EXPERIMENTAL STUDY OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF BRASS AND MARBLE DUST COMPOSITES FABRICATED BY FSP

A Thesis Submitted

In partial fulfillment for the award of the degree of

Master of technology

In

Production Engineering

SUBMITTED BY

Nitin Ruhela
(2k17/PIE/08)

UNDER THE GUIDANCE OF

Prof. A.k.Madan

DEPARTMENT OF MECHANICAL, PRODUCTION & INDUSTRIAL AND AUTOMOBILE ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
BAWANA ROAD, DELHI-110042
JULY 2019

CANDIDATE'S DECLARATION

I, NITN RUHELA, hereby certify that the work which is being presented in this thesis entitled "**EXPERIMENTAL STUDY OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF BRASS AND MARBLE DUST COMPOSITES FABRICATED BY FSP**" being submitted by me is an authentic record of my own work carried out under the supervision of **Prof. AK. Madan, Professor, Department of Mechanical Engineering, Delhi Technological University, Delhi.**

The matter presented in this thesis has not been submitted in any other University/Institute for the award of M.Tech Degree.

NITIN RUHELA
(2K17/PIE/08)

CERTIFICATE

I, NITIN RUHELA, hereby certify that the work which is being presented in this thesis entitled "**EXPERIMENTAL STUDY OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF BRASS AND MARBLE DUST COMPOSITES FABRICATED BY FSP**" in the partial fulfillment of requirement for the award of degree of **Masters of Technology** submitted in the **Department of Mechanical Engineering** at **Delhi College Of Engineering**, **Delhi University**, is an authentic record of my own work carried out during a period from July 2018 to June 2019, under the supervision of **Prof. A.K.Madan, Professor, Department of Mechanical Engineering, Delhi College of Engineering, Delhi.**

The matter presented in this thesis has not been submitted in any other University/Institute for the award of M.Tech. Degree.

Prof. A.K.Madan
Department of mechanical
Engineering
Delhi Technological University, Delhi

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It is a matter of great pleasure for me to present my dissertation report on "**EXPERIMENTAL STUDY OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF BRASS AND MARBLE DUST COMPOSITES FABRICATED BY FSP**". First and foremost, I am profoundly grateful to my guide **Prof. A.K.Madan, Professor, Mechanical Engineering Department** for his expert guidance and continuous encouragement during all stages of thesis. I feel lucky to get an opportunity to work with him. Not only understanding the subject, but also interpreting the results drawn thereon from the graphs was very thought provoking. I am thankful to the kindness and generosity shown by him towards me, as it helped me morally complete the project before actually starting it.

Last, but not the least, I would like to thank my family members for their help, encouragement and prayers through all these months. I dedicate my work to them.

DATE:

PLACE:

Abstract

Friction stir processing(FSP) has developed over the past few years as technique of solid-state surface modification, which is now commonly used in the manufacture of surface composites. Surface composites can be fabricated in such a way that, the reinforcement particles which was marble dust filled into the prepared groove on the plate. Firstly, the groove was packed without probe then mixing of advancing side of material to retreading side was done by tool with probe. Surface composites gives some rare properties combination such as hardness, yield strength and wear resistance etc. which offers a wide application in many industries sectors. The greater micro-hardness, fine grain structure, high-temperature strength materials can be used in may application such as radiator. The literature review is available on the basis of FSPed, process parameters, tool design and rotational speed of tool. The present study investigates the use of marble dust obtained at the time of marble cutting, alternative reinforcement. The composites of brass alloy and marble dust was fabricated effectively. The FSPed parameters were: rotational speed of tool 900rpm, traverse speed 20mm/min and 0^o tilt angle. Then composite was tested by microstructure and XRD analysis. The micro-hardness test was performed by vicker hardness machine and results revels that hardness increased. Wear test pin-on-disc was performed by tribometer.

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Chapter 1

1.0 Introduction to brass

Brass is an alloy (mixture) of copper and zinc and with the addition of small amount of other elements may be added to the alloy for special uses **[Paul T. Craddock]**. Alloys can be defined as the combination of two different metals. Alloys are made to increase a metal's strength, to make it more resistant to corrosion and wear to make it lighter and even to change its color. To make it lighter and even to change its color. For making alloys, first the metal is heated at high temperature when it became in liquid form then other metal is combined. Copper is a metal used in many alloys because it is abundant, lustrous and easy to shape. Brass is an alloy which is made by combining copper with zinc **[John Zronik**]. Brass is a metal composed primarily of copper and zinc. Copper is the main component, and brass is usually classified as a copper alloy **[Brady, George S].** The color of brass varies from dark reddish brown to a light silvery yellow that depends upon the zinc(Zn) amount present, the color become lighter when more Zinc(Zn) present. The percentage of zinc present in brass vary between 10 to 45. Due to unique mixture of properties likes harder and stronger than copper(Cu), it can easy get any shape and also known as good conductor of heat, generally resistant to corrosion from salt water because of these properties **[William Benham and Richard K.Meade**]. The first choice material is brass that can be used for making many components such as radiators. In industries, brass used for making tubes, pipes, radiators, screw, musical instruments, weather stripping, casting of cartridge for firearms and architectural-trim pieces. Matched by no other material, those make it indispensable where a long, cost effective service life is required **[S.W.Fortune]**. Armies that possessed metal knives, swords, and shields were no match for those that did not. The first two metal and its alloy widely used by humans, copper (and its alloy brass) and gold are still important in people's lives today **[John Zronik]**.

Advantages

- It is used in radiator and bushings.
- It can be where less friction required like gears, looks and valves.
- It can be used for plumbing applications and electrical applications.
- It can be also used in musical instruments likes belts and horns.

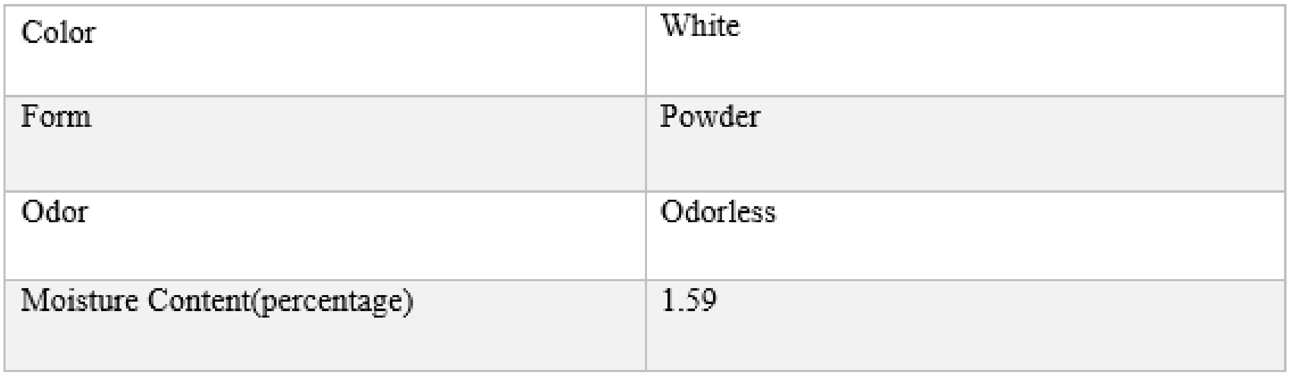
1.1 Reinforcement

Marble dust (M.D) used as reinforcement as shown in figure 1. Since ancient time, marble dust has been used for building material. M.D is a waste product that produced during marble manufacturing. During cutting time, a big amount of powder is produced. This result in the loss of 25% of the initial marble in the powder form. Leaving the waste products into the atmosphere can trigger the environmental issues like alkalinity increase, impacts on plants and human body. M.D, waste products produced at the time of marble processing that can be used as reinforcement during the experiment that helps to increase the strength. The physical and chemical properties as shown in table 1-2.

Figure 1. Marble dust

1.1.1 Physical Properties:

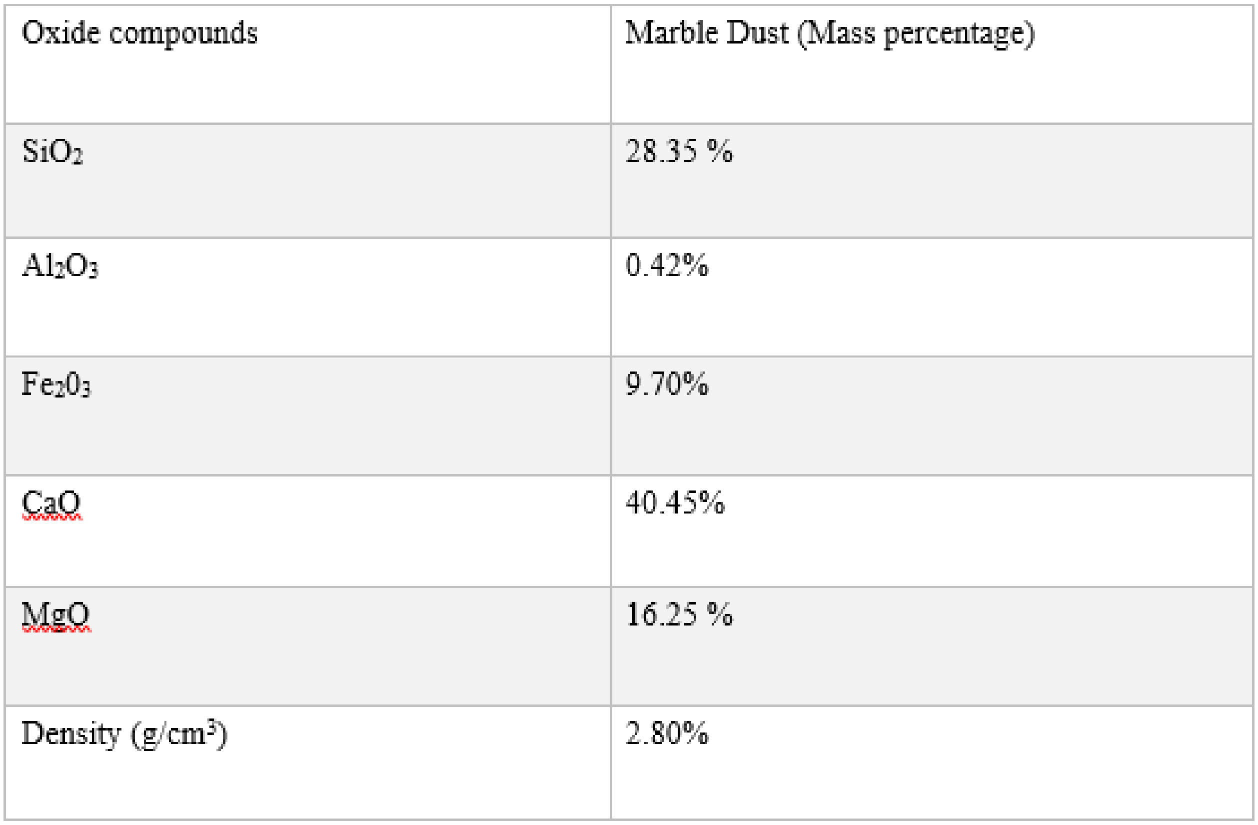
Table 1: Physical properties of marble dust



Color	White
Form	Powder
Odor	Odorless
Moisture Content(percentage)	1.59

1.1.2 Chemical properties:

Table 2: Chemical Composition of Marble Dust



Oxide compounds	Marble Dust (Mass percentage)
SiO_2	28.35 %
Al_2O_3	0.42%
Fe_20_3	9.70%
CaO	40.45%
MgO	16.25 %
Density (g/cm^3)	2.80%

1.2 FRICTION STIR PROCESSING

Friction stir processing (FSP) is green, developing novel, energy effective preparing technique to create the surface composites. FSP technique was basically first introduced by **Mishra** from FSW(Friction stir welding) **et al. (2003)**. FSP was created and take over by (TWI)The Welding Institute, UK**(Thomas et. al 1991).**

FSW in case of Butt joint is achieved by injecting a tool probe into sheet of butting edge to be welded and then moved in the direction of joint line. The movement of tool helps to control heat generation because of the plastic deformation and friction force. FSW is the solid-state process that consume less energy and power in comparison of electric arc **(Rajiv Sharma and ma et al 2005).** The working principle of FSP is similar as the FSW. A schematic diagram of FSP is shown in Figure 2.

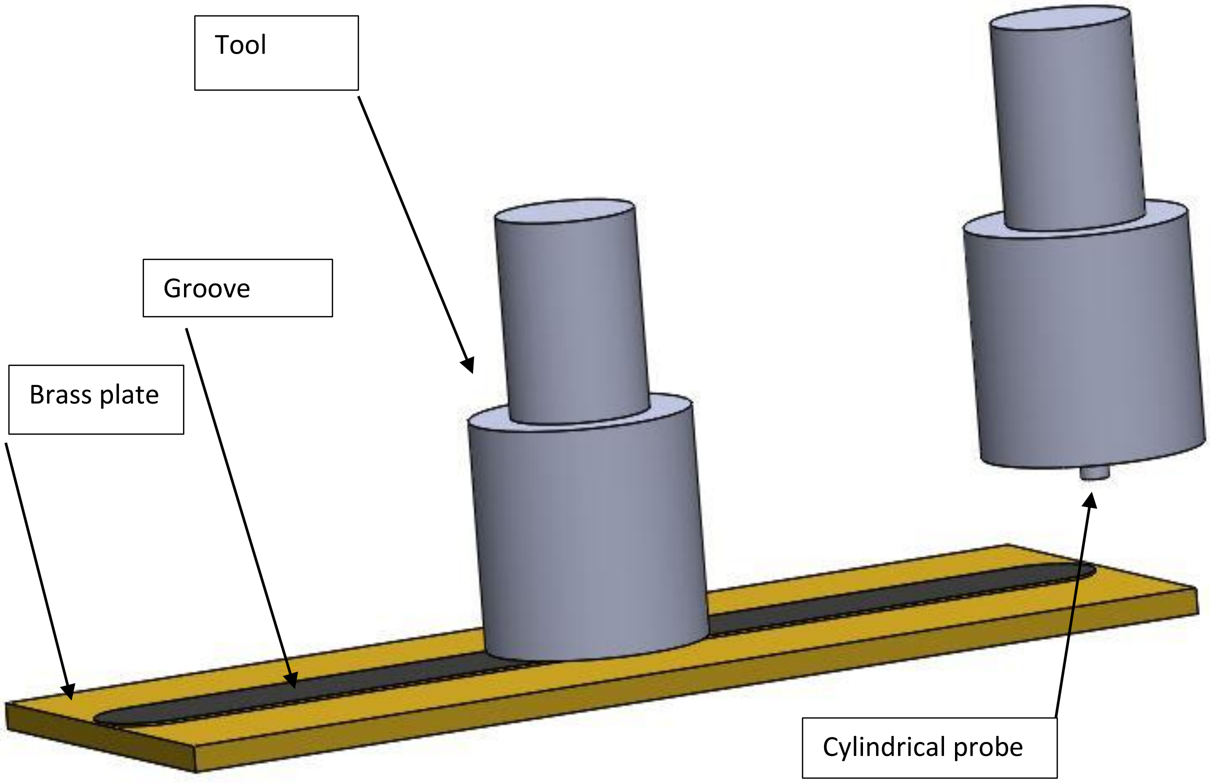


Figure 2 : Schematic diagram of FSP

FSP is the simple form that have non-consumable rotating-tool that dove into the base material (work-piece) then proceed in interest direction. The tool perform two primary task (1)Heating & (2)Deformation of Base material(Work-piece). The heat created due to the friction between the base material and rotating shoulder. When material heated become softens and then move from retreading to advancing side of rotating pin. The material moves from retreading to advancing side of the tool cause thermal exposure and plastic deformation that leads to important microstructure refinement in processed zone. Stir zone(SZ) is the zone which is stir with the help of tool probe **(Mishra and Ma et al 2005).** The leading mechanism of dynamic recrystallization(DRX) is help for developing the equiaxed and fine grain in SZ.

1.2.1 Advantage of Friction Stir processing(FSP)

Selection of material with appropriate properties and attributes is important parts in the area of industrial applications. Selection of an alloy with appropriate properties like uniform grain-structure and the strength which is highly definitive in industries like an automotive and aircraft. A few favorable FSP advantages that make it remarkable from another metal-working process.

