Fabrication of Al/SiC Metal Matrix Composite by Stir Casting and Machinability Study by Micro-Drilling

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Abstract - *On account of the excellent physical and mechanical properties of composite materials, they are widely used in many engineering applications such as in tank armors and automotive disc brakes. Metal- matrix composites are a relatively new range of materials possessing several characteristics that make them useful in situations where low weight, high strength, high stiffness, and an ability to operate at elevated temperatures are required. Despite the superior mechanical and thermal properties of metal-matrix composites, their poor machinability has been the main cause to their substitution for metal parts. The hard abrasive reinforcement causes rapid tool wear during machining and, consequently, high machining costs. In this work an attempt is made to fabricate Al/SiC Metal Matrix Composite with 6.6% weight fraction constituted by SiC particles and the machinability of the fabricated specimen is evaluated by micro-drilling process on a CNC Vertical Machining Centre using 800μm diameter Tungsten Carbide tool. Design and optimization of the experiment is implemented with the help of Full factorial method. The holes are then analyzed to evaluate their surface integrity including taper and, burr formations.*

Key Words: **Al/SiC Metal Matrix Composite, Micro-Drilling, Full factorial method**

1. INTRODUCTION

Metal matrix composites (MMC) are materials which combine tough metallic matrix with a hard ceramic reinforcement. The continuous evaluation of emerging trends introduces novel materials to meet the requirements of various strategic application leads to development of composite materials. These materials are widely used in aerospace, automotive and electronics. SiC particle reinforced Aluminium composites have received more commercial attention than other kinds of MMCs due to their high performance viz. high mechanical properties, wear resistance, low coefficient of thermal expansion and high thermal conductivity. Aluminium reinforced with ceramic reinforcements is rapidly replacing conventional materials in various automotive aerospace and automobile industries.

There are numerous methods to fabricate MMCs which include vapour state methods, liquid phase methods (melt stirring and squeeze casting) and solid state methods (powder forming and diffusion bonding). Among the various systems that have been explored, cast composites of an Aluminium-based matrix reinforced with ceramic particles (typically SiC) are particularly attractive because of their comparatively low fabrication cost. The most important limitation of stir casted composites is non-uniform dispersion of SiC particles. The resulting non-uniform dispersion of SiC particles may further lead to agglomeration of the same which poses a critical obstacle for machinability of the fabricated composite.

Most of the researchers on the machining of Al/SiC MMC have focused on turning and facing while drilling have received less attention[1].In this work an effort is made to conduct micro-drilling process using Tungsten Carbide twist drill and analyze the machinability by varying the machining parameters like spindle speed and feed rate. The drilled holes are subjected to critical study using a non-contact profilometer to appreciate the burr formations, taper and the geometrical parameters of drilled holes.

2. LITERATURE REVIEW

Thella Babu Rao from his work found that the agglomerations and segregation of the reinforced SiC particles were increased for the increased SiC particulate content while the dispersion of SiC was decreased when larger the SiC particle size [1]. Sijo M T and K R Jayadevan analyzed from their work that clustering of reinforcement particles, wettability of reinforcement (SiC) in molten aluminium are the prime concern in the production of composites through stir casting [2]. Manoj Singla et.al found out from their research carried out that with increase in composition of SiC, an increase in hardness, impact strength and normalized displacement have been observed [4]. S.Balasivanandha Prabhu et.al found from the hardness test, the speed and time influence the hardness of the composite. Higher stirring speed and stirring time, gives better hardness composite of MMC as compared to as-cast condition [7]. A. Manna and B. Bhatttacharayya suggested from their work that cutting speed zone between 60 and 150 m/min is recommended for machining of Al/SiC-MMC, where cutting forces are more or less independent of cutting speed. High speed, low feed and low depth of cut are recommended for better surface finish [8].

