STUDY ON MACHINING CHARACTERISTICS OF METAL MATRIX COMPOSITES USING ABRASIVE FLOW MACHINING

B LIKITESHWAR[1] Dr.P.SRIKAR[2]

[1]M. Tech Student Department Of Mechanical Engineering, Malla Reddy College Of Engineering And Technology, Maisammaguda, Bahadurpally, Hyderabad, Telangana 500100

[2]Professor, Department Of Mechanical Engineering, Malla Reddy College Of Engineering And Technology, Maisammaguda, Bahadurpally, Hyderabad, Telangana 500100

Abstract *In the realm of unconventional finishing processes, a crucial focus is on their adaptability to composite materials, which have supplanted conventional materials in numerous applications. Attaining precise finishing in small slots of composite materials, now extensively employed in aerospace, automotive, medical industries, among others, is a challenging task. These composite materials have gained prominence due to their exceptional attributes, including lightweight properties, robust strength, and cost-effectiveness. Among the advanced finishing techniques, Magnetic Abrasive Flow Machining (MAFM) stands out as a suitable method for refining intricate and hard-to-reach surfaces. Despite of significant use of composites materials in the automobile and space applications, the machining of metal matrix composites still remains a challenging task. An abrasive flow machining process has been adopted in the present research using variable magnetic field for enhancing the surface finishing of the workpiece. Experiments were performed on the Al/SiC/B4C composites. The cutting tool action was obtained using the magnetic abrasive particles.*

The design of experiments has and the optimization has been conducted using the Taguchi's method. The process parameters significance has been established using analysis of variance technique. The scanning electron microscope was used to check surface finishing and the XRD technique was used to check the presence of impure compounds in the workpiece. The suitable value of magnetic field resulted into the optimum surface roughness and MRR. Existing literature has documented MAFM applications on materials such as aluminium, brass, and EN8, among others. In this study, MAFM setup has been used to experimentally investigate the finishing of composite materials Al/SiC/B4C containing 10-30% SiC. The influence of various input parameters such as magnetic field, fluid pressure, grit size, abrasive concentration, work piece material and the number of machining cycles has been assessed on critical performance metrics such as material removal rate (MRR), surface roughness and surface topography. Employing the desirability approach, response parameters were also optimized. Mathematical modeling of the material removal rate using Finite Element Method for the magnetic abrasive flow machining was studied. Specimens were carefully examined and analyzed using scanning electron microscope. The observations revealed that magnetic abrasive flow machining effectively eliminates the defects and significantly enhances the surface finish and MRR, particularly when applied to work pieces initially cut by the Electric Discharge Machining (EDM) process.

I. INTRODUCTION

Abrasive flow machining is defined as the process of finishing internal surfaces, slots, holes, cavities and difficult to reach areas of metals using abrasive laden viscous fluid. It was first patented by extrude hone corporation in 1970. Abrasive flow machining is widely used in different industries. The major applications of abrasive flow machining are found in inner finishing of turbo engines, aerospace and tool engineering. It also found applications in edge rounding, de-burring and finishing diesel motor components of rail. The use of abrasive flow machining on these components showed the improvement of surface roughness from 2 µm to 0.2 µm within 2 minutes [1]. Various loose abrasive based machining processes are shown in the Fig.

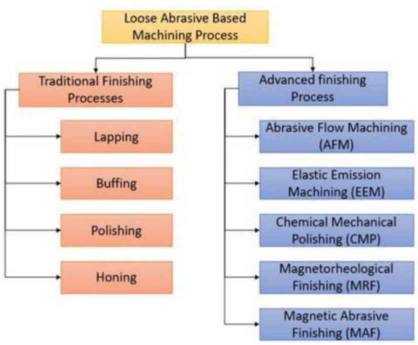

Fig 1: Various loose abrasive based machining processes

The non-conventional machining processes provide micro to nano level surface finishing in the minimum of time and without any application of heavy efforts which were required in case of conventional machining processes [4-5]. The AFM and MAFM process is an advanced machining process for finishing the hybrid composites [6]. AFM uses the abrasive particles flow for machining whereas the MAFM process uses the magnetic field and carbonyl powder in addition to abrasive particles flow for machining [7]. Abrasive flow machining provides a very good surface finishing and high material removal rate for different metals and hybrid work piece such as Al/SiC metal matrix composites. The metal matrix composites components are widely used in defence, automotive, aerospace and electronic industries. The Al/SiC/B4C metal matrix composites are shown in Fig. 2. The abrasive particles such as iron powder, Al2O3, SiC, boron carbide, cubic boron nitride and polycrystalline diamond are generally used as a cutting tool with hydraulic oil to finish the hybrid work pieces [8-9]. Al/SiC/B4C metal matrix composites machined using magnetic abrasive flow machining has been shown in the Fig.