1. It tends to be done in one pass improve microstructural, homogenizing and densifying.
2. The microstructure behavior and mechanical-properties of stir-zone can be managed by parameters of FSP and startup heating or cooling.
3. Modifying the length of the rotational tool probe that help to control the depth of stir zone. This ability demonstrates FSP flexibility for supporting the depth range from 10mm to 100um.
4. In this process, the heat is generated by friction and the plastic-deformation; for this reason, it is known as green, energy efficient method and this process is free from noise and harmful gases.
5. Employing FSP technique does not change the material shape and size and keep them same.

1.2.2 Fundamental of Friction Stir Processing

FSP technique is also known as solid-state process. The material used during the process should be in the form of solid. The rotating tool consist of probe and the shoulder with sufficient dimension that is proportioned with diameter of the work-piece. The probe is applying on work-piece surface then it can move in decided direction. The heat is generated by touching the rotating tool probe with the work-piece and improve the material hardness and also help to achieve the recrystallized grains.

1.2.3 Fabrication of surface composites by FSP

It’s a conventional technique that helps for making the surface composites contains liquid-phase process at high temperatures like plasma spraying and laser-melt treatment which may prompt the weakening of composite properties because of interfacial response among reinforcement and metal-matrix **(Meng et al 2013, Pantelis et al 1995).** Besides, the proper control of handling parameters required to acquire wanted microstructure after solidification in the surface layer. FSP has shown its potential in creation of all variations of surface composites with practically zero interfacial reaction with reinforcement. In previous studies, ceramic particles layer is applying in volatile medium for fabricated surface composites **(Mishra et al 2003).** Now, the reinforcement is filled into the machine groove which is made on work-piece plate **(Arora et al 2011).** The main approaches for fabricated surface composite by FSP is shown schematically in figure 3.

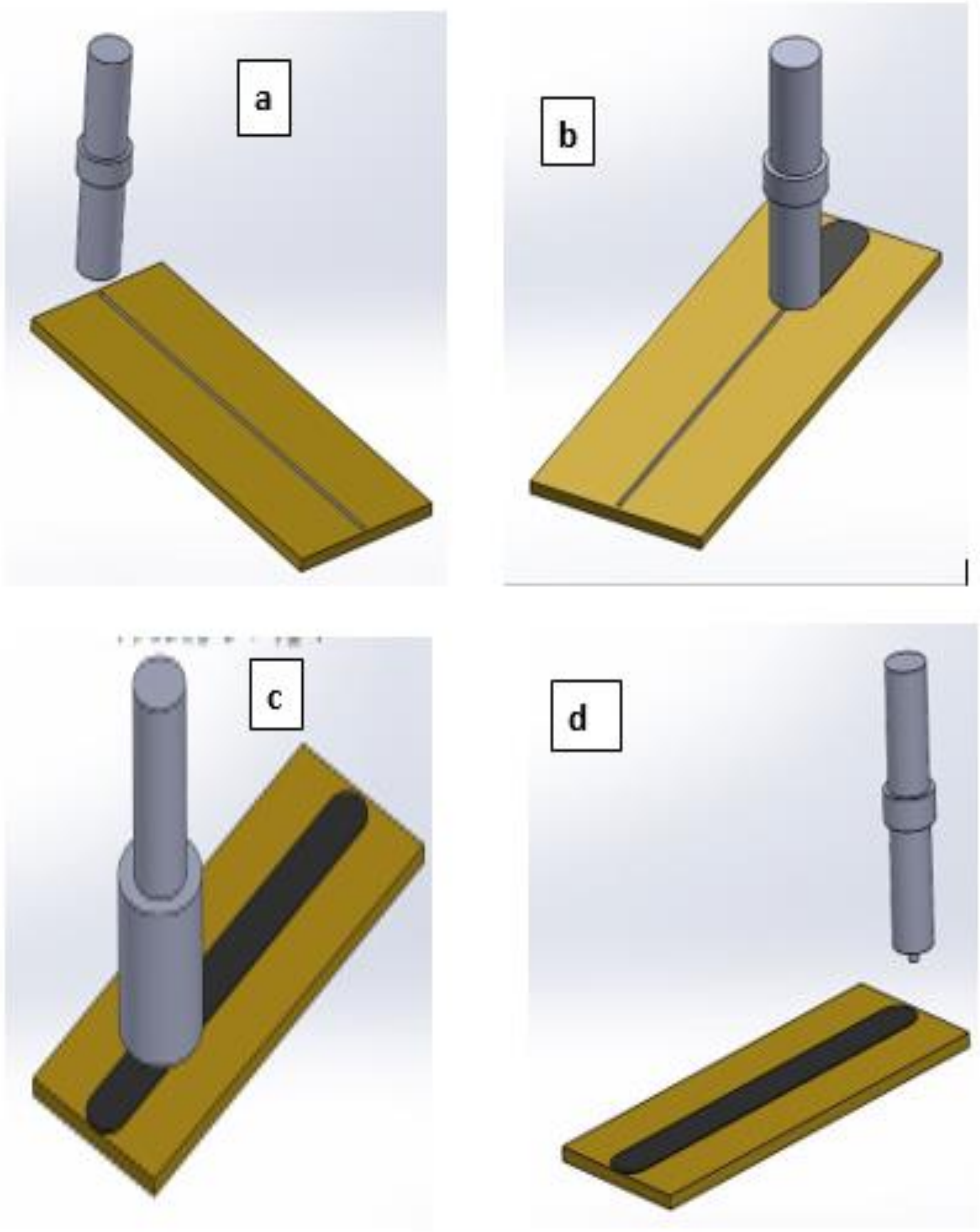


Figure 3: Groove Technique

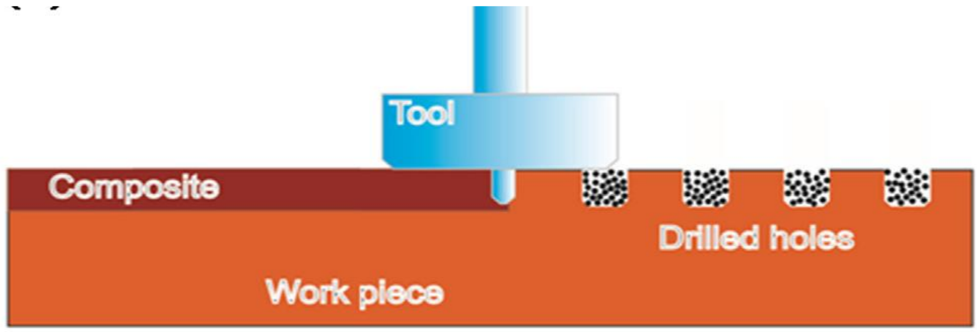


Figure 4: Drilled Holes Technique

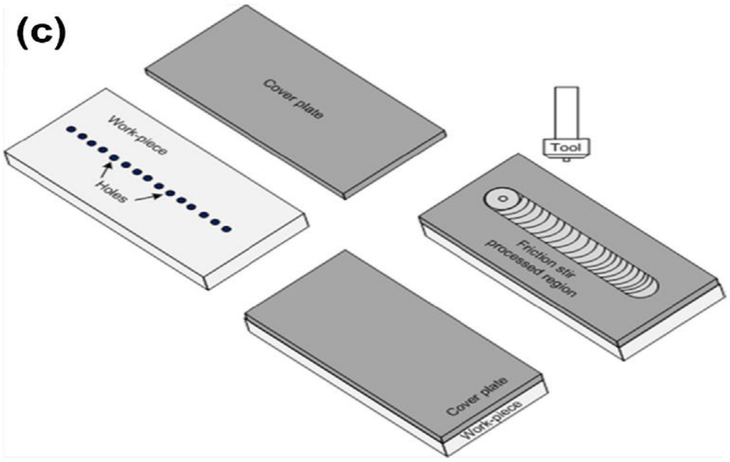


Figure 5:Cover Plate Technique

These are Common technique for filled reinforcement particles into surface composites fabrication a) **By groove** b) **By drilled holes** c) **By using cover plate.**

In groove method following steps are as follow shown in figure 3. In first step, groove is made on the work-piece then reinforcement filled into it. Second step involve that the tool without probe is applied on the groove for complete packing. After that last involve that tool with probe is applied on complete packed groove for mixing the material from retreading to advancing side. The shape, dimension and the number of grooves made on the work-piece in order to get the appropriate volume fraction. The surface composite made by drilled hole as shown in figure 4. **(Li et al 2003)** represent that can help to eliminate the steps of closing groove with no probe side tool by combining the reinforcement through drill hole in the fabrication of surface composite. In figure 5 a thin sheet used to cover the groove in this way reinforcement is not ejected from the groove.

Chapter 2

Literature Review

2.1 On the basis of FSP

(N. Yuvaraj et al. 2015) Studied the fabrication of Al5083 surface composites in which B_4C used as reinforcement. The dimension of the plate was 8mm thickness, 75mm width, 200mm length. The tool material was H13 with threaded cylindrical probe. The diameter of the shoulder 18mm and the length of probe was 5mm. Results shows that mechanical and the tribological properties were improved.

(Bahram A.khiyavi et al. 2014) Studied the FSP on pure Cu material that contain purity of 99.91% . The dimension of copper plate 6mm thickness 70mm width 100mm length. Particles size of Cr smaller than 43µ. The material of tool was Hot working steel and the profile of tool was cylindrical probe with concave shoulder that contain 6° between the probe and the shoulder edge. During processing consider the following parameters like tool rotational speed was constant of 1600mm/min for 3 traverse speeds such as 40mm/min, 80mm/min, 160mm/min and the tool titled at an angle 1.5°. The major aims of this research was to study the effect of Cr particles when added to copper for fabrication of MMC.

(H.Khodaverdizadeh et al. 2013) Discussed the pure copper. There are two kinds of tool were used one was cylindrical probe with thread and other was square probe profile for fabricate the joint. The processing parameters are 75mm/min traverse speed and rotational speed 600rpm. The major aims were to investigate the effects of probe profile on mechanical and microstructure properties.

(L. Ke et al. 2010) Worked on Al1060 plate which was 5mm thick. The profile of the tool was threaded probe, shoulder diameter was 28mm, probe diameter was 10mm, probe length was 8.5mm and pitch was 1mm. Processing parameters was: rotational speed of tool 1500rpm, table traverse speed 23.5mm/min, tilt angle 3° and three passes was performed on it. After FSP, plate was heated at 550°C for 6 hours. Results shows that Hardness was increased and the yield strength of composite was 110MPa and 140MPa.

(H.sarmadi et al. 2013) Studied the pure Cu material in which graphite particles were used as reinforcement and the size of particles 5 µm. The tool material was H13 steel, the diameter of shoulder and probe was 20mm, 6.5mm, length of the probe was 3mm.There are five kinds of tool were used with different prone such as tapered cylindrical, straight cylindrical, threaded cylindrical, triangular and the square. The major aims were to avoid wear by the fabrication of copper graphite composites.

(Shigematsu et al. 2003) investigated the composite properties of Al1050 by FSP. Author discovered that tensile strength and the hardness of Al1050 was increased as rotational speed of tool decrease. At 500rpm, Grain refinement increases by up to 37% as 46% relative to the base material.

(Mohsen Barmouz et al. 2011) Studied the pure Cu material. The dimension of base material plate was 6mm thickness, 75mm width, 130mm length. The tool material was hot-working steel and the diameter of shoulder, square probe and the length was 20mm, 5mm, 2mm respectively. The processing parameters were tilted angle 2°, traverse speed and the rotational speed were between 40mm/min to 200mm/min and 710rpm to 1120rpm. The major aims of this research to fabricate MMC in which SiC particles used as reinforcement that helps to improve the mechanical properties. Optical microscopy used for microstructure evaluation.

(J. Qian et al. 2012) Worked on Al1100-H14 plate which was 8mm thick. The groove of 3mm was made on the plate. The profile of the tool was threaded tapered probe, shoulder diameter was 25mm, probe diameter was 9.6mm, probe length was 6mm. Processing parameters was: rotational speed of tool 1180rpm, table traverse speed 60mm/min and six passes was performed on it. Results shows that Al_3Ni was exits in stir zone, micro-hardness increased as increasing in number of passes.

(P. Xue et al. 2013) Studied the pure Cu material. The dimension of the plate was 5mm thick, 100mm width, 300mm length. The tool was made up of M42 material, diameter of the shoulder 20mm and diameter of cylindrical threaded probe 6mm and length 2.7mm. There are two different approached can be done one was single pass other was 5 pass. The traverse speed 50mm/min and the rotational speed of tool 400rpm. The major aims were to prepare the (UFG)ultrafine grain by multiple pass that can be done successfully. After that there were no significant effect on mechanical and microstructure properties.

(R. Sasthisk umar et al. 2014) Studied the fabrication of pure Cu composites in which various reinforcement such as B_4C, SiC, AL_2O_3, WC and TiC respectively. Tool was made up of H13 with the diameter of shoulder, probe and probe length 20mm, 5mm, 2.7mm. The processing parameters are rotational speed of tool 800rpm, 900rpm, 1000rpm and the traverse speed are 20mm/min, 30mm/min, 40mm/min, 50mm/min and 60mm/min. There was an Empirical relationship that created to calculates the effect on parameters of FSP like wear rate, micro-hardness.

(V.Jeganathan, Ranganath M. S et al. 2015) Studied the FSP on Cu material. The tool made up of H13 with cylindrical probe. The diameter of shoulder, probe and the probe length are 15mm, 5mm, 1.5mm. The processing parameters was spindle rotating speed 1600rpm and feed 10mm/min. Material strength improved and the behavior of wear was high in processed zone with lower (COF) coefficient of friction and micro hardness improved.

(A. Shahi et al. 2014) Worked on Al1100 plate which was 8mm thick and Ni used as reinforcement <10µm. The profile of the tool was tapered probe, shoulder diameter was 20mm, probe diameter was 6mm, probe length was 4mm. Processing parameters was: rotational speed of tool 1600rpm, table traverse speed 12 mm/min, 25 mm/min and 2, 4, 6 passes was performed on it. Results shows that Al_3Ni was exits in stir zone, micro-hardness was increased 60% as increasing in number of passes.

(R. Sasthisk umar et al. 2013) Studied the pure Cu material plate. The dimension of plate 6mm thick, 50mm width and 100mm length. The diameter of tool shoulder, probe length and probe diameter are 20mm, 3mm, 5mm. The processing parameters are traverse speed, rotational speed and axial force are 40mm/min, 1000rpm, 10kN. The major aims to fabricate the Cu composite in which B_4C are reinforcement. Results shows that the reinforcement particles of B_4C significantly influenced grain size, dispersion, sliding wear and microstructure behavior.

(Salar salahi et al. 2013) Studied the pure Cu material plate 5mm thickness. The tool made up of H13 steel with cylindrical probe profile. The diameter of shoulder, probe and probe length are 17mm, 8mm, 4mm. The processing parameters are rotation speed 300rpm and 600rpm, traverse speed are 40mm/min to 100mm/min. The major aims to fabricate the Cu composite in which rotating tool is plunged into the work-piece that provide plastic deformation and heat transfer. Ductility test was determined by the tensile elongation.

2.2 FSP variable for fabrication of composite

FSP variable primarily falls into three different groups such as tool geometry, machine variables and numbers of passes as shown in figure 6 that helps to increase the mechanical properties.