3. EXPERIMENTAL PROCEDURES

3.1 Charge Calculation

Pure Aluminium (99.9%) is chosen as the matrix in which a weighted percentage of 6.6% SiC particles are added as the reinforcement. Higher values of SiC possess a critical obstruction for machining and further severe damage to the cutting tool. The average density of the MMC comes near to the value of 3g/cm^3. Total mass of the fabricated specimen for 200cm^3 volume die is calculated to be close to 600g considering ignorable contribution to volume reduction of fabricated MMC by shrinkage during solidification. Therefore a total mass of 40g of SiC is added as reinforcement for 560g of Aluminium matrix. SEM images of SiC powder sample were taken to visualize the particle size. Increase in particle size results in more agglomerations when compared to smaller particles [5]. The irregular morphology of the SiC particles with varying particle size (micrometer to nanometer) is clearly observed from the SEM images shown in Fig-1.

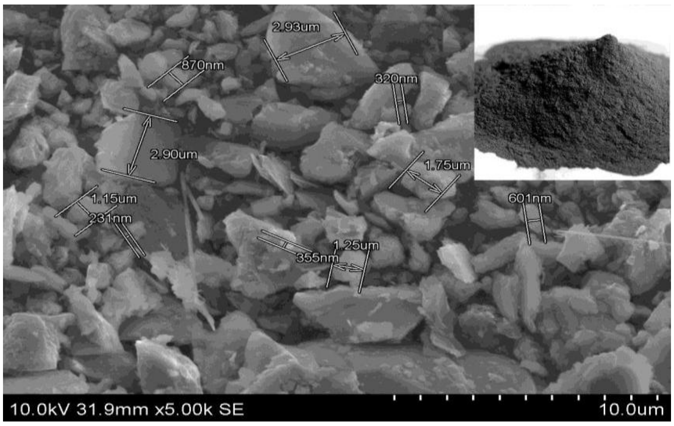

Fig -1: Silicon Carbide SEM image

3.2 Casting of Al/SiC

A weighted quantity of Aluminium was melted in a graphite crucible using a Muffle furnace, shown in Fig 2. A calculated quantity of SiC was heated for 600 °C for 1hr. The heat treatment on the SiC particle was done in order to form a layer of SiO_2 on the SiC, which improves the incorporation of SiC in molten metal [2]. The preheated SiC was fed into the molten Aluminium and kept at 1000°C for 20 minutes. Manual stirring was employed for 300 seconds to agitate the mixture thereby improving dispersion of SiC in Aluminium. The molten metal was poured into the mild steel die which is preheated to 100°C. Mild Steel die, as shown in Fig 4, is used instead of sand moulds as to eliminate casting defects such as blow holes. The volume of cavity of 200cm^3 is machined by a CNC Vertical Machining Centre. The cavity produced for pouring the melt into is of the dimension 100*100*20 mm. Fig 3 shows pouring of metal into the die.

Fig -2: Muffle Furnace

Fig -3: Pouring melt into Die

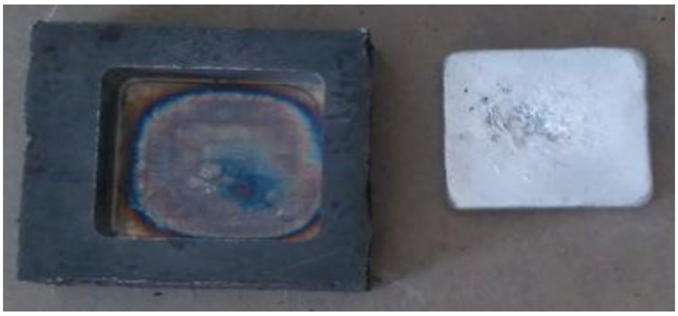

Fig -4: M S die (left) and casted Al/SiC MMC (right)

3.3 Micro-Drilling

Micro-Drilling test was carried out on the fabricated Al-SiC specimen. A tungsten carbide twist drill, as shown in Fig 5, of cutting edge diameter 800 μm is used to drill holes on the fabricated MMC specimen. The Twist drill selected for machining has a shank diameter of 3mm and a flute length of 9mm. Micro-drilling is carried out using a CNC Vertical Machining Center under wet lubrication condition having a total discharge of 0.02 liter per second, depicted in Fig 6.