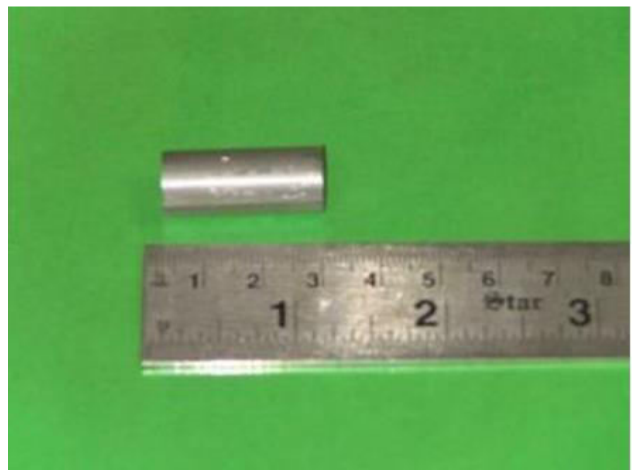

Fig 2: Al/SiC/B4C metal matrix composites

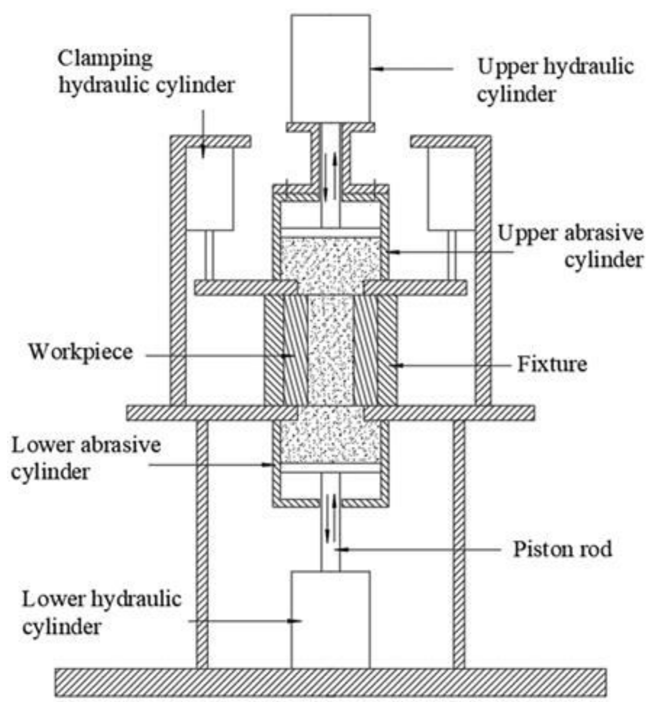

Fig 3: Components of an abrasive flow machine

II. LITERATURE STUDIES

Prakash et al. examined wear as well as mechanical behaviour of Mg/SiC/Gr composites. The miniature hardness increased up to 80 HV after adding 10 wt% SiC. Hardness of the composites was decreased with the addition of Gr content because of crack occurring in the composites which was seen from SEM images. The SiC added composites showed better wear attributes as compared with the Gr added composites.

Chawla et al. investigated the magnetic abrasive flow machining process. Composites reinforced with SiC and B4C with aluminum as base material were machined using magnetic abrasive flow machining showed good surface finishing. The various surface defects remained after EDM process were successfully removed by the MAFM process.

Ravindran et al. investigated the mechanical properties for the composites. Composites reinforced with SiC and Gr showed greater wear resistance and strength as compared to single reinforcement SiC.

Radhika and Krishanan et al investigated the wear resistance for the reinforced and unreinforced composites. The reinforced composites showed greater wear resistance and strength as compared to unreinforced material.

Wensheng Li et al. investigated the magnetic abrasive flow machining of the zirconium alloy tube. The zirconium alloy tube was finished using the magnetic abrasive flow machining. The increase in the number of cycles increases the surface finishing of the zirconium alloy tube. The surface roughness was significantly reduced after finishing with magnetic abrasive flow machining.

III. METHODOLOGY

The composite materials are difficult to machine using traditional machining processes. The abrasive flow machining process provides machining of reinforced and unreinforced composite materials. However, the machining becomes difficult when the hardness of the workpiece gets increased. The problem of recast layer and heat affected zones are some issues in case of EDM machining. The process of obtaining good surface finish and high MRR in case of composite materials using EDM machining is a challenging task which leads to the identification of problem of obtaining good surface finishing and high MRR for machining the composite materials.

The magnetic abrasive flow machining provides good surface finishing and high MRR for the composite materials in comparison to the abrasive flow machining and EDM process as per the available literature studies but very little research work has been done on the magnetic abrasive flow machining of the composite materials. The present research provides the experimental insight into the magnetic abrasive flow machining process for the machining of composite materials.

The sparkonix company EDM machine was used for obtaining the through holes in the specimens after the stir casting process. The EDM machine setup used in the present research has been shown in the Fig.