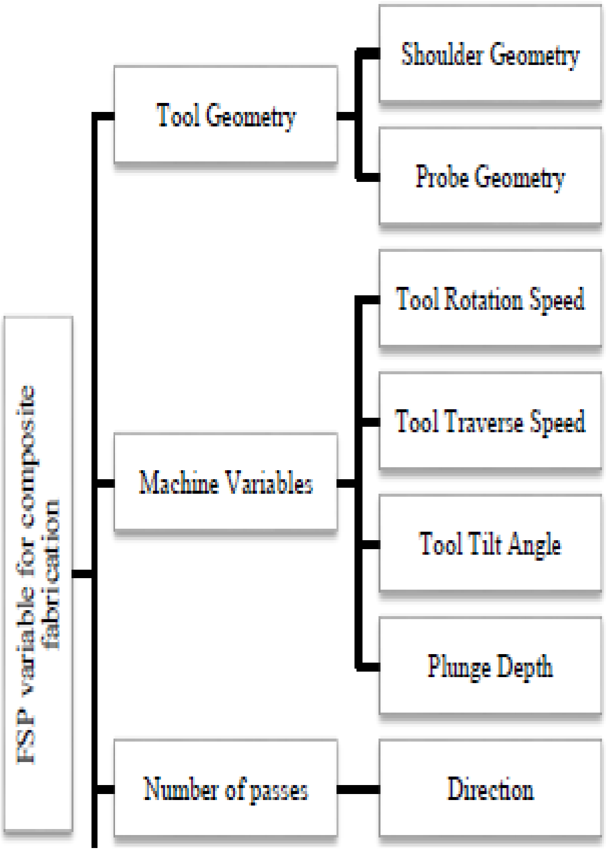


Figure 6: FSP variable

2.3 Tool geometry

Tool geometry mostly consists of shoulder features, shoulder diameter, probe feature, probe shape and probe size. The plasticized material is flow in stir zone that affect by tool geometry and also by rotational and traverse motion of tool **(Zohoor et al., 2012, Palanivel et al. 2012)**. The important aspects of tool geometry that affect the material flow, heat generation and resulting microstructure **(Mishra and Ma, 2005)**. Mainly FSP tool geometry displayed in figure 7. The tool shoulder is of concave shape used as it helps as reservoir or an escape volume for the moved plasticized material from the probe. The tilt angle is essential to keep the material reservoir lower the tool that allows the shoulder tool of trailing edge to release processed material. Heat generation mainly cause by the tool shoulder. Larger diameter of tool shoulder increases the heat generation and also higher material flow where the small diameter of tool shoulder resulted in development of defects in material matrix composites **(Elangovan et. al 2008).**

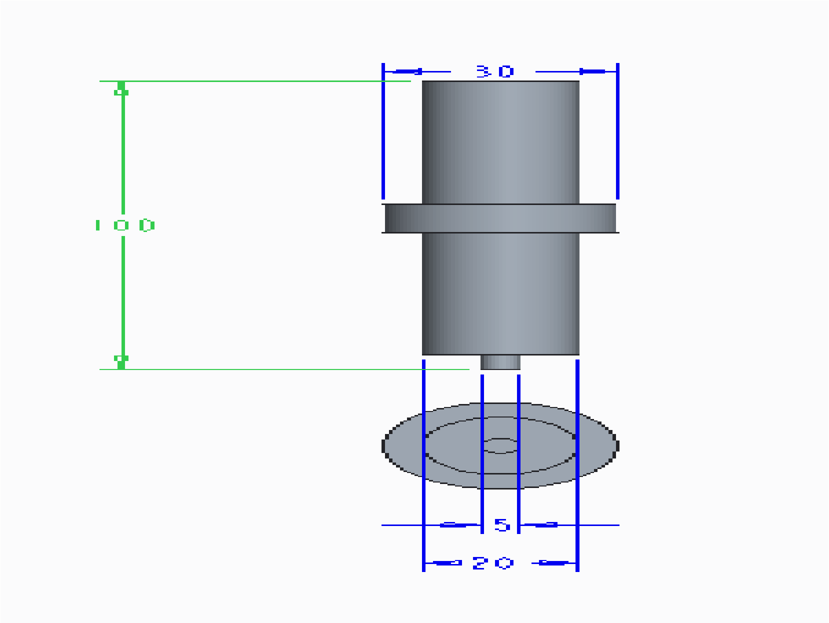


Figure 7: FSP Tool

Different kinds of geometries of tool probe such as triangular, conical, threaded, square, cylindrical etc. adopted for fabricating of surface composite. cylindrical, triangular, square and threaded have been used mostly. The outer surface of tool probe has various kinds of features and shape like flats and threads. For harder alloys, thread-less probes are adopted due to that the feature of threaded can be without difficulty worn away. **(Elangovan et al. 2007)** detected that the profile of square probe tool produces Pulse/Sec higher than the profile of triangular probe. The profile of square probe tool produces 80 Pulse/Sec (Pulse/Sec is the product of rpm and number of flat face). Profile of triangular probe produces 60 Pulse/Sec at rotational speed of tool is 1200rpm

(Balasubramanian and Padmanaban 2009) observed that probe with thread produces extra heat than the probe without thread that helps to enhance flow of material in stir zone. The effect of D/d ratio was studied and found that D/d should be 3 for getting the defects free stir zone. where ‘D’ denote diameter of shoulder and ‘d’ denote diameter of probe.

2.4 Machine variable

Main machine variable like speed of tool traverse and rotating rate of tool. Tool traverse speed and tool rotational rate can be determining by the amount of heat produces in work piece. Tool penetration depth and tilt angle can affect the development of Stir zone but these parameters generally kept constant. Heat is produce due to the friction when interaction of work piece and tool. In stir zone, heat input influence the material run and the microstructure progression that affects the tribological and mechanical properties. Tool traverse speed and rotational speed helps to determine the how much heat is input in stir zone **(Khayyamin et al. 2013).** Adequate amount of heat is produces in the sir zone for obtaining defects free stir zone. Likely FSP on other alloys such as titanium, copper and magnesium heat is produces in stir zone mainly depends upon the traverse and rotational speeds **(Li et al. 2013: Azizieh et al. 2011**).

2.5 Tool speeds effect

Traverse speed and rotational speed (ʋ and ω) determine the how much heat is input in the stir zone that affects the resultant properties and microstructure. Grain refinement is more when lower heat is input and vice-versa, adequate amount of heat is input for soften material **(Moghaddas et. al 2013).** For fabricating surface composite, rotational speed of tool is required higher for breaking up and distribution reinforcement particles, but grain particles affected by higher tool rotational speed due to higher input heat **(Moghaddas et.al 2013)**. Thus, traverse speed and rotational speed raised to obtain defect free stir zone and grain size may be reduced. For fabrication of composite SiC/AZ91, it shows that increase in tool rotational speed helps to increase grain size when traverse speed increased then grain size would be decrease. This was clarified by observing that when traverse speed increase then the exposure time of processing heat would be decrease **(Asadi et al. 2010).** The flow of material increase in stir zone while increasing in tool rotational speed**. (Khayyamin et al. 2013)** when traverse speed 20,40 and 60mm/min for the fabricating of nano-composite SiO2/AZ91. They detected that while increasing in traverse speed grain size would be refined in the stir zone and resulting hardness increase.

2.6 Number of passes

The grouping of reinforcement particles is the main problem in the fabrication of composite that affects the composite strength harmfully. In FSP, multi-pass reduces the cluster size and reinforcement particles are uniformly distributing thus matrix of grain size would be decrease. In FSP, the distribution of reinforcement particles in primarily depend on number of passes **(Zohoor et al. 2012).**

Chapter 3

3.1 Experimental set-up and methodology

This chapter deals with studies of some different set-up of experiment. Then descriptions of mechanical properties test such as tensile test, wear test, hardness test, microstructure test & XRD etc. with details procedure.

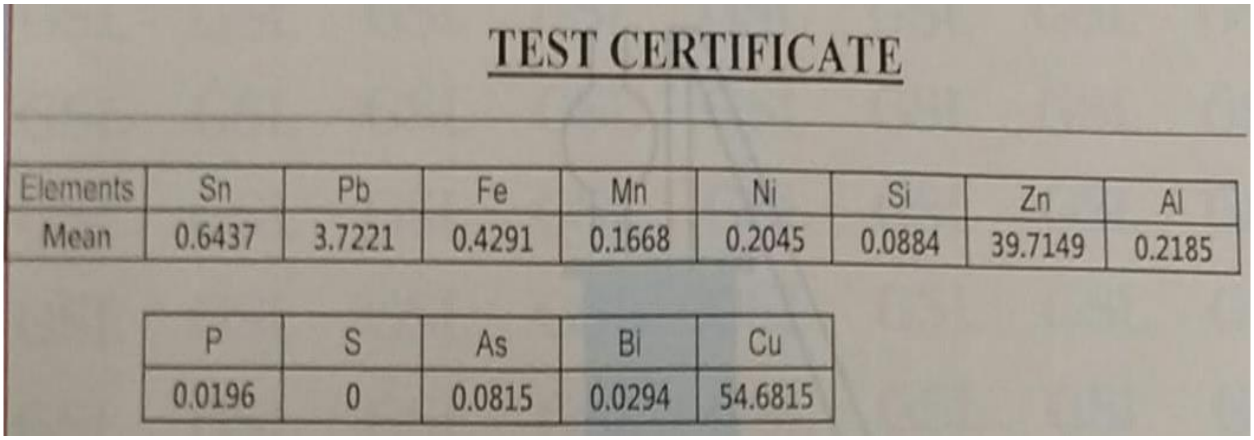
3.2 EXPERIMENTAL SET-UP, FIXTURES & TOOLING

This section deals with materials of work-piece, Experimental set-up of machine, fixture and tooling. Furthers, the processing parameters of FSP & stir casting with details procedure.

3.2.1 Materials

A plate of brass with the dimension of 30mm width, 80mm length and 8mm thickness used for the experiments. The chemical composition of brass plates is shown in table 3. This test was done by spectrometer. Marble dust used as reinforcement.

Table 3: Chemical Composition of Brass Plate



TEST CERTIFICATE

Elements	Sn	Pb	Fe	Mn	Ni	Si	Zn	Al
Mean	0.6437	3.7221	0.4291	0.1668	0.2045	0.0884	39.7149	0.2185

P	S	As	Bi	Cu
0.0196	0	0.0815	0.0294	54.6815

3.2.2 Preparation of workpiece for FSP

Firstly, Groove is made on the surface of brass plate which is of 2mm deep with the help of milling machine as shgown in figure 8. The slitting saw cutter was used for machining and thickness of cutter was 1.75mm as shown in figure 9. then after marble dust which is used as reinforcement feed into the groove.

Figure 8: Groove made on workpiece

Figure 9: Slitting saw cutter

Similarly, this process done on remainig brass plate. Then after four brass plate was pre-heated at different temperature such as 27°C(room tempreature), 150°C and 300°C respectively. Muffle furnace was used for pre-heated the brass plate.

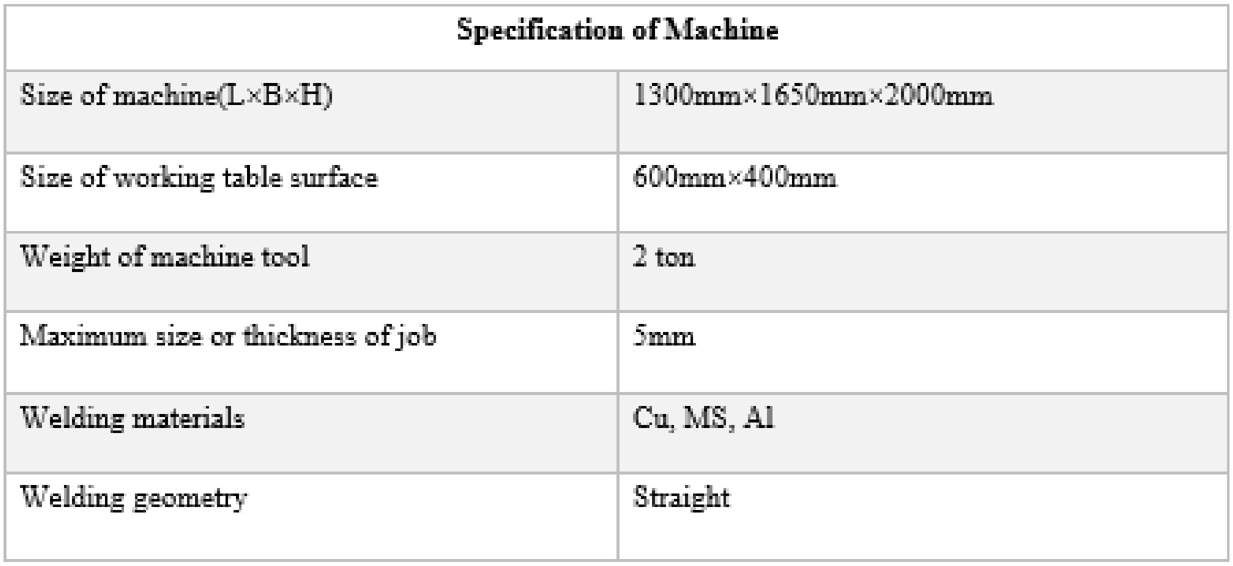
3.2.3 FSP Machine & Fixture System

FSW machine was used for performing the experiment as shown in figure 10. It contains of spindle speed and table travel speed. The maximum spindle speed 1400rpm These were run by gear. The range of tool tilt angle is ±7^o. The specification of FSP machine as shown in table 4.

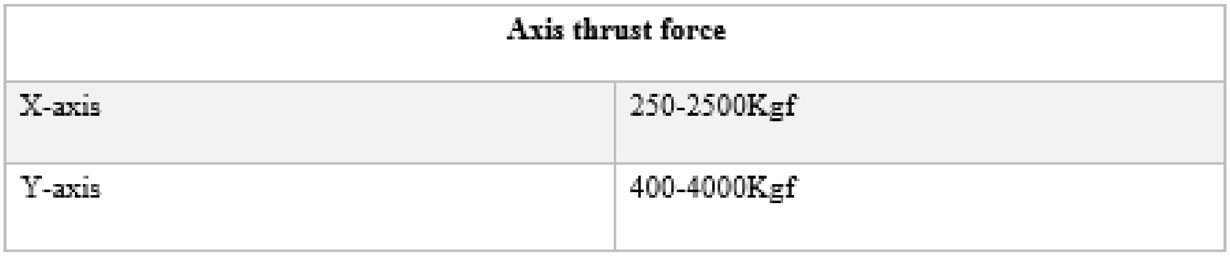
Figure 10: FSP machine

3.2.3.1 Specification of FSP Machine

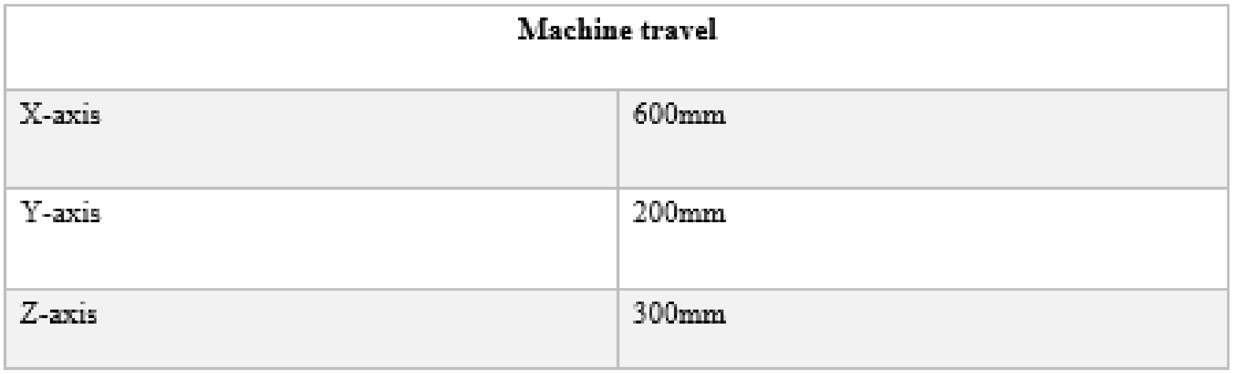
Table 4: FSP machine specification



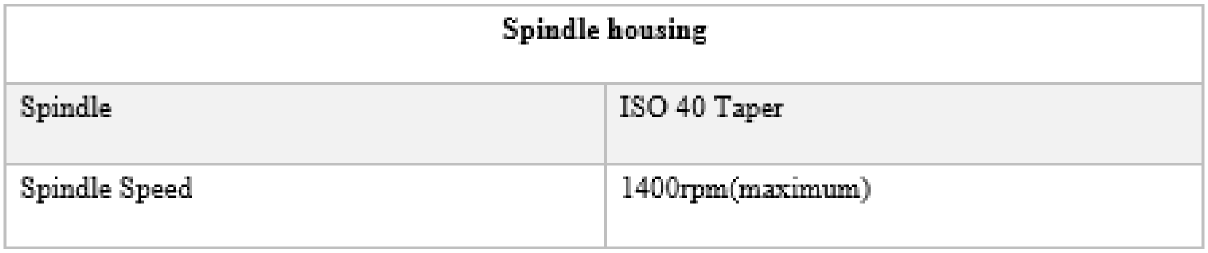
Specification of Machine	
Size of machine(L×B×H)	1300mm×1650mm×2000mm
Size of working table surface	600mm×400mm
Weight of machine tool	2 ton
Maximum size or thickness of job	5mm
Welding materials	Cu, MS, Al
Welding geometry	Straight



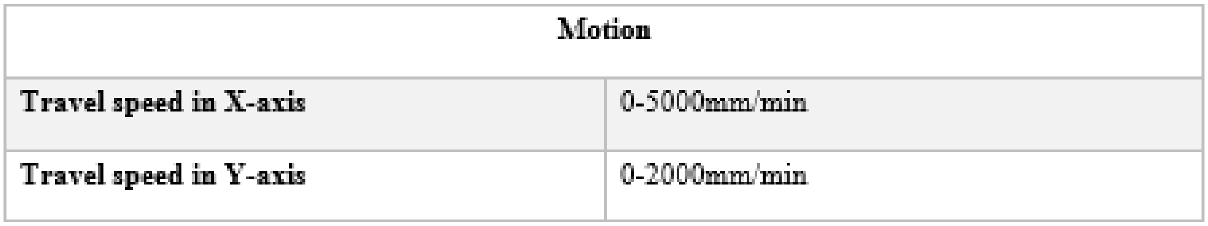
Axis thrust force	
X-axis	250-2500Kgf
Y-axis	400-4000Kgf



Machine travel	
X-axis	600mm
Y-axis	200mm
Z-axis	300mm



Spindle housing	
Spindle	ISO 40 Taper
Spindle Speed	1400rpm(maximum)



Motion	
Travel speed in X-axis	0-5000mm/min
Travel speed in Y-axis	0-2000mm/min

The fixture was made of mild steel backing that helps to clamp the work-piece as shown in figure 11. The dimension of fixture was 200mm×100mm×5mm. It was designed in such a way that controls work-piece lateral movement when axial load applied.

