Relationship between process parameters and mechanical properties of friction stir processed AA6063-T6 based composite

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ABSTRACT - *In this study, the effects of FSP on mechanical properties of aluminum alloy 6063 were analyzed statistically and graphically. The experiment was performed on vertical milling machine and conducted on the bases of full factorial, which was employed to optimize the process parameter i.e. rotational speed, tool feed, reinforcements and tool profile to improve the mechanical properties. From the results it was revealed that optimal hardness achieved at 1400 rpm, 40mm/min with SiC reinforcement and threaded cylindrical tool profile. It was revealed from the research paper that a tool profile is most influent factor to increases the hardness followed by reinforcement and speed. The highest rank 1 is of threaded cylindrical tool profile with contribution 62.13% in the hardness of composite after that speed showed 25.15% contribution with rank 2 and in the last reinforcement showed 11.48% contribution of the hardness of processed Al6063 alloy. Tensile strength decreases as compare to base metal due to presence of SiC powder. Optimal yield strength was achieved at rotational speed 1300 rpm, travel speed 50mm/min, SiC powder and threaded cylindrical tool profile and for yield strength tool profile shows first rank with 73.72% contribution and speed show second rank with 21.45% contribution and reinforcement particles shows third rank with contribution 4.82%. Ductility was achieved at rotational speed 1400rpm, 60mm/min, SiC powder with threaded cylindrical tool profile. Al6063 based composite was also examined by scanning electron microscopy for dispersion of reinforced particles.*

Keywords: AMMCs,reinforcements, Friction stir processing, mechanical properties, SEM.

1. INTRODUCTION

AA6063 is an aluminum alloy with alloying elements magnesium and silicon. The Aluminium Association controlling its composition standard. It has various good mechanical properties, good heat treatable and wieldable. British aluminum alloy HE9 is 6063 and is used in various applications such as extruded shapes used in architecture, especially in frames like window frames, door frames, roofs, and sign frames. It is generally generated with the help of very smooth surfaces that are fit for anodizing.Density of 6063 is 2.68g/cm^3 [1].Temper and heat treatment of the material affect the mechanical properties of 6063. 6063 is used for architectural fabrication, window and door frames, pipe and tubing, and aluminum furniture. Due to low hardness, wear and abrasion resistance of AA6063, improvements of the surface of the same could be done using various processes [2].

There are several fabrication techniques to produce AMMCs such as powder metallurgy, plasma spraying and casting. In these techniques,it is difficult to ignore interfacial reactions and generation of detrimentalphases and it includes liquid phase deal with at elevated temperatures, their utilization becomes further tough, thus in order to acquire solidified microstructure, crucial control over processing parameters is done in the layer of surface. These problems can be avoided by performing the process at temperature which is less than the melting point of the given substrate,which is done only by FSP;hence we opted for FSP for the fabrication of AMMCs, according to Jerome et al., 2012.But above written problems are not faced by friction stir processing as faced by casting and powder metallurgy[3].We are using FSP because it is a easiest job to disperse anodize particle in aluminum and aluminum alloys by FSP(Chen et al.,2010). First Al-SiC composite fabricated by FSP was found by R.S.Mishra et al.

FSP is purely based on the principle of FSW and is a latest processing technique. It was first developed for aluminum alloys and then developed by Mishra et al. It was developed to modify the microstructure and to improve the mechanical properties by Ma say. 2008. The reason is that aluminum alloys have many excellent properties i.e. light weight, high strength to weight ratio and good resistance to corrosion, thus used in structural applications such as aerospace, military and transpiration industries[4]. It is advisable that surface layer of the component is reinforced by hard ceramic particles to get the particular hardness and microstructure (Gupta ET al.2013). FSP produces refined microstructure and free from defects with super plasticity properties. Studies on the relationship between process variables and mechanical properties are less in number [5].

