRB)
1.	Base metal specimen	36
2.	Specimen Processed without GP	97
3.	Processed with GP single pass	101
4.	Processed with GP double pass	106
5.	Processed with GP triple pass	110
6.	Processed with GP four pass	116

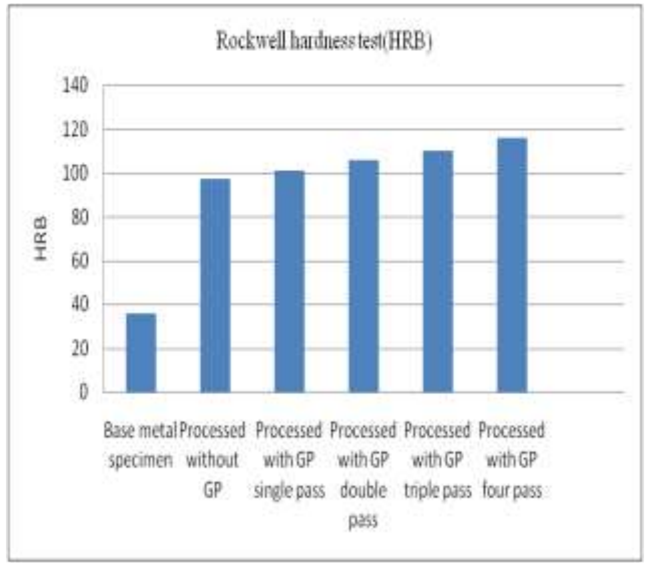

Fig. 3. Rockwell hardness number (HRB) Vs No of passes

From the above table and bar chart it is clear that base metal has been got minimum(36 HRB) hardness number and processed with GP in four passes has been got maximum (116 HRB) hardness number. It is clearly seen that as the number of passes increases hardness of the material also increases. We can see that drastically increase in the hardness from base metal to the fsp processed. Total increase in the hardness has been got 222.22%.

3.2 Wear Test

Wear is a process of removal of outer surface from one or both of the material of the two solid plates in contact. Wear test is conducted on the "Pin on disc" wear testing machine. In this case a pin is held against the rotating disc.[12] Pin is held stationary and disc is rotating. Surfaces of pin and plate are in contact and due to friction between the two surfaces wear of the pin is takes place. A counter weight of 30 N is placed against the pin. Wear test were completed for a total distance of 3000 meter in three stages 1000 meter at each stage. Pin diameter is taken as 10mm. total five specimen of pin is taken for the test. Track diameter is taken as 130, 120, 110, 100, 90mm for the processing without powder, 1st pass with powder, 2nd pass with powder, 3rd pass with powder and 4th pass with powder respectively.

Formula:

$$L = \frac{\pi DNT}{60{,}000}$$

L- Sliding distance.

D- Track diameter in mm.

N- RPM.

T- Time in Sec.

From above equation time is calculated for constant siding distance.

Table 3. Input parameters for wear test

	Wear rate at different sliding distance					
	At 1000 m	1000-2000 m	2000-3000m	WEAR RATE(cm^3/m)	AVG FRICTIONAL FORCE	AVG COF
Without powder	0.196	0.54	0.184	0.307	14.772	0.492
1st pass with powder	0.319	0.208	0.184	0.237	14.68	0.489
2nd pass with powder	0.233	0.196	0.171	0.2	14.246	0.475
3rd pass with powder	0.171	0.147	0.122	0.147	13.713	0.457
4th pass with powder	0.147	0.147	0.11	0.045	13.63	0.454

Wear rate formula:

Wear rate (W) = $\frac{\Delta m}{\rho L}\ cm^3/mm$

Specific wear rate = $\frac{\Delta m}{\rho LF}\ cm^3/N-mm.$

Wear resistance = 1/ Wear rate

Δm - Weight loss.

ρ - Density of composite material.

L – Sliding distance.

