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

M.Tech Major Project

Submitted in partial fulfillment for the award of the Degree of
Master of Technology in Production Engineering

By

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2K14/PIE/10

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DECLARATION

I hereby declare the work which is being presented in this dissertation, entitled **"Friction Stir Processing Of Copper And Enhancement Of Its Mechanical Properties Using Graphite Powder (CAS-7782-42-5)"** towards the partial fulfillment of the requirements for the award of degree of Masters of Technology, from Delhi Technological University is an authentic record of my own work carried under the supervision of **Dr. RANGANATH M. SINGARI** Associate Professor and **Sh. V. JEGANATHAN ARULMONI** Associate Professor, Department of Production and Industrial Engineering, Delhi Technological University, Delhi.

The matter embodied in this dissertation has not been submitted by me for award of any other degree.

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Certificate

This is to Certify that Md. Noorul Hoda of 4th sem M.tech-Production. with Examination roll Number- 2k14/PIE/10 respectively has satisfactorily given the report on "Friction Stir Processing Of Copper And Enhancement Of Its Mechanical Properties Using Graphite Powder (CAS-7782-42-5)." in production engineering of Delhi Technological University, Delhi. It is certified that all corrections/suggestions indicated for internal assessment has been incorporated in report deposited in the departmental library. The report has been approved as it satisfies the academic requirements in respect of project work.

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Generally, individuals set aims, but more often than not, their conquest are by efforts of not just one but many determined people. This complete project could be accomplished because of the contribution of a number of people. We take it as a privilege to appreciate and acknowledge the efforts of all those who have, directly or indirectly helped me in achieving my aim.

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LIST OF ABBREVATION AND KEYWORDS

FSP - FRICTION STIR PROCESSING

FSW - FRICTION STIR WELDING

SEM - SCANNING ELECTRON MICROSCOPY

OM - OPTICAL MICROSCOPY

SZ - STIR ZONE

BHN - BRINELL HARDENESS NUMBER

GP - GRAPHITE POWDER

HAZ - HEAT AFFECTED ZONE

RPM - REVOLUTION PER MINUTE

ABSTRACT

This project investigates change in micro structure, hardness, tensile strength 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, tensile strength 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 tensile test, hardness test, wear test and microstructure test has been successfully examined and results are analyzed.

CHAPTER - 1

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. 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. 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. 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. 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. 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. Usually a concave shoulder and threaded cylindrical pins are used. Tool rotational speed depends upon the hardness of the work piece. 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

1.1. Problem statement

Tensile strength, hardness, microstructure and wear resistance of copper are to be analyzed. The composite material i.e. graphite particle used in the processing is to be studied and its effect on process parameters of FSP is determined. Microstructure of processed copper with and without GP in multiple passes is discussed.

1.2. Organization of the report

Chapter 1 includes the Introduction of project. It gives brief idea about FSP and its processing parameters. It also tells recent engineering application based on FSP.

Chapter 2 includes the previous research and work towards FSP by various researchers.

Chapter 3 includes experimental setup and all the experimental procedure required in FSP of copper- graphite powder composite and test performed on the specimens.

Chapter 4 includes the result and discussion of the tests performed in FSP of copper.

Chapter 5 deals with conclusion and

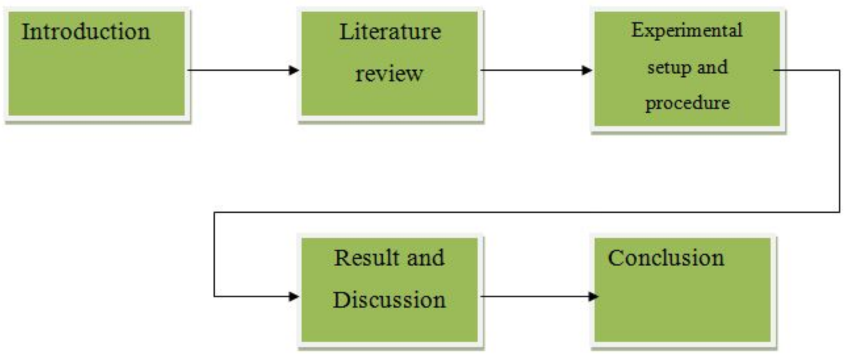


Fig 1.1 Flow chart of report

CHAPTER - 2

LITERATURE REVIEW

In the literature review, recent work and research on the friction stir processed copper has been studied.

2.1. Isaac Dinaharan, Ramasamy Sathiskumar, Nadarajan Murugan [1] aims to produce copper matrix composites (CMCs) using FSP and analyze the effect of ceramic reinforcement type (SiC, Al2O3, B4C and TiC) on the evolving microstructure, micro hardness and wear resis-tance behavior. A groove was prepared on 6 mm thick copper plates and filled with different ceramic particles. A single pass friction stir processing was carried out by a tool rotational speed of 1000 rpm, traverse speed of 40 mm/min and an axial force of 10 kN. The microstructure and allocation of the ceramic particles were studied by the help of optical and field emission scanning electron microscopy. The sliding wear behavior of composite was calculated using a pin-on-disk apparatus. The results indicate that the change in the stir zone, distribution, grain size, hardness and wear resistance of CMCs were within a short range. Nevertheless, Cu/B4C CMC exhibited superior hardness and wear resistance compared to other CMCs produced in this work under the same set of experimental conditions.

2.2**.** V.Jeganathan Arulmoni, Ranganath M S, R S Mishra. [2] Investigates the parameters influencing the friction stir processed copper and improvement of the mechanical properties of the composite material studied by different researchers. The effect of friction stir processing parameters such as tool rotational speed, traverse speed, axial load, groove width and depth, investigates changes in micro structure, micro hardness, tensile strength and wear resistance have been discussed . the result showed that the grain size of the fabricated composite reduce, also it is indicated that in comparison to base material (copper) micro hardness of friction stir processed composites in stir zone increases significantly. The results obtained also indicated that the selected FSP parameters significantly affecting the area of surface composite by the mixing of material particles. Larger tool rotational speed and lower processing speed produces an excellent distribution of material particles and higher area of surface composite due to greater frictional heat, increased stirring and material transportation.

2.3. M.-N. Avettand-Fenoel, A. Simar, R. Shabadi, R. Taillard, B. de Meester [3] Aims to show for the first time the ability of FSP in incorporating particles into copper to generate an oxide dispersion strengthened material. The microstructure of the developed composites was characterized at different scales by microscopy, electron microanalysis and scanning and transmission electron microscopy. The oxide powder was found to be circulated in the Cu matrix as established at various length scales from the micro-metric to the nano-metric level. The enhance in the number of FSP passes shows more homogeneous and finer allocation of the particles as it privileged the dissociation of the clusters of initial powder particles and the intergranular fracture of individual particles. Transmission electron microscopy interpretation reveal that the constitutive crystallites of the initial powder, normally 10 nm in size, are repeatedly dissociated and isolated into the copper matrix.

2.4. H.R. Akramifard, M. Shamanian, M. Sabbaghian, M. Esmailzadeh. [4] Investigated pure Cu sheets were reinforced with 25 micrometer silicon carbide particles to fabricate a composite surface by friction stir processing. In order to get better distribution of reinforcing SiC particles, a grid of holes were designed by drill on the surface of Cu sheets. For valuation of microstructure, Optical Microscope and SEM were used. Micro structural study confirmed fine and equi-axed grains in the stir zone and showed that silicon carbide particles act as heterogeneous nucleation sites in the dynamic recrystallization of copper grains. in addition, agglomeration of particles was not observed and fine particles had a good allocation in SZ. In the SEM graphs, porosities were found as microstructure defects. Microhardness examination showed that surface hardness was two times as high as that of substrate. The pin on disc wear tests confirmed that use of SiC particles improved wear resistance and better average friction coefficient of pure Cu.

2.5. L. Suvarna Raju, A. Kumar [5] Works on The effect of three factors, such as volume % of reinforcement particles, tool tilt angle and concave angle of shoulder, on the mechanical properties of copper- aluminum oxide surface composites made-up via friction stir processing was studied. Taguchi method was applied to optimize these factors for maximizing the mechanical properties of the composite material. The fabricated surface composites were studied by optical microscope for dispersion of reinforcement particles. It was found that aluminum oxide particles are uniformly distributed in the stir zone. The tensile strength properties of the surface composites improved with the increase in the volume % of the Al_2O_3 particles. This is due to the addition of the particles which increases the temperature of recrystallization via pinning the grain boundaries of the copper matrix composite. The experiential mechanical properties are associated with microstructure and fracture features

2.6. M. Sabbaghian, M.Shamanian, H.R.Akramifard, M.Esmailzadeh. [6] Studied a Copper-based composite was made by TiC reinforcement using friction stir processing. Holes with the 2mm diameter and depth of 2 mm were prepared on the surface of a copper specimen and filled by TiC powders. FSP was carried out with transverse and rotational speeds of 50 mm/min and 1000 rpm, respectively. Optical and scanning electron microscope interpretation discovered that FSP produced a fine grain microstructure with a homogeneous sharing of particles on the surface. Reinforcing particles gave a good bonding with the base metal. Mechanical test outcome also proved that FSP improved the microhardness and the wear resistance of specimen as a effect of grain refinement and the continuation of TiC particles in the FSP zone. Maximum hardness in the stir zone was 117 Vickers, while the hardness of pure copper was 65 Vickers. X-Ray analysis says no intermetallic compounds in the stir zone.

2.7. Esther T. Akinlabi1, Anthony Andrews, Stephen A. Akinlabi. [7] investigated the effect of fsw processing parameters on dissimilar joints conducted between aluminum alloy (AA5754) and pure copper was studied. The welds were formed by varying the rotational speed from 600 - 1200 RPM and the feed rate from 50 to 300 mm/min. The resulting microstructure and the corrosion properties of the specimen were studied. It was obtained that the joint interfacial region of the welds was characterized by interlayers of aluminum and copper. The corrosion tests discovered that the corrosion resistance of the welds was enhanced as the rotational speed was increased. The corrosion rate of the welds compared to the base metals was enhanced compared with copper and decreased a little compared with the aluminum alloy. The lowest corrosion rate was found at welds carried out at rotational speed of 950 rpm and feed rate of 300 mm/min which correspond to a weld formed at a low heat input.

2.8. Nan Xua,b, Rintaro Uejia, Hidetoshi Fujiia. [8] Understand the microstructural evolution during FSW, the plastic deformation phase and the post-annealing phase of the friction stir welding were separated by a stop action technique related with liquid CO2 cooling and a successive annealing treatment. During the plastic deformation phase, the large grains in the base metal were subdivided with the rising strain and temperature, and the stir zone showed ultrafined grains with a huge quantity of low angle boundaries and a symmetrical simple shear texture. During the subsequent annealing period, static recrystallization obtained, which led to the grain growth.

2.9. R. Sathiskumar, N. Murugan, I. Dinaharan, S.J. Vijay. [9] applied the friction stir processing technique to make boron carbide particulate reinforced cu surface composites and examine the effect of B4C particles and its volume fraction on microstructure and sliding wear resistance behavior of the same. A deep groove was prepared on 6 mm thick cu plates and filled with B4C particles. The magnitude of the groove was varied to result in five different volume fractions of B4C particles (0, 6, 12, 18 and 24 vol. %). A single pass FSP was done using a tool rotational speed of 1000 rpm, traverse speed of 40 mm/min and an axial load of 10 kN. Metallurgical characterization of the Cu/B4C surface composites was found out using optical microscope and scanning electron microscope. The sliding wear resistance behavior was calculated using a pin-on-disk apparatus. Results showed that the B4C particles significantly affect the area, grain size, microhardness and wear behavior of the Cu/B4C surface composites.

2.10. R. Sathiskumar, N. Murugan, I. Dinaharan, S.J. Vijay. [10] Investigated FSP successfully**.** In this work, friction stir processing technique has been successfully applied to practice copper surface composites reinforced with different type of ceramic particles such as SiC, TiC, Al_2O_3 B_4C and WC and. relationships are obtained to predict the effect of FSP parameters on the properties of copper surface composites so that the area of the surface composite, microhardness and wear rate. The factors considered are tool rotational speed, travel speed, groove size and type of ceramic particle. The result of those factors on the properties of copper composites is analyzed using the developed empirical relationships and explained. B_4C reinforced composites have better microhardness and lower wear rate.

2.11. H. Sarmadi N, A.H.Kokabi, S.M.SeyedReihani. [11] Has been used FSP to create copper graphite surface composites. Five tools with different pin profile were used in order to achieve a broad dispersion. Results explain that the tool with triangular pin gives rise to a better distribution of graphite powder. Furthermore, four copper–graphite composites containing dissimilar graphite content were made using triangular tool through repeating the process. Friction and wear performance of the composite material were studied using a pin-on-disc tribometer. It was found that the friction coefficients of composites were lesser than pure annealed copper and decreased with increase in graphite powder content. The reduction in coefficient of friction is due to decrease in metal to metal contact points, originated from the occurrence of graphite particles as a solid lubricant. Wear rate of the composites was also decreased with increase in graphite content.

2.12. Bahram A. Khiyavi, Abdolhossein Jalali Aghchai,Mohammadreza Arbabtafti, Mohammad KazemBesharati Givi, Jalal Jafari, [12] Produced copper reinforced metal composite using micron sized chromium particles by friction stir processing (FSP) in order to study special effects of adding Cr particles to copper based matrix by driction stir processing. Microstructures, hardness and wear rasistance properties were examined in order to calculate the micro structures and mechanical properties of made-up composite material. The micro structure properties were studied by optical microscopy and field emission scanning electron microscopy. The mechanical properties of the samples were determined by micro hardness and wear tests. The results obtained that the grain size of fabricated composite material reduced. Also it was found that in comparison to base copper, hardness of friction stir processed composites in stir zone improved significantly. The results of wear rasistance test showed that in higher traverse speed of 160 mm/min increase wear rate of cylindrical pins with respect to the 80mm/min..

2.13. Galvao, A. Loureiro and D. M. Rodrigues. [13] In their work, one and three mm-thick copper-DHP composite were processed with the aim of simulating surface (SFSP) and bulk (VFSP) processing. The effect of the processing conditions on the microstructure and mechanical properties of the processed composite was analyzed. It was establish that the tool geometry, which has a relation with the plastic deformation and dynamic re crystallization inside the stirred zone, the processing parameters and the heat exchange conditions, which find out the extent of dynamic re crystallization and annealing phenomenon, are determinant in friction stir processing.

2.14. Kudzanayi Chiteka. [14] Studied making a choice in selection tool material of friction stir welding/processing (FSW/P) which has turn out to be an important task in determining the quality of the weld produced. The tool material choice depends on the operational feature such as temperature, wear resistance and fracture toughness that decide the type of materials to be used. Soft materials be able to easily welded using tool steels though harder materials need harder tool materials such as carbide based alloy materials and PCBN.

2.15. Mohsen Barmouz, Mohammad Kazem Besharati Givi, Javad Seyfi. [15] Produces copper reinforced metal composite (MMC) using micron sized SiC particles FSP in order to improve surface mechanical properties. Micro structural valuation using optical microscopy (OM) and scanning electron microscopy indicated that an increase in travel speed and a decrease in rotational speed cause a drop in the grain size of stir zone for the work piece friction stir processed without SiC particles. With the aim of deciding the optimum processing parameters, the effect of travel speed as the major processing variable on microstructure and hardness of MMC layers was investigated. Higher travel speeds resulted in bad dispersion of SiC particles and as a result reduced the micro hardness of MMC layers. It was obtained that by the addition of SiC particles, wear resistance properties were enhanced. This action was further supported by SEM images of wear surfaces. Results confirmed that the micro composite obtained by FSP exhibited improved wear resistance and better average friction coefficient in comparison with pure copper.

2.16. A. Heidarz adeh and T. Saeid, [16] Used Pure copper plates of 2 mm thickness with UTS of 272 MPa, TE of 42% and hardness of 102 HV. Tool used as square tool pin profile and Processing Parameters has been taken as the three welding parameters considered were rotational speed, welding speed, and axial load. The Research is conducted on Microstructural characterization of the composite and fractography of joints were examined using optical and scanning electron microscopes. Also, the special effects of the welding parameters on mechanical properties of FSW joints were analyzed in detail.

2.17. D. Mandal, B.K. Dutta, S.C. Panigrahi. [17] Used steel fibers were coated with cu by electrolyses deposition procedure to obtain short fibers. The reinforcing fibers were prepared using available steel wool. The tests were completed on 6 mm diameter, 35 m long cylindrical specimens against a rotating disc EN-32 steel disc(counter face) having hardness 63Rc. A pin on disc wear test machine, Make was used for carrying out these tests. Processing Parameters has been taken The steel fibers were dipped into an aqueous solution that contains 20% HCl for surface cleaning. The steel fibers were immersed in calcium sulphate solution bath for 30 min. The fibers were then deoxidized in a hydrogen atmosphere at a temperature of 800 ◦C for 2 h. This process produces short steel fibers of about 550 to 850 μm average length and 85 to 120 μm average diameters with a fine coating of copper.

2.18. H. Barekatain, M. Kazeminezhad, A.H. Kokabi. [18] Used AA1050 aluminum alloy and commercially pure copper in annealed and rigorously plastic deformation conditions were used. Tool utilized Welding tool of 15 mm diameter shoulder and 3 mm of diameter pin, which was made up of H13 tool steel. FSW was conducted at rotation speeds of 600, 800, 900, 1000, 1200 and 1400 r/min, and traverse speeds of 50, 63, 80, 100 and 125 mm/min. The tilt angle of the tool was 2.5. Degrees.

2.19. H. Bisadi , A. Tavakoli , M. Tour Sangsaraki , K. Tour Sangsaraki. [19] Sheets of AA5083 aluminum alloy and commercially 99.99 % pure copper has been used as a material. A H13 quenched and tempered steel tool was used for the welding process. Through shoulder diameter of 19 mm and cylindrical without thread pin 5 mm in diameter and 3.8 mm in length. The study's aim was to investigate the effects of rotational and welding speeds of the FSW tool on the microstructures and mechanical properties of the lap joints.