A full factorial experiment is an experiment whose design consists of two or more factors, each with discrete possible values or "levels", and whose experimental units take on all possible combinations of these levels across all such factors. Such an experiment allows the investigator to study the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable. For the vast majority of factorial experiments, each factor has only two levels [6]. The simplest factorial experiment contains two levels for each of two factors. In this investigation, effects of process parameters on Sped AA6063-T6 based composite were studied.Full factorial method was used to develop to create the relationship between process variables and their mechanicalproperties [7].

2.EXPERIMENTAL PROCEDURE

The aim of the experimentation is to attain the superior results on the basis of selected parameters during FSP. In the experiment first trials were carried out using conventional semiautomatic vertical milling machine with the help of specially designed tool. The trials were carried out to finalize the parameters. The matrix material used in the experiment was Al6063-T6 alloy. Al in the form of plates was purchased from Ludhiana metal shop, Ludhiana, Punjab into 150mm×50mm×12mm dimensions. The mark of 6063 was stamped on the plate to conform the alloy. The alloy composition of AA6063 is Silicon minimum 0.2%, maximum 0.6% by weight, Iron no minimum, maximum 0.35%, Copper no minimum, maximum 0.10%, Manganese no minimum, maximum 0.10%, Magnesium minimum 0.45%, maximum 0.9%, Chromium no minimum, maximum 0.10%, Zinc no minimum, maximum 0.10%, Titanium no minimum, maximum 0.10%, Other elements no more than 0.05% each, 0.15% total, Remainder Aluminium[8].

The reinforcement material used was silicon carbide. The powders were collected from Ludhiana drug house. Each parameter has different influence on the properties of processed Al6063. Three different parameters speed, type of reinforcement and type of tool was taken for to process the Al6063 by FSP. Before selection of parameters, some trials experiment was done on several speed ranges from 400 to 2000 rpm on the basis of that parameters were confirmed [9]. The milling machine was of Bfw Company and mode was Surya with programming of FANUC series Oi mate MC. A milling machine was transformed into a FSP machine by the use of tool which is used to process the grooved work piece (Al6063 base plate). The specification of the machine used wasMaking: XYZ machine tool, Type: Vertical milling machine, Table size: 1270×254mm, Inline direct drive spindle with motor: 2.25KW (3HP), Variable speed range: above 12000 rpm, High speed tool changer [10].

The formation of groove was made by vertical milling machine on base plate before carrying out FSP and fabricated in workshop with dimensions 100mm length, 5.6mm width and 2mm depth. This grooving of plate was done to place reinforcement particles in it to fabricate aluminum matrix composite. The plain cylindrical and threaded probe is used for effective stirring of the metal and efficient filling reinforcement in the groove [11]. The tool used for FSP was manufactured from Research and development centre, Ludhiana. The specifications of tool employed are Material: H13 Hot die steel, Hardness: 55 HRC, Shoulder dimensions: Dia= 18mm, length= 50mm, Pin dimensions: Die= 6mm, length= 6mm, Thread= M6.A feed was given to the machine around 40 to 60 mm/min and rotational speed was 1200-1400 rpm.When tool reaches to the end of the groove the tool unplugged from the aluminum alloy plate. This process we repeated again and again for different experiments. The processed joints machined to required dimensions, so as to get specimens for tensile testing, micro hardness and microstructure [12].

Fig.2.1-Sic reinforced in the groove of the base metal and plain cylindrical tool used for FSP