Fig 4: EDM machine setup

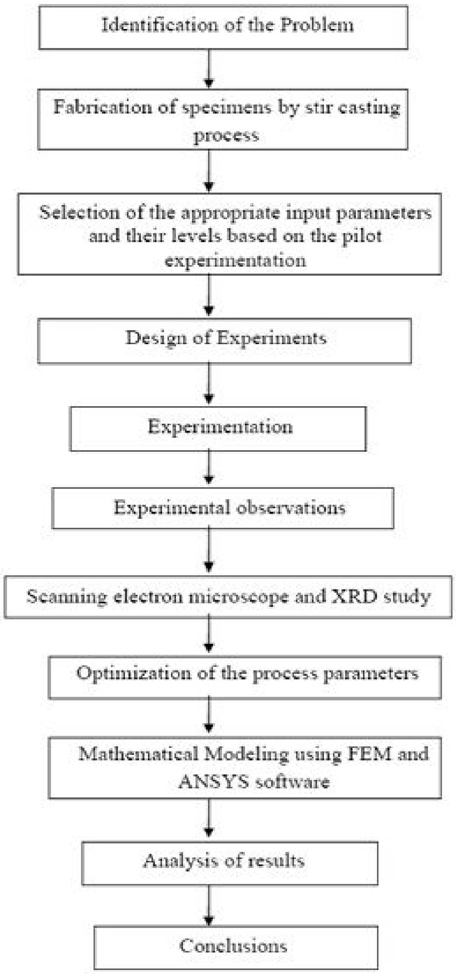

Fig 5: Flow diagram of the methodology adopted

Percentage composition of elements in the workpieces

Elements	Material Composition 1 (10% SiC and 0.5% B_4C in Al/SiC/B_4C)	Material Composition 2 (20% SiC and 0.5% B_4C in Al/SiC/B_4C)	Material Composition 3 (30% SiC and 0.5% B_4C in Al/SiC/B_4C)
Cu	0.014	1.540	0.002
Mg	0.476	0.262	0.102
Si	10.036	20.044	30.066
Fe	2.840	0.954	0.216
Ni	0.012	0.034	0.016
Mn	0.018	0.010	0.004
Zn	0.036	0.526	0.030
Pb	0.038	0.060	0.022
Sn	0.016	0.062	0.014
Ti	0.014	0.074	0.030
Cr	0.022	0.015	0.006
Al	Remainder	Remainder	Remainder

The outer surface of the specimens obtained after stir casting process has roughness due to the process limitations in the stir casting method, So, the outer surface roughness of the specimens was finished using CNC turning machine. The photograph of some specimens obtained after CNC turning machining is shown in Fig

Fig 6: Some specimens obtained after stir casting process

In order to check the effect of MAFM on the inner side of a cylindrical part, the pieces obtained using stir casting were made hollow using EDM machine. The length of the work piece was 40 mm. The size of the hole produced using EDM machine was 12.5 mm and the outer diameter of the work piece was 20 mm.

IV EXPERIMENTATION

The experimental setup for MAFM process consists of the electromagnets, media cylinders, pistons, work piece fixtures and hydraulic unit. The electromagnets provide the magnetic field using the electric current. Nylon fixture with a hole of size 20.05 mm was used to hold the work piece in the right position. Hydraulic unit having pressure capacity up to 10 MPa was used for the experimentation. Hydraulic unit consists of direction and pressure control valves, hydraulic cylinders, tank, pressure gauges and gear pumps.

Materials and Methods

Nylon fixture is used to hold the work piece in the machine is shown in the Fig. The variable electromagnets were used around the work piece to produce the desired magnetic field. The abrasives mixture used in the present experimentation is made up of boron carbide powder (80% Boron, 18% Carbon, 1% Fe, 0.5% Si and 0.5% Ca), carbonyl powder (98% Fe, 0.7% Carbon, 0.3% O, 0.25% S and 0.75% N), silicon polymer made up of siloxane, hydraulic oil which passes through the hollow work piece. The hydraulic cylinders are made up of EN8 material and are equipped with direction and pressure controlled valves for regulating the flow of the abrasives mixture passing through the workpiece. The reciprocating movement of the piston in the upper and lower cylinder leads to the cutting of the hollow workpiece through abrasives mixture. The hydraulic oil provides the lubrication to the hollow workpiece during machining.

Fig 7: Nylon Fixture for holding the work piece

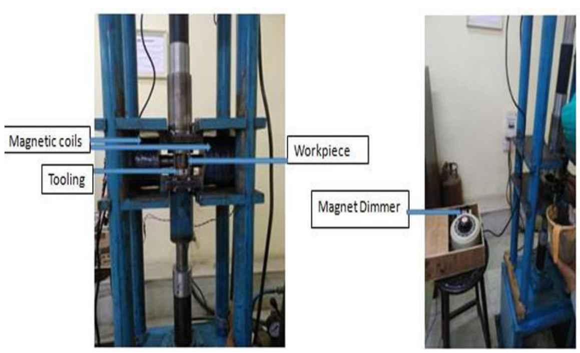

Fig 8: MAFM setup for the experimentation

Magnetic Abrasive Flow Machining (MAFM) setup system consists of several components and considerations. While specific configurations may vary depending on the design and purpose, the following are the key components of the MAFM setup used in the present research.

V EXPERIMENTATION

Experiments were conducted as per the DOE table and three repetitions were done for each experiment and in this way, total 81 experiments were conducted. The results for surface roughness and material removal rate were recorded. The surface roughness was tested using talysurf PRO surface roughness testing machine. The initial surface roughness is the surface roughness before machining and final surface roughness is the surface roughness after machining. ΔR is the difference between initial and final surface roughness. Three readings were taken at different places and their average is shown in Table 4.15.