Fig -5: Tungsten Carbide twist drill bit (800μm)

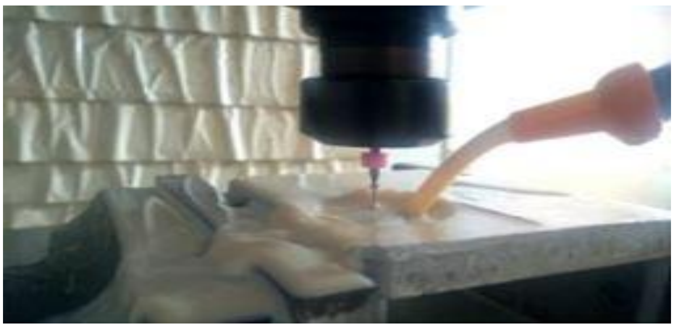

Fig -6: Micro-Drilling using CNC milling machine

Micro-drilling process was optimized using Full Factorial DOE. The parameters chosen as shown in Table-1 were spindle speed and feed rate. The responses analyzed are top diameter of the hole, bottom diameter of the hole and taper formation.

Table -1: Parameters chosen for machining

Parameter	-1	0	+1
Spindle Speed (RPM)	4000	5000	6000
Feed Rate (mm/min)	4	5	6

4. RESULTS AND DISCUSSIONS

4.1 Metallurgical Properties

4.1.1 Microstructure Analysis

Microstructure of the fabricated Al-SiC MMC as shown in Fig 6 was observed after proper polishing using disc polishing

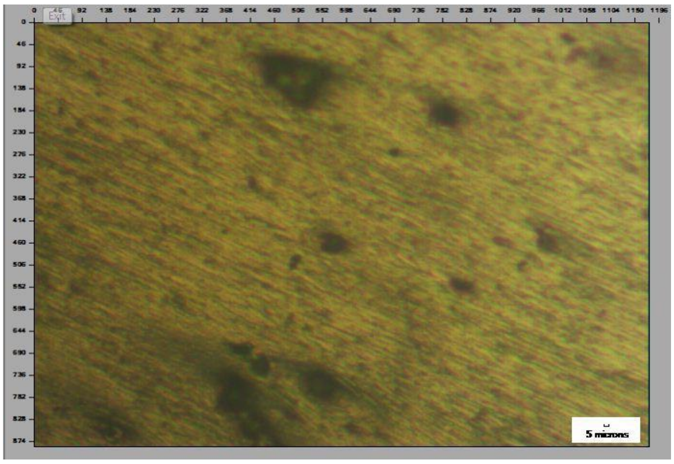

Fig -7: Microstructure image of fabricated Al/SiC

machine of varying grit sizes (P400, P600, P1000 and Diamond paste). Afterwards etching is done using Modified Keller's Reagent to reveal the microstructure under a metallurgical microscope.

4.1.2 Composition Analysis

The composition of the fabricated MMC is quantified by conducting EDS Test. EDS test was conducted on a 1.2*1.2cm size sample at a magnification of 11x, result shown in Fig 8.The sample was gold coated to ensure conductivity while test is conducted. EDS test results reveal the presence of Si and C elements in the fabricated MMC. 0.37% of Si element ensures the relevant presence of SiC particles under a magnification of 11x.