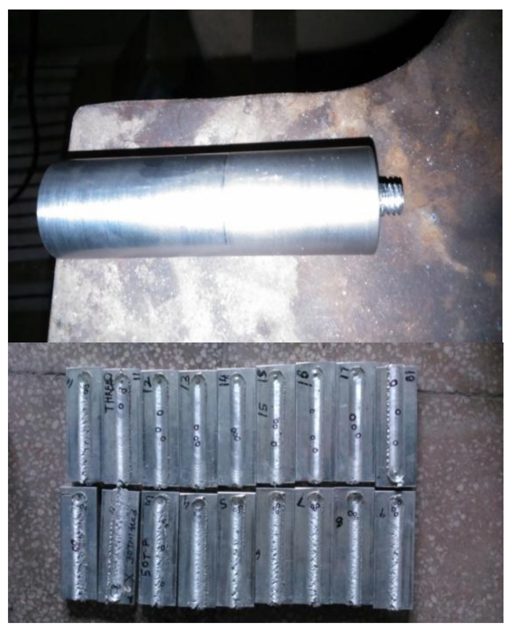


Fig.2.2-Threaded cylindrical tooland Set of FSP specimens

Tensile testing was done on Universal testing machine and mechanical properties such as yield strength, ultimate tensile strength and ductility were calculated, specimen made as per ASTM. Microhardness measurements were done with Rockwell hardness tester with main load of 100 Kef. The microstructure of the samples were observed using SEM. Specimens were prepared for equal to or less than 32×32mm size were prepared by polishing also[13].

3. RESULT AND DISCUSSION

In this work full factorial is used to reduce the number of experiments during FSP. Result of the research was studied graphically and by comparing the values of each processed samples with base metal. Thus optimum FSP parameters for hardness, tensile strength are obtained. The experiment conducted on the basis of full factorial that gives different combinations of parameters at different levels. In the experiment, graphical results indicate the effects of each parameter at different level for hardness and tensile strength. Microstructure has been also studied of the specimen to find the various results for reinforcement distribution and grains quality [14].

3.1Results for hardness

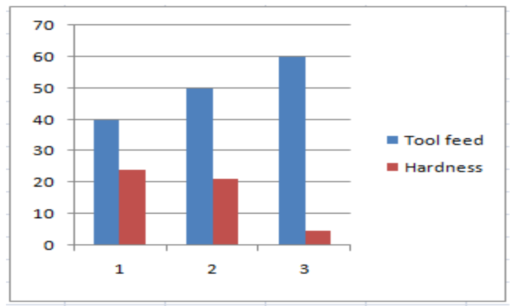
The hardness test has been done on base metal as well as on 18 samples i.e. Al6063 based composite. The hardness of the specimens was tested with the help of Rockwell hardness testing machine on the Scale. For study the result of hardness first of all find the hardness of various processed samples and then compare it with base metal plate which has hardness value of 90 HRB and with other reading i.e. differ from each 9 sample because we used two kind of tool. Thus by comparing us get four best samples which has higher value of hardness i.e. sample no. 14, 16, 17 and 18 as these hardness value is greater as compared to base plate. Thus we can easily find out the contribution of each parameter to the hardness graphically [15].

Table 3.1: Hardness of specimens

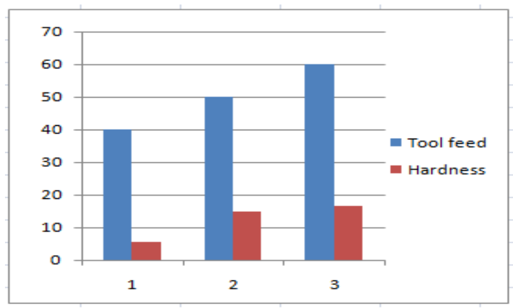
Experiment no.	Travel speed(mm/min)	Rotational speed(rpm)	Tool profile	Hardness
Al6063			Plain cylindrical	90 HRB
1.	40	1200		24
2.	50	1200		21.33
3.	60	1200		4.6
4.	40	1300		17.66
5.	50	1300		10.33
6.	60	1300		14
7.	40	1400		5.66
8.	50	1400		14.66
9.	60	1400		16.66
Al6063			Threaded cylindrical	90HRB
10.	40	1200		6.66
11.	50	1200		5
12.	60	1200		35.33
13.	40	1300		67
14.	50	1300		68.66
15.	60	1300		38.66
16.	40	1400		99.33
17.	50	1400		94.66
18.	60	1400		97.33

3.1.1 Effect of process parameters on hardness

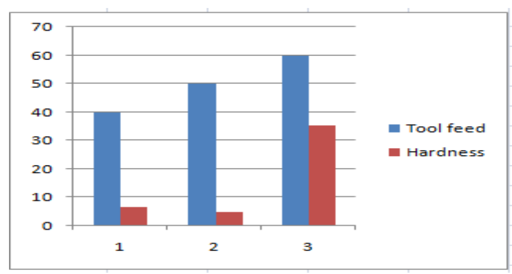
Effect on hardness is shown in fig.3.1 graphically.