The minimum value obtained for the mean surface roughness is 0.47 µm, average value 1.00 µm and maximum value 1.74 µm. Table 4.16 shows the Mean MRR for the experimental observations. The minimum value obtained for the Mean MRR is 1.91 µg/sec, average value 5.18 µg/sec and maximum value 9.66 µg/sec. The material removal rate is the difference between initial weight before machining and final weight after machining of the work piece per unit time. The finished work pieces are shown in the Fig

Fig 9: Finished work pieces

VI RESULTS AND DISCUSSIONS

Experiments have been performed using different combinations of the process parameters for their effects on surface roughness and MRR. The various statistical tools have been used to analyze the results. Optimization of the process parameters has been done using the Taguchi methodology. An optimum combination of the process parameters has been presented. Multi response optimization was obtained using the desirability approach. Samples were scanned using scanning electron microscope and examined using XRD technique. Mathematical modelling was performed using the Finite Element Method. The validation of the model was performed for the validation of the results. Table 5.1 shows response table for means for the surface roughness. The Taguchi method was used in the experimental design and the significant process parameters were assessed using the ANOVA technique.

Response Table for Means for Surface Roughness

Level	A	B	C	D	E	F
1	0.6611	1.0211	1.0254	1.0452	0.6832	0.5733
2	1.0211	0.9106	1.0101	0.9889	0.7131	0.6378
3	1.3389	0.8322	1.0176	1.0082	0.8156	0.7014
Delta	0.6778	0.3187	0.0154	0.0462	0.0532	0.2188
Order of Rank	**1**	**2**	**6**	**5**	**4**	**3**

ANOVA results for Surface Roughness

Source	D.F.	Seq. SS	Adj. MS	F-Value	p-Value	Contribution
A	2	2.404	1.202	150.25	0.003	46.1%
B	2	1.392	0.696	87.00	0.007	25.2%
C	2	0.001	0.0005	0.0625	0.324	0.6%
D	2	0.0238	0.0119	1.48	0.290	1.4%
E	2	0.964	0.482	60.25	0.004	14.9%
F	2	0.224	0.112	14.00	0.003	11.4%
Error	2	0.0161	0.0080			0.40%
Total	14	3.1609				100%

Response Table for Means for MRR

Level	A	B	C	D	E	F
1	3.255	5.188	4.131	5.221	1.064	0.018
2	4.689	4.991	4.128	5.302	2.094	1.683
3	7.238	4.274	4.147	5.102	3.714	2.526
Delta	4.67	1.230	0.088	0.116	0.188	0.423
Order of Rank	**1**	**2**	**6**	**5**	**4**	**3**

ANOVA results Table for MRR

Source	D.F.	Seq. SS	Adj. MS	F-Value	p-Value	Contribution
A	2	2.85	1.42	39.44	0.01	42.6%
B	2	1.48	0.74	20.55	0.04	20.8%
C	2	0.072	0.036	1.00	0.44	0.8%
D	2	0.197	0.098	2.72	0.42	0.6%
E	2	0.926	0.463	12.86	0.03	18.6%
F	2	0.464	0.232	6.44	0.03	16.3%
Error	2	0.072	0.036			0.3%
Total	14	6.061				

Optimal Combinations of the process parameters for the best value of surface roughness and MRR

Process Parameter	Optimal value
Magnetic Field (T)	0.5
Extrusion pressure (MPa)	7
Number of Cycles	300
Workpiece materials	10% SiC and 0.5% B_4C in Al/SiC/B_4C (Al as a base material)