Table 4. Wear rate, frictional force and Coefficient of friction at different passes

	Track diameter(mm)	Sliding distance	RPM	Time in sec	Normal load(N)
Without powder	130	1000*3	700	210	30
1st pass with powder	120	1000*3	700	228	30
2nd pass with powder	110	1000*3	700	248	30
3rd pass with powder	100	1000*3	700	273	30
4th pass with powder	90	1000*3	700	303	30

From the above table it is clear that processing without powder is getting maximum (.307 cm^3/m) wear rate and processing with graphite powder in 4th pass getting minimum (0.045 cm^3/m) wear rate. As we can clearly see that as the number of passes are increases wear rate reduces. We can also see that as the sliding distance is increasing wear rate reducing means as we go in the inner surface of the specimen wear rate reduces.

In the 4th pass with powder wear rate is reduced by 85% or we can say that wear resistance is increased by 85%

The different value of frictional forces is directly obtained from the computer data base and after that coefficient of friction has been calculated.

$$F = \mu N.$$

$$\mu = \frac{F}{N}$$

F = frictional force. N = normal load

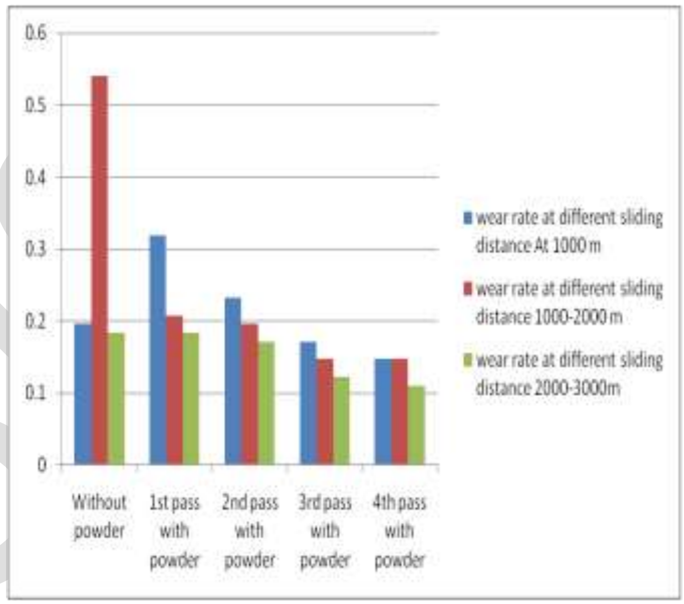

Fig 3. Wear rate graph at different sliding distance

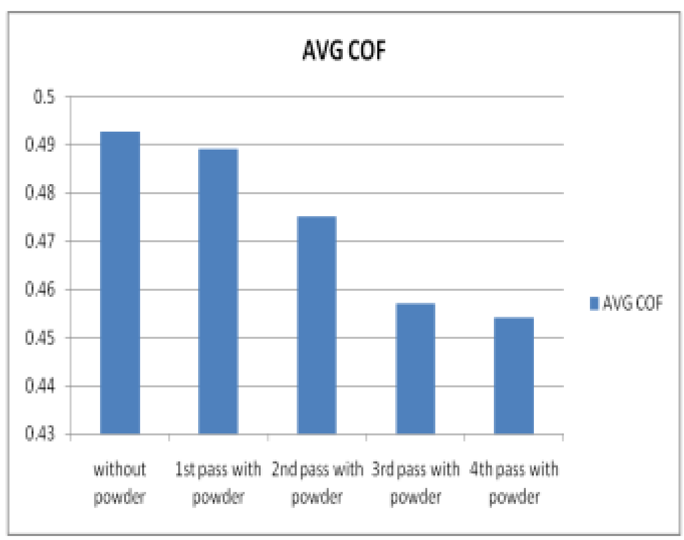

Fig 4. Avg COF Vs number of passes

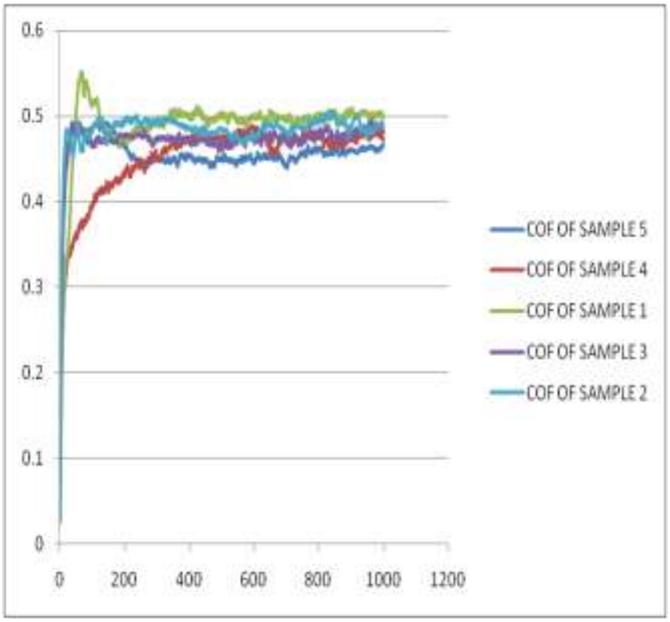

Fig 5. COF Vs sliding distance at different number of passes

sample 5 -4th pass with powder, sample 4- 3rd pass with powder, sample 1- Without powder, sample 3- 2nd pass with powder, sample 2- 1st pass with powder.