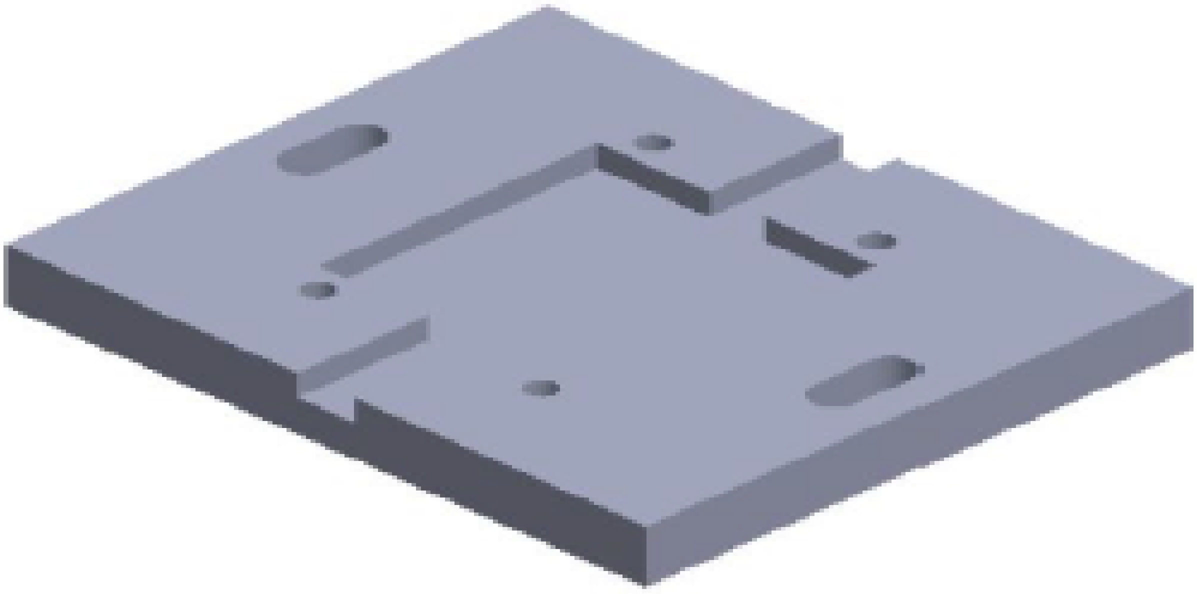
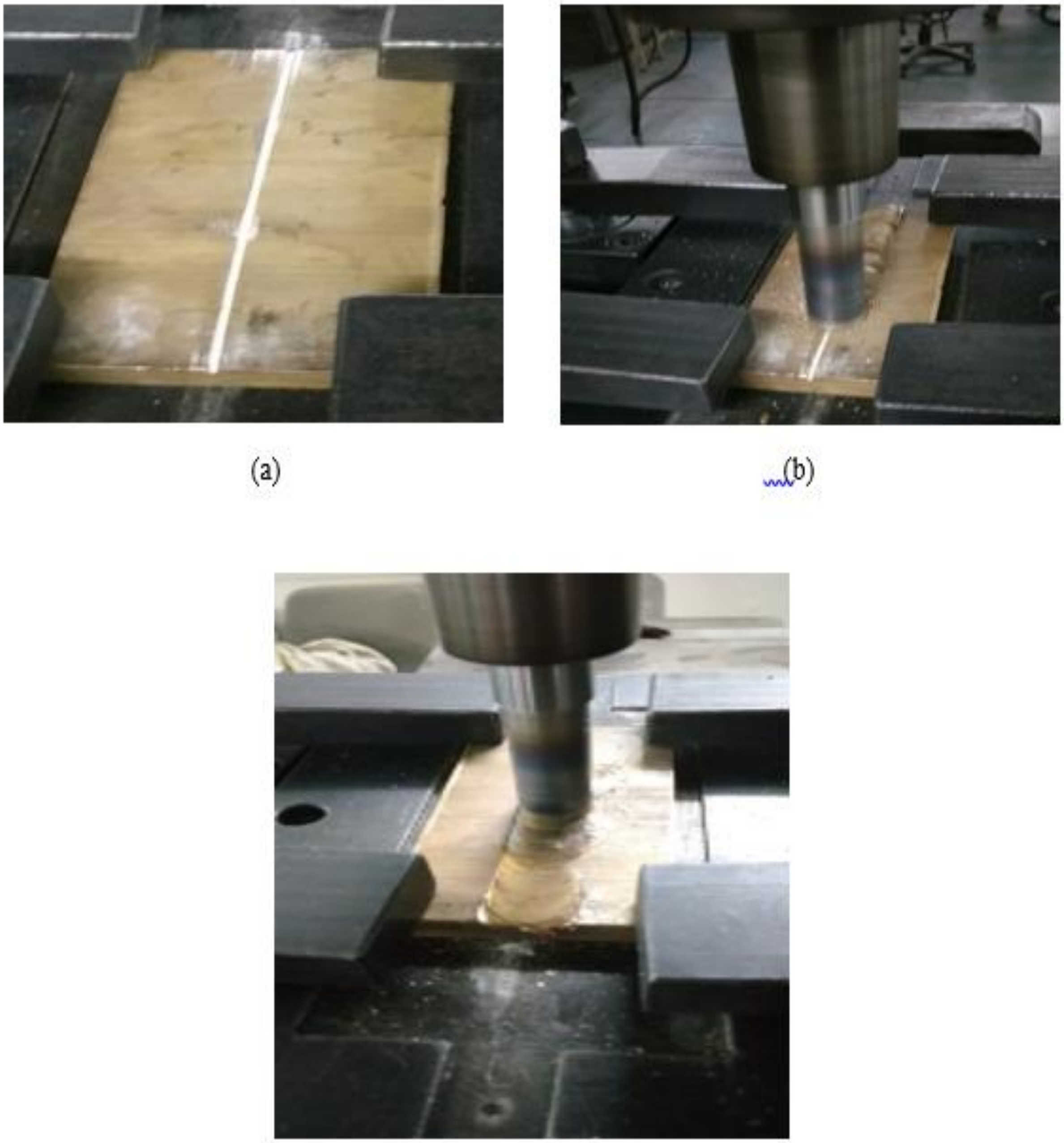


Figure 11: illustration of Fixture



(a) (b)

(c)

Figure 12: FSP Done on Work-Piece

The figure (a) shows that, after pre-heated of work-piece, marble dust was put into the groove then clamped on the fixture. The complete closing of groove was done with the help of tool without probe as shown in figure (b). The mixing of material and reinforcement from retreading to advancing side was done with the help of tool with probe as shown in figure (c).

3.2.4 Tooling System

The tool was design with the help of CNC machine and material used for making tool was mild steel as shown in figure 13. Cylindrical tool profile was made. One side of the tool was probe-less which is used for complete closing of the groove and another side of the tool was probe which is used for proper mixing of material and reinforcement from retreading side to advancing side. The diameter of shoulder and the diameter of probe was 19.95mm, 3mm. The length of probe was 5mm.

Figure 13: Tool

Chapter 4

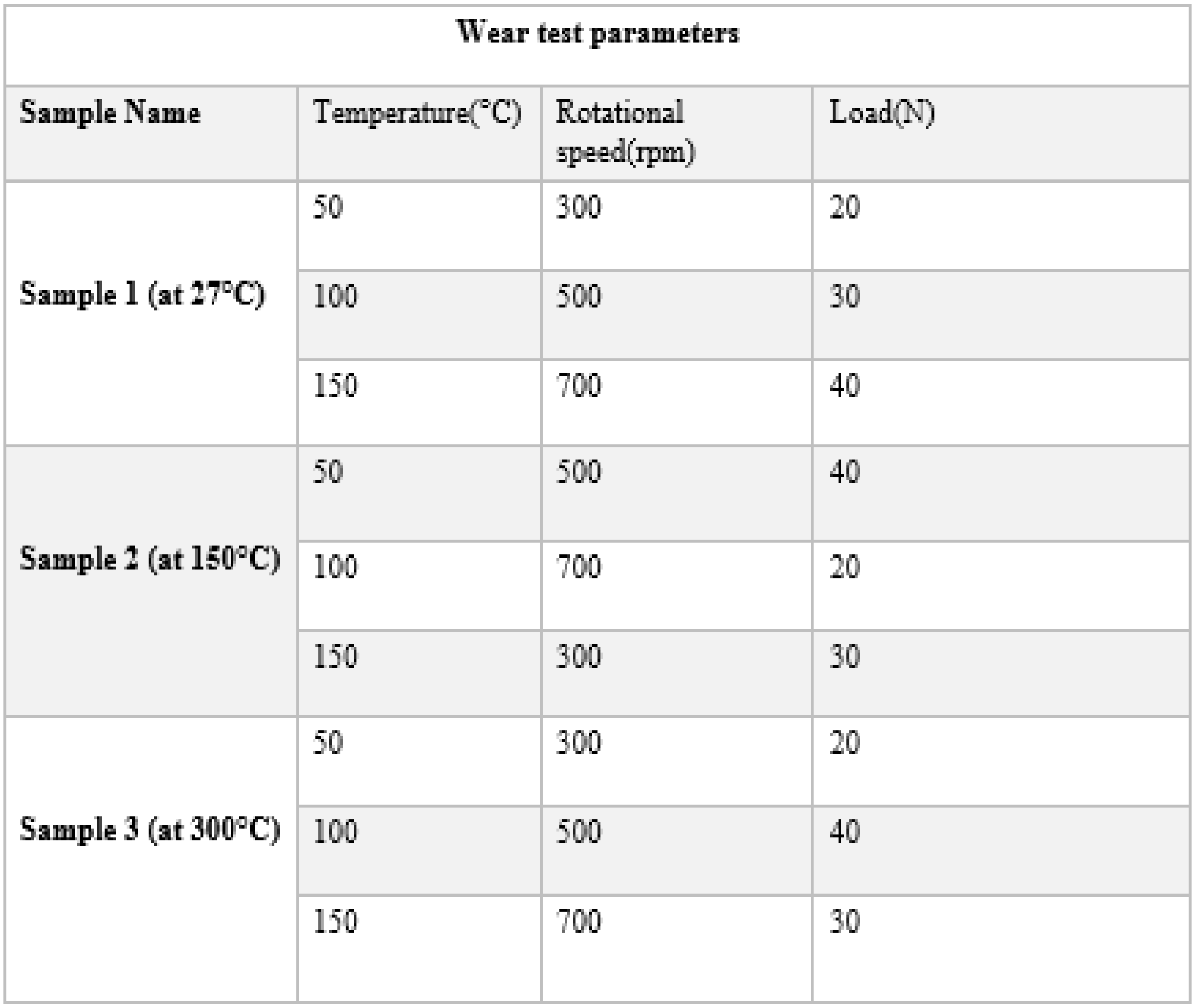
4. Preparation of Specimen for Testing

The specimen was prepared for performing the test such as tensile test, wear test, microstructure test, micro-hardness test and XRD etc.

4.1 Wear test

Firstly, the specimen of wear test was prepared with the help of wire-cut EDM machine. Cylindrical specimen(pin) with diameter of 8mm was prepared. EN-31 disc was used for performing the pin-on disc wear test as shown in figure 15. The upper surface of the pin was rubbed on the E-31 disc. The following parameters for performing the test: wear track diameter was 70mm, sliding distance was 500m, variable load was 20N, 30N and 40N and variable temperature was 50°C, 100°C and 150°C. The wear out with respect to COF and sliding distance were investigated. The wear test parameters as shown in table 5.

Table 5: Wear Test Parameters



Wear test parameters

Sample Name	Temperature(°C)	Rotational speed(rpm)	Load(N)
Sample 1 (at 27°C)	50	300	20
	100	500	30
	150	700	40
Sample 2 (at 150°C)	50	500	40
	100	700	20
	150	300	30
Sample 3 (at 300°C)	50	300	20
	100	500	40
	150	700	30

Sample 4 (Base material)	50	300	20
	100	300	30
	150	300	40
	100	500	20
	150	500	30
	50	500	40
	150	700	20
	50	700	30
	100	700	40