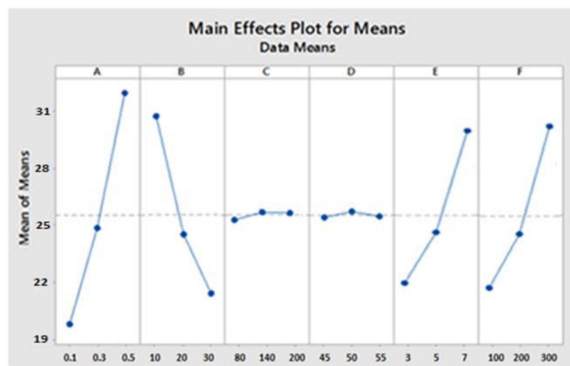

Fig 10: S/N ratio plots for the surface roughness

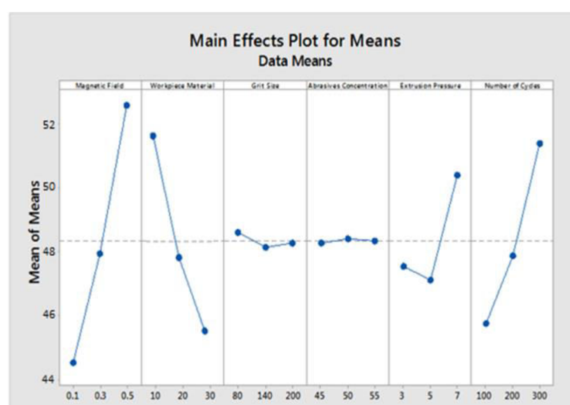

Fig 11: S/N ratio plots for the MRR

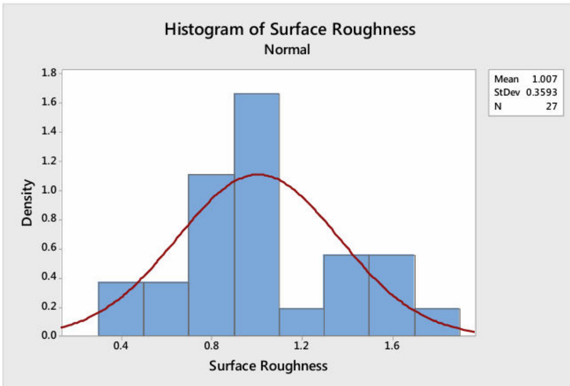

Fig 12: Histogram for the surface roughness

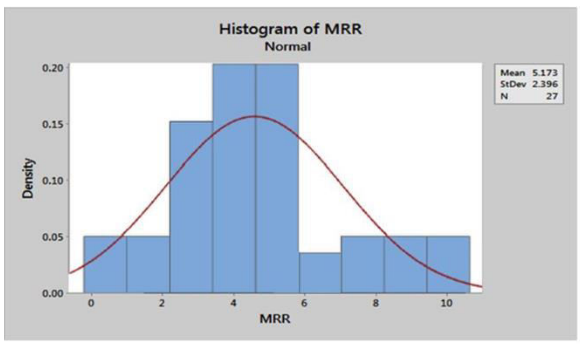

Fig 13: Histogram for the MRR

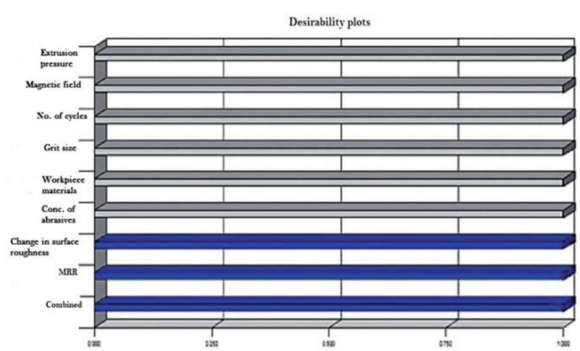

Fig 14: Desirability plots for the process and response parameters

Microstructure Analysis – Scanning Electron Microscope (SEM) Stud

SEM study has been done to compare the surface finishing before and after finishing. The SEM images at different values of the SiC percentages have been investigated. It was observed that surface roughness was significantly improved at 0.5 T magnetic field with 10% SiC composition in the workpiece. From the SEM images, it is clear that significant improvement has been noticed after finishing with MAFM process. However, the increase in the hardness of the material increases the surface roughness as it is difficult to obtain good surface finishing at the increased value of the hardness of the material. The surface defects, cracks and irregularities were significantly removed from the workpiece using MAFM.