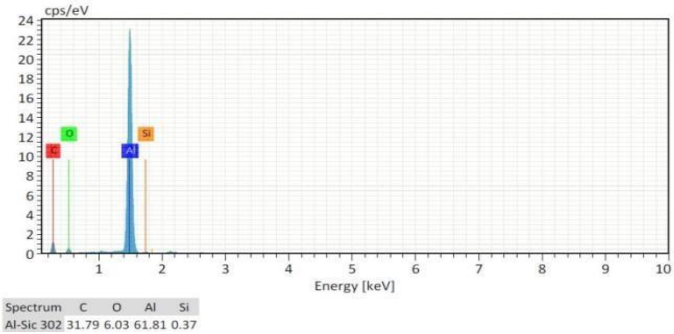

Fig -8: EDS result of Al/SiC

4.2 Mechanical Properties

4.2.1 Hardness

The samples for hardness test were polished by disc polishing machine. The hardness of the fabricated MMC were obtained using Brinell apparatus (5mm diameter ball indenter at a load of 250kgf). A total of six indentation were considered at different regions in each specimen to avoid the influence of particle segregation and agglomeration at the test zone [7]. Diameter of indentation was measured by Brinell microscope. The corresponding values of hardness (BHN) were calculated from the standard formula, as shown in Table-2. Average value obtained from calculation is 47.37 BHN. The hardness value increases due to local increase in particle concentration with indentation[4]. Fig 9 shows the hardness tested samples.

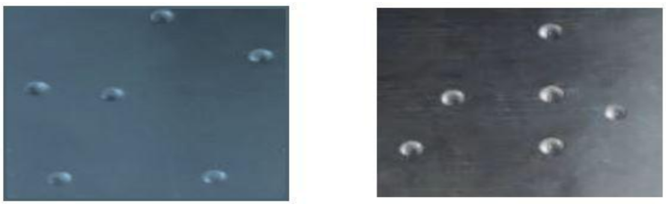

Fig -9: Hardness tested samples

Table -2: Hardness test values

Test no.	1	2	3	4	5	6
Diameter of indentation(mm)	2.4	2.6	2.4	2.5	2.5	2.6
BHN	51.87	43.65	51.87	47.51	47.51	43.65

Test no.	7	8	9	10	11	12
Diameter of indentation(mm)	2.5	2.6	2.4	2.5	2.5	2.6
BHN	47.51	43.65	51.87	47.51	47.51	43.65

4.3 Optimization of Micro-Drilling

The holes obtained by conducting micro drilling test on Al-SiC MMC are shown in Fig 10. The geometry variations of the holes slightly from circular profile may be assumed due to machine incapability. Due to primitive method of manual stirring agglomeration of SiC particles may have arised, which may have further resulted in variations in profile of drilled holes.

Analysis of experiment of micro-drilling is carried out using ANOVA. It does not involve complicated mathematical theory or computation and thus can be employed by the engineers without a strong statistical background[5]. It does not involve complicated mathematical theory or computation and thus can be employed by the engineers without a strong statistical background [5]. The table below shows the parameters varied with the corresponding responses. The

variation of the responses to a larger extent is a clear indication of poor machinability. Non uniform dispersion of

the reinforcement (SiC) and poor wettability between reinforcement (SiC) and matrix (Al) are the reasons for poor machinability. Table 3 shows the results obtained after micro-drilling.