Figure 14: Wear Test Machine

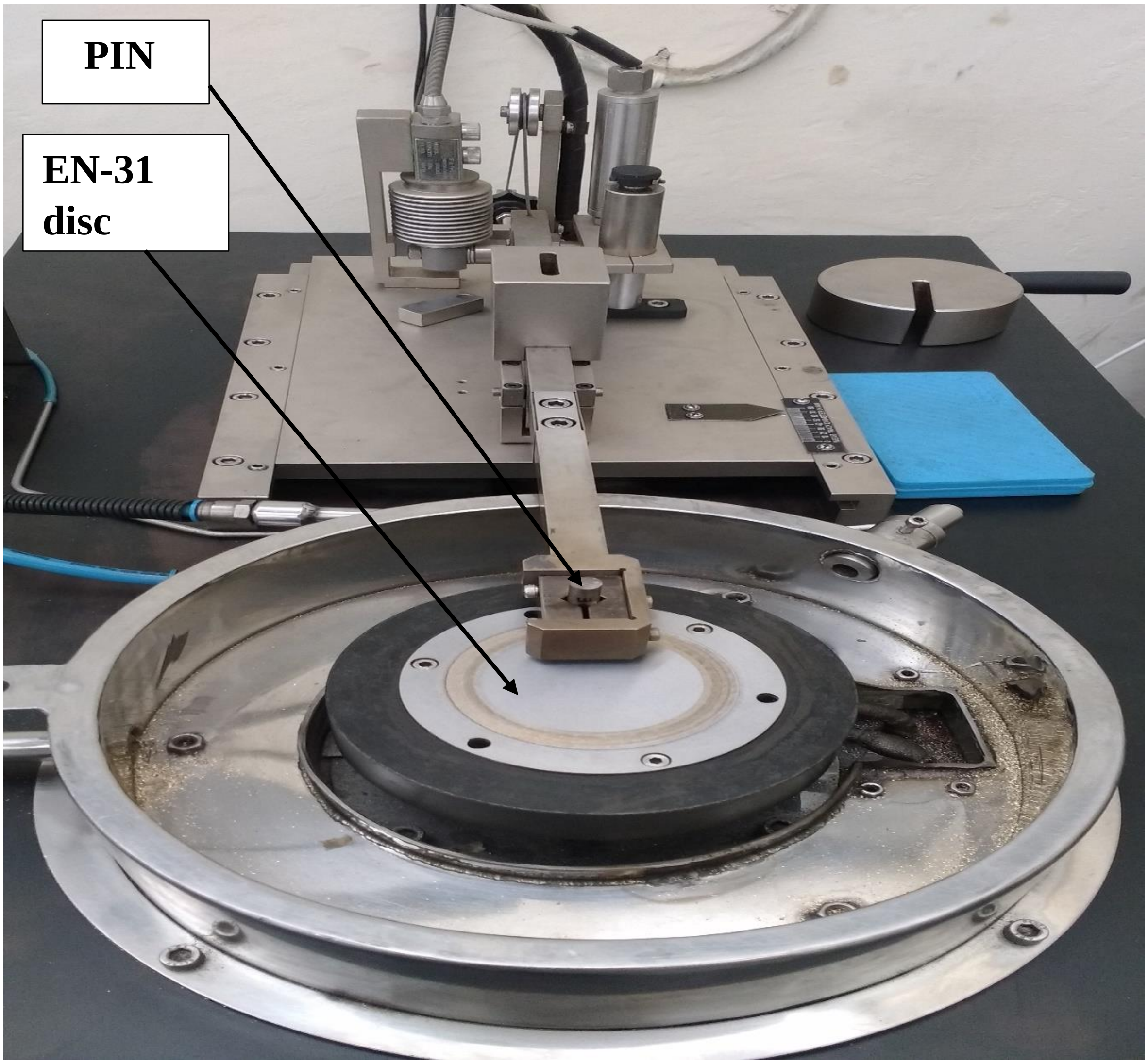


Figure 15: Pin-on Disc

4.2 Microstructure test

The specimen for microstructure were prepared by wire-cut by EDM machine. Then these specimens were mounted with the help of hot mounting process. Firstly, the piece was placed onto the machine then 20ml of Bakelite powder were placed on the piece after that cylindrical support was placed on Bakelite powder and clamped tightly. The temperature was set at 135°C for 35minutes. The whole process as shown in figure 16. After this process, the mounting specimen was rubbed and polished with the help of abrasive paper and velvet cloth step by step. These mounting specimen was rubbed on 200 mesh, 300 mesh, 500mesh, 800 mesh, 1000mesh, 1200mesh and 1500 mesh. Final finished was obtained with the help of diamond paste of 1μm put onto the velvet cloth. Then after prepared sample were etched (50% HNO_3 + 50% H_2O). The microstructure test was performed by electron microscopy as shown in figure 17.

(a) (b)

(c) (d)

Figure 16: Mounting Process

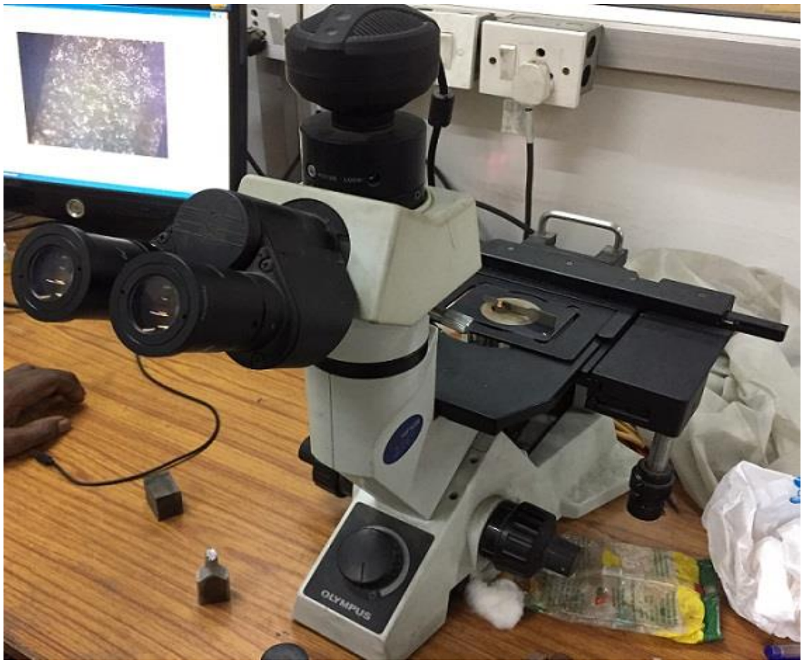


Figure 11(b): Optical Microscopy

4.3 Hardness test

The hardness test was performed by Vicker Hardness Machine (FISCHERSCOPE HM20005) as shown in figure 12. The specimen was prepared by taking the traverse cross-section of the stir zone. During the test, load and dwell time was 300gf, 5seconds. The avg. of five hardness values was regarded within each test region.

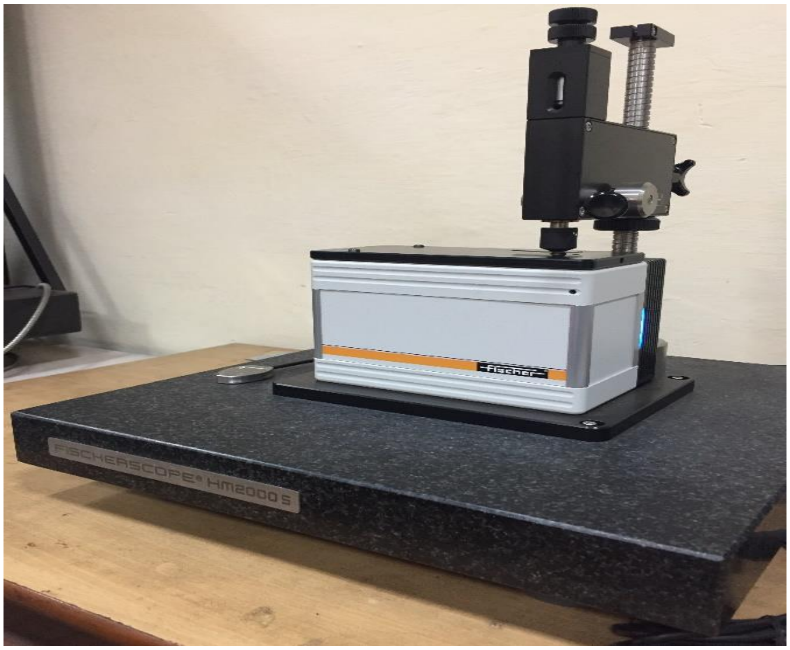


Figure 17: Vicker hardness test machine

4.4 Tensile Test

The standard of E-8 Tensile specimen was prepared by wire-cut EDM machine as shown in figure. The length, width and thickness of specimen was 70mm, 12mm and 5mm respectively as shown in figure18. This test was performed by UTM (Tinius Olsen) as shown in figure 19.

Figure 18: Tensile Specimen

Figure 19: UTM

4.5 XRD

XRD (BRUKER D8 ADVANCE) was done to verify the presence of reinforcement particle which was marble dust in the brass matrix. XRD spectrums were taken using a powder diffractometer with Cu-kα. Before going diffraction study, the specimens were polished and cleaned.

Chapter 5

5. Results and discussion

5.1 Micro-hardness Test

Hardness is a material feature. It is described as “resistance to indentation” and that can be acquired by determining the permanent depth of indentation(DOI). The micro-hardness test was performed by Vicker Hardness testing Machine. Five reading were taken in the FSPed zone and their average was taken as the hardness value for each sample. The hardness of sample which was pre-heated at 150°C was comparatively better than the base material as shown in figure 20. It provides a positive suggestion that particle dispersion increased that increased hardness value. The hardness values increased in processing zone as compared to base material due to marble dust. Additional important reason that hardness increased due to decrease or fine grain size. Basically, when grain size reduced that effects mechanical properties.

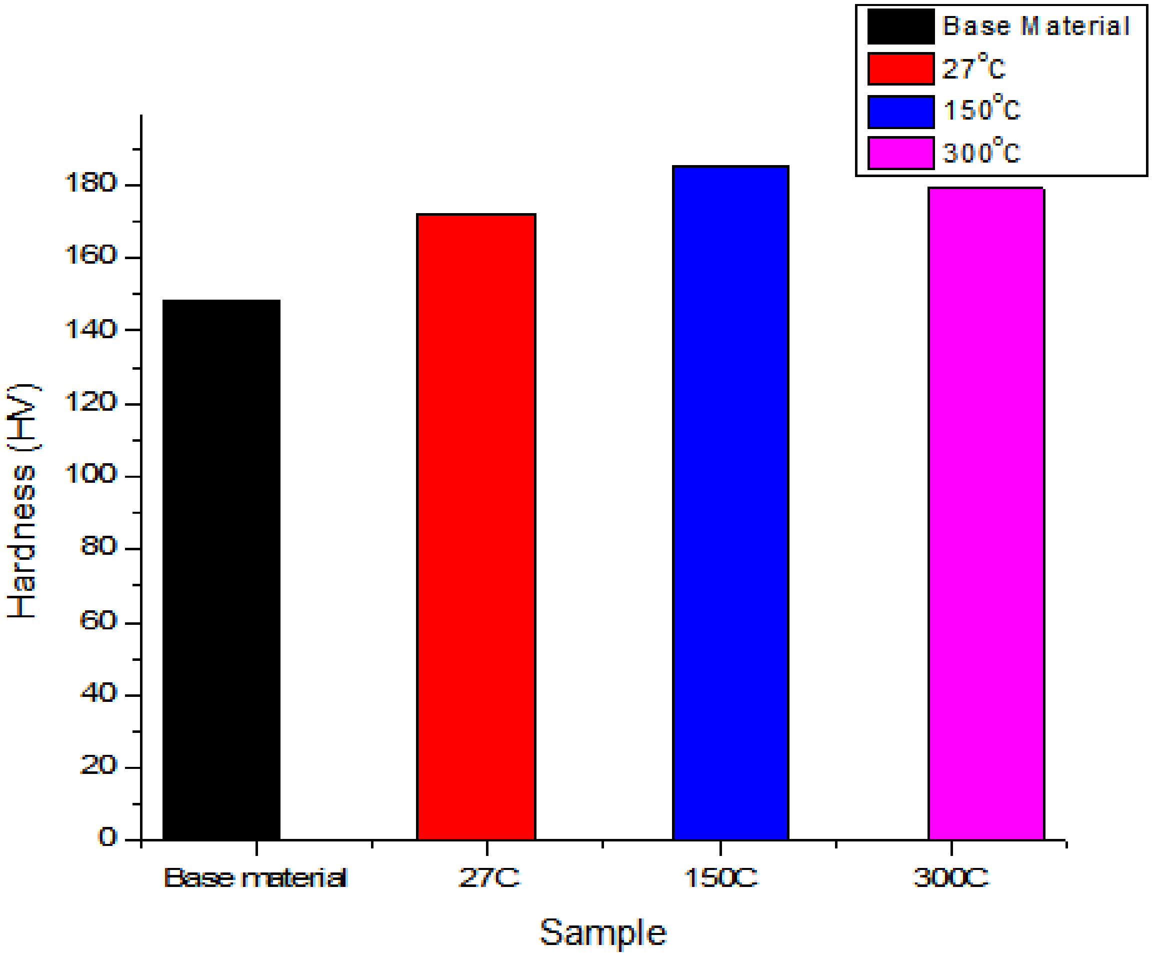


Figure 20: Hardness values of sample

5.2 Microstructure

Microstructure are used to depict the grain boundaries, reinforcement particles, crystal imperfection like voids, porosity etc. and surface cracks. Figure 21-24 shows the microstructure of Stir zone of base material, pre-heated at room temperature(27^{o}C), pre-heated at 150^{o}C and pre-heated at 300^{o}C respectively with the help of Olympus GX41 compact inverted metallurgical microscope.