From the above table and bar chart it is clear that processing without powder is found maximum (0.492) coefficient of friction and processing 4th pass with graphite powder is gating minimum (0.454) coefficient of friction. We can also see that as the number of passes is increasing coefficient of friction is decreasing. We can observe from the graph that coefficient of friction is gating between 0.4 and 0.5. It is also clear that processing without powder is found maximum (14.772) frictional force and processing 4th pass with graphite powder is gating minimum (13.63) frictional force. We can also see that as the number of passes is increasing frictional force is decreasing.

3.3 Microstructure

Optical Microscopy Analysis:-

Optical Microscopy is a valuable technique used by the materials engineer. This technique allows for full color representation at a fraction of the cost. The main principal of optical microscopy is to shine a light through (transmitted light) or onto the surface of a specimen of experiment and examine it under different magnification. The main parts of the optical microscope are the objective lens, eyepiece, and light source. The specimen of experiment is placed in front of the microscope so that its surface is perpendicular to the optical axis.

Before microscopic analysis we go through certain process so as to obtain the desired result which is as follows.

- Mounting of the Specimens
- Grinding Of The Specimens
- Wet Polishing
- Etching

Since Copper is taken for the experiment, the Etching agents used here have the following composition.

- Distilled water or Ethanol 50 ml.
- Nitric acid 50 ml.