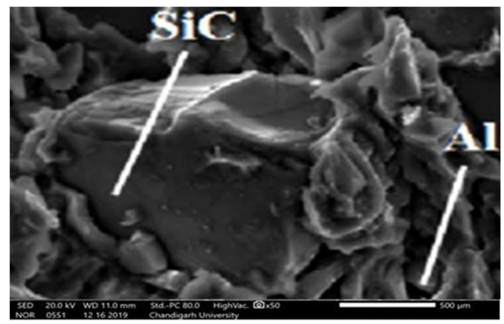

Fig 15: SEM image of Al reinforced with 10 % SiC

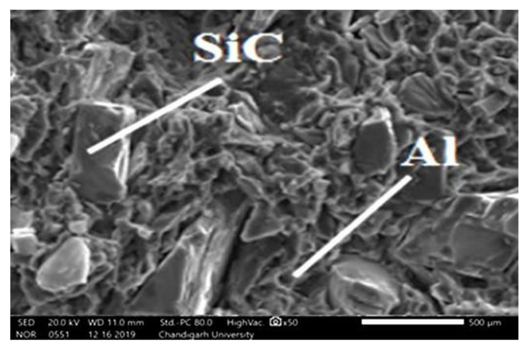

Fig 16: SEM image of Al reinforced with 20 % SiC

Fig 17: SEM image of EDM cut sample at 30% SiC showing rounded pore features

Significance of SEM in engineering

Fig 18: SEM image of EDM cut sample at 20% SiC showing sharp edged voids

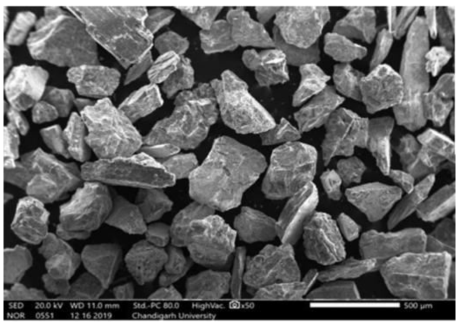

Fig 19: SEM image of abrasives mixture at mesh size 80

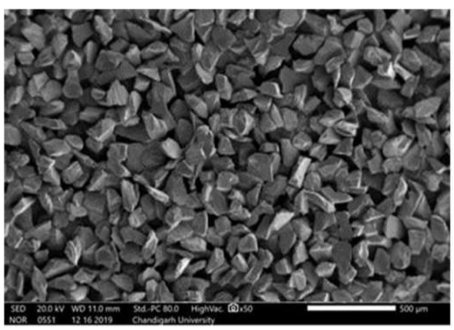

Fig 20: SEM image of abrasives mixture at mesh size 140

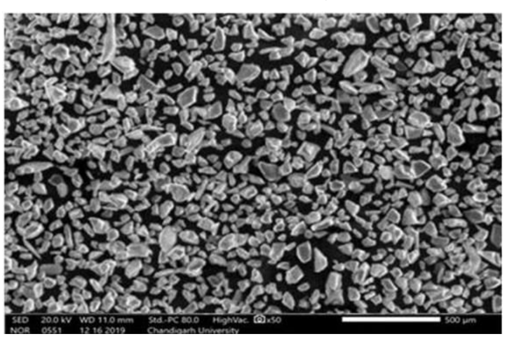

Fig 21: SEM image of abrasives mixture at mesh size 200

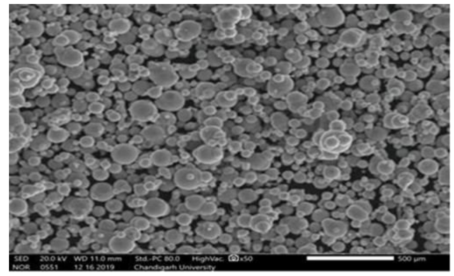

Fig 22: SEM image of carbonyl iron powder

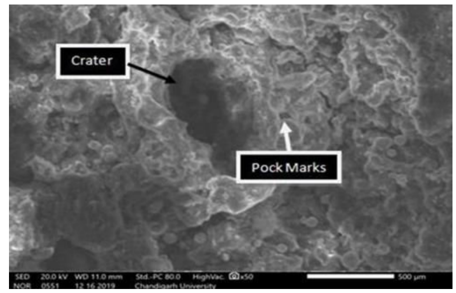

Fig 23: SEM image at 30% SiC (before finishing)

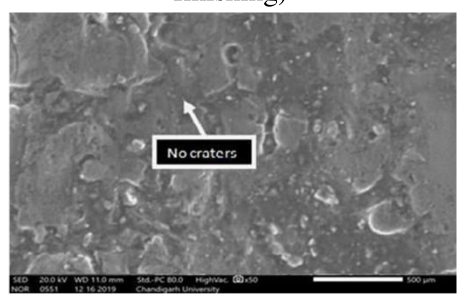

Fig 24:SEM image at 30% SiC (after finishing)

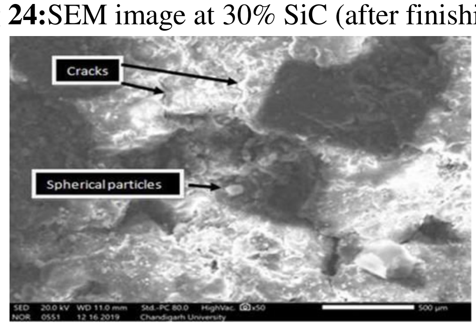

Fig 25:SEM image at 20% SiC (before finishing)

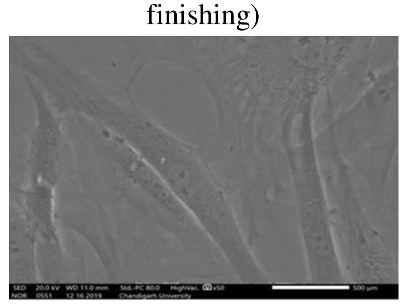

Fig 26:SEM image at 20% SiC without cracks (after finishing)

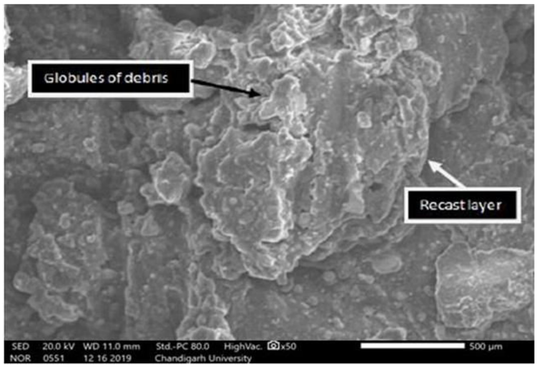

Fig 27:SEM image at 10% SiC (before finishing)

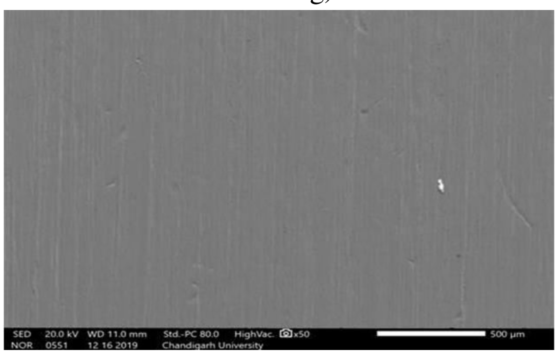

Fig 28:SEM image at 10% SiC without recast layer (after finishing)

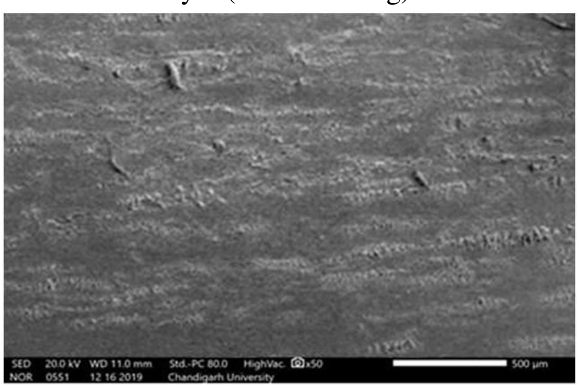

Fig 29:SEM image at 20% SiC (before finishing)