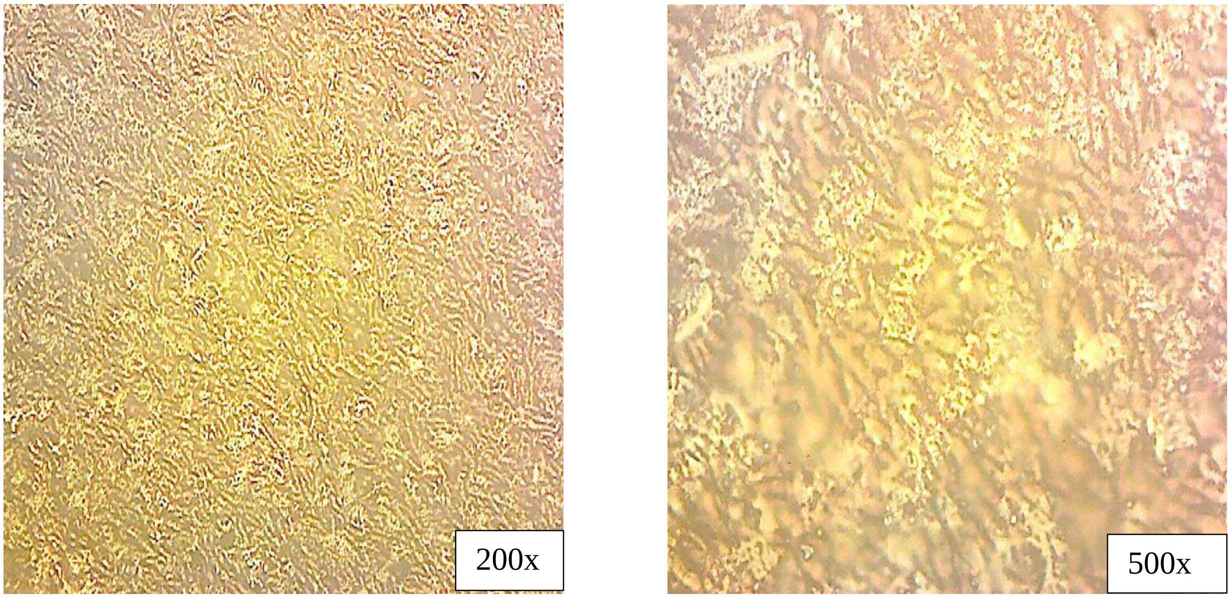


Figure 21: Base material

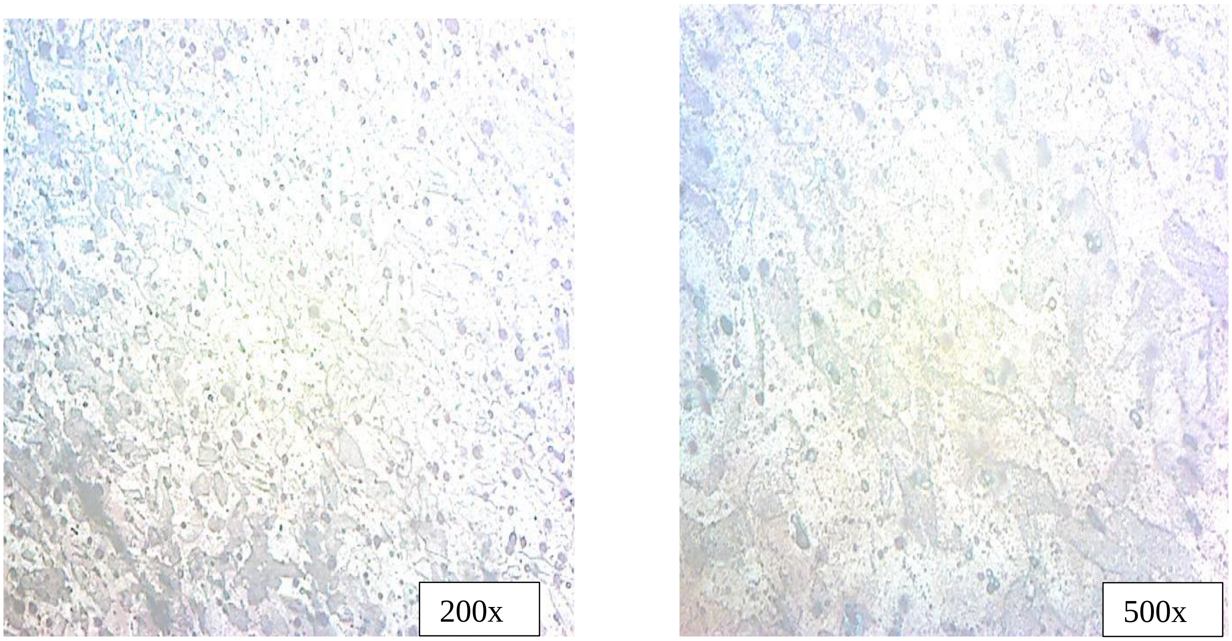


Figure 22: Pre-heated at 27^{o}C

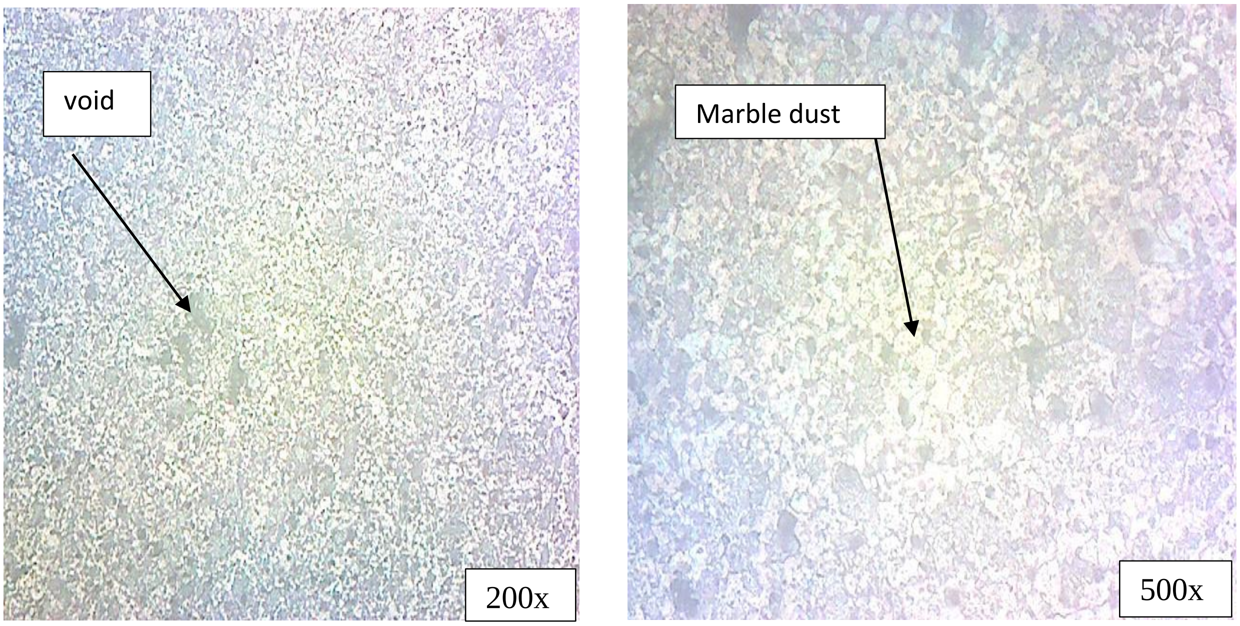


Figure 23: Pre-heated at 150^oC

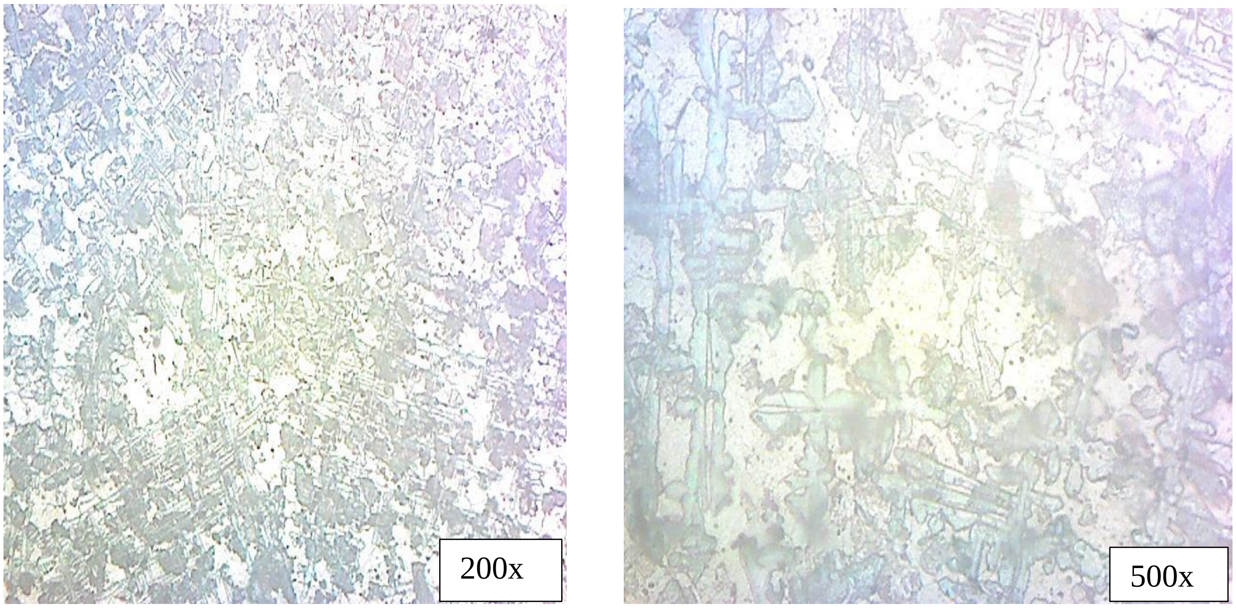


Figure 24: Pre-heated at 300^oC

5.3 Tensile Test

Tensile Strength is a material feature. It can be described as “Material resistance to breaking under tension” and Tensile test was performed by UTM. The tensile strength of Base Material was comparatively better than the sample which was pre-heated at 27°C, 150°C and 300°C as shown in figure 25. The results revels that the composite produce out of the experiment as have tensile strength 79.5%, 82.35% and 91.17% with respect to base material.

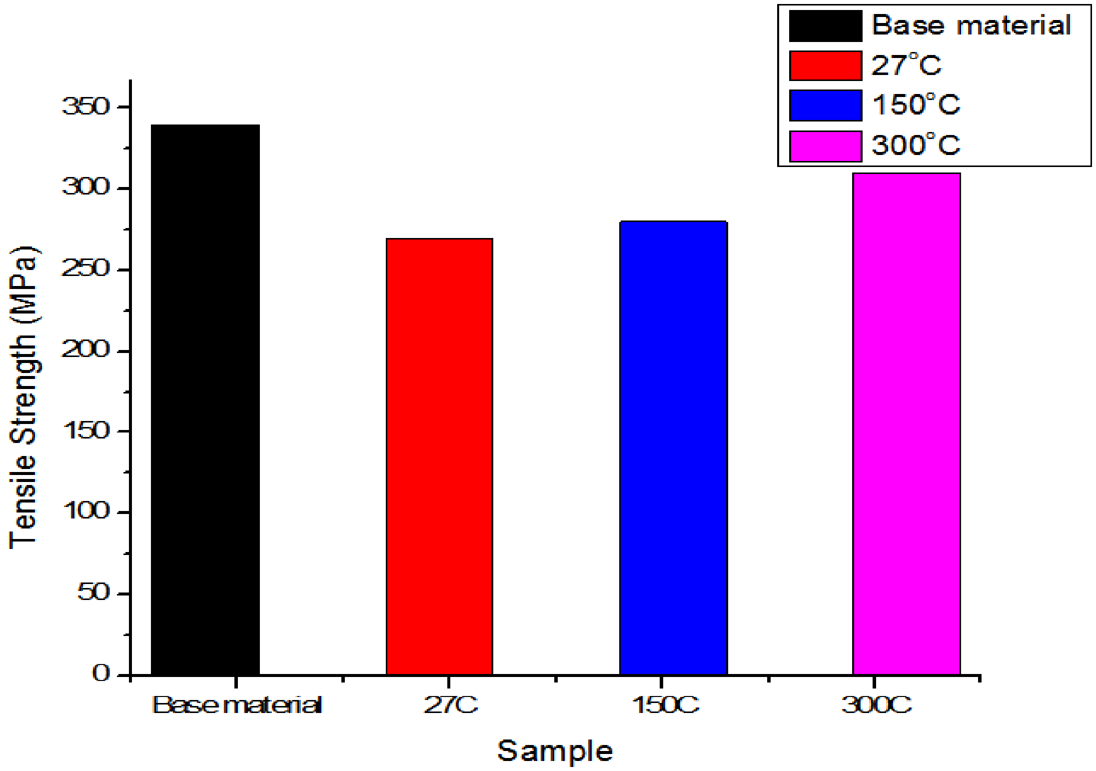


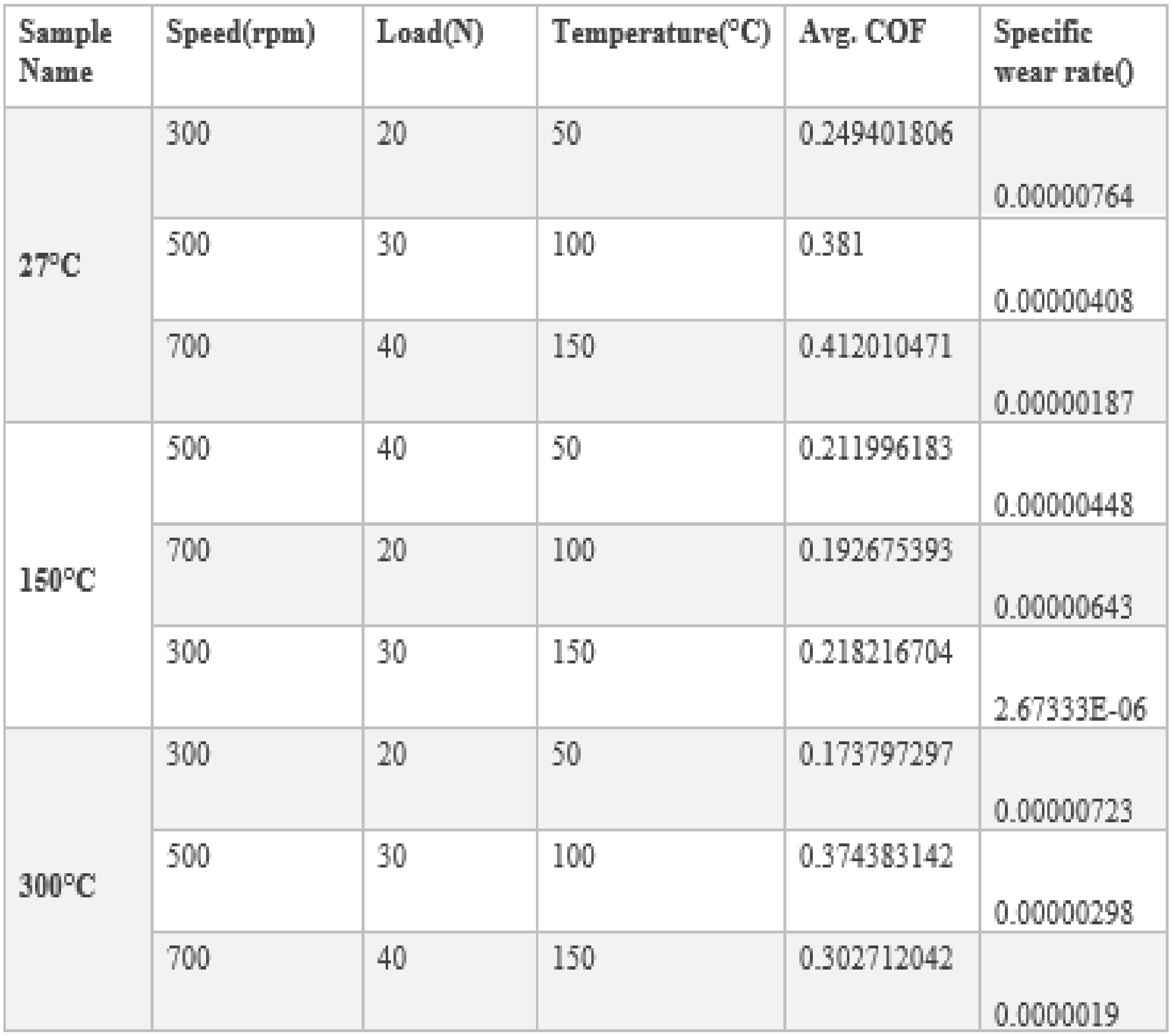
Figure 25: Tensile Strength of Samples

5.4 Wear Test

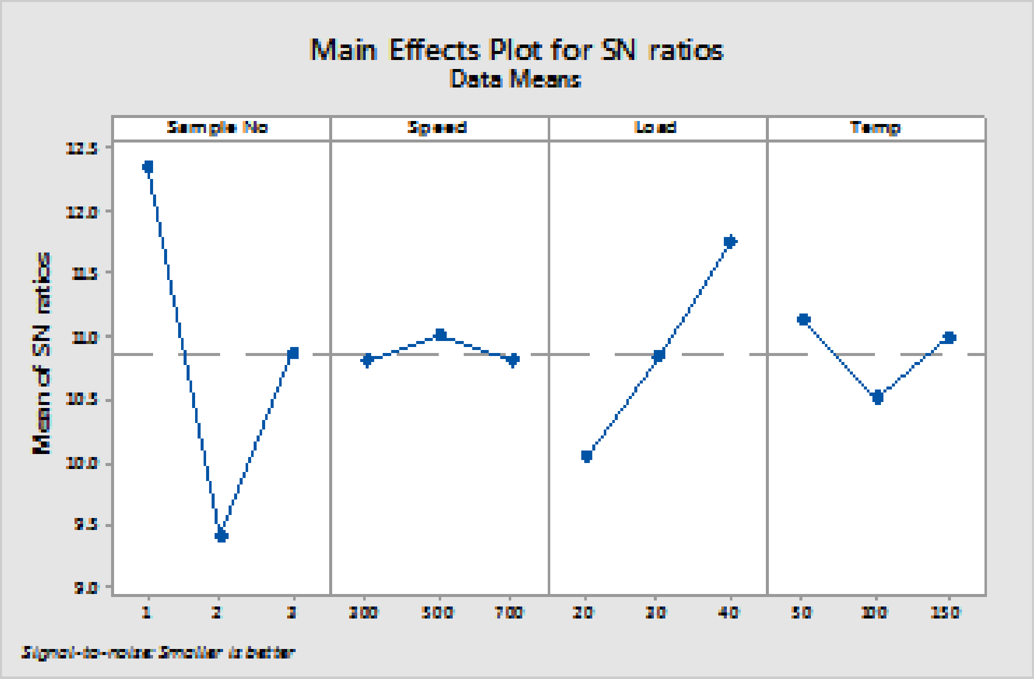
5.4.1 COF of Pre-Heated Material

The Tribological analysis of Pin-on-Disc was completed by tribometer and COF of Preheated sample was Computed. Taughi analysis L9 was applied. The COF decreased when speed increased up to certain point at 500rpm then after COF increased as shown in figure 26. In case of load, COF decreased when load increased. In case of temperature, COF increased when temperature increased up to certain point at 100°C. The graph was prepared with the help of table 6 by Taguchi analysis. The sample which was preheated at 27°C (room temperature) has minimum wear. The optimum condition was 500rpm, 40N and 50°C.