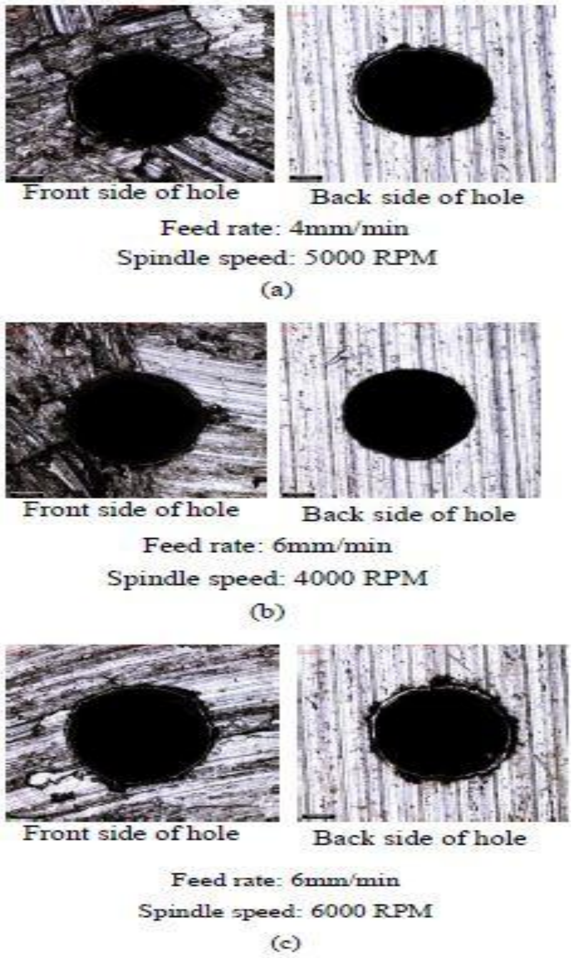

Fig -10: Drilled hole profiles for various machining parameters

The main effects plot shown below indicates the trend of responses such as taper%, bottom and top diameters of the drilled holes with respect to varying parameters of spindle speed and feed rate. From the Fig 11, for top diameter for which the desirable value is in proximity to 800 µm is found to be 5000 RPM of spindle speed and 5mm/min feed rate. At higher feed there is a drastic increase in top diameter of hole which may be due to incapability of the tool material to resist shock.

Table -3: Optimization of micro-drilling

Run Order	Speed (RPM)	Feed (mm/min)	Top Diameter (µm)	Bottom Diameter (µm)	Taper %
1	6000	6	861.327	807.325	67.5
2	4000	6	851.675	810.455	51.5
3	6000	5	848.31	815.275	56.7
4	4000	5	863.923	804.008	74.9
5	6000	4	874.072	801.545	90.7
6	5000	5	845.124	801.437	54.6
7	5000	6	880.448	805.311	93.9
8	4000	4	866.065	813.489	65.7
9	5000	4	844.461	796.861	59.5

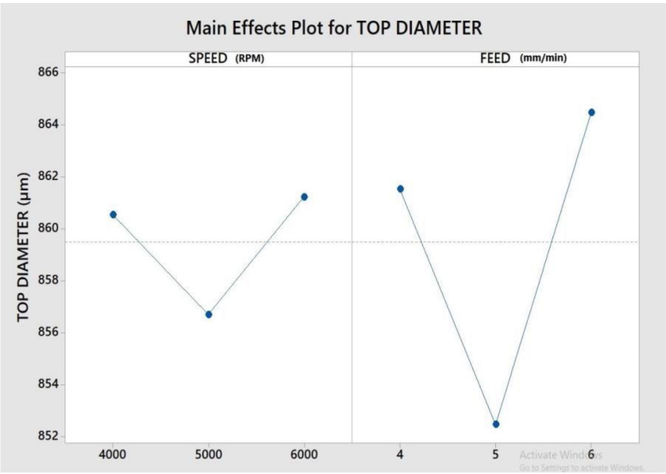

Fig -11: Mean Effects Plot for top diameter

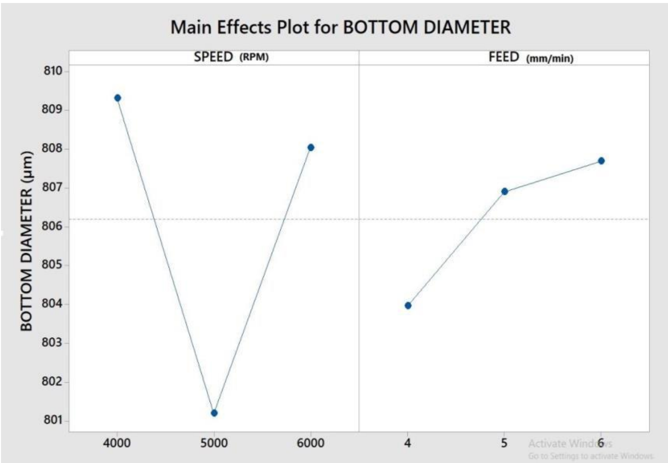

Fig -12: Mean Effects Plot for bottom diameter

From the Fig 12, for bottom diameter for which the desirable value is in proximity to 800 µm is found to be 5000 RPM of spindle speed with a feed rate of 4 mm/min. In case of bottom diameter as the feed increases the value of bottom diameter also increases.