2.20. H. Khodaverdizadeh , A. Mahmoudi , A. Heidarzadeh , E. Nazari. [20] Used Commercial pure copper plate with a thickness of 5 mm was joined by FSW. Two traverse speeds of 25 and 75 mm/min at constant rotation rate of 600 rpm (R600T25 and R600T75 samples) and two rotation rates of 600 and 900 rpm has been taken. Effect of tool rotation rate and travel speed on strain hardening behavior of friction stir welded copper joints were examined using hardening capacity and strain hardening exponent concepts. Kocks Mecking type plots were used to show different stages of strain hardening.

2.21. H. Khodaverdizadeh, A. Heidarzadeh, T. Saeid. [21] Material has been chosen as a pure copper. Two different tools with threaded cylindrical and square pin profiles were used to fabricate the joints. Processing parameters at constant rotation rate of 600 rpm and traverse speed of 75 mm/min has been taken. In the present study, the effect of tool pin profile on microstructure and mechanical properties of friction stir welded pure copper joints were investigated.

2.22. Hamed Pashazadeh , Jamal Teimournezhad , Abolfazl Masoumi. [22] uses Copper plates of dimension 220 mm x 75 m x 4 mm with a chemical composition of 0.7Ni–0.3Cr–0.12Fe–0.04Ti, wt.%) Were employed for FSW experiments. The tool pin and shoulder is made of tungsten carbide (WC) and HSS respectively. The tool geometry is shown. The tool shoulder diameter, pin diameter, and pin length was 17.8, 6.5, and 3.5 mm, respectively. The objective of this study was to develop a numerical model for the prediction of temperature distributions, effective plastic strain distributions, and especially material flow in Friction Stir Welding of copper plates.DEFORM-3D was used by incorporating the Arbitrary Lagrangian Eulerian (ALE) formulation. Three-dimensional results of the material flow pattern extracted using the point tracking are in good agreement with the experiment. It was shown that the main part of material flow occurs near the top surface.

2.23. Hamed Pashazadeh, Abolfazl Masoumi,Jamal Teimournezhad. [23] Investigated friction stir welding experiments using a copper, beside with the process control necessary for a successful FSW process. The friction stir welding tool material H13. The tool pin and shoulder were prepared of tungsten carbide and HSS respectively. This work designed at exploring the hardness of a copper work piece undergoing butt joint FSW. Hardness measurements and microstructural measurement were performed on the welded work piece. Also a3D Arbitrary Lagrangian Eulerian (ALE)numerical model was developed to acquire hardness values. Numerical results for hardness of the specimen values showed excellent agreement with recorded experimental data.

2.24. I. Galvao, D. Verdera, D. Gesto, A. Loureiro, D.M. Rodrigues. [24] Uses 1 mm thick joints of oxygen free cu with high phosphorous content and 5083- H111 aluminum alloy (AA 5083-H111), friction stir butt welded. Using conical and scrolled shoulder tools, H13 Steel, Conical shoulder of 14 mm diameter Smooth cylindrical pin of 3 mm diameter, 0.9 mm length Scrolled shoulder of 14 mm diameter threaded cylindrical pin of 3 mm-diameter. The aim of present work was to analyze the effect of the shoulder geometry on the development and distribution of brittle structures in friction stir welding of aluminum and copper. With this aim, welds were carried using two different FSW tools: a scrolled tool and a conical shoulder tool. It was found that, welding under the same parameters but with different tools, the nugget of the welds had totally different inter metallic content.

2.25. I. Galvao, R.M. Leal, D.M. Rodrigues, A. Loureiro. [25] Has been taken Copper plates of 1 mm thick and 250 mm long, were butt joined by FSW. Three tools with a 3mm diameter and 0.9 mm length right-handed threaded cylindrical pin of tool and a 13 mm diameter shoulder be used. The shoulder diameter of the tool was chosen in order to maximize the cause of this part of the tool. The aim of this paper is to study the effect of the shoulder geometry on FSW of 1mm thick copper-DHP plates. The welds were created using three dissimilar shoulder geometries, flat, conical and scrolled pin, and varying the rotation and traverse speeds of the tool.

2.26. J.J. Shen, H.J. Liu , F. Cui. [26] The base metal used in this experiment was a 99.99 % copper plate of 3 mm thickness. The tool was made of high-speed steel, with a pin (φ/3 x 2.85 mm) having good right-hand threads and a shoulder of 12 mm diameter having a concave profile. friction stir welding was conducted at a constant rotational speed at 600 rpm together with varied welding speeds of 25, 50, 100, 150 and 200 mm/min.

2.27. Jiahu Ouyang, Eswar Yarrapareddy, Radovan Kovacevic. [27] The tool pin material was a tool steel with a excellent balance of abrasive resistance, strength, and fracture toughness. The diameter of the pin is about 12 mm. A number of friction stir welding experiments on 6061 aluminum alloy to copper were carried out to find the optimal parameters by adjusting the rotational speed and the welding speed of the tool is in the range of 151–1400 RPM and 57– 330 mm/min, respectively. Other parameters like threaded geometry and plunge depth of the pin were kept constant.

2.28. LI Xia-wei, ZHANG Da-tong, QIU Cheng, ZHANG Wen. [28] In his work commercially available pure copper and 1350 aluminum alloy plates with a thickness of 3 mm has been used. A tool with a concave shoulder of 16 mm in dia, and a cone threaded pin of 5.2 mm in dia and 2.75 mm in length was functional at a tool rotational rate of 1000 RPM and a travel speed of 80 mm/min with the butt joint parallel to the rolling direction of the plates. The tilt angle of the tool has been taken as 2.5° from the normal surface of the plates.

2.29. M. Sarvghad Moghaddam , R. Parvizi , M. Haddad-Sabzevar , A. Davoodi. [29] FSW process is conducted on Cu–30%Zn brass plates of 300 mm of length, 100 mm breadth and 5 mm of thickness. The chemical composition of the material is; 28.66% Zn, 1.54% Mn, 0.99% Al, 0.25% Ni, 0.19% Pb, 0.1% Fe, 0.034% Si and copper as balance. The welding tool made up of a 15 mm in diameter concave shoulder with circular threads and a conical pin of 4.9 mm in length with parallel threads. the tool is made from H13 hot work steel. In this study, the significance of various feed and speeds on microstructure and mechanical properties of friction stir welded Cu–30Zn brass alloy is examined. test of the microstructure showed extremely fine grains with some distorted grains in the stirred zone and some coarser grains in the THAZ and base metal.

2.30. Masoud Jabbari. [30] used Pure copper plates With Chemical composition of Cu 99.85 Ni 0.08 Zn 0.041 Si 0.007 Al 0.006 Fe 0.006 Mn 0.006 B 0.002 Sb 0.001.Pin dia 5 mm, Shoulder diameter 15 mm, Pin length 3.95 mm and cylindrical pin has been taken. Welding was obtained in constant travel speed of 25 mm/min with various rotational speed of 400, 600, 900, 1200 and 1500 rpm.

2.31. Nan Xu , Rintaro Ueji, Yoshiaki Morisada, Hidetoshi Fujii. [31] Commercially copper plates (99.97 %,) were used for the FSW. The rotating tool was prepared of a WC based material and prepared with a columnar probe with no thread. The tool was tilted backwards at a 30 from the normal direction of the plate and the axial force was 11500 kg. A notable cause of the retained heat after the fiction stir welding of copper was studied with the application of extra liquid CO2 cooling. The regulation of the welding parameters made it possible to perform the FSW processes, but the cooling rate of the joint was not adequately changed due to the continuation of the post-annealing effect.

2.32. P. Xue, B.L. Xiao, Z.Y. Ma. [32] used Commercially pure Cu (w99.9%) plate with 5 mm in thickness, 300 mm in length and 100 mm in breadth, was used in this work. the tool was made of heat-treated tool steel (M42). a tool with a shoulder of 20 mm in diameter, a cylindrical threaded pin of 6 mm in diameter and 2.7 mm in length were used. Large-area bulk ultrafine grained (UFG) of pure Cu was successfully carried out by multiple-pass overlapping FSP. Overlapping FSP did not exercise a significant effect on the microstructure and mechanical properties of the friction stir processing UFG Cu.

2.33. R. Keivani, B. Bagheri, F. Sharifi, M. Ketabchi, M. Abbasi. [33] used Copper C11000 work pieces with dimensions of 60 mm×20 mm×3.1 mm. Welding tool is made of SKH9 HSS and comprised of a shank, shoulder, and pin was used through the welding. shoulder diameter of 12mm, conical pin diameter of 3 mm, Pin length of 2.8mm has been used. An tilt angle of 1°, with respect to the axis of welding tool and the normal vector of the work piece, was put before welding to permit the tool to smoothly traverse the work piece. The spindle of this self designed FSW apparatus can rotate with rotational speeds from 400 to 1200 RPM, and the fixture table, driven by a servomotor, be able to move at speed of 20 to 60 mm/min. During the friction stir welding process, the pin was initially plunged into the work piece with 2.85 mm deep. A 3D model based on finite element method was used to study the thermal characteristic of cu C11000 in the FSW process.

2.34. R Sathiskumar, N Murugan, I Dinaharan and S J Vijay. [34] Used commercially available copper plates of 100mm length, 50mm breadth and 6mm of thickness in this study. Tool shoulder diameter of 20 mm, Tool shoulder Flat surface, Pin diameter of 5 mm, Pin length of 3 mm, Pin profile Straight cylindrical has been taken. FSP was applied to fabricate boron carbide (B4C) particulate reinforced Cu surface composites. The influence of FSP parameters such as rotational speed, traverse speed and groove size on microstructure and micro hardness was investigated.

2.35. Salar Salahi and Vahid Rezazadeh. [35] In his study pure copper plate of 5mm thickness has been used. A high carbon steel cylindrical tool, with 14 mm shoulder dia, 8 mm pin diameter and pin high of 4 mm was used. The friction stir processing tool was made of H13 tool steel and was heat treated to 58 HRC. Ductility was calculated using tensile elongations at temperature of 20°C. By changing the travel speed from 40 to 100 mm/min at rotational speeds of 300 and 600 rpm, the ultrafine grain microstructure was obtained.

2.36. S. Cartigueyen, K. Mahadevan. [36] Has been studied the effect of rotational speed on the formation of FSP zone in commercial copper at low-heat input conditions. The experiments were carried out using K-type thermocouples to record the max temperature at different locations on the workpiece. The results advise that the temperature achieved during processing plays a vital role in determining the microstructure and properties of the processed specimen. FSP created very fine and homogenous grain structure and it is found that smaller grain size structure is obtained at lesser rotational speed whereas a tunnel defect was produced at lower speed of 250 rpm.

2.37. M. Felix Xavier Muthu, V. Jayabalan. [37] Investigated pin profile has more effect on material flow particularly in welding of dissimilar materials with different strengths. In the dissimilar welding of aluminum and copper, the material flow actions is complex to understand and thus a study is required to reveal the method of flow behavior and the resultant mechanical properties. Three pin profiles, whorl pin profile, plain taper pin profile and taper treaded pin profile were selected. The special effects of pin profile on the microstructure, microhardness and tensile properties were examined. Optical microscope, scanning electron microscope, XRD and EDS analysis were used to describe the microstructural features. amongst the three pin profiles, PTP profile shows defect-free stir zone and maximum joint properties of yield strength of 101 MPa, ultimate strength of 116 MPa and joint efficiency of 68% compare to the other pins.

2.38. S. Mukherjee*, A.K. Ghosh. [38] Friction stir processing was conducted on a multi-layered copper nickel (30%), deposited on a copper–nickel substrate through laser-assisted direct metal deposition (DMD). Microstructural changes related with single and overlapping passes were analyzed by electron microscopy. Mechanical property and corrosion activities were also examined before and after FSP. It was found that FSP reduces porosity, refines grain structure, increases micro-hardness, reduces ductility and increases corrosion rate in comparison to DMD copper–nickel.

2.39. T. K. Bhattacharya, H. Das, T. K. Pal. [39] Studied that Joining of dissimilar aluminum–copper is a rising area of interest for both research and industry due to its complexity. Friction stir welding was attempted to estimate the joint strength at the butt line between AA6063 to HCP copper plate under dissimilar combination of rotational speed of 800 and 1000 RPM and traverse speed of 20 and 40 mm/min. Material flow was examined in detail for various combinations of parameters with optical microscopy and energy dispersive X-ray spectroscopy (EDS). The results were associated with the microstructural characteristics and development of intermetallics at the bond interface by microhardness test and X-ray diffraction (XRD) test.

2.40. L. Suvarna Raju, A. Kumar. [40] In this study Cu-Al2O3 surface composites are formed with different volume % using micron sized particles by friction stir processing in order to improve surface mechanical properties. Tool rotational speed and travel speeds were fixed at 900 rpm and 40 mm/min respectively. The made-up surface composites have been studied by optical microscope for distribution of reinforcement particles and found that Al2O3 particles are uniformly distributed in the stir zone. It is also clear that the microhardness at the greater volume percentage increases due to existence of hard Al2O3 particles. The tensile strength properties of the composites increased with the increase in the volume % of the Al2O3 particles.

MY WORK

I have Investigate the state of development of FSP for processing of copper with graphite powder. The project done, determines the parameters affecting the friction stir processed copper with graphite powder and enhancement of the hardness, microstructure, and tensile properties of the composite material. The behavior of copper with graphite powder studied with single pass, double pass, triple pass and four pass.

CHAPTER – 3

EXPERIMENTAL SETUP AND PROCEDURE

To observe the above advantages and effects, experiment and analysis are performed on the copper sample.

The experiment is further divided as following:

- Experimental setup.
- Formation of the Work piece and Tool used.
- Filling of powder in the groove.
- Processing on the FSP machine.
- Cutting of test samples from the Bead Area.

The theory and the procedure behind the each step given above are described in brief.

3.1. Experimental Setup:

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.

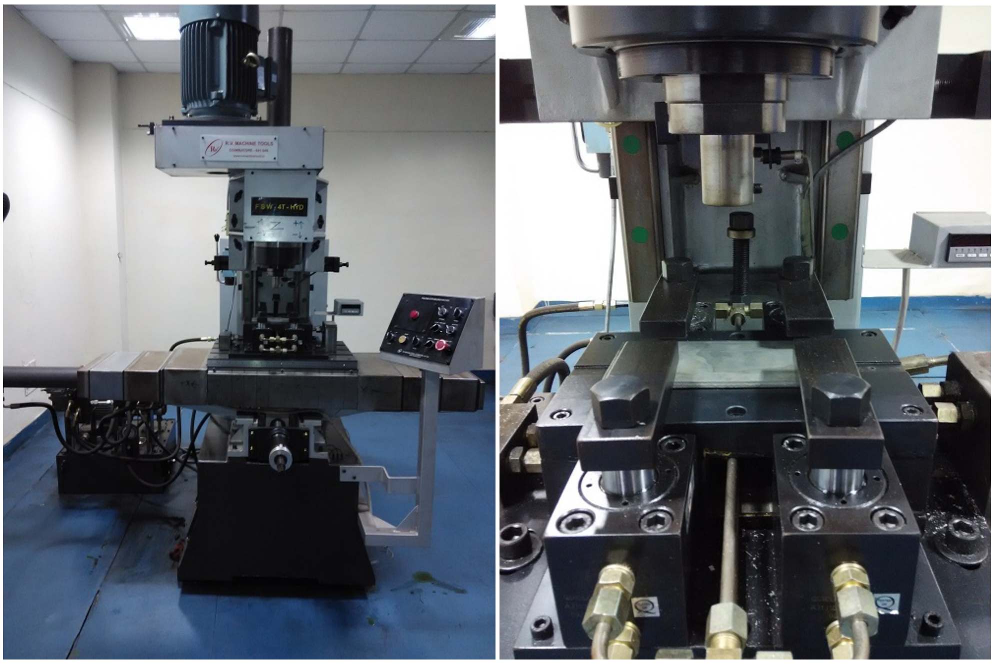


Fig 3.1 Friction Stir Welding Machine at Mechanical Department, DTU

The machine specification of the FSP machine is as follow.

Table 3.1 Machine Specification

Machine capacity	
Machine size(L*W*H)	1300(mm)*1650*2000
Table working surface	600*400mm
Total weight	2 ton
Welding material	Mild steel, aluminum, copper
Job size maximum	Thickness 5mm
Welding geometry	straight
Machine travel	
x- axis stoke	600mm
y- axis stoke	200mm
z- axis stoke	300mm
Axis thrust force	
x- axis force	250-2500 kgf
y- axis force	400-4000 kgf
Motion	
X-axis feed rate	0-5000MM/MIN
Y-axis feed rate	0-2000MM/MIN
Spindle Housing	
Spindle	Iso 40 taper
Spindle speed	1440rpm(max)

3.2. Formation of the Work-piece and Tool:

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.