Fig 6. Base Metal without processing at 100X

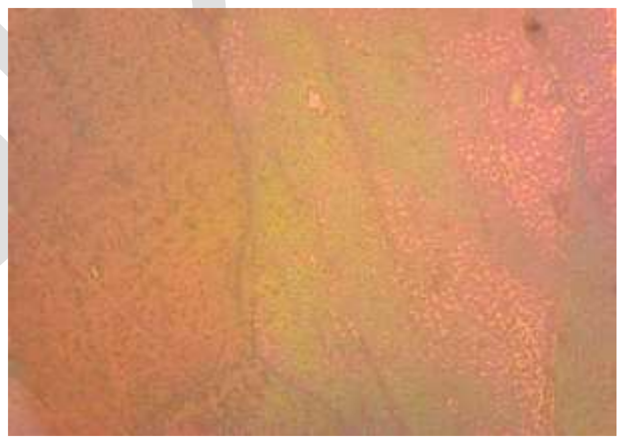

Fig 6. Base Metal without processing at 500X

Fig 7. Specimen without GP with single pass at 100X

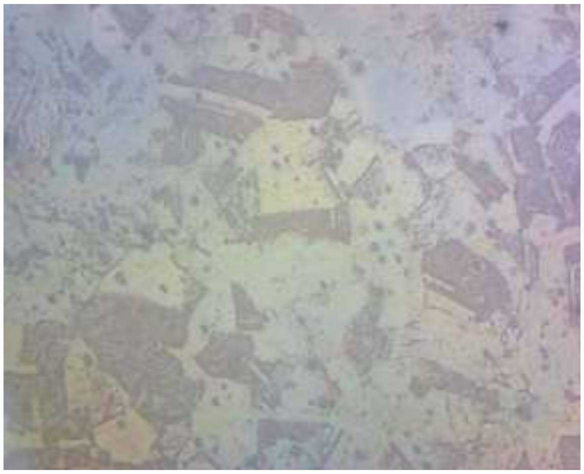

Fig 7. Specimen without GP with single pass at 500X

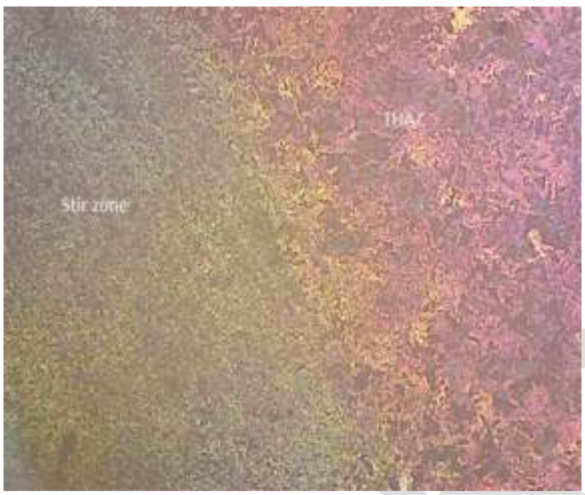

Fig 8. Specimen with GP single passes at 100X

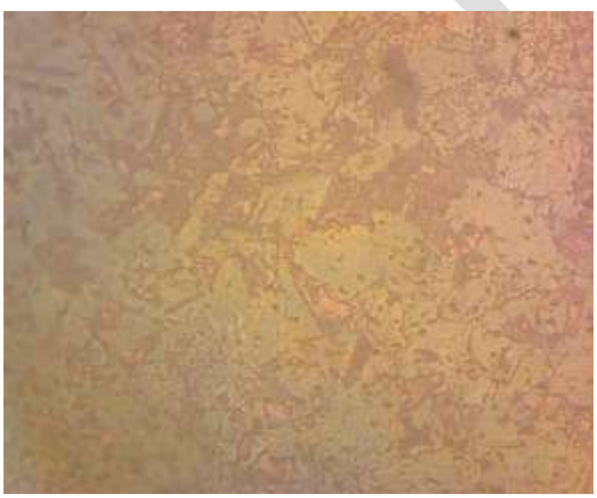

Fig 8. Specimen with GP single passes at 500X

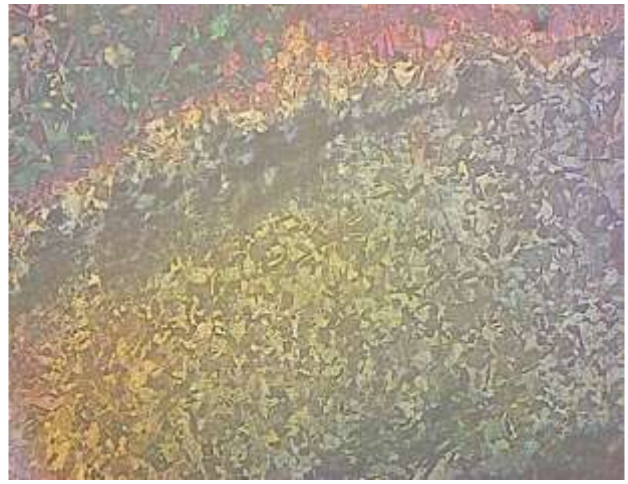

Fig 9. Specimen with GP double pass at 100X.

Fig 9. Specimen with GP double pass at 500X

Fig 10 Specimen with GP triple pass at 100X

Fig 10 Specimen with GP triple pass at 500X

Fig 11. Specimen with GP four pass at 100X

Fig 11. Specimen with GP four pass at 500X

Scanning Electron Microscope (SEM):-

The different specimen is also checked on the scanning electron microscope. The different images have been got as follow.