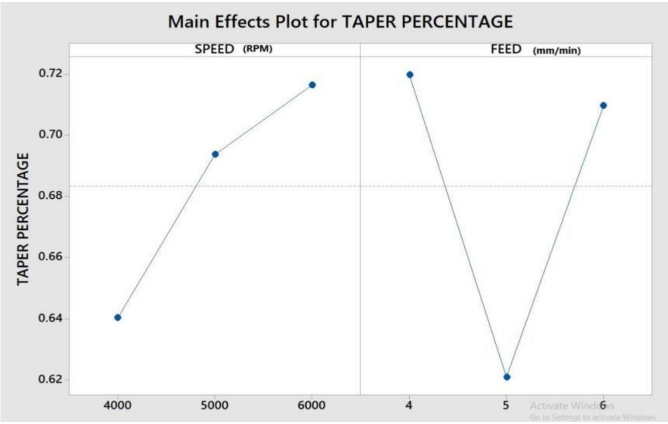

Fig -13: Mean Effects Plot for taper%

From Fig 13, for minimum percentage of taper which is desirable, the spindle speed must be near to 4000 RPM with a feed rate of 5 mm/min. Taper formation may have occurred due to interaction of hard SiC particles with Tungsten Carbide tool material.

Surface plots below shows the Multi response by considering speed and feed factors with a response such as top diameter, bottom diameter or taper. Fig 14 shows the Surface plot of top diameter Vs speed and feed. From the plot it is clearly observed that top diameter of drilled holes is attaining value closer to 800µm (which is desirable) at 5mm/min feed rate. Higher feed rates and higher spindle speed causes a drastic increase in top diameter value which may be due to interaction between highly wear resistant SiC particles and Tungsten Carbide tool material.

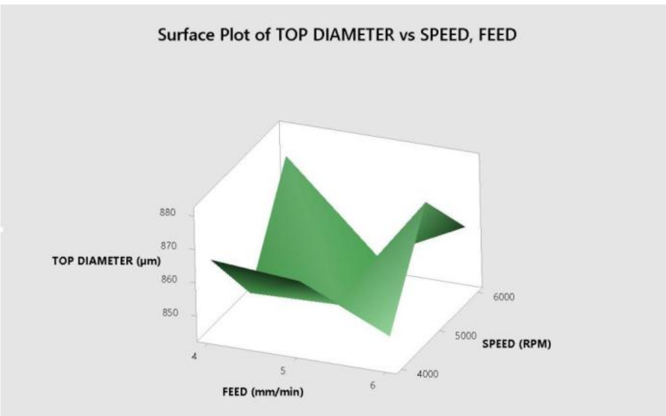

Fig -14: Surface plot of top diameter Vs speed and feed

From Fig 15 which shows the surface plot of bottom diameter Vs speed and feed. Almost a proportional relation between feed rate and bottom diameter is evident from the plot. In case of spindle speed 5000 RPM is the most suitable value for bottom diameter reaching a value close to 800 µm, which is desirable value. Variation in the bottom diameter may be due to agglomeration of SiC particles embedded in Aluminium matrix.