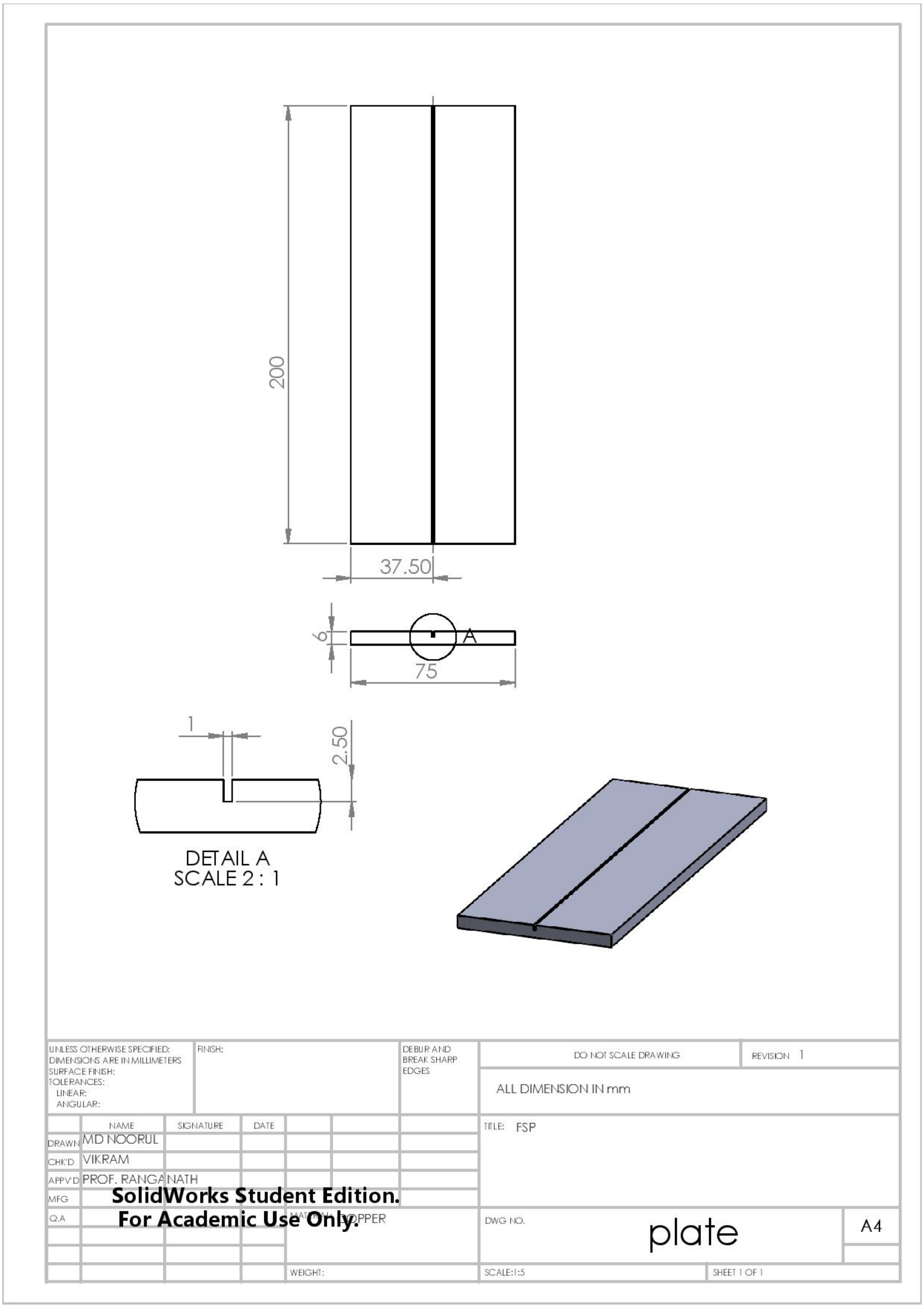


Fig 3.2 Copper plate drawing at solid work

Dimension of the work piece produced are as follows:

Table 3.2 Work piece dimension

Length(mm)	200 mm
Breadth(mm)	75 mm
Thickness(mm)	6 mm

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.

Fig 3.3 Groove cutting on the Milling machine

1 mm thick milling cutter has been used for cutting the groove in the middle of the plate along longitudinal axis. Material of cutter is High Speed Steel (HSS).Dimension of groove are as follows:

Table 3.3 Groove dimension

Depth of cut(mm)	2.5mm
Width(mm)	1mm
length	200 mm

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 **"Vaccum Hardened" to** gain hot hardness of the tool. in my case I have used a triangular pin tool of 7 mm each side without thread.

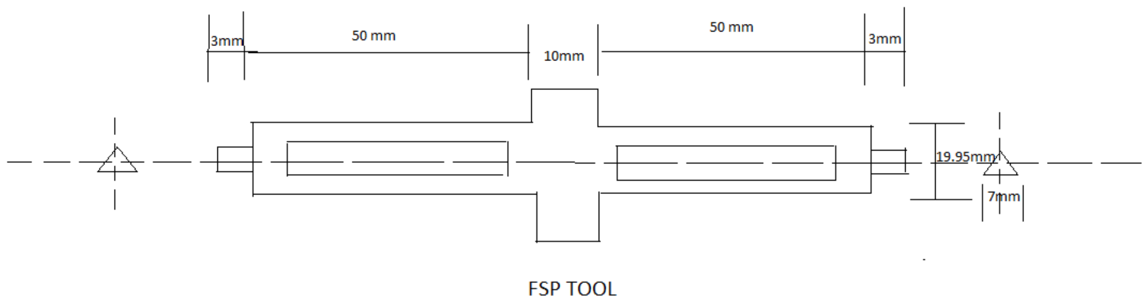


Fig 3.4 Tool drawing 2D

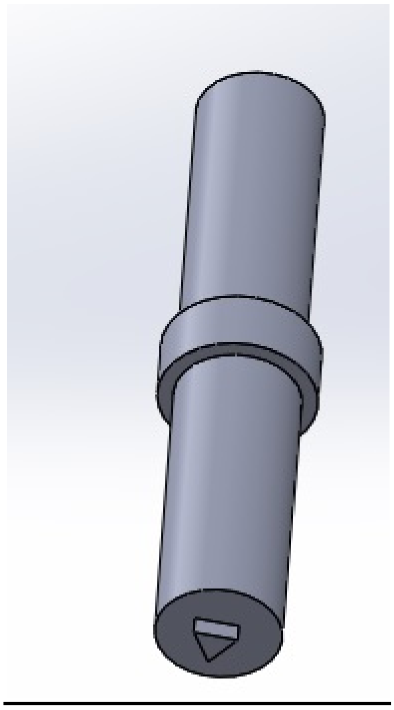


Fig 3.5 Tool drawing 3D

Table 3.4 Tool dimension

Length of tool	120 mm
Diameter of the shoulder	19.95 mm
Width of the pin	3 mm
Diameter of the pin	6 mm
Pin type	Triangular

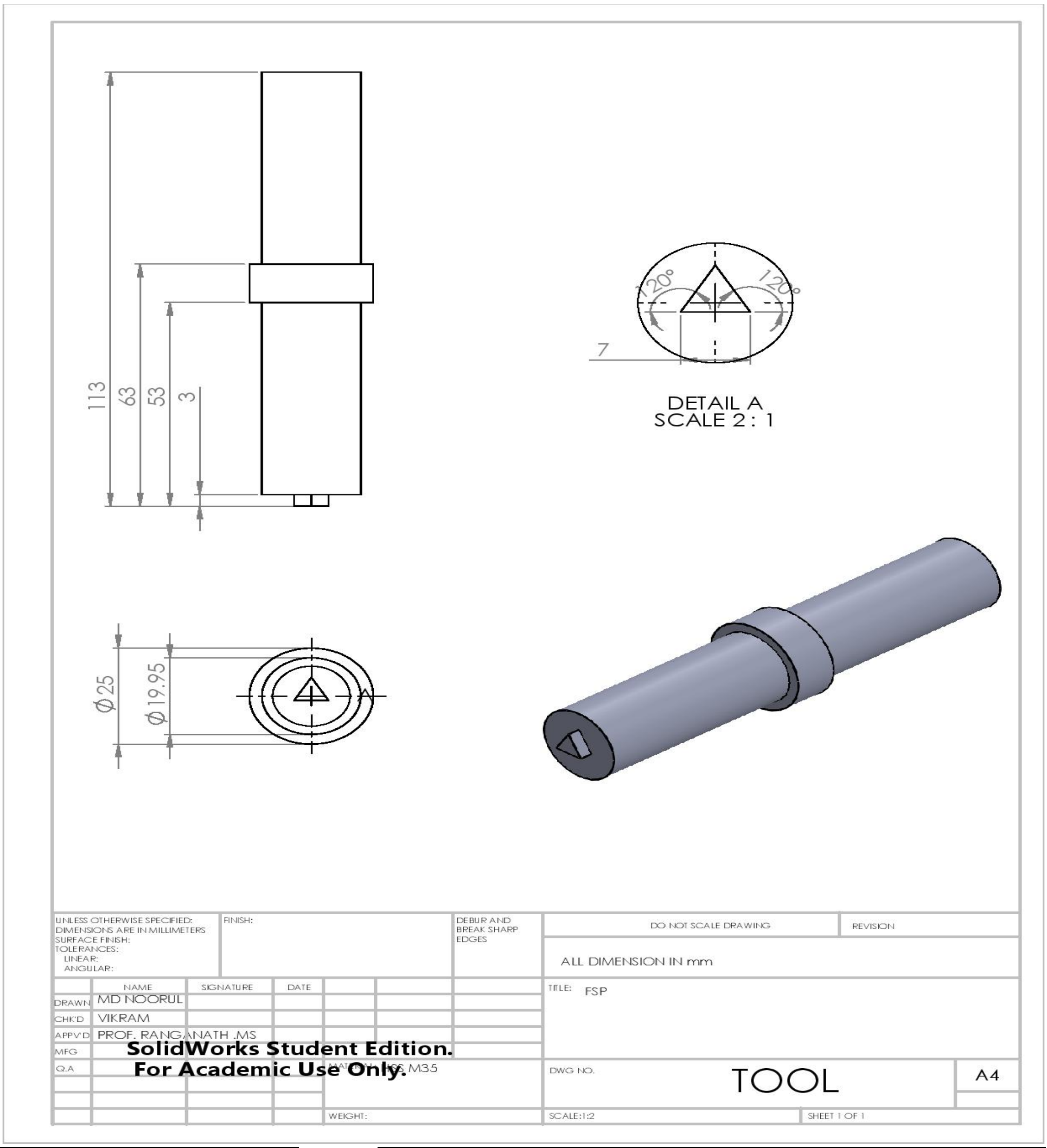


Fig 3.6 Drawing of tool on solid works

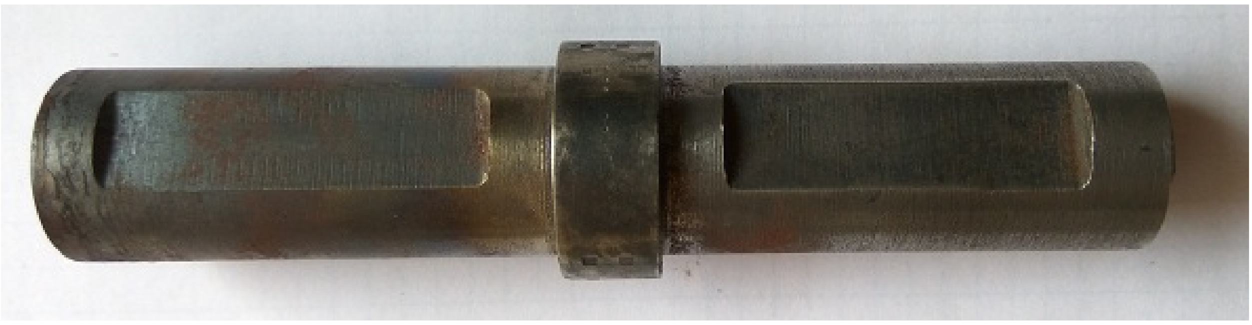


Fig 3.7 Vacuum Hardened Tool

Fig 3.8 Triangular Pin tool

Triangular tool have certain advantages over the cylindrical tool are as:

- Better processing results
- Better mixing of material.
- Increase interface between the pin and the plasticized material, thereby increasing heat generation.

3.3. Filling of Powder in the Groove:

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.

Properties of graphite powder are as follows:

Table 3.5 Graphite powder properties

Diameter	50μm
Density	2.2 gm/cm^3
Carbon content	>99.5%
Weight/plate used	1.1 gm
% volume in stir zone	12 %

Advantages of using graphite powder in the Processing:

- Graphite particularly resistant to heat shock. Therefore, short-term heating and cooling are no problem
- Good mechanical strength: Compared with other materials, the graphite before reaching 2700 ℃, tensile strength, compressive strength and bending strength is enhanced with increasing temperature.
- Graphite has good machinability.
- Increases the wear resistance.

3.4. Processing on the FSP machine:

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 processing 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 as shown in the figure below.

Fig 3.9 Closing of the groove by flat pin tool

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.

Firstly, 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 parameters used during processing are as follows:

Table 3.6 Processing parameters

Load(Kg)	1000kg
Feed(mm/min)	20mm/min
Rotational speed of tool (rpm)	1100rpm

Fig 3.10 FSP on the work piece

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.

Fig 3.11 FSP Sample after Processing

3.5. Cutting of Test Samples from the Bead Area:

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 tensile test, hardness test, wear and microstructure test

For Tensile test, hardness test, wear and microstructure test specimens are being cut as shown below.

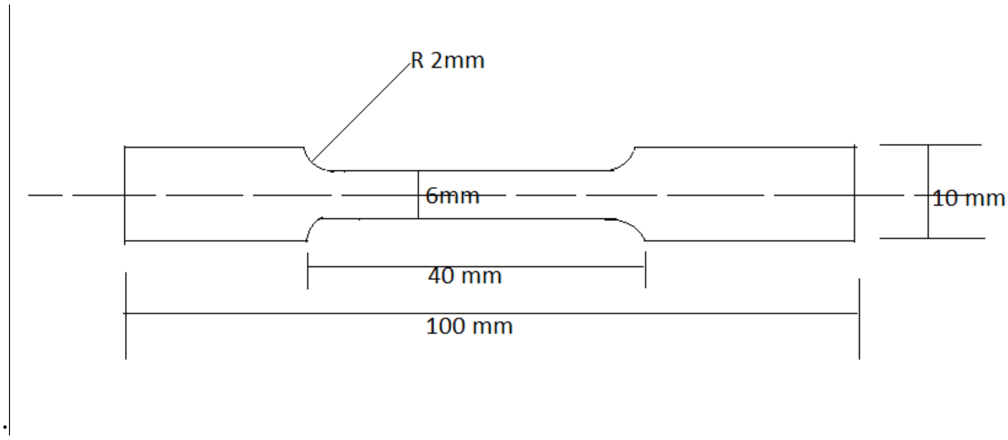


Fig 3.12 Tensile test specimen drawing

Fig 3.13 Tensile test specimens

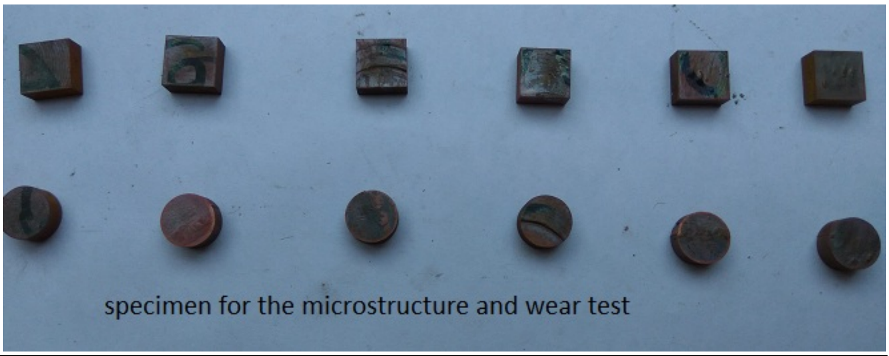


Fig 3.14 Wear and microstructure test specimens

Fig 3.15 Hardness Test Specimens

CHAPTER – 4

RESULT AND DISCUSSION

The following test has been conducted for examine mechanical properties of the copper composite.

- Hardness Test.
- Wear test.
- Tensile test.
- Microstructure.

4.1. 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.

I have performed the hardness test on **Rockwell Hardness Testing Machine.** Rockwell hardness test method is the most commonly used hardness test method. 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. 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.

Fig 4.1 Rockwell hardness testing machine at mechanical department, DTU

Fig 4.2 Specimen for the hardness test

Output result from the hardness test is shown below. Test was performed on Rockwell hardness machine.

Table 4.1 Rockwell hardness number of specimen

Specimen	Rockwell hardness test(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

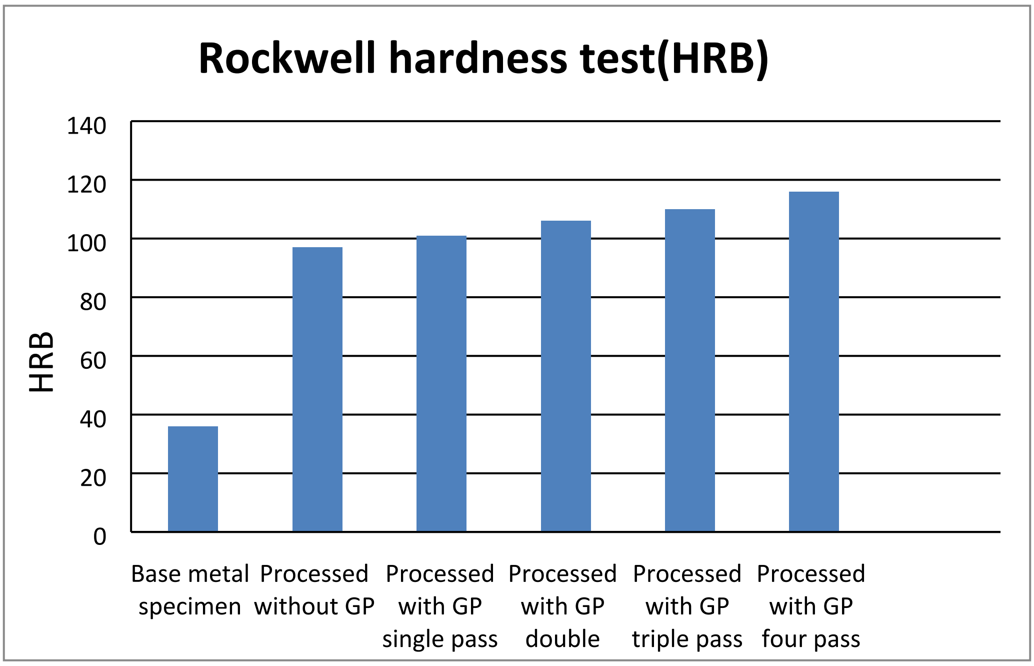


Fig 4.3 Rockwell hardness number (HRB) Vs No of passes chart.