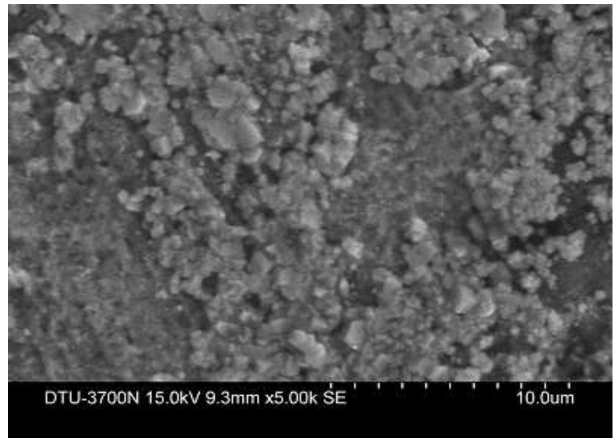

Fig 12. Specimen processing without powder

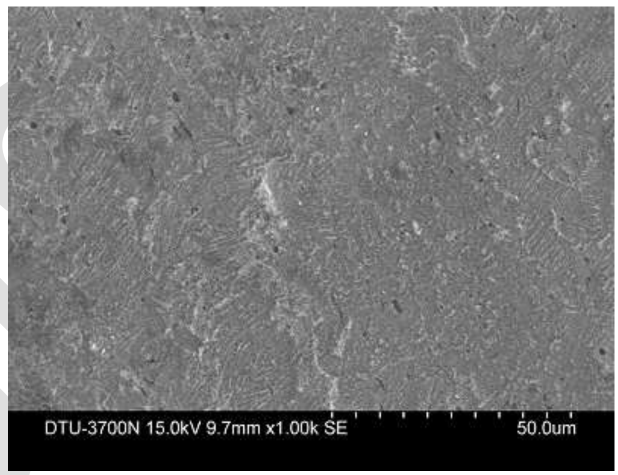

Fig 13. Specimen processing single passes with powder

Fig 14. Specimen processing double passes with powder

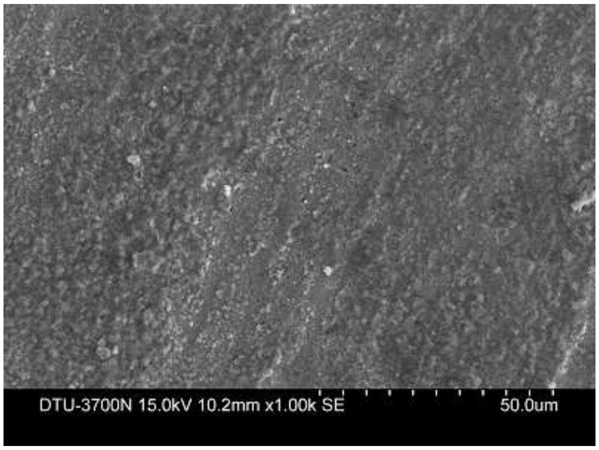

Fig 15. Specimen processing triple passes with powder

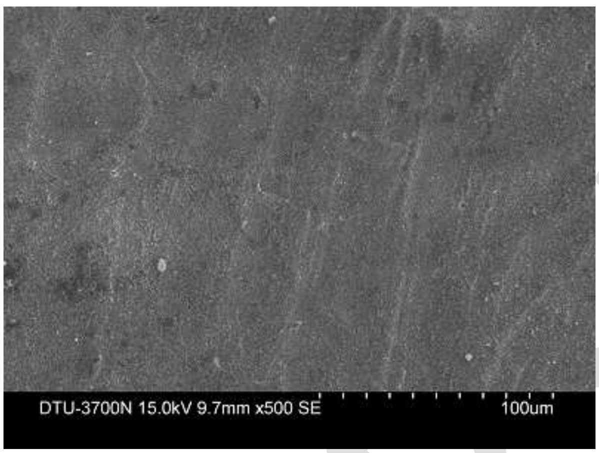

Fig 16. Specimen processing four passes with powder

From the above result it is clear that after every pass grain structure is refined. We are getting a fine structure of composite after increasing the number of passes. Also the defects like porous is reduced at four passes.