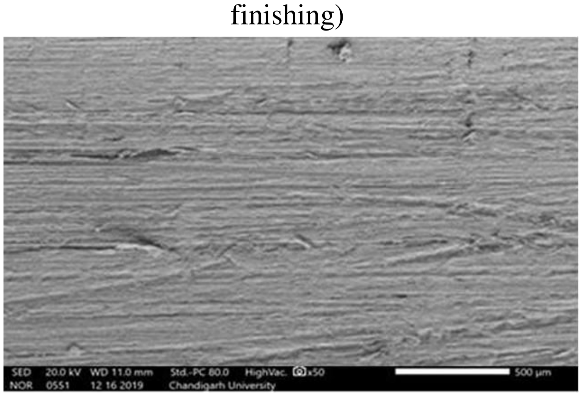

Fig 30:SEM image at 20% SiC (after finishing)

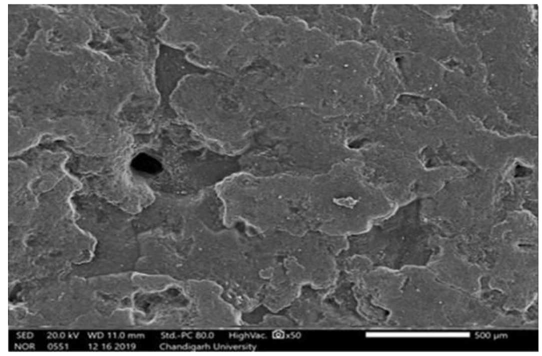

Fig 31:SEM image at 30% SiC (before finishing)

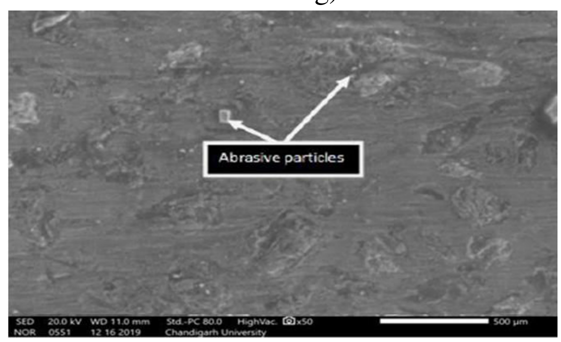

Fig 32:SEM image at 30% SiC (after finishing)

XRD Study

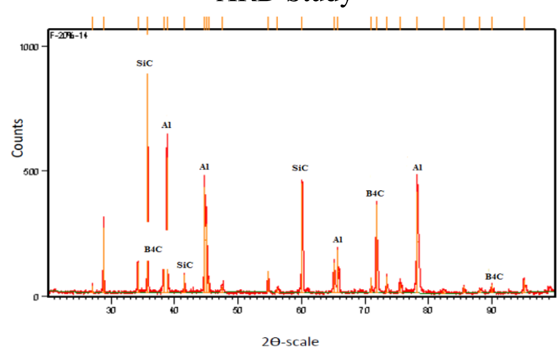

Fig 33:XRD graph for the Al/SiC/B4C hybrid MMCs with 10% SiC (after finishing)

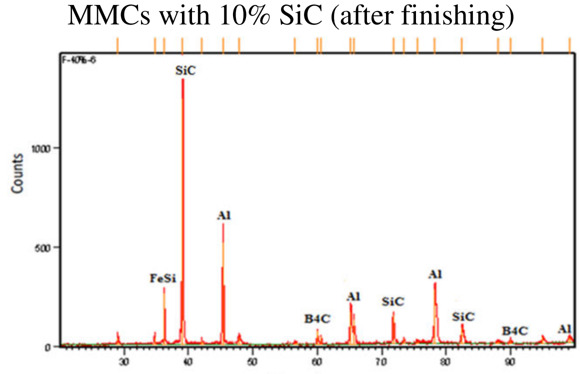

Fig 34:XRD graph for the Al/SiC/B4C hybrid MMCs with 20% SiC (after finishing)

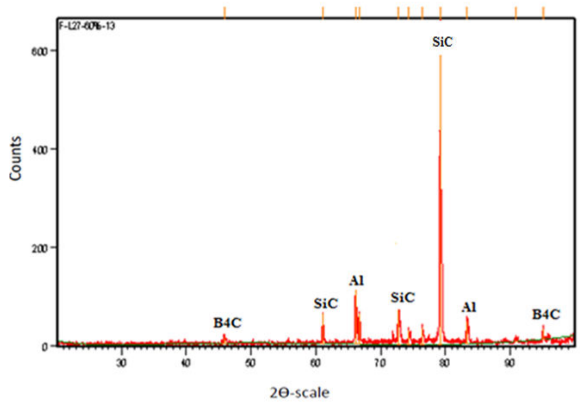

Fig 35:XRD graph for the Al/SiC/B4C hybrid MMCs with 30% SiC (after finishing)

Mathematical Modelling

In the present work, FEM based mathematical model of material removal has been proposed for MAFM process. The purpose of the proposed model is to understand the abrasive action during the MAFM process. In magnetic abrasive flow machining, the abrasion between the abrasive particle and surface to be machined can be divided into microploughing and microcutting.