Table 6: Wear Test(Pin-On-Disc) preheated Material



Sample Name	Speed(rpm)	Load(N)	Temperature(°C)	Avg. COF	Specific wear rate()
27°C	300	20	50	0.249401806	0.00000764
	500	30	100	0.381	0.00000408
	700	40	150	0.412010471	0.00000187
150°C	500	40	50	0.211996183	0.00000448
	700	20	100	0.192675393	0.00000643
	300	30	150	0.218216704	2.67333E-06
300°C	300	20	50	0.173797297	0.00000723
	500	30	100	0.374383142	0.00000298
	700	40	150	0.302712042	0.0000019



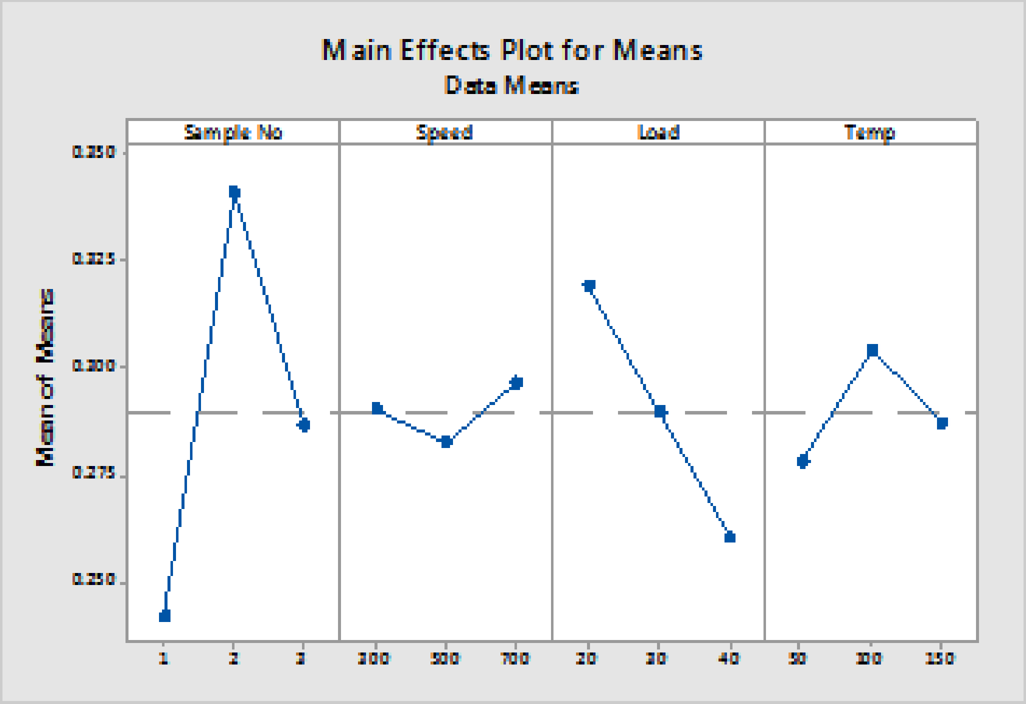


Figure 26: COF of Pre-Heated Samples

5.4.2 Specific Wear Rate(SWR) of Pre-Heated Material

The Tribological analysis of Pin-on-Disc was completed by tribometer and SWR of Preheated sample was Computed. Taughi analysis L9 was applied. SWR increased when speed increased as shown in figure 27. In case of load, SWR increased when load increased up to certain point at 30N then after SWR decreased. In case of temperature, SWR increased when temperature increased. The graph was prepared with the help of table 6 by Taguchi analysis. The sample which was preheated at 300°C has minimum wear. The optimum condition was 700rpm, 30N and 150°C

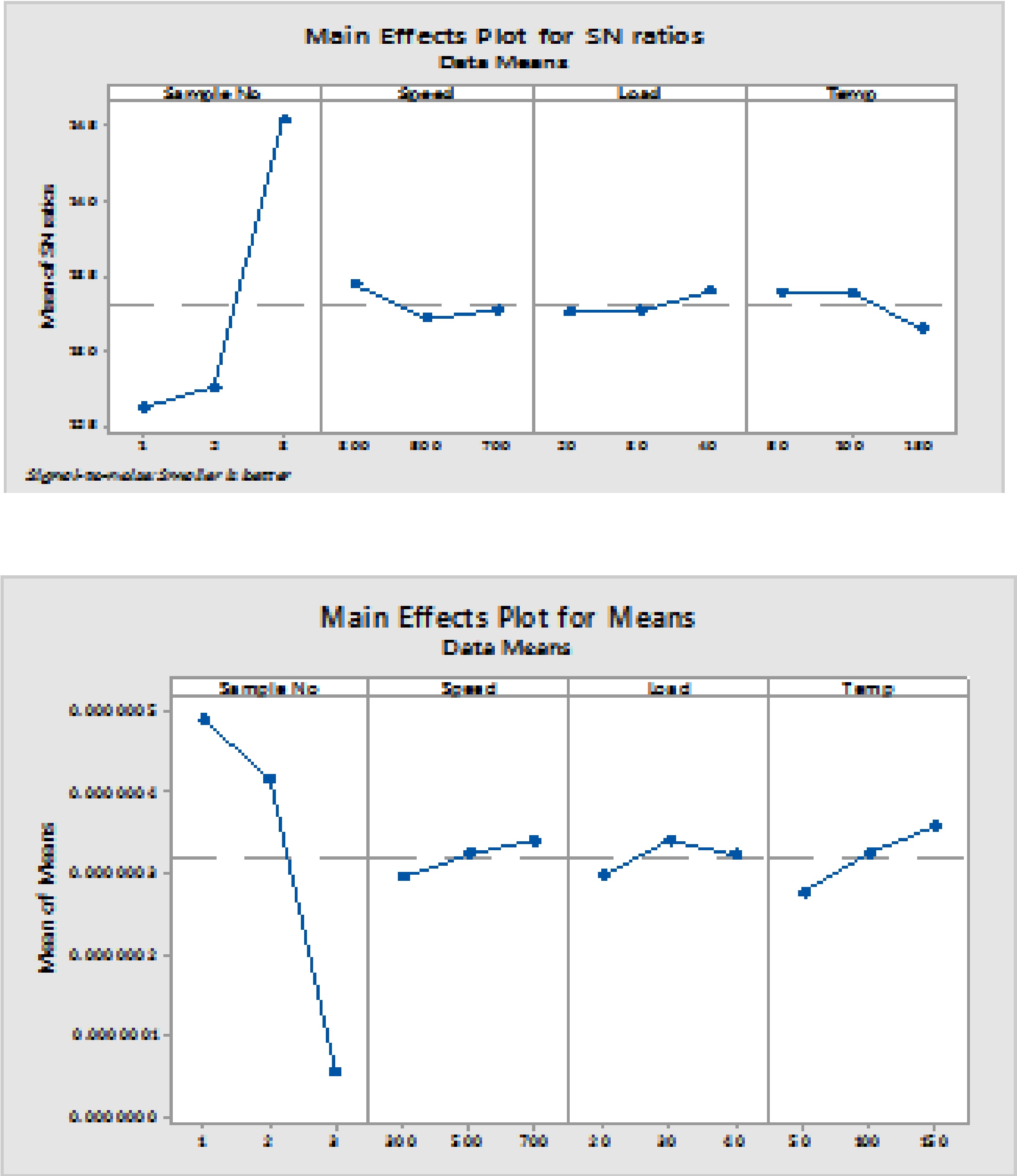
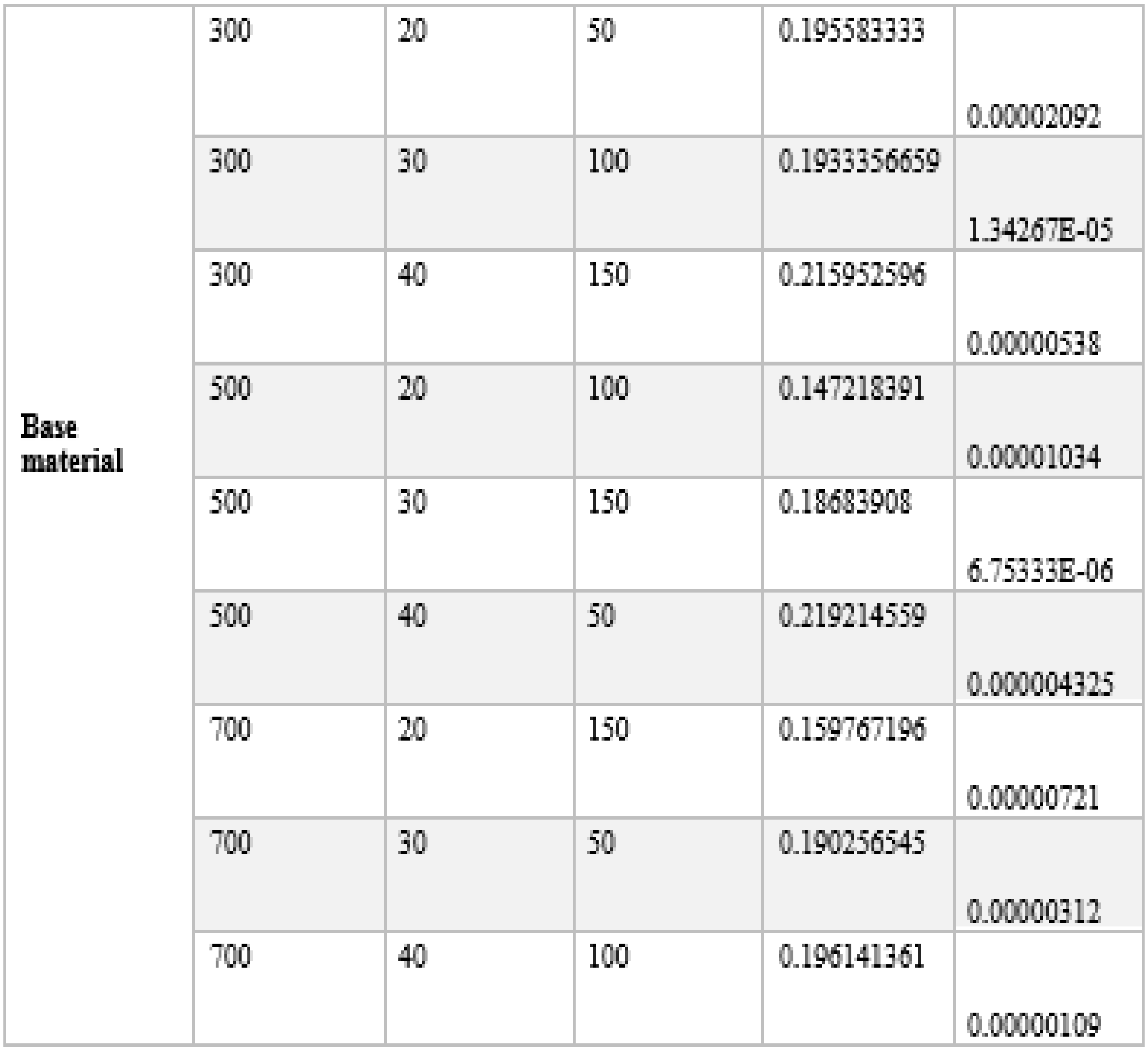


Figure 27: SWR of Pre-Heated Samples

5.4.3 COF of Base Material

The Tribological analysis of Pin-on-Disc was completed and COF of base material was Computed. The COF increased when speed increased as shown in Figure 28. In case of load, COF increased at certain point when load was 30N then after COF was decreased. In case of temperature, COF decreased when temperature increased up to certain temperature at 100^{o}C then after COF increased. The graph was prepared with the help of table 7 by Taguchi analysis. Speed shows the highest impact on COF then after temperature and load. For COF, the optimum condition was 700rpm, 30N and 150^{o}C.

Table 7: Wear Test(Pin-on-disc) Base material



Base material	300	20	50	0.195583333	0.00002092
	300	30	100	0.1933356659	1.34267E-05
	300	40	150	0.215952596	0.00000538
	500	20	100	0.147218391	0.00001034
	500	30	150	0.18683908	6.75333E-06
	500	40	50	0.219214559	0.000004325
	700	20	150	0.159767196	0.00000721
	700	30	50	0.190256545	0.00000312
	700	40	100	0.196141361	0.00000109

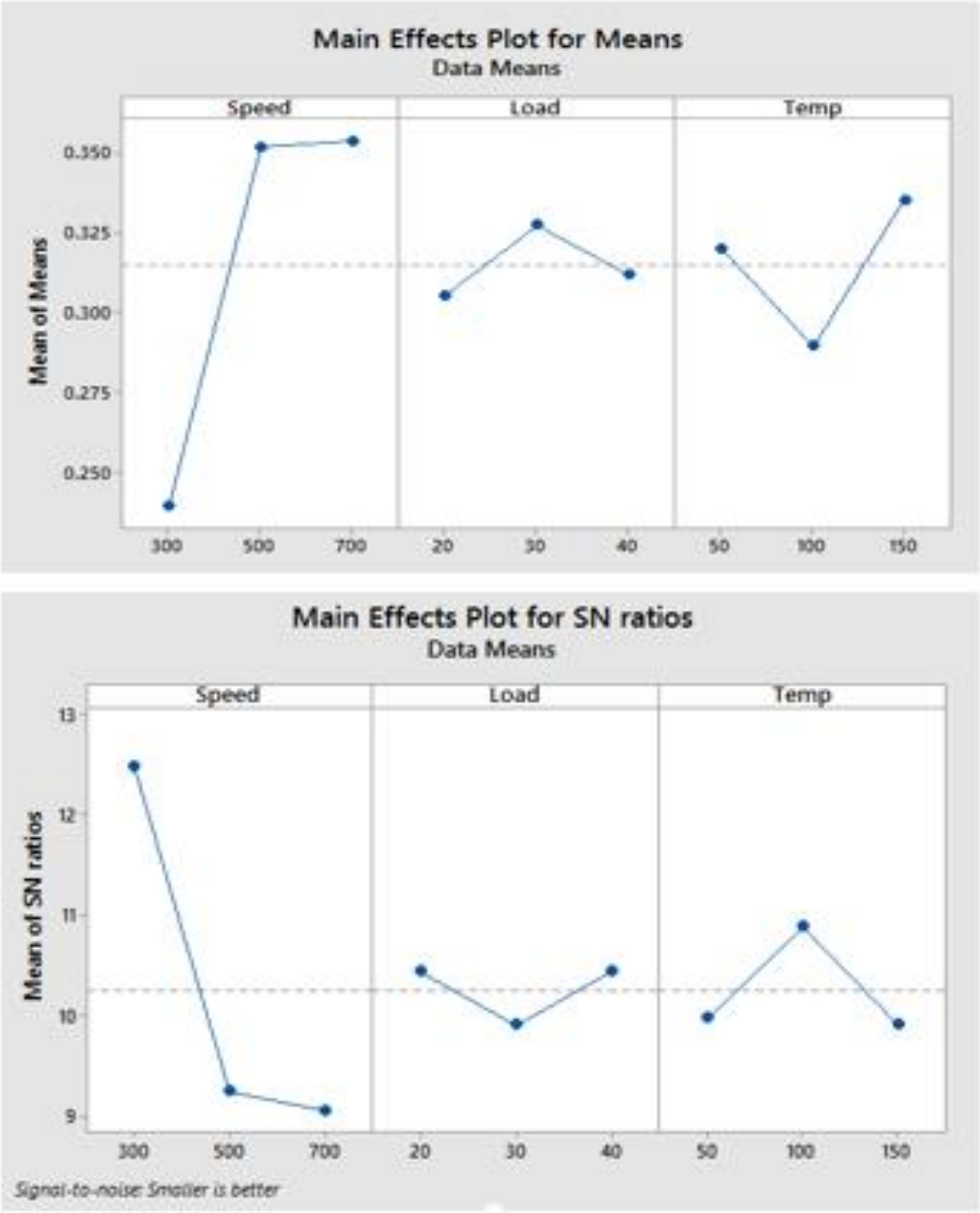


Figure 28: COF of Base Material

5.4.4 Specific Wear Rate(SPW) of Base Material

The Tribological analysis of Pin-on-Disc was completed and SWR of base material was Computed. SWR increased when speed increased up to certain point at 500rpm then after decreased as shown in figure 29. In case of load, SWR increased when load increased. In case of temperature, SWR increased when temperature increased. The graph was prepared with the help of table 7 by Taguchi analysis. Temperature shows the highest impact on SWR the after load and speed. For SWR, the optimum condition was 500rpm, 40N and 150^{o}C.