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%.

4.2. Wear Test of the Specimen:

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. 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, 1^{st} pass with powder, 2^{nd} pass with powder, 3^{rd} pass with powder and 4^{th} pass with powder respectively.

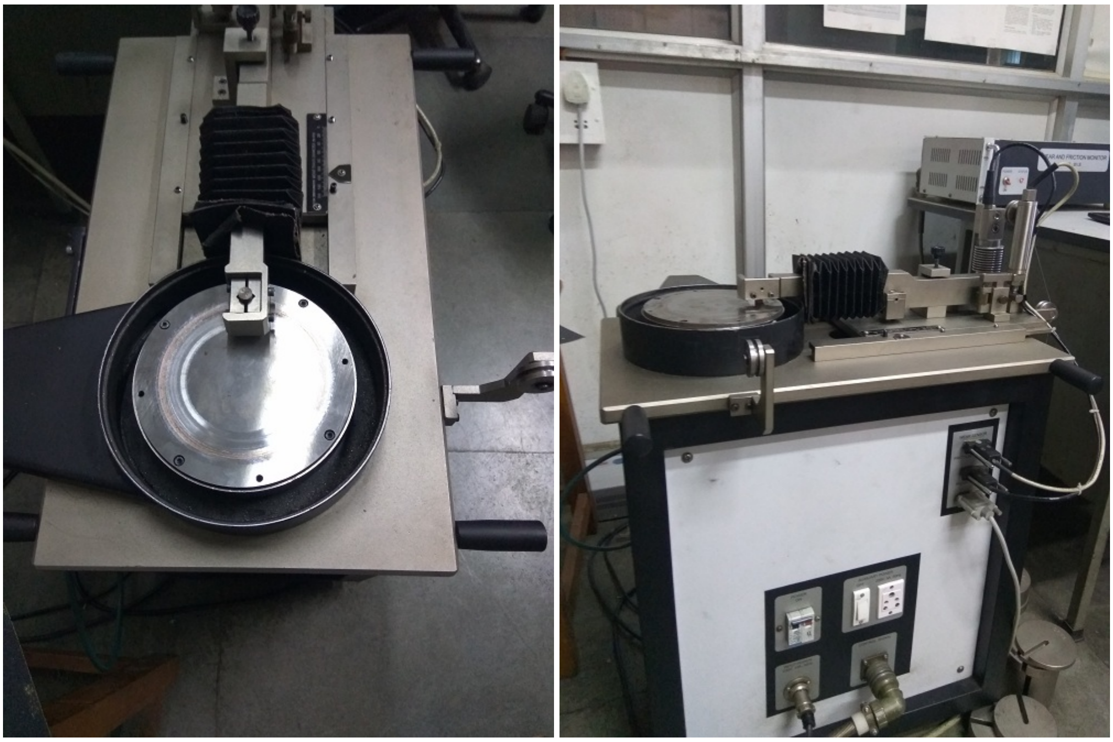


Fig 4.5 Wear Testing Machine at Mechanical Department, DTU

Dimension of specimen was 10mm dia and 6 mm thickness which was unable to hold by machine. for this purpose special pin of 30 mm length and 10mm diameter of mild steel was prepared and pin specimen is mounted on the mild steel by using araldite.

Fig 4.6 Mild steel holding pin for wear test

The pin specimen is held against the rotating disc so that every portion of the cross-section should touches the surface of rotating disc.

Different Parameters for Wear Test:

Table 4.2 Input parameters for wear test

	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

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. From the above table I have got following result.

Table 4.3 Output table (initial and final weight)

	Weight of specimen before and after test(gram)				Weight loss(milligram)		
	Initial	**At 1000m**	**1000-2000m**	**2000-3000m**	**At 1000m**	**1000-2000m**	**2000-3000m**
Without powder	19.1256	19.124	19.1196	19.1211	1.6	4.4	1.5
1st pass with powder	18.6414	18.6335	18.5636	18.5622	2.6	1.7	1.5
2nd pass with powder	20.467	20.4644	20.4627	20.4642	1.9	1.6	1.4
3rd pass with powder	18.6326	18.6314	18.6302	18.6314	1.4	1.2	1.1
4th pass with powder	18.635	18.6336	18.6324	18.6314	1.2	1.2	0.9

Wear rate formula:

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

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

Wear resistance = 1/ Wear rate

Δm - Weight loss.

ρ - Density of composite material.

L – Sliding distance.

F – Load

1st we have to calculate density of the copper composite material.

Density of 99.99% copper (ρ_c) = 8.941 gm/cm^3 = 0.00894 gm/mm^3

Density of the graphite powder used (ρ_g) = 2.2 gm/cm^3= 0.0022 gm/mm^3.

Total volume of the stirred zone (V) = 7*3*200 =4200mm^3.

Volume of the graphite powder used (V_g) = 1*2.5*200 =500mm^3.

Volume of the copper used (V_c) = 4200-500=3700mm^3.

Now

Mass of the copper in stirred zone (m_c) = ρ_c*V_c

= 0.00894*3700 = 33.082 gm.

Mass of the copper in stirred zone (m_g) =ρ_g*V_g

=0.0022*500 = 1.1 gm.

Mass of composite (m_{comp}) = $m_c + m_g$

$= 34.187$gm.

$V_{comp} = V_c + V_g$.

Now we can write as

$$\frac{m_{comp}}{\rho_{comp}} = \frac{m_c}{\rho_c} + \frac{m_g}{\rho_g}$$

From above equation we can calculate the value of ρ_{comp}

ρ_{comp} = .00814 gm/mm^3.

Now we can put this composite material density in the wear rate formula and calculate the wear rate of different specimen.

Table 4.4 Wear rate, frictional force and COF

	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

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.

The above result can be easily discussed on the graph**.**

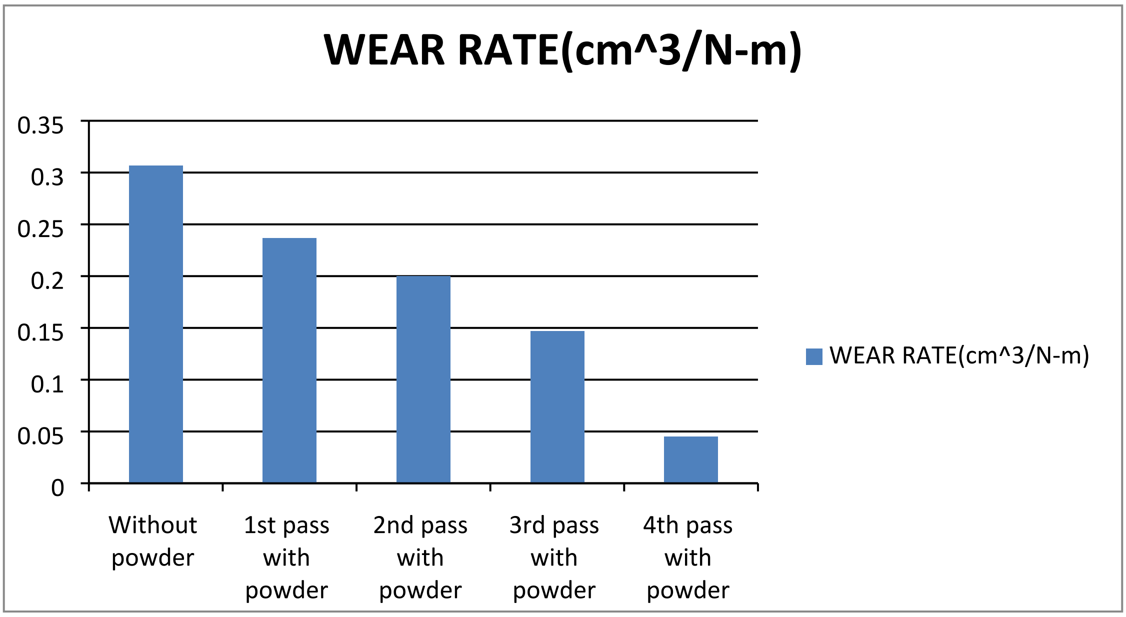


Fig 4.7 Wear rate graph at different passes

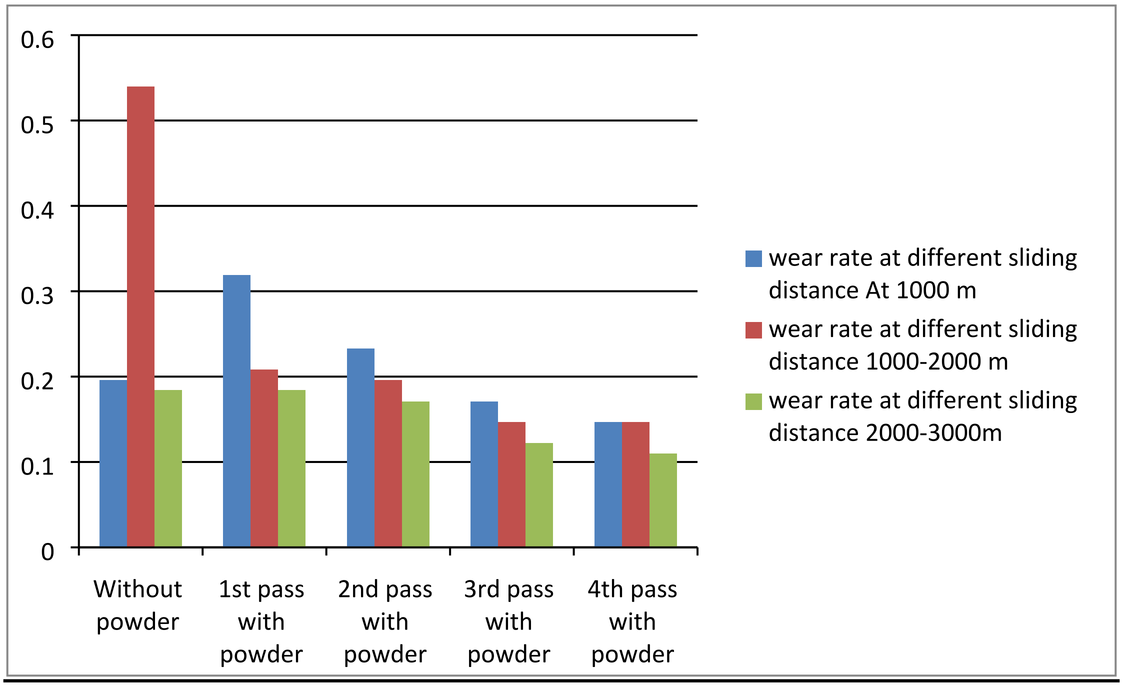


Fig 4.8 Wear rate graph at different sliding distance

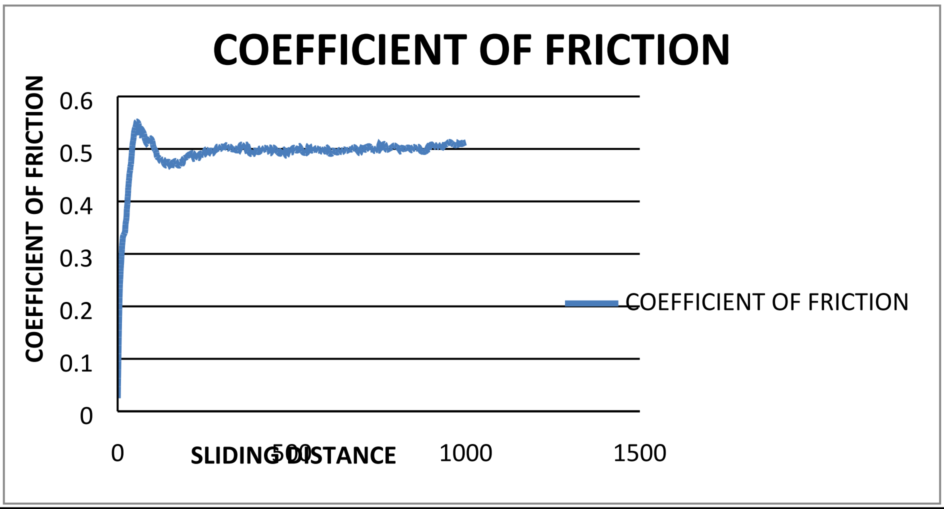


Fig 4.9 Coefficient of friction vs sliding distance (processing without powder)

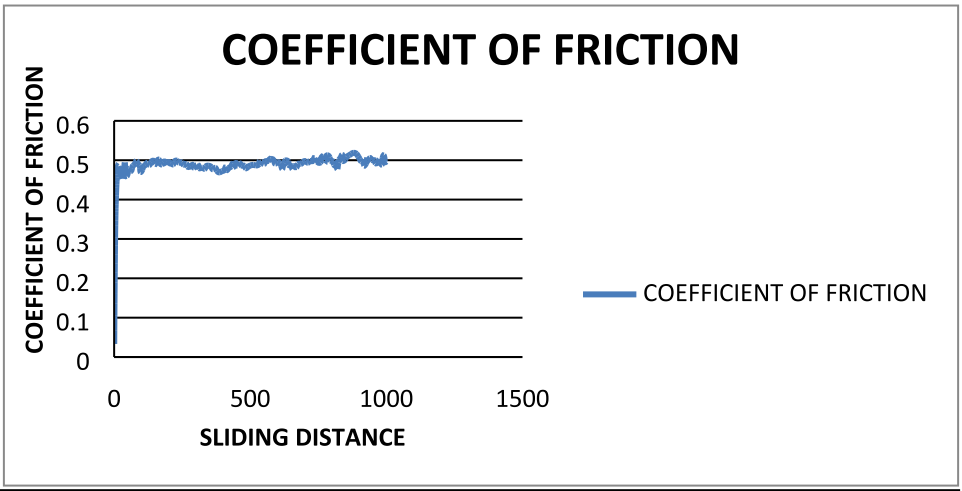


Fig 4.10 Coefficient of friction vs sliding distance (processing 1st pass with powder)

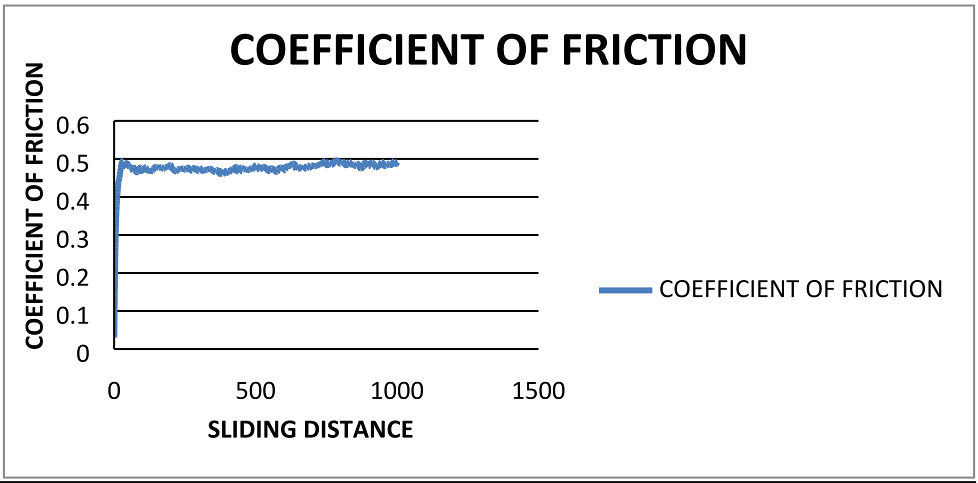


Fig 4.11 Coefficient of friction vs sliding distance (processing 2nd pass with powder)

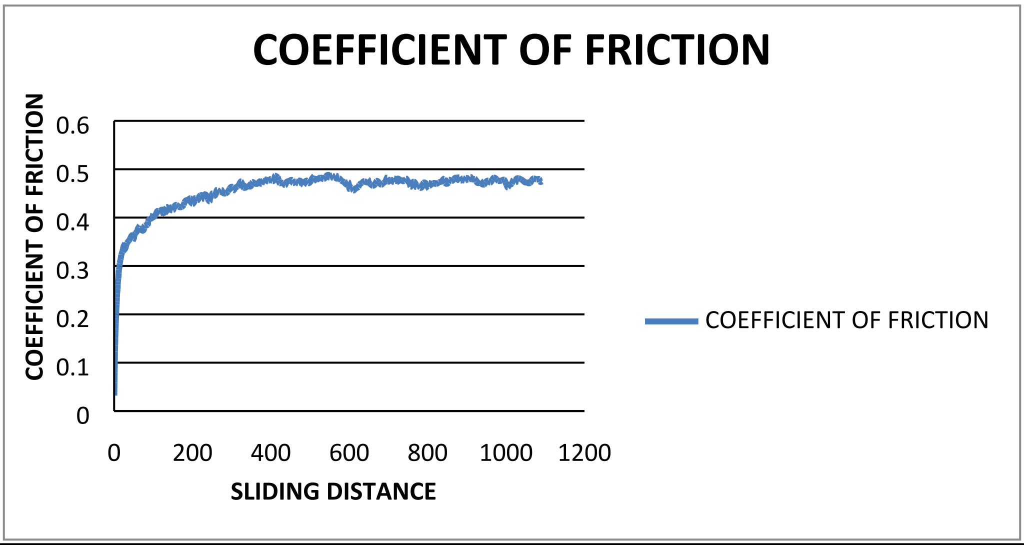


Fig 4.12 Coefficient of friction vs sliding distance (processing 3rd pass with powder)