Plain cylindrical tool at 1200 rpm



Plain cylindrical tool at 1400 rpm



Threaded cylindrical tool at 1200 rpm

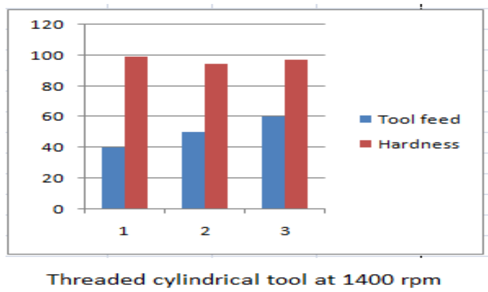


Fig.3.1- Effect of various parameters on hardness

When travel speed increases then hardness decreases at constant rotational speed of tool i.e. 1200 rpm. But at 1400 rpm, hardness increases slowly with increase in feed rate. As rotational speed increases up to 1400 rpm hardness increases which is due to increase heat input that provide better stirring action of the pin resulting better mixing of reinforcement particles thus increases hardness[16]. This is due to the high heat generation that softening the matrix cause decreases in hardness as compare to 1400 rpm (Devaraju ET al.2013). It is observed from graphical representation that as we changed our reinforcement hardness of Al6063 based composite changes, hardness increases when reinforced the Sic instead of no reinforcement. This is due to the presence of pinning effect of the Sic particles and is effective for fine grain structure. In plain cylindrical tool, with the increase of speed of tool, first hardness decreases then increases afterwards. But in threaded cylindrical tool, with the increase of speed of tool, hardness decreases then increases, then again follows the same pattern. This is because of the fact of change in tool profile. Plain cylindrical tool follows uniform criterion whereas threaded cylindrical follows increase decrease phenomenon repeatedly [17]. Here threaded cylindrical tool provides more hardness as compared to plain cylindrical tool (Devaraju et al. 2013).

3.2 Results for tensile strength

The tensile strength has been done on base metal and 18 samples. The tensile strength test of the specimens was tested with the help of tensile strength testing machine making Dumble shaped specimen. Load applied up to fracture with tensile strength testing machine. First of all find the tensile strength of various processed samples and then find we compare them with each other reading and especially with base metal. Find the contribution of each parameter to the tensile strength graphically [18].

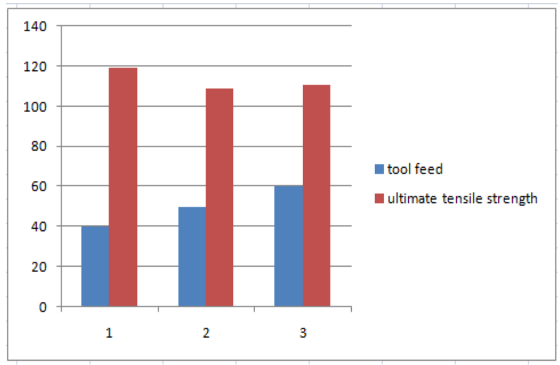
Fig.3.2-Specimens after tensile testing

Experiment no.	Tool feed	Rotational speed	Tool profile	Yield strength (N/mm^2)	Ultimate tensile strength (N/mm^2)	Ductility
Al6063			Plain cylindrical	133.40	142.10	30.20
1.	40	1200		118.80	124.80	15.70
2.	50	1200		115.00	121.60	12.40
3.	60	1200		109.10	114.70	15.90
4.	40	1300		104.20	111.80	16.40
5.	50	1300		108.30	113.70	16.50
6.	60	1300		98.20	104.20	13.00
7.	40	1400		111.60	119.20	17.60
8.	50	1400		102.40	108.90	14.50
9.	60	1400		103.00	110.60	13.80
			Threaded cylindrical			
10.	40	1200		100.00	108.80	13.90
11.	50	1200		114.50	117.80	21.60
12.	60	1200		111.80	117.30	19.10
13.	40	1300		114.90	120.40	20.80
14.	50	1300		123.00	129.50	29.20
15.	60	1300		120.00	128.70	27.90
16.	40	1400		118.10	128.90	25.60
17.	50	1400		116.40	127.30	22.60
18.	60	1400		121.20	130.90	29.60