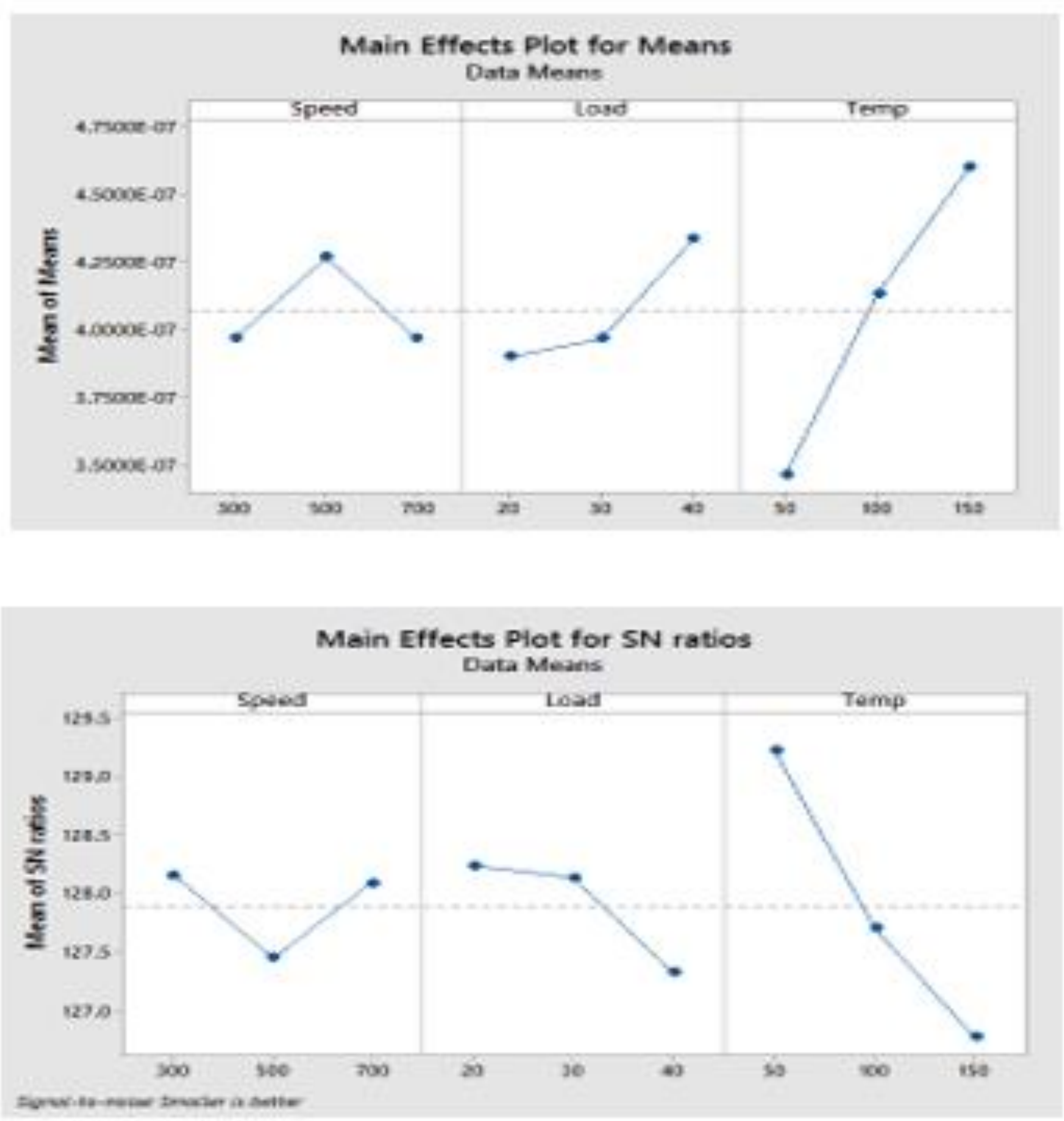


Figure 29: SWR of Base Material

5.5 XRD Test

XRD is the “Non-destructive method” for describing material composition. It gives the information of structure, texture, phase and further essential parameters likes crystallinity, average grain size, crystal defects and strain. In XRD, the peaks are generated at particular angle with the help of constructive interference. The graph of XRD was plotted between 2theta and intensity. The maximum peaks in base material was (Cu, Zn) as shown in figure 30. The proper mixing of material and reinforcement was done by FSP as shown in figure 31-33 β,* and π display the composition of CuZn5 and λ, δ, ☐ shows that proper mixing of material and reinforcement.

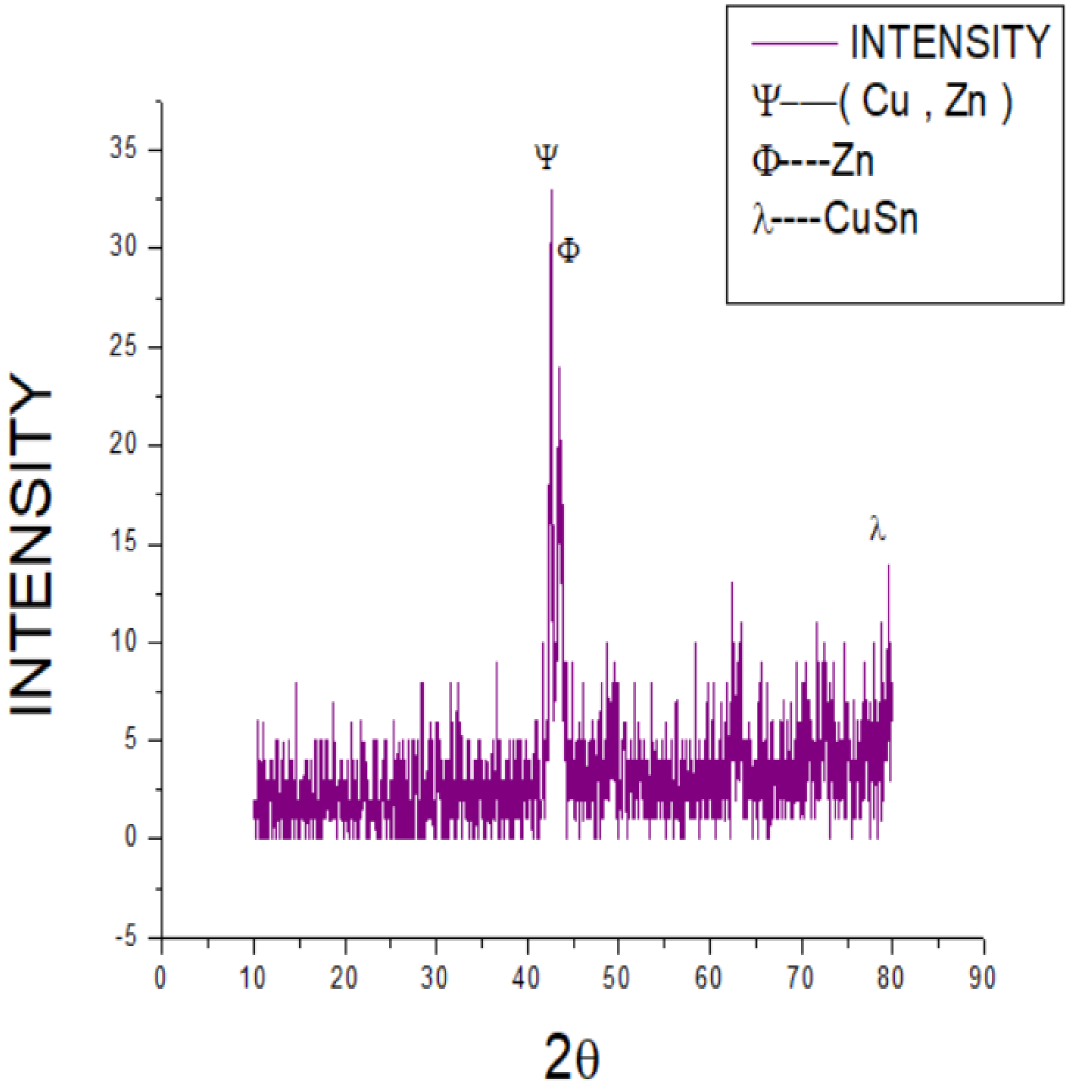


Figure 30: XRD of Base Material

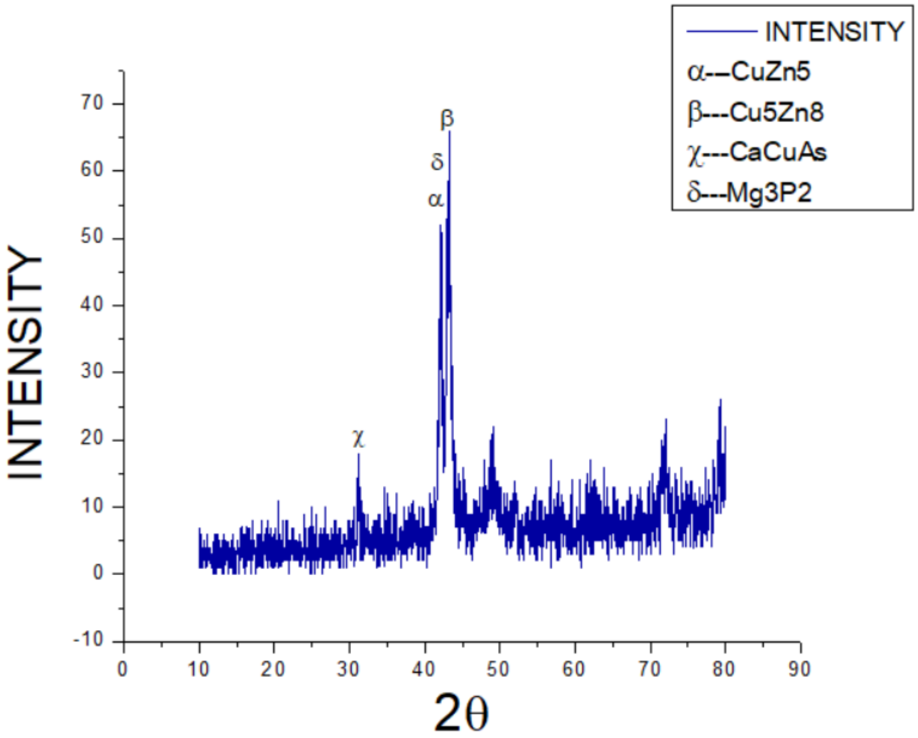


Figure 31: XRD of Sample Pre-heated at 27°C

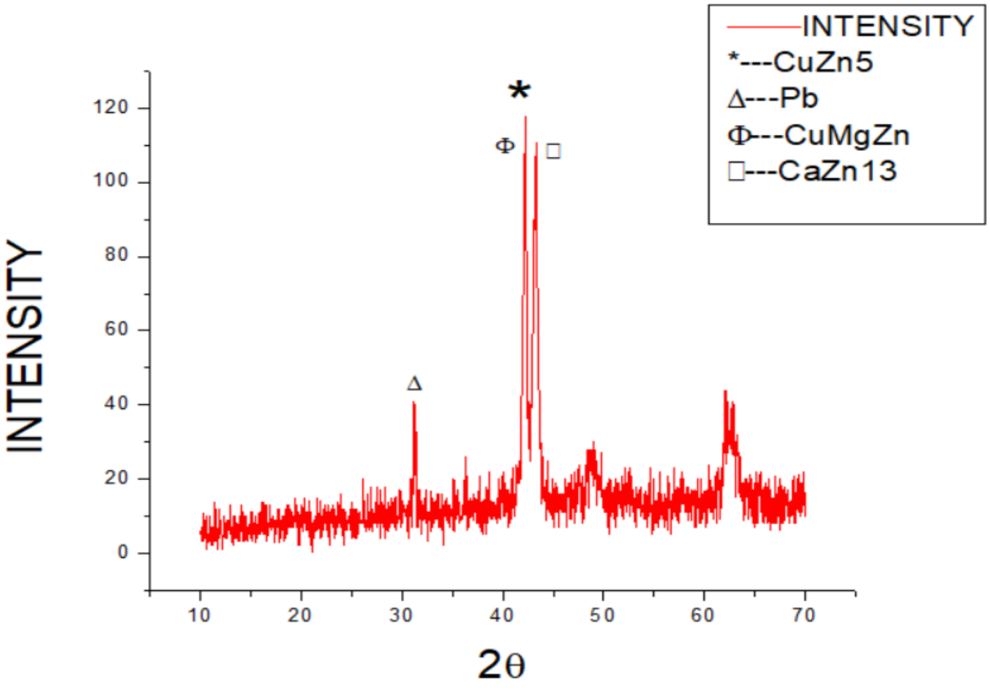


Figure 32: XRD of Sample Pre-heated at 150°C

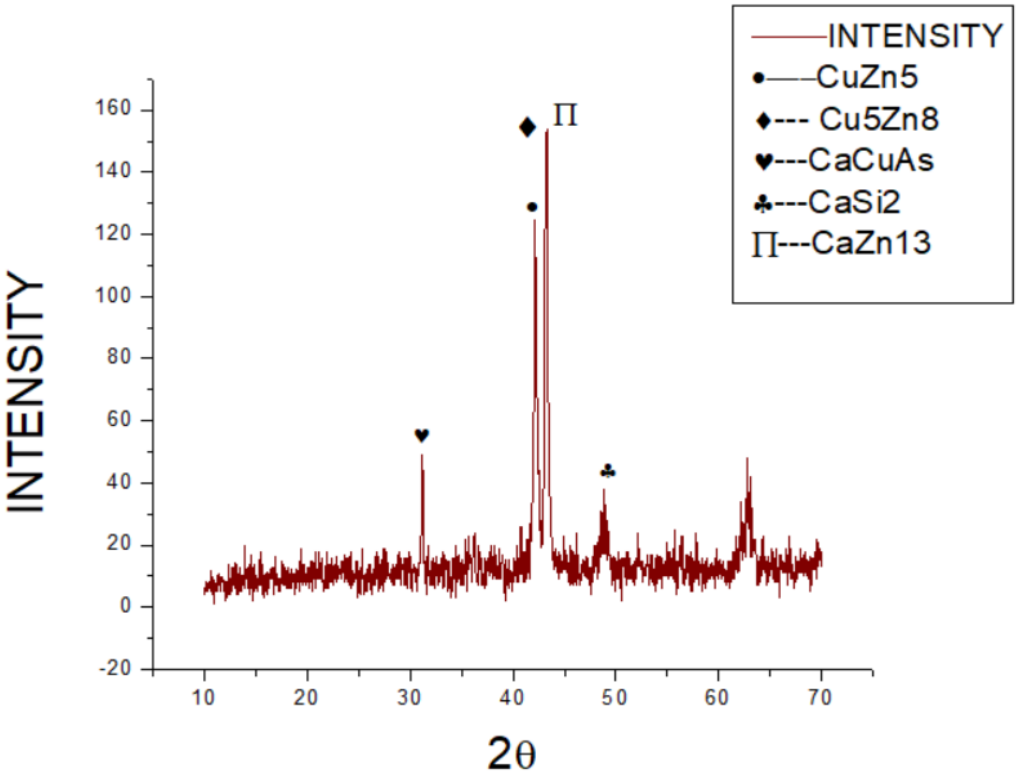


Figure 33: XRD of Sample Pre-heated at 300^{o}C

Chapter 6

6. Conclusion

The brass alloy based composite was fabricated in which marble dust was used as reinforcement with thw help of FSPed. The Tribological, Mechanical and Morphological properties of prepared specimens was evaluated and then compared with properties of base material.

- The Micro-hardness of base material and preheated samples at 27°C(room temprature), 150°C, 300°C was noted as 148.3HV, 172.12HV, 184HV and 178HV respectively.
- The Tensile strength of base material and preheated samples at 27°C(room temprature), 150°C, 300°C was noted as 340MPa, 270MPa, 280MPa and 310MPa respectively.
- The Morphological properties revels the samples which was prepared by FSPed have finer grain structure.
- XRD results shows that the particles Cu, Zn and Pb was presented in base material then after FSPed Si, Ca, Mg and Al was presented.
- The Pin-on-Disc test was performed to investiagate the tribological properties by tribometer. Taguchi L9 was applied and results shows that Speed shows the highest impact on COF then after temperature and load. In case of SWR, that temperature shows the highest impact on COF then after load and speed.
- Microstructure test was performed by optical microscopy shows that cracks, voids, wear debris was much reduced in FSPed samples.

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