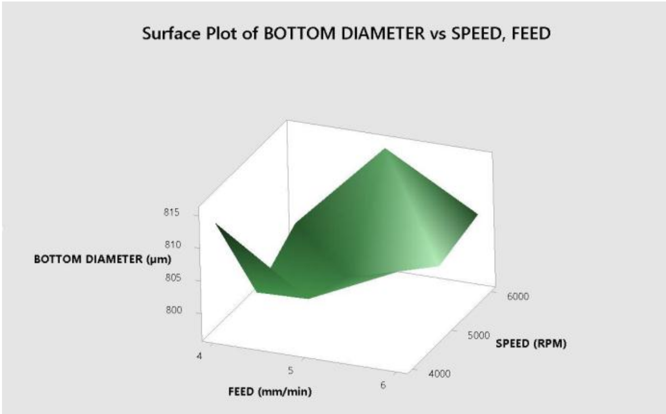

Fig -15: Surface plot of bottom diameter Vs speed and feed

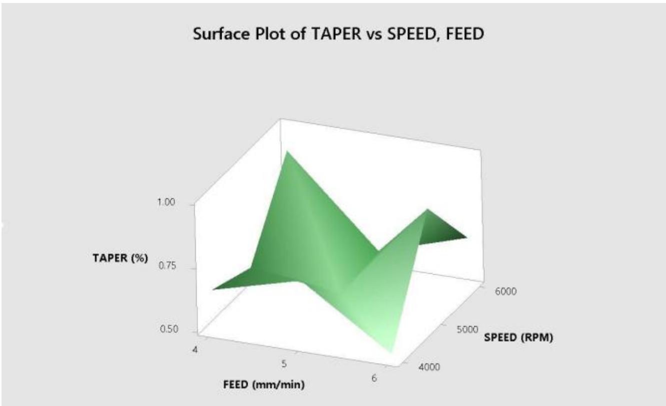

Fig -16: Surface plot of taper% Vs speed and feed

From Fig 16 which shows surface plot of taper% Vs speed and feed. From the above plot it is clear that with increase in spindle speed the taper formation is becoming more evident. When considering the feed rate taper is minimal when the feed rate is 5mm/min. The radical change in taper formations as seen from the profile of surface plot may be due to generation of entry and exit burrs.

4.3.1 Burr Characteristics

Burr formations are critical indications of extent of machinability. Entry and exit burrs formed during machining process are evidences of interaction between workpiece material and tool material. The irregular surface of silicon carbide particles acts as cutting edges and creates an obstruction for machining by interacting with the surface of cutting tool which in turn creates uneven surface of workpiece and burr formations [3]. Due to friction, high temperature and pressure the particles AlSiC MMC adhere to the cutting tool material which is also a reason for morphological irregularities of the machined surface [8].

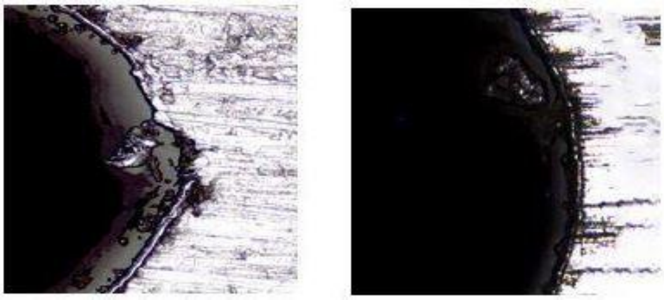

Fig -17: Entry burr formation (left) & Exit burr formation (right) at 5000RPM and 6mm/min

5. CONCLUSIONS

Based on the performance and test results of various sets of experiments performed for analyzing the machinability, we arrived at the following conclusions.

Machinability of MMC is very different from traditional materials because of abrasive reinforcement element. This is due to abrasive element causes more wear on cutting tools [6]. Microstructure of Al-SiC revealed dispersion of SiC particles in Aluminium Matrix , but the dispersion was found to be non-uniform which resulted in varying hardness values at different regions of Al-SiC MMC. Optimal machining parameters obtained is at 4500 – 5000 RPM at 4.75 - 5.5 mm/min feed rate. Tool breakage was a main problem when considering dry machining, therefore wet machining was adopted.

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