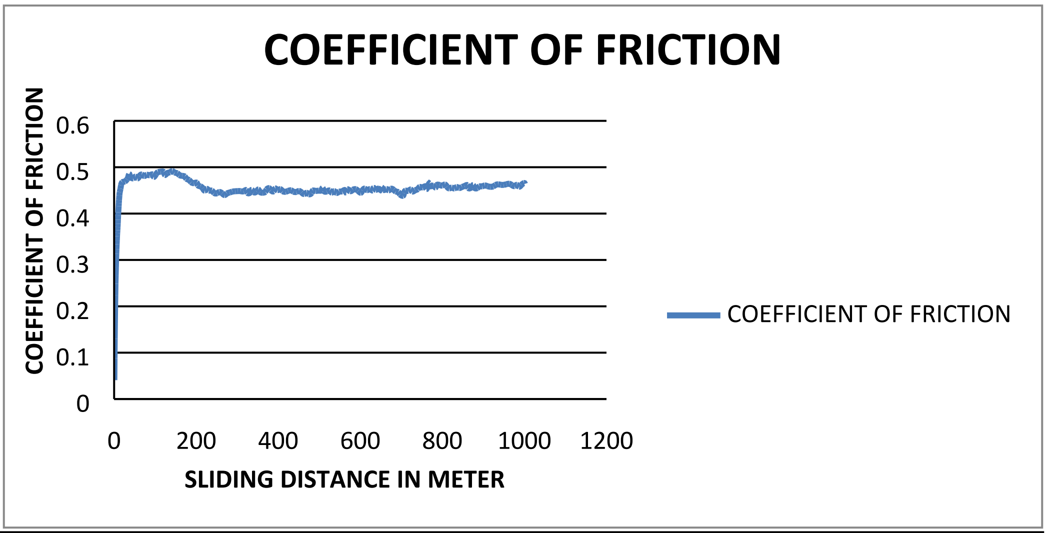


Fig 4.13 Coefficient of friction vs sliding distance (processing 4th pass with powder)

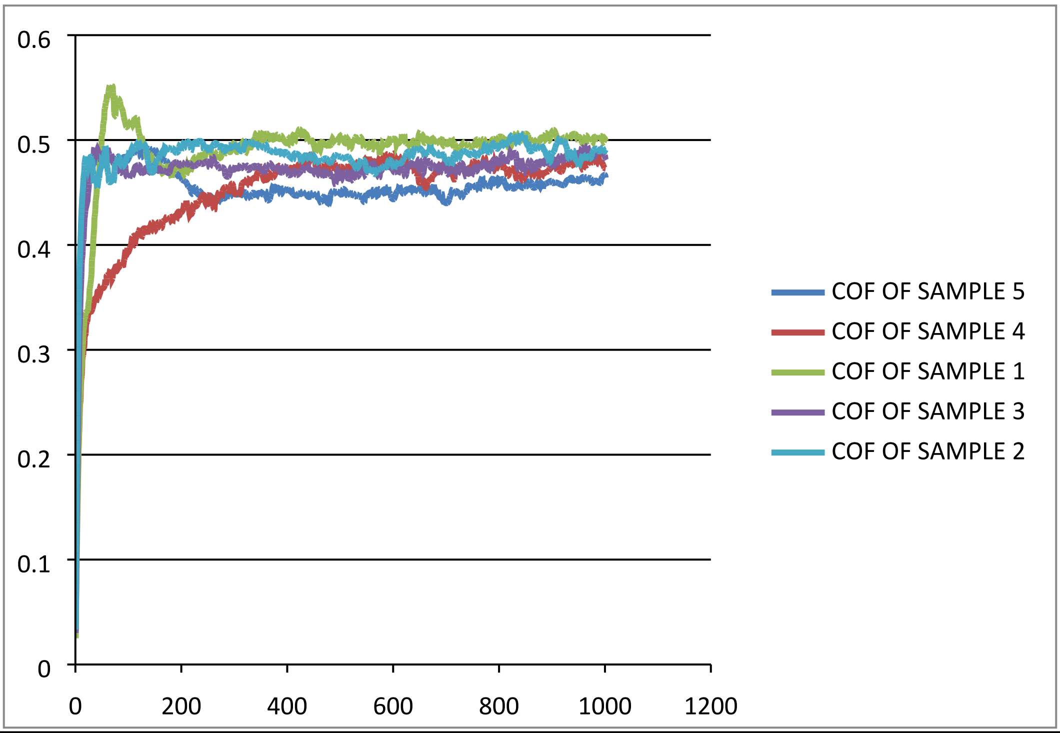


Fig 4.14 Coefficient of friction comparison graph

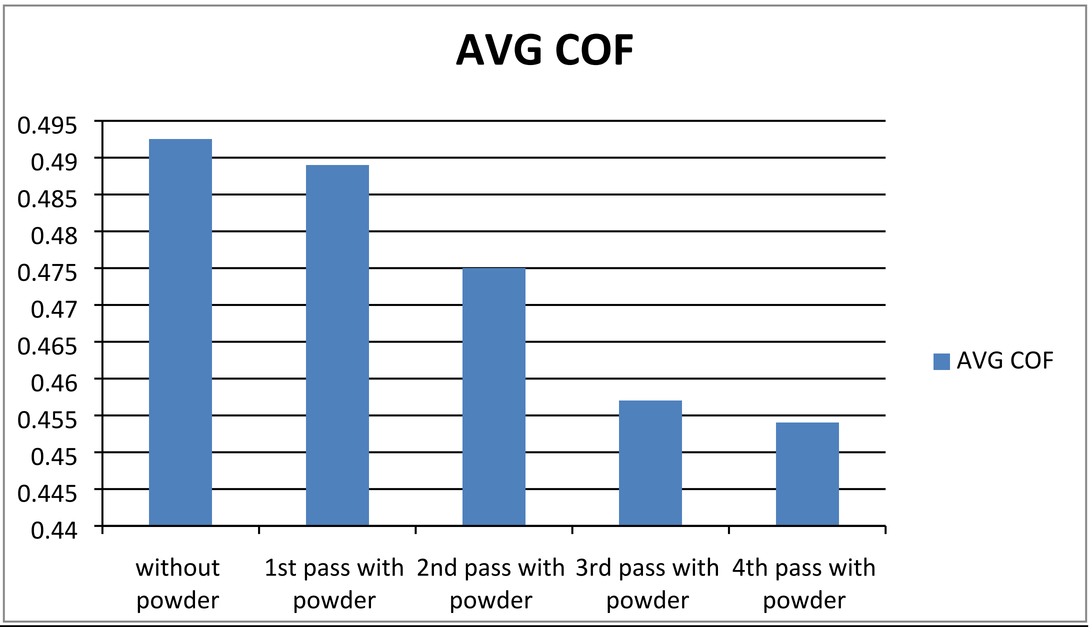


Fig 4.15 Coefficient of friction vs No of passes (comparison chart)

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.

Graph between Frictional Force and Time at Different Passes:

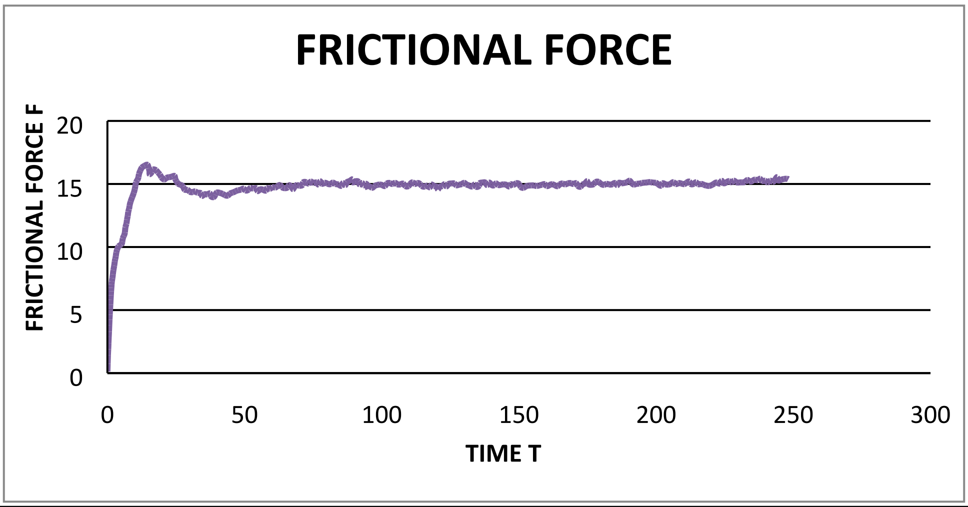


Fig 4.16 Frictional force vs time (processing without powder)

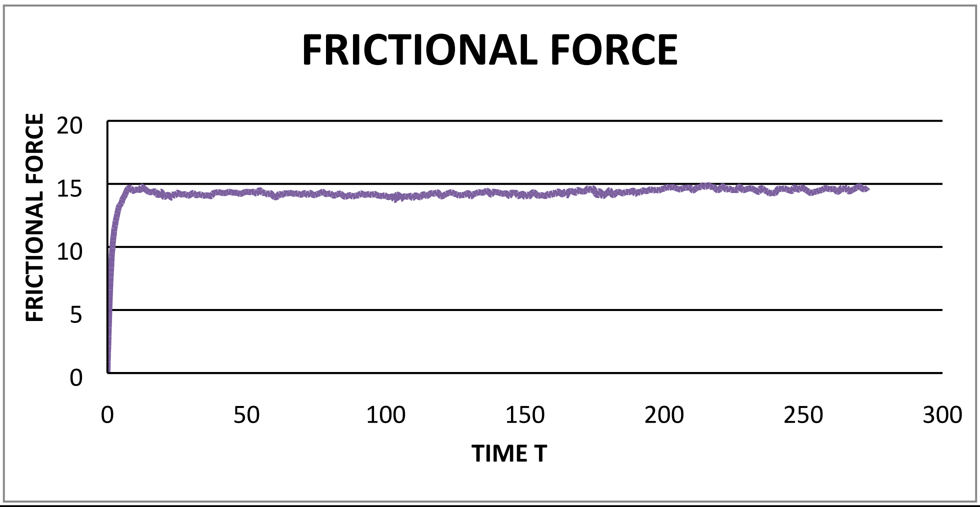


Fig 4.17 Frictional force vs time (processing 1st pass with powder)

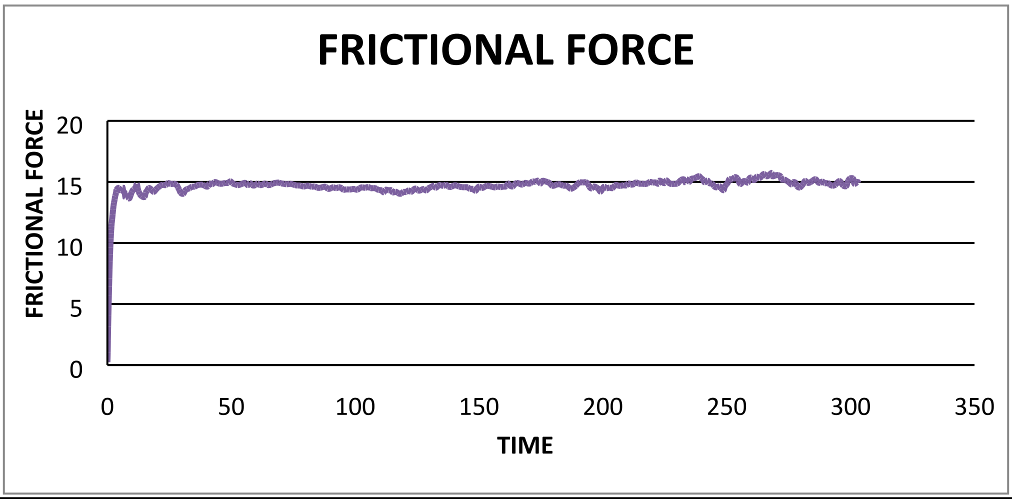


Fig 4.18 Frictional force vs time (processing 2nd pass with powder)

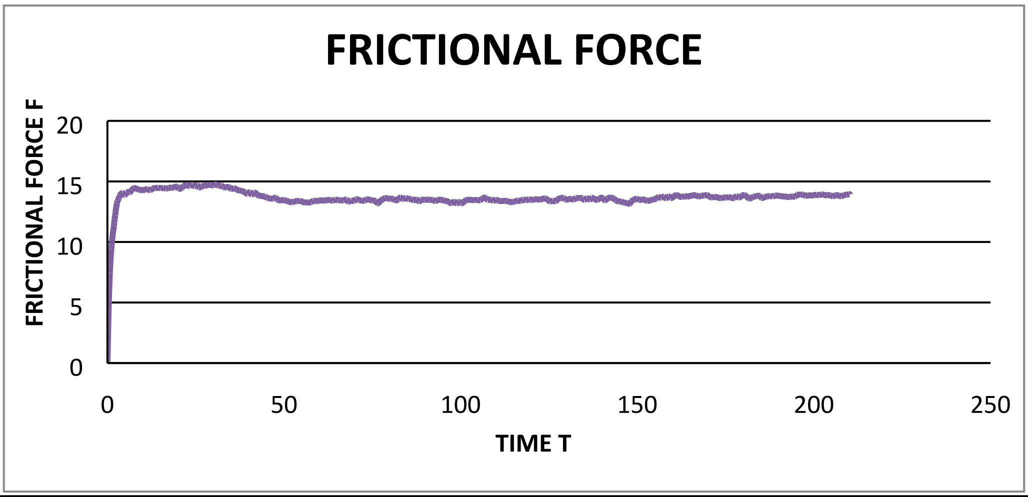


Fig 4.19 Frictional force vs time (processing 3rd pass with powder)

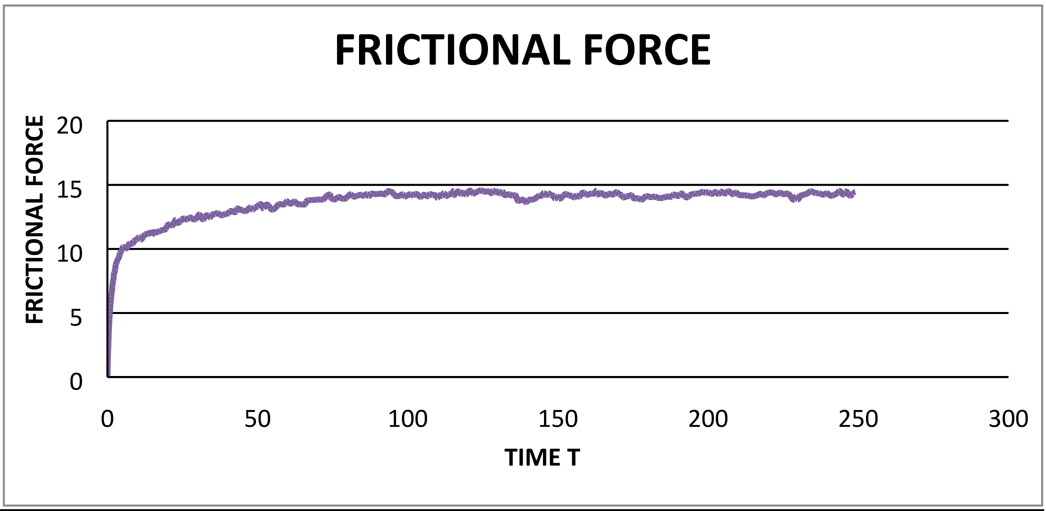


Fig 4.20 Frictional force vs time (processing 4th pass with powder)

From the above table and bar chart it is 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.

4.3. Tensile Test

Tensile test determines the strength and elongation of the material subjected to a simple stretching procedure. The primary use the testing machine is to create the stress-strain graph. The aim of the test is to asses some mechanical characteristics of the testing material. The results of the tensile tests are used in selecting materials for engineering applications. Tensile properties frequently used in material specifications to guarantee quality.

In this project I am determining the tensile strength of specimens of multipassed friction stir processed copper. A universal testing machine (UTM) is used to test the tensile strength, elongation and compressive strength of the materials.

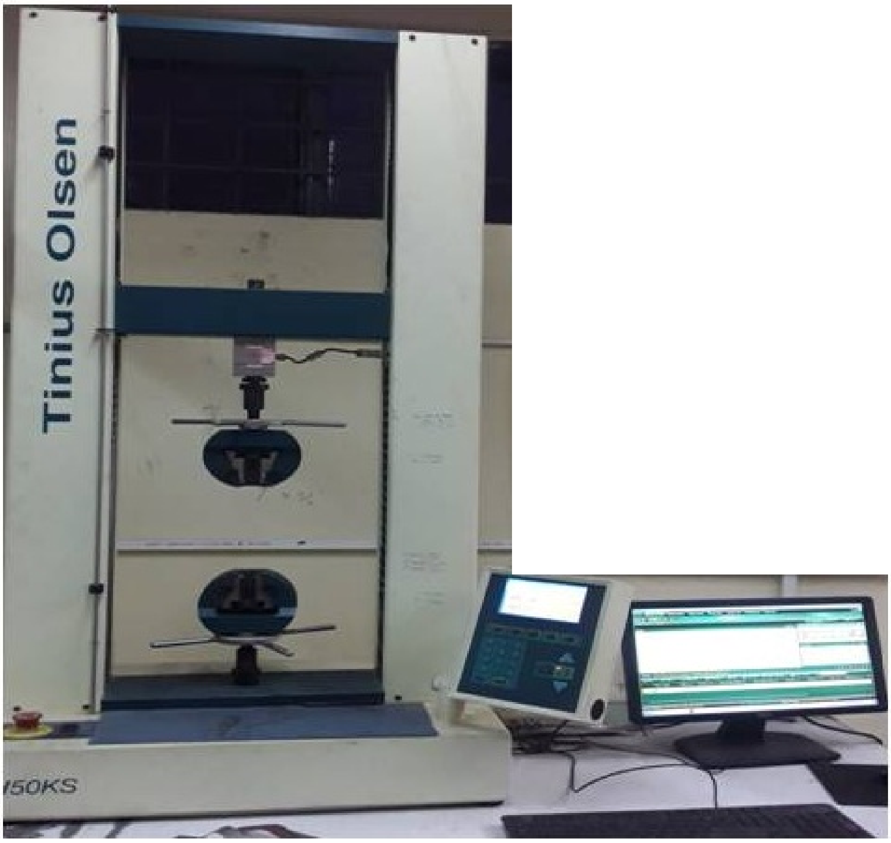


Fig 4.21 Universal Testing Machine at Mechanical Department,DTU

The specimen was chosen marked with marker on their ends. Care was taken to ensure that the specimen did not have any notching or cracks or any surface defects that would adversely affect the tensile tests. Before loading in the machine, computer system was prepared to record data and output necessary load –deflection graphs. The specimens were loaded into the machine and tensile test was performed. The data was recorded electronically in the XPS file and the load to deflection graph was shown on the computer as a visual representation. The average of the different values was taken as the final values. The stress-strain curve and force- elongation curve are shown; the ultimate tensile strength of the processed material comes out to be lesser than the original material.