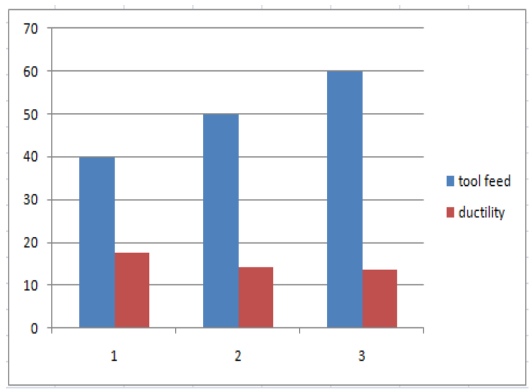
Table 3.2 Tensile strengths of specimens

3.2.1 Effect of process parameters on tensile strength

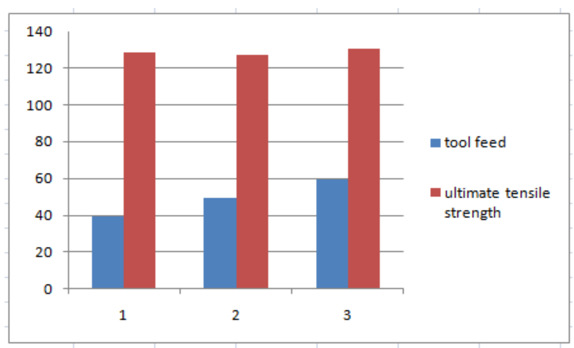
Effect of various process parameters on tensile strength is shown in fig.5.4 graphically.



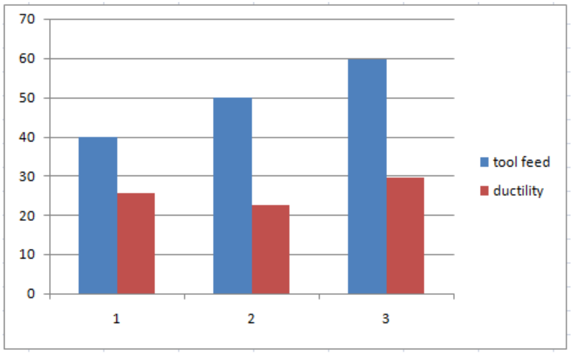
Plain cylindrical tool at 1400 rpm



Plain cylindrical tool at 1400 rpm



Threaded cylindrical tool at 1400 rpm



Threaded cylindrical tool at 1400 rpm

Fig.3.3- Effect of various parameters on tensile strength

It is revealed that from results that the overall tensile strength of the processed Al6063 by FSP decreases as compare to base metal due to presence of reinforcement particles which makes the matrix brittle. As we know the overall tensile strength of the composite is less as compared to base metal but when we studied the effect of speed individually on the tensile strength we find that, as showed in graphical representation i.e. tensile strength increased as increased speed which is due to the increasing the rotational speed[19]. With the increase of rotational and travel speed of tool, yield strength increases and ductility decreases. It is revealed that as the reinforcement changed tensile strength decreases as shown in fig.3.3. A specimen without reinforcement showed higher tensile strength but as we used Sic our tensile strength decreases which is due to weak interfacial bond between reinforcement particles and matrix (Devaraju ET al.2013). A Sic powder showed less tensile strength as compared to other reinforcement particles. Similarly yield strength and ductility also decreases with reinforcement particles as compared to no reinforcement particles.In case of plain cylindrical tool, ultimate tensile strength, yield strength increases but ductility decreases whereas in case of threaded cylindrical tool, ultimate tensile strength, yield strength and ductility increase [20].