IV. CONCLUSION

In this report, the effect of Friction Stir Processing (FSP) parameters on Copper material with graphite powder as composite material has been studied. Hardness test, wear resistance test and optical microscopy analysis were conducted on the specimens

The following conclusions have been made from present investigation

- The Microstructure for different specimen showed that after single, double, triple and four passes the Microstructure gets more compact and refined grains and observed no defects after processing.
- Fabrication of Copper-graphite composite by friction stir processing (FSP) is possible.
- Hardness of Friction stir processed material become higher as the number of passes is increases. Hardness increases from 36 HRB to 116 HRB. Total hardness increased by 222.2%.
- Use of graphite powder in FSP as composite material increases hardness at greater extent.
- Wear rate decreases from 0.307 cm^3/m in the 1st pass to the 0.045cm^3/m in the 4th pass so percentage decrease in wear rate is 85.34%.
- Wear rate of the composite decreases as the number of passes increases from 1st to 4th pass. Also frictional coefficient and frictional force increases as the number of pass increases.

REFERENCES

[1]. Jeganathan Arulmoni, Ranganath M S , R S Mishra, Effect of Process Parameters on Friction Stir Processed Copper and Enhancement of Mechanical Properties of the Composite Material. IRJSSE, 2 (2014) 4-6.

[2]. M.-N. Avettand-Fènoël, A. Simar, R. Shabadi, R. Taillard, B. de Meester, Characterization of oxide dispersion strengthened copper based materials developed by friction stir processing. Materials and Design 60 (2014) 343–357.

[3]. H.R. Akramifard, M. Shamanian, M. Sabbaghian, M. Esmailzadeh, Microstructure and mechanical properties of Cu/SiC metal matrix composite fabricated via friction stir processing. Materials and Design 54 (2014) 838–844.

[4]. L. Suvarna Raju, A. Kumar, Influence of Al2O3 particles on the microstructure and mechanical properties of copper surface composites fabricated by friction stir processing. Defense Technology 10 (2014) 375-383

[5]. M. Sabbaghian, M.Shamanian, H.R.Akramifard, M.Esmailzadeh, Effect of friction stir processing on the microstructure and mechanical properties of Cu–TiC composite. Ceramics International 40 (2014) 12969–12976.

[6]. Esther T. Akinlabi1, Anthony Andrews, Stephen A. Akinlabi, Effects of processing parameters on corrosion properties of dissimilar friction stir welds of aluminum and copper. Trans. Nonferrous Met. Soc. China 24 (2014) 1323−1330.

[7]. Nan Xua,b, Rintaro Uejia, Hidetoshi Fujiia, Dynamic and static change of grain size and texture of copper during friction stir welding. Journal of Materials Processing Technology 232 (2016) 90–99.

[8]. R. Sathiskumar, n. Murugan, i. Dinaharan, s.j. vijay, characterization of boron carbide particulate reinforced in situ copper surface composites synthesized using friction stir processing. 84 (2 0 1 3) 1 6 – 2 7.

[9]. R. Sathiskumar, N. Murugan, I. Dinaharan, S.J. Vijay, Prediction of mechanical and wear properties of copper surface composites fabricated using friction stir processing. Materials and Design 55 (2014) 224–234.

[10]. H. Sarmadi n, A.H.Kokabi, S.M.SeyedReihani, Friction and wear performance of copper–graphite surface composites fabricated by friction stir processing (FSP). 304(2013) 1–2.

[11]. BahramA.Khiyavi, Abdolhossein Jalali Aghchai, Mohammadreza Arbabtafti, Mohammad Kazem Besharati Givi, Jalal Jafari, Effect of friction stir processing on mechanical properties of surface composite of Cu reinforced with Cr particles, Advanced Materials Research 829 (2014) 851-856.

[12]. I. Galvao, A. Loureiro and D. M. Rodrigues, Influence of process parameters on the mechanical enhancement of copper-DHP by FSP, Advanced Materials Research 445(2012) 631-636.