The result of tensile test is shown below:-

Table 4.5 Specimen Details and output Results during Tensile Tests

Output(Generic metals tensile from position)	**Without processing**	**Single pass without GP**	**Single pass with GP**	**Two pass with GP**	**Three pass with GP**	**four pass with GP**
Width(mm)	5.98	6.01	6.01	6.01	6.0	6.0
Thickness(mm)	5.87	5.81	5.81	5.66	5.40	5.79
Gauge Length(initial)(mm)	25	25	25	25	25	25
Gauge Length(final)(mm)	32.9	46.4	31.5	28.7	26.9	29.1
Area (mm^2)	35.1	34.9	34.9	34	32.7	34.7
Ultimate Force(N)	8560	6840	2520	2570	2840	4340
Ultimate Stress(MPa)	244	196	72.1	75.5	86.7	125
Offset @ 0.2%(N)	7600	4120	1610	2340	71.6	3760
Offset @ 0.2% (MPa)	217	118	46.2	68.7	2340	108
TE(Auto)(%)	30.5	91	24.6	13.3	7.33	16.0

The stress-strain curves for respective specimens are shown as:-

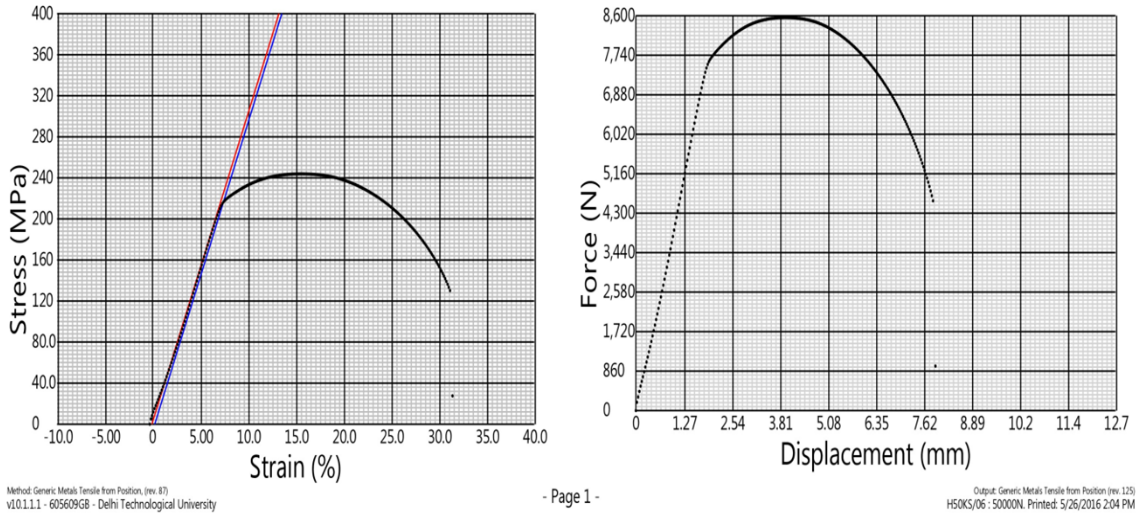


Fig 4.22 Stress-Strain and force-Displacement curve for Specimen base metal

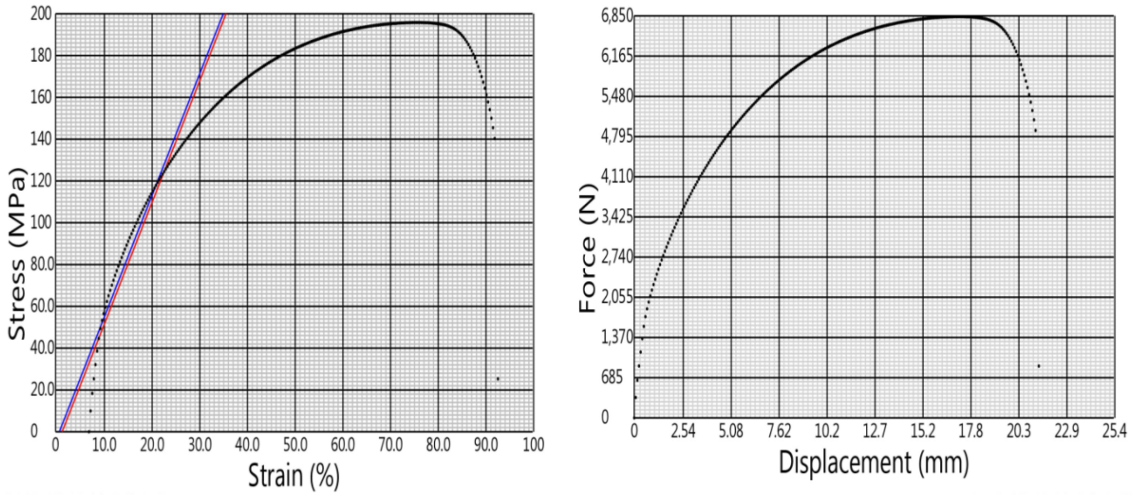


Fig 4.23 Stress-Strain and force-Displacement curve for Specimen processing without GP

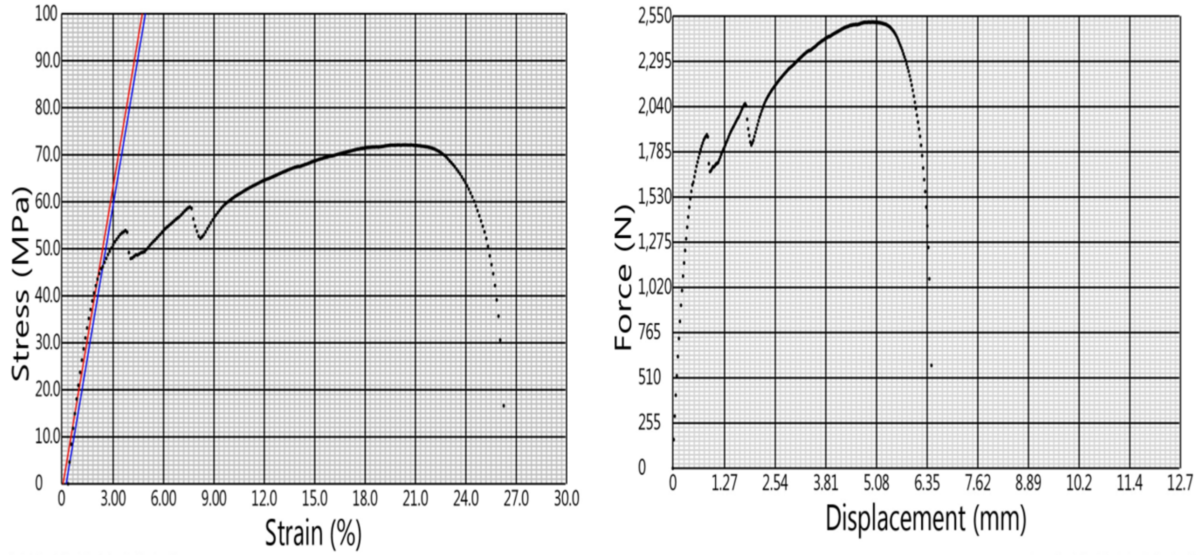


Fig 4.24 Stress-Strain and force-Displacement curve for Specimen with GP single pass processing

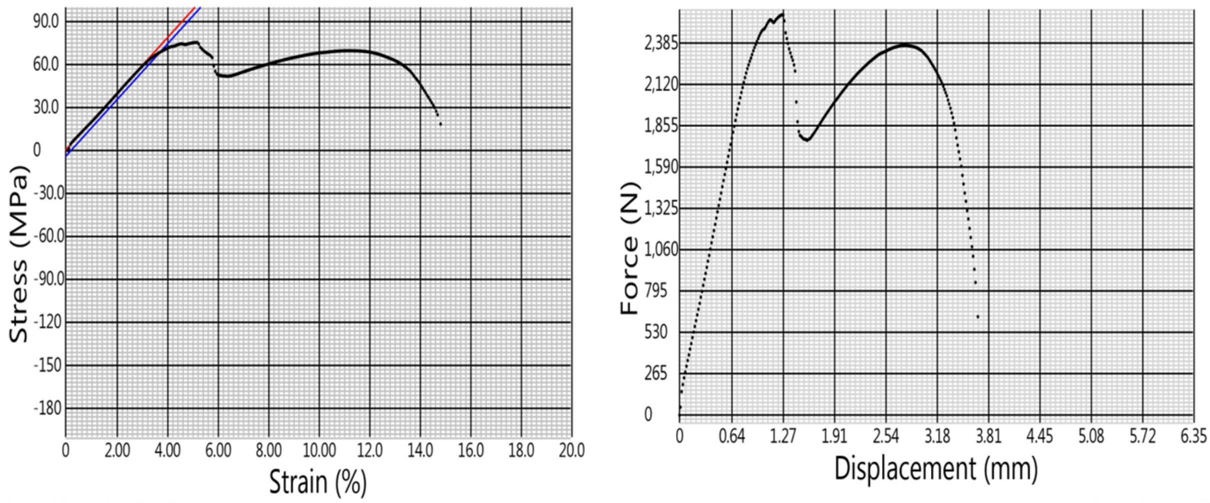


Fig 4.25 Stress-Strain and force-Displacement curve for Specimen with GP double pass processing

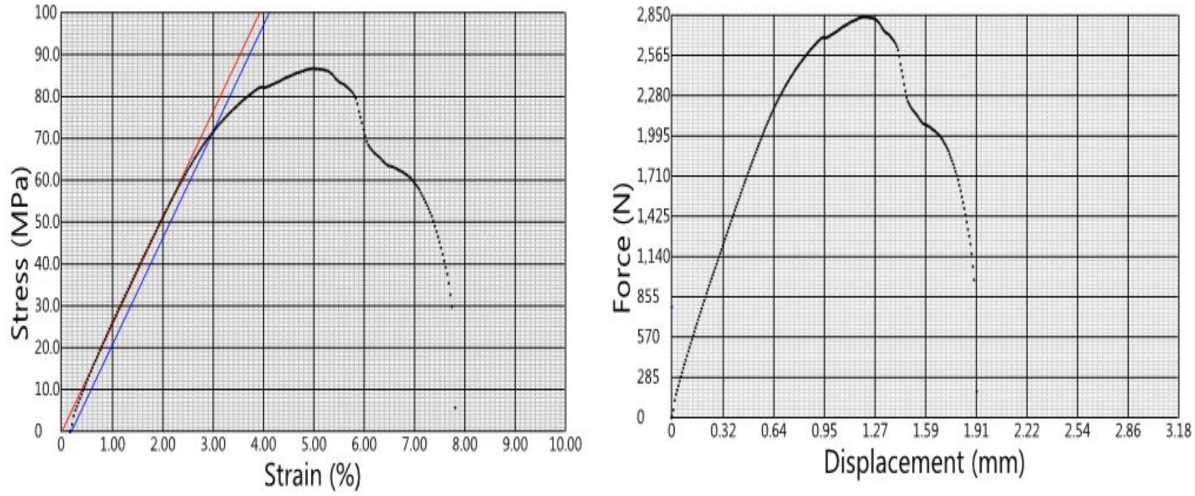


Fig 4.26 Stress-Strain and force-Displacement curve for Specimen with GP triple pass processing

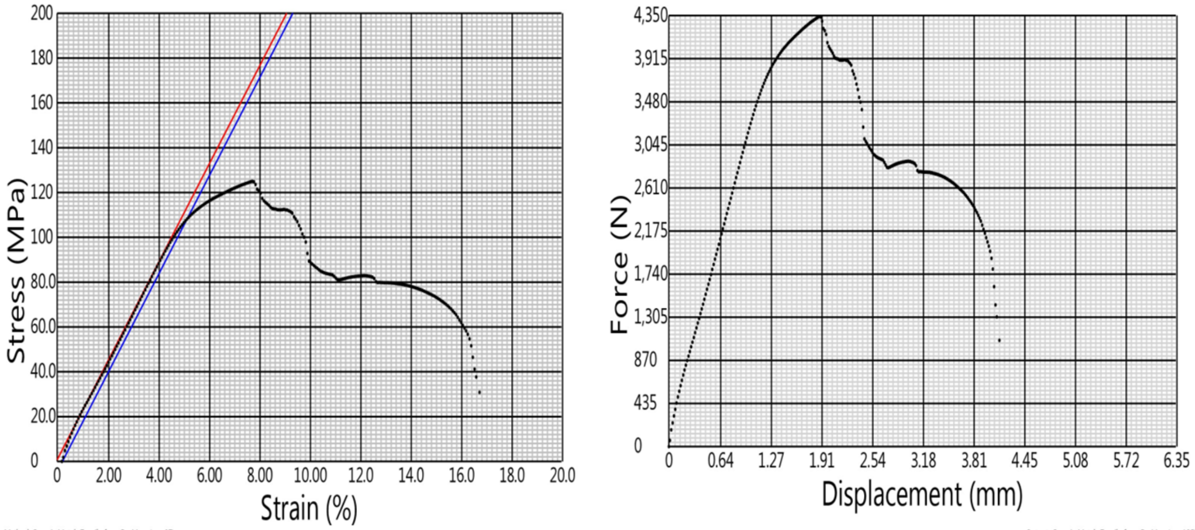


Fig 4.27 Stress-Strain and force-Displacement curve for Specimen with GP four pass processing

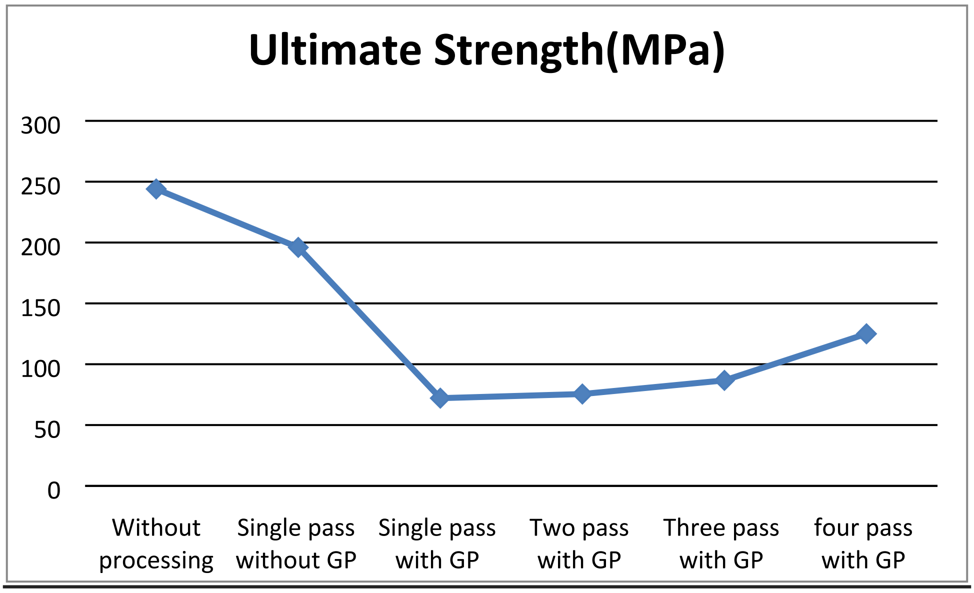


Fig 4.28 Ultimate strength vs No of passes (comparison graph)

From above table and graph it is clear that base material has been got maximum (244Mpa) ultimate tensile strength and after processing without powder ultimate tensile strength has been got 196 Mpa but the elongation of the material was increased by 41% extra with respect to elongation of the base material so that its plasticity behavior has been increased.

after adding the graphite powder we can see the tensile strength of the composite decreased drastically because of the porous created between the graphite powder and copper material but after increasing the number of passes composite material become fine and eliminate the possibility of the porous so that tensile strength increases as the number of passes increase.

4.4. 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. Detailed viewing is done with Optical Microscope. A optical microscope has a system of lenses (objectives and eyepiece) so that different magnifications (10X to 100X) can be determined. The important feature of the optical microscope is: magnification of the specimen, resolution and flatness of field. The resultant magnification is the product of the magnifying power and that of the ocular.

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

Mounting of the Specimens:-

Small Samples are generally mounted in plastic for convenience in handling and to protect the edges of the specimens. Initially our specimen size was 10*10mm but after molding size of specimen become 20mm of diameter. We have used **Resins** for molding of the specimens as shown below:-

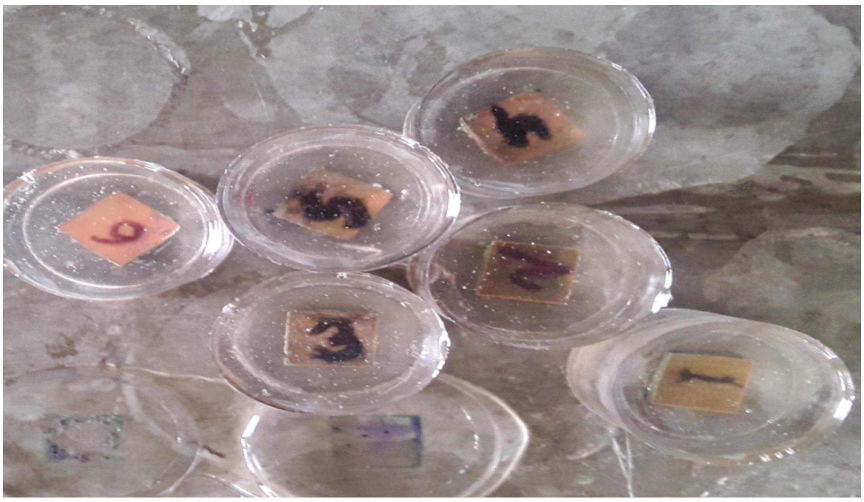


Fig 4.29 Molding of the Specimens

Grinding Of The Specimens:-

For increasing the very good surface finish grinding has been done on the surface o the specimen. Coarse and fine grinding is done on the specimens so that the specimen must be free from scratches, stains and other imperfection tend to mark the surface. Grinding can be accomplished either wet or dry using 120, 220, 320, 400 grit electrically powered disks.