3.3 Study of microstructure

To investigate the microstructure of processed sample SEM (Scanning electron microscopy) is used. Samples are cut from nugget zone and then they investigated by SEM. According to investigation by SEM, presence of worn surface and cluster of reinforced particles are also present as shown in fig.3.4 to 3.7. The SEM images of some sample of processed Al based composite are given below [21].

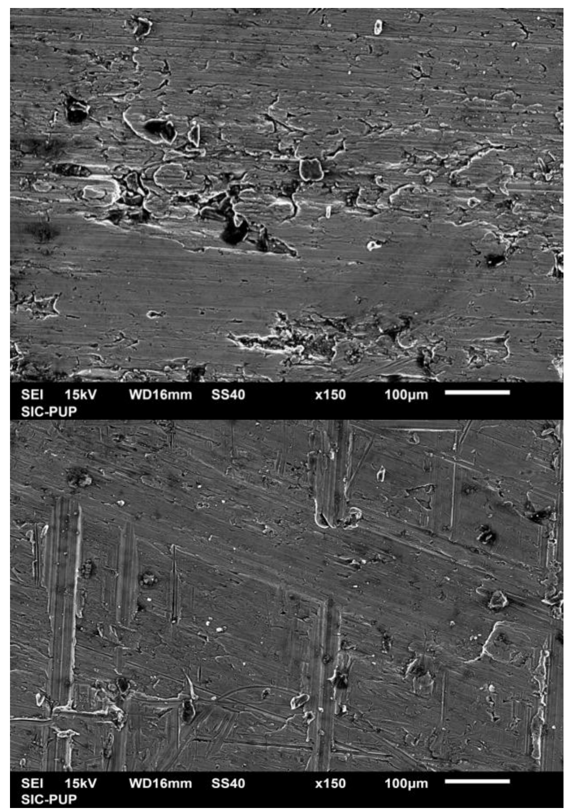


Fig.3.4- (Sample 14) Central and side view at magnification 150 and size 100µm

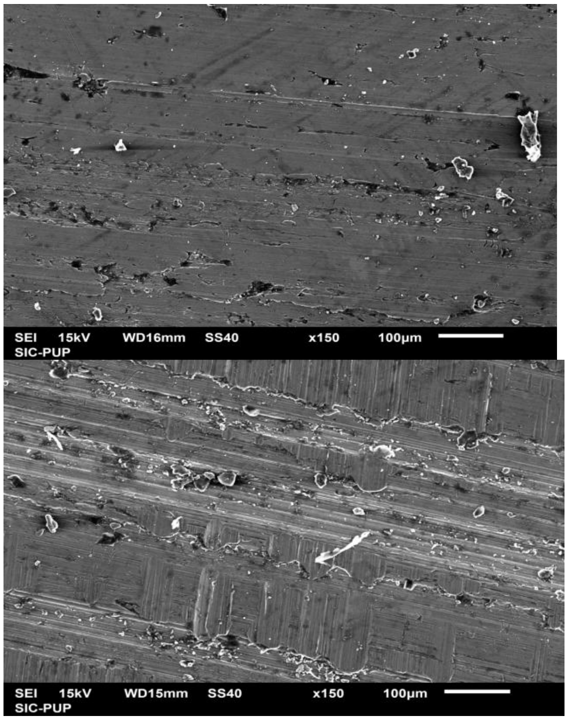


Fig.3.5- (Sample 16) Central and side view at magnification of 150 and size 100µm

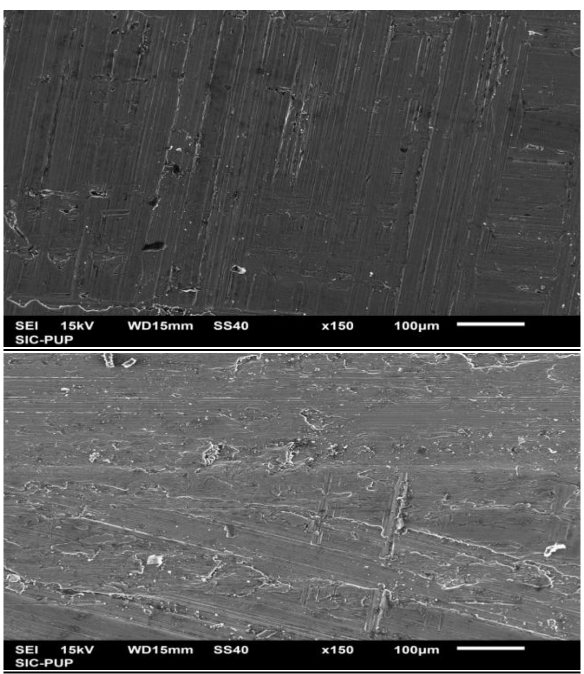


Fig.3.6-(Sample 17) Central and side view at magnification of 150 and size 100µm

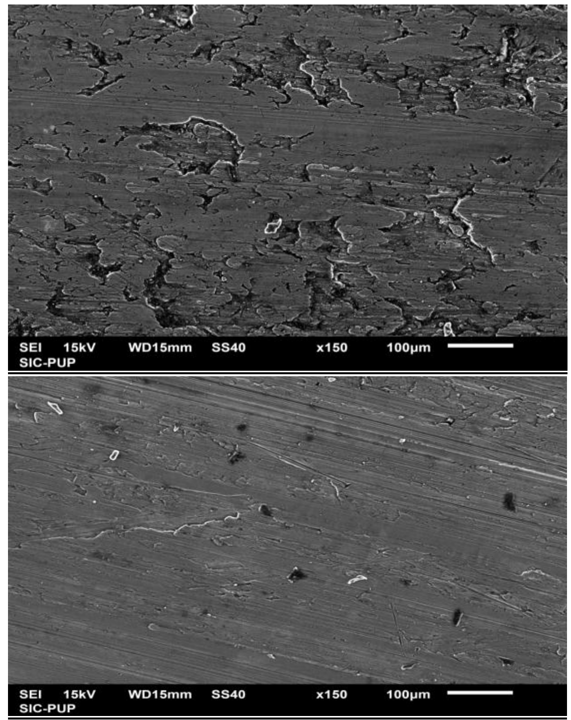


Fig.3.7- (Sample 18) Central and side view at magnification of 150 and size 100µm

Table 3.3 Optimum value of mechanical properties

Mechanical properties	Optimum condition	Optimum value
Hardness	Sample 16 i.e. 1400 rpm, 60 mm/min with Sic powder and threaded cylindrical tool.	99.33 HRB
Ultimate tensile strength	Sample 18 i.e. 1400 rpm, 60mm/min with Sic powder and threaded cylindrical tool.	130.90 N/mm^2
Yield strength	Sample 14 i.e. 1300 rpm, 50mm/min with Sic powder and threaded cylindrical tool.	123.00 N/mm^2
Ductility	Sample 18 i.e. 1400 rpm, 60 mm/min.	29.60

4. CONCLUSION

The effects of FSP on mechanical properties of aluminum alloy 6063 by using full factorial method were investigated. We can successfully use Sic for fabrication of Al6063 based composite via FSP.Hardness of the Al 6063 based composite increases as compare to base metal due to presence of Sic Optimum condition of hardness is sample 14,16,17 and 18 i.e. rotational speed of 1300, 1400 rpm and tool feed of 40, 50, 60 mm/min with Sic powder and using threaded cylindrical tool.Speed is most influent factor to increase the hardness as compare to reinforcement.Tensile strength decreases as compare to base metal due to presence of Sic reinforcement particles which makes matrix brittle.Yield strength increases as compare to base metal and optimum condition for yield strength is sample 14, 16, 17 and 18 with 1300, 1400 rpm and 40, 50, 60 mm/min in both tool profiles.Ductility decreases as compare to base metal in case of plain cylindrical tool and it increases in case of threaded cylindrical tool with optimum condition of sample 14, 16,17 and 18 with 1300 and 1400 rpm and 40, 50, 60 mm/min tool feed. Full factorial method, graphs and comparison with base metal was also successfully applied to find the contribution of each parameter for the mechanical properties.

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