Wet Polishing:-

Wet polishing has been done on the polishing wheel in which very fine grit is used. The work piece is initially kept at one position on the wheel, without rotation, until all of the previous grinding scratches are removed. It should be rotated slowly, counter to the wheel rotation, until only scratches from the 25-micron oxide are visible. During the initial polishing stage, less pressure should be applied to the work piece and the entire stage should generally take 1 or 2 minutes. After washing the specimen, proceed for the 5-micron polishing stage. Repeat the all procedure stated above using lesser pressure and a gradual rotating motion across the polishing cloth.

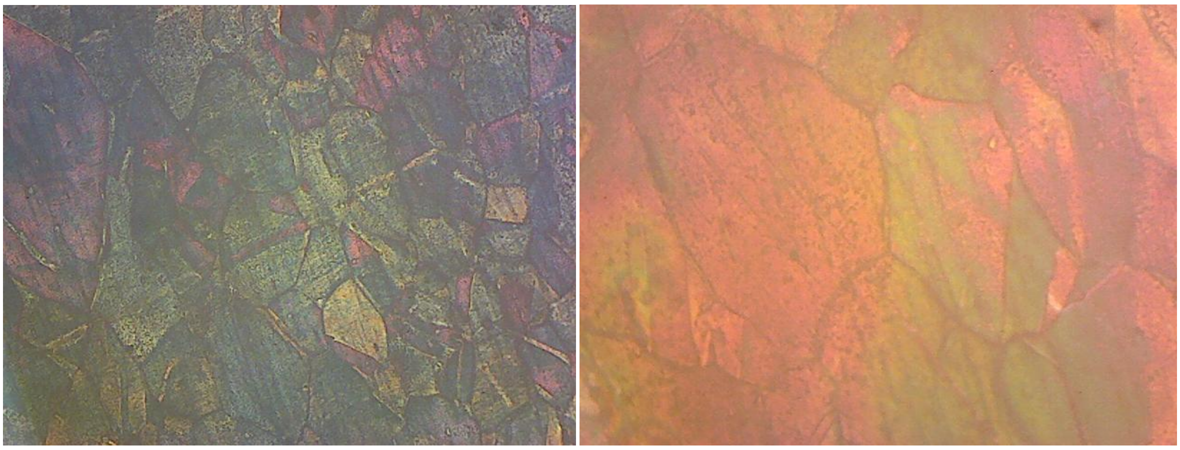
Etching:-

Etching is used to highlight and identify micro-structural characteristics or phases present. Even in a carefully prepared sample a surface layer of disturbed metal resulting from the polishing stage is always present and must be removed. Etchants are gnarly dilute acid in water, alcohol or some other solvent. Etching obtained when the acid or base is kept on the specimen surface because of the difference in rate of attack of the different phases present and their orientation.

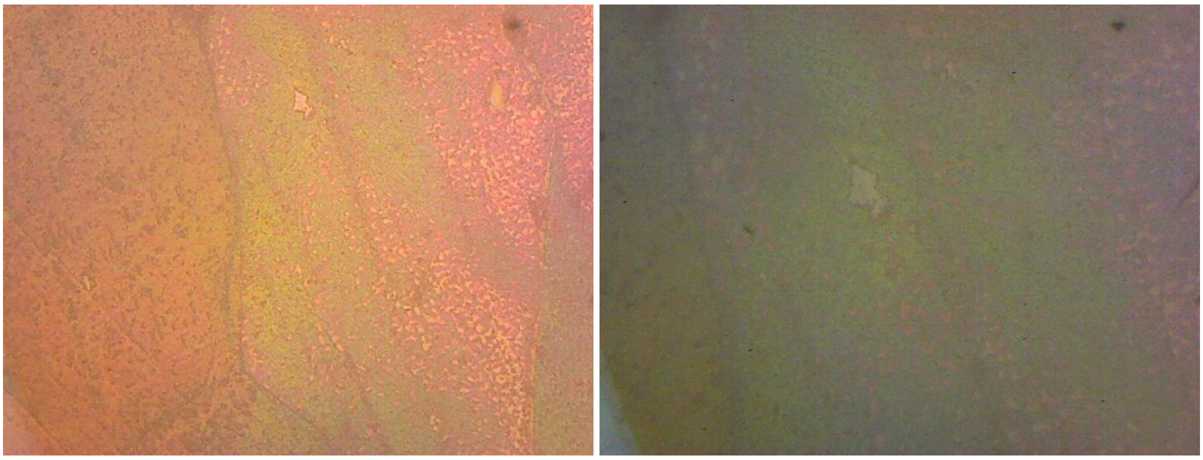
Since Copper is taken for the experiment, the Etching agents used here have the following composition:-

1) Distilled water or Ethanol 50 ml.
2) Nitric acid 50 ml.

The Microstructure Obtained From The Test Is As Follow.

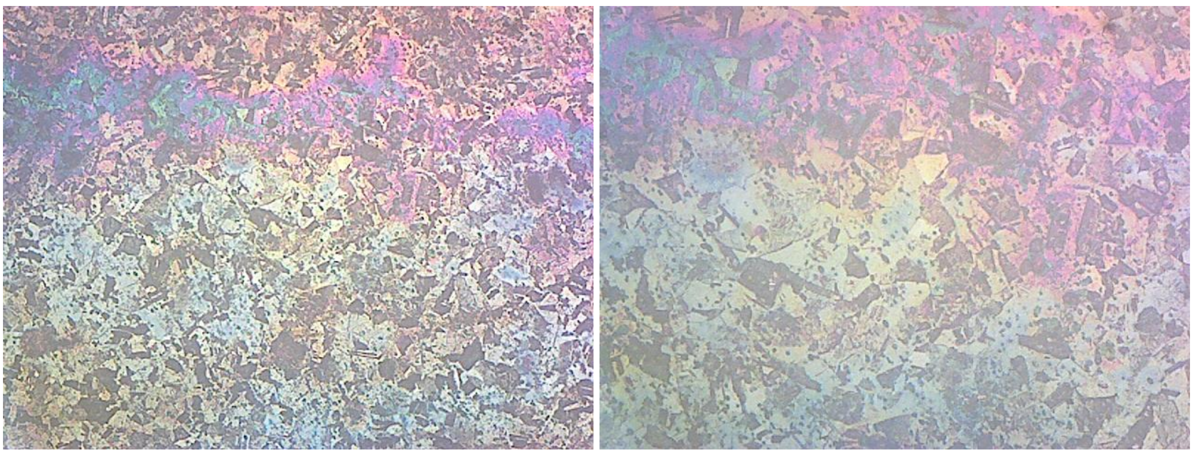


45(a) Specimen at100x and 200x

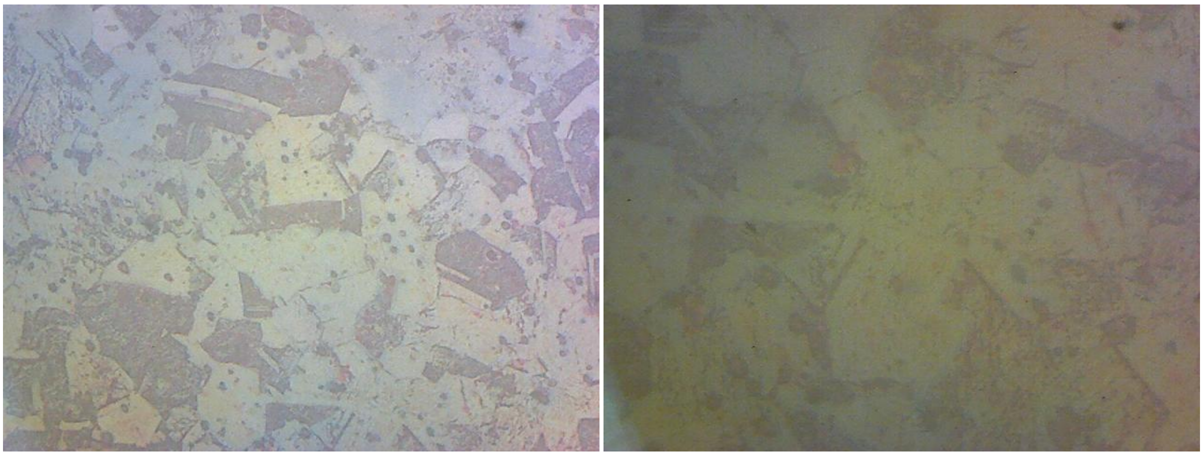


45(b) Specimen at 500x and 1000x

Fig 4.30 Base Metal without processing

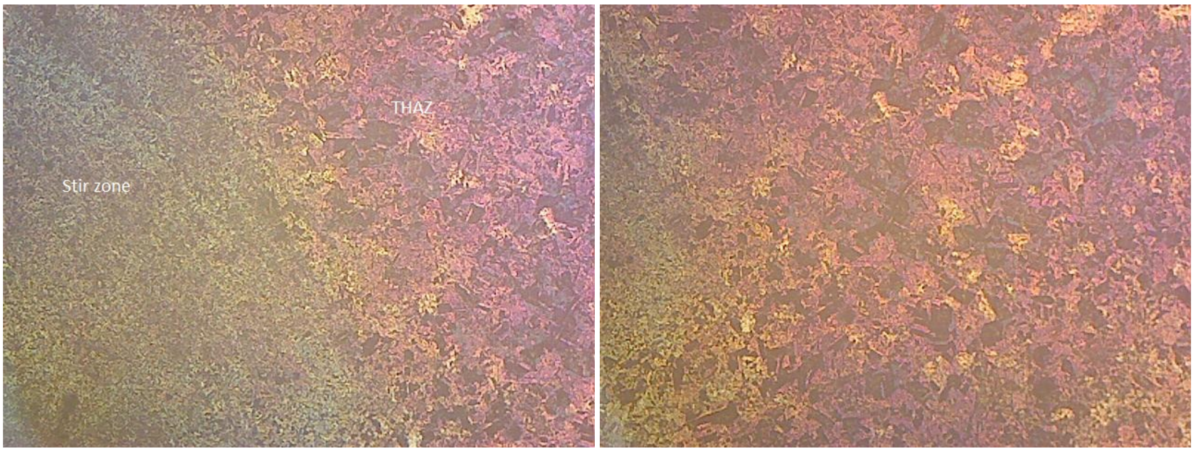


2(a) Specimen at 100x and 200x

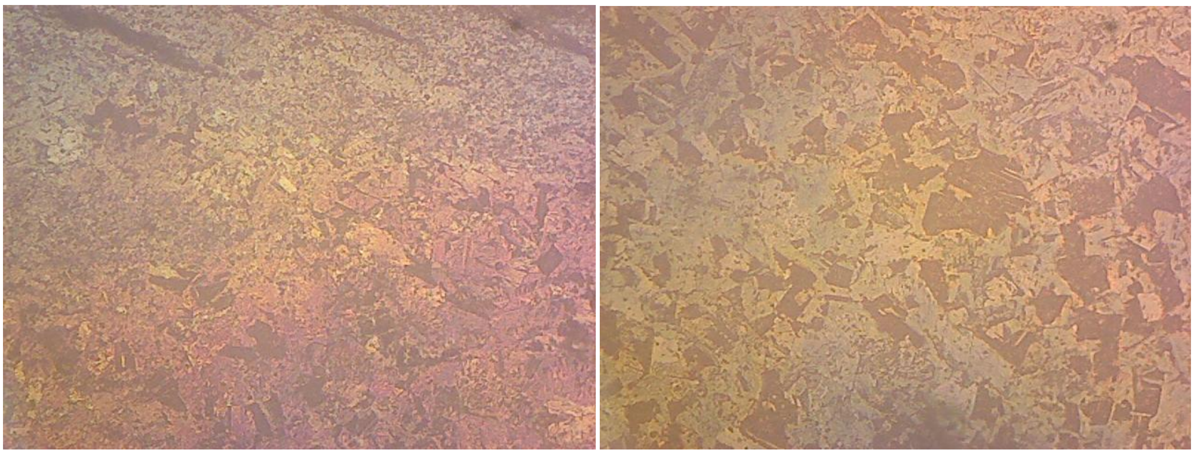


2(b) Specimen at 500x and 1000x

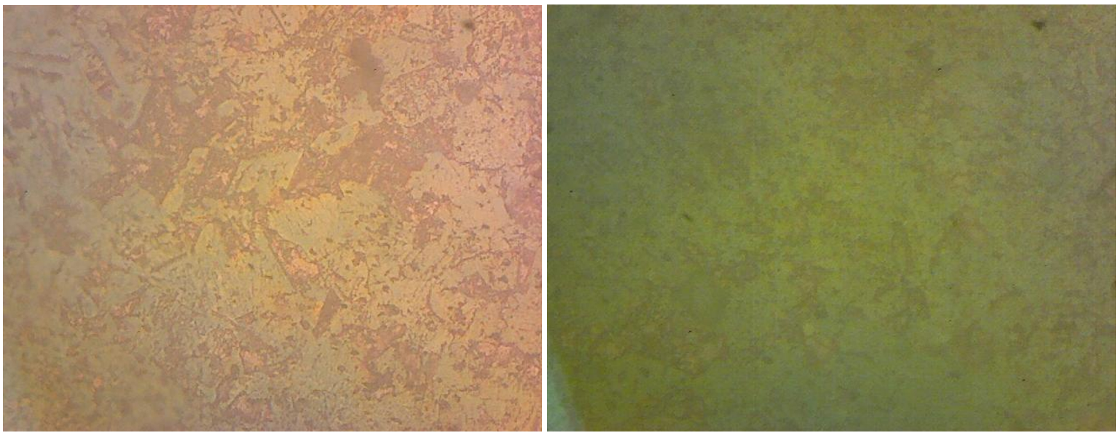
Fig 4.31 Specimen without GP with single pass



3(a) Specimen at 100x. Boundary stirs zone and THAZ

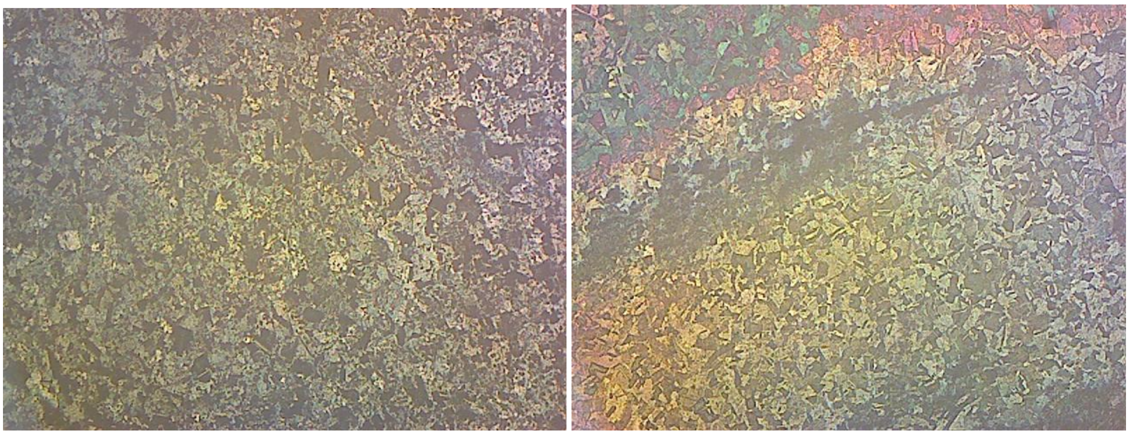


3(b) Specimen at 200x. Boundary stir zone and NZ

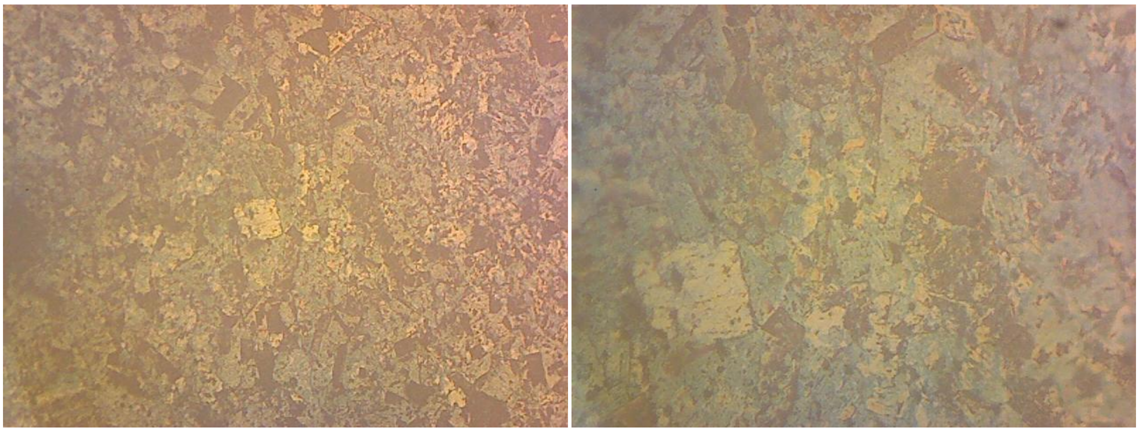


3(c) Specimen at 500x and 1000x.

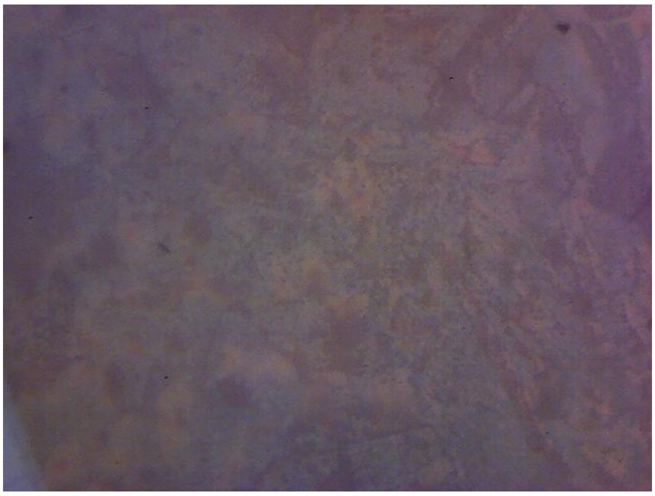
Fig 4.32 Specimen with GP single passes



4(a) Specimen at 100x. Boundary stir zone and THAZ.

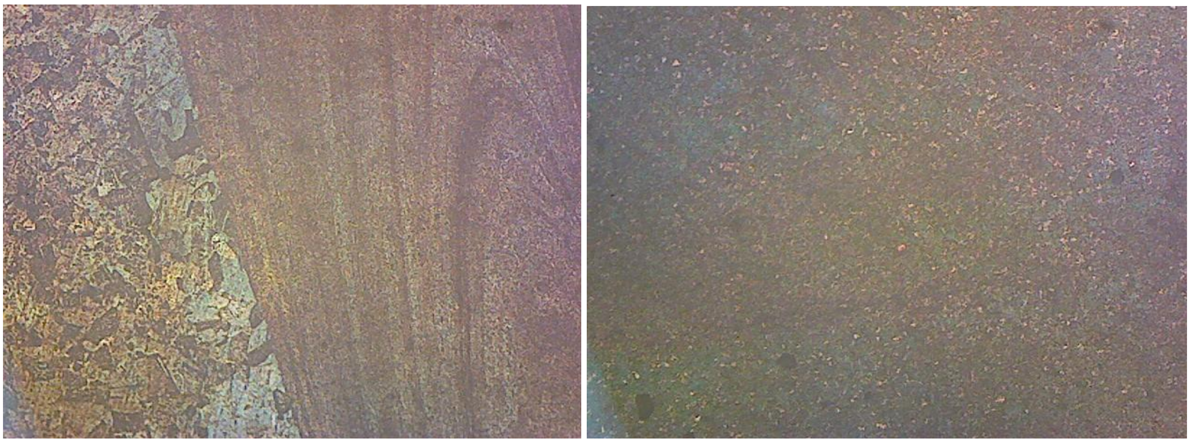


4(b) Specimen at 200x and 500x.

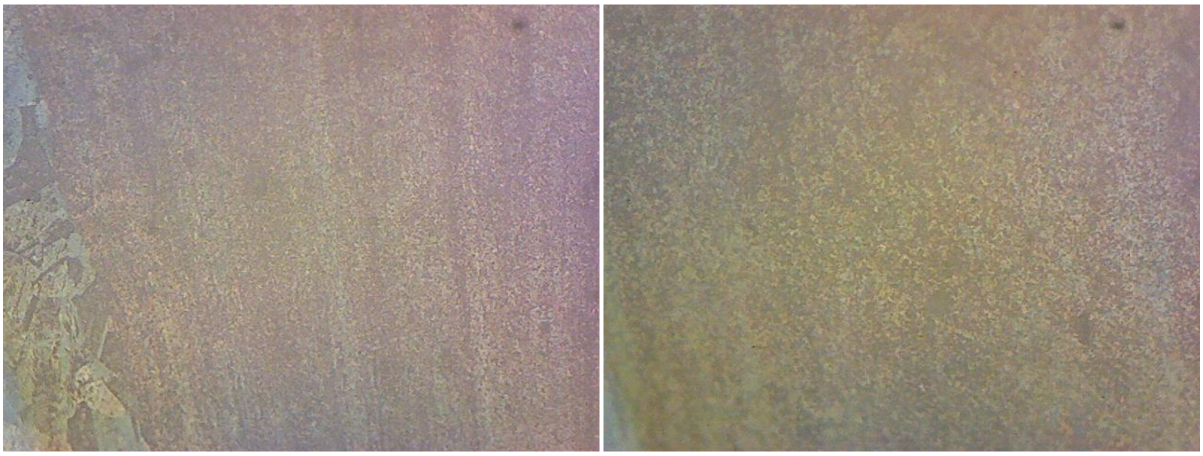


4(c) Specimen at 1000x

Fig 4.33 Specimen with GP double pass



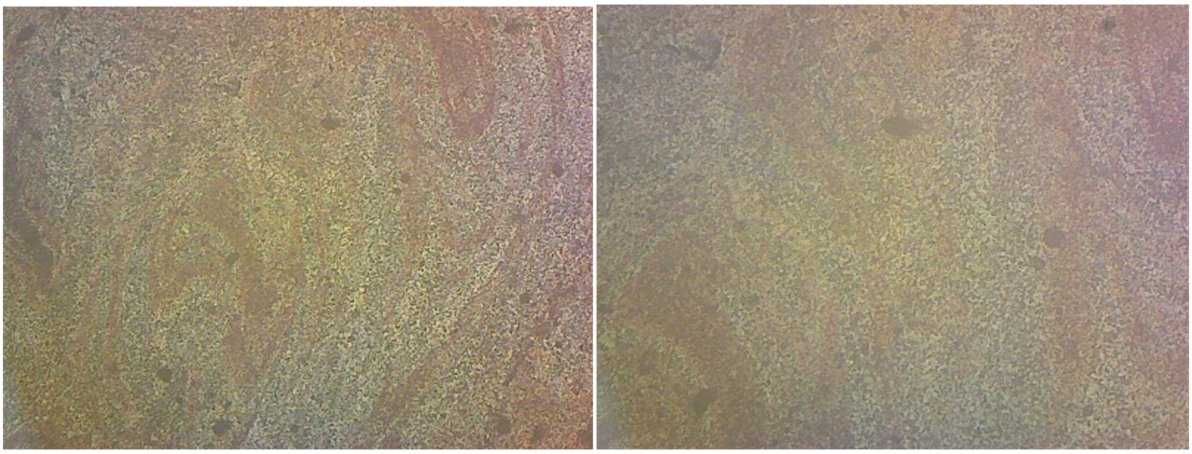
5(a) Specimen at 100x. boundary, THAZ and stir zone



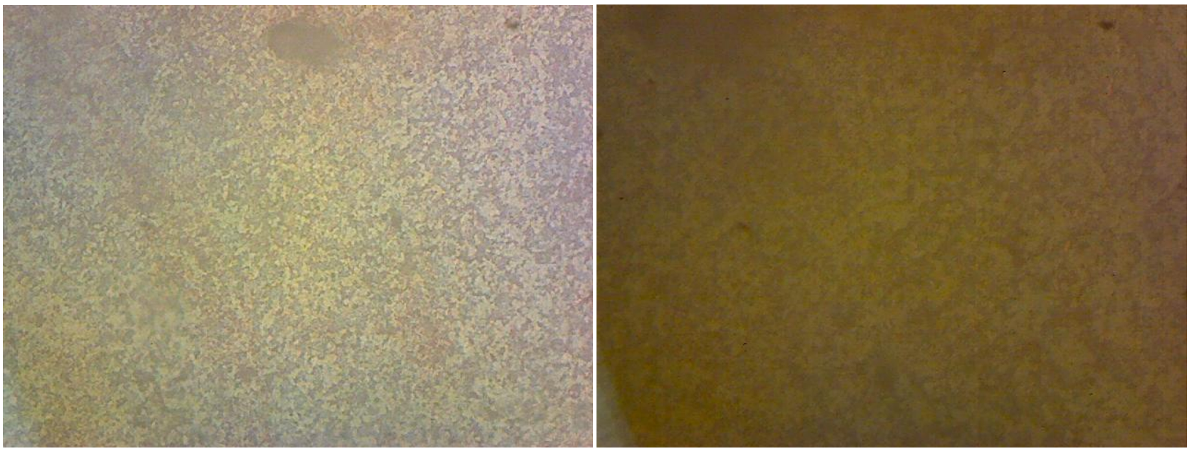
5(b) Specimen at 200x and 500x

5(c) Specimen at 1000x

Fig 4.34 Specimen with GP triple pass.



6(a) Specimen at 100x and 200x.



6(b) Specimen at 500x and 1000x.

Fig 4.35 Specimen with GP four pass.

Scanning Electron Microscope (SEM):-

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

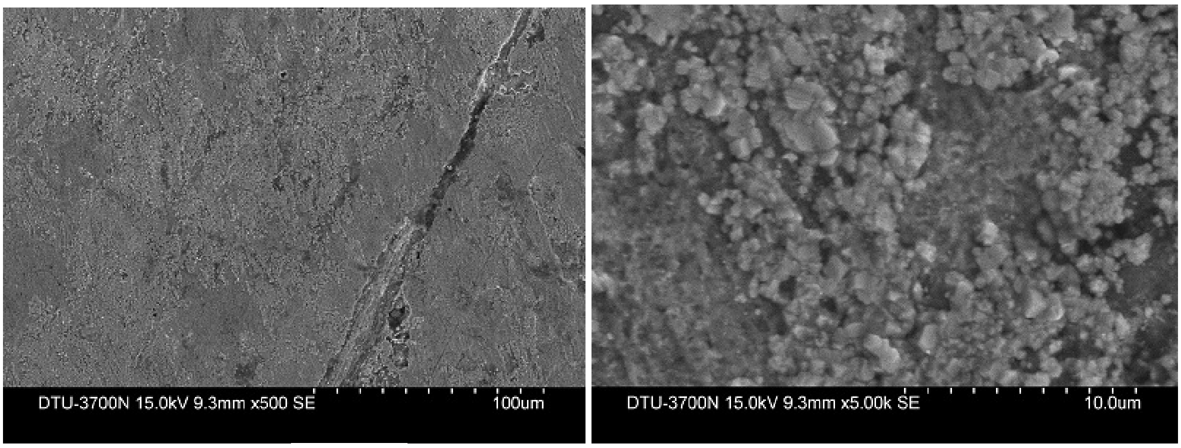


Fig 4.36 Specimen processing without powder

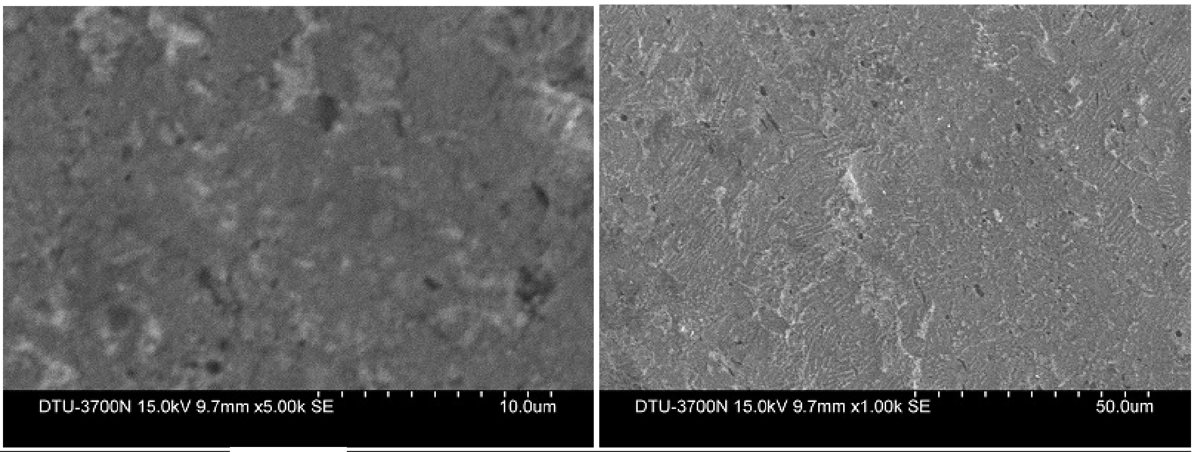


Fig 4.37 Specimen processing single passes with powder

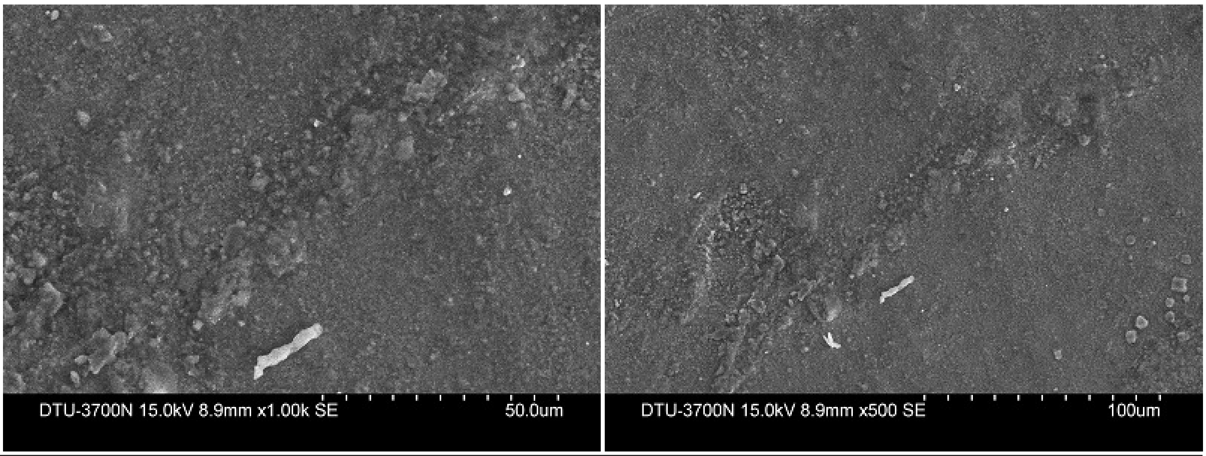


Fig 4.38 Specimen processing double passes with powder

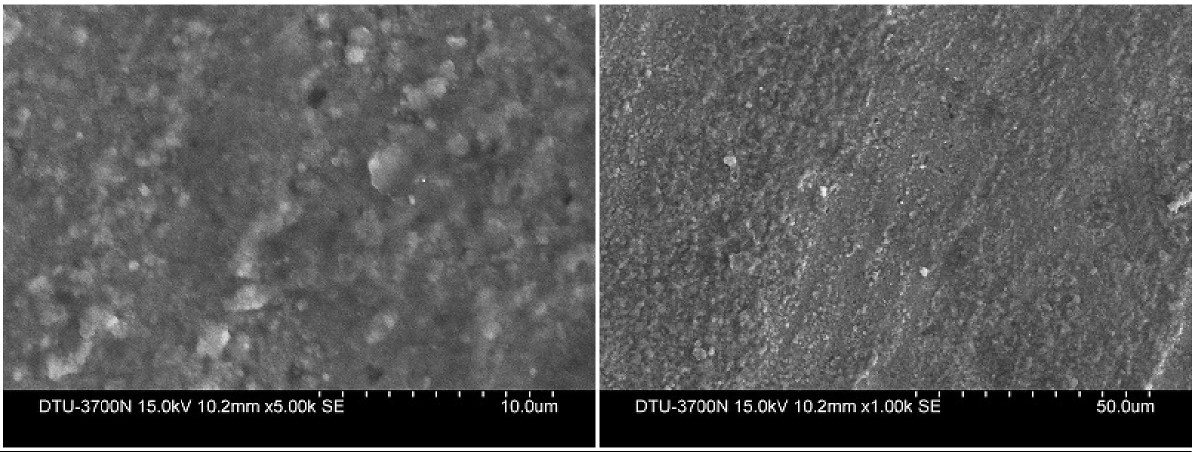


Fig 4.39 Specimen processing triple passes with powder

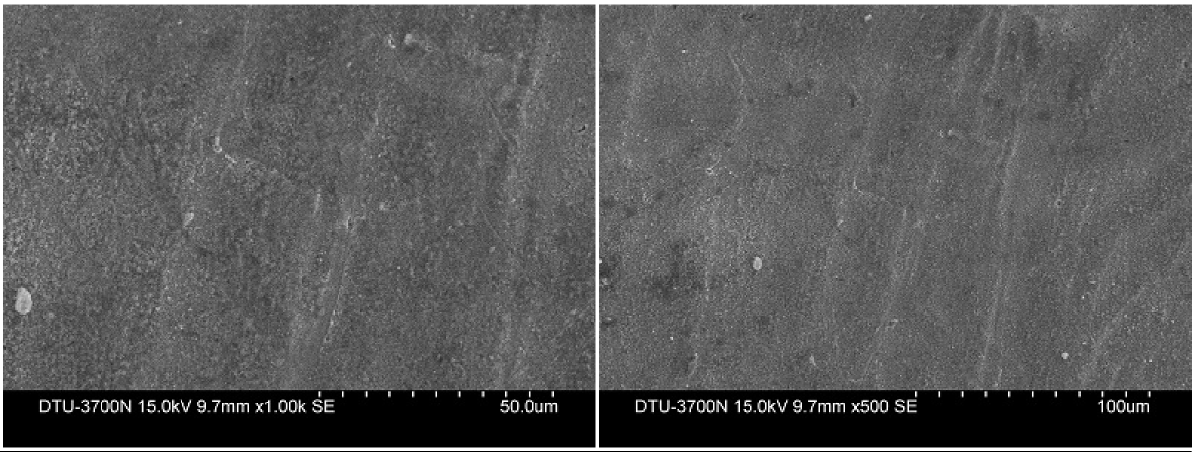


Fig 4.40 Specimen processing four passes with powder

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.

CHAPTER – 5

CONCLUSION

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

The following conclusions have been made from present investigation:-

a) 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.
b) Fabrication of Copper-graphite composite by friction stir processing (FSP) is possible.
c) 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%.
d) Use of graphite powder in FSP as composite material increases hardness at greater extent.
e) Ultimate tensile strength increases as number of passes increases.
f) 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%.
g) 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.

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