Micro-ploughing due to a single pass of one abrasive particle may not detach any material from the work piece surface. Material can be removed due to repeated action of single or more abrasive particles. Ploughing may take place because of micro-fatigue occurring due to repeated passage of particles. The finite element method based mathematical model for material removal in magnetic abrasive flow machining processes has been developed.

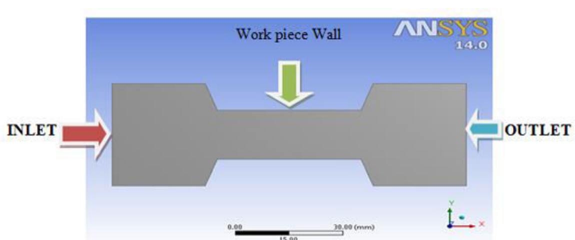

Fig 36: Geometry of the MAFM setup

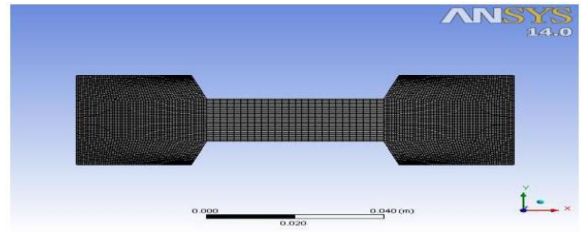

Fig 37: Finite element analysis for the MAFM setup

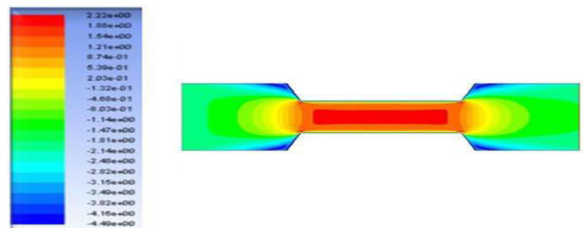

Fig 38: Pressure distribution

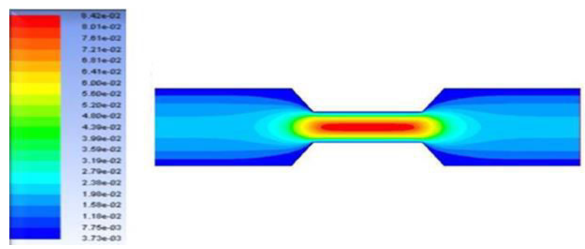

Fig 39: Velocity distribution

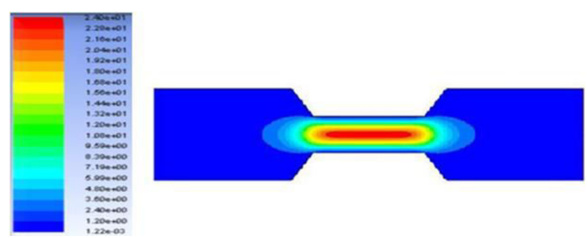

Fig 40: Strain distribution

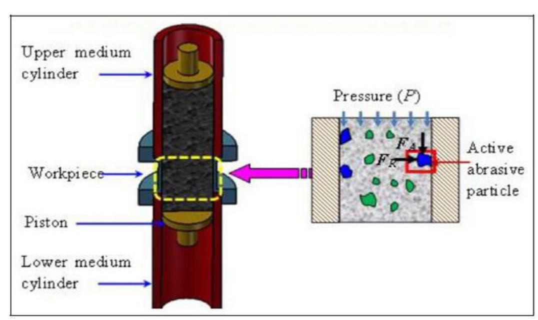

Fig 41: Cutting forces acting during magnetic abrasive flow machining

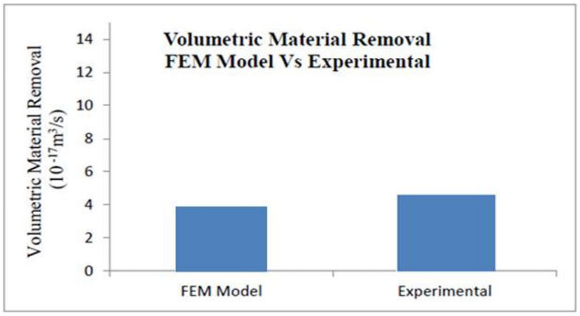

Fig 42: Validation of the FEM model

CONCLUSIONS

Based on the experimental results, following results have been concluded:

1. Magnetic abrasive flow machining is a process that can be used effectively for finishing of internal sides of cylindrical parts.
2. Among different process parameters, it was found that magnetic flux density, extrusion pressure, number of cycles and workpiece material are the significant factors in MAFM process.
3. Material removal rate increases with increase in the magnetic flux density. As the surface is subjected to repeated cycles, there occurs decrease in the no. of peaks and their respective heights on the workpiece surface. So, the MRR decreases after the certain value of magnetic flux density.
4. The surface finish increases with increase in the magnetic flux density. This is due to the fact that, when magnetic flux density increases, more number of peaks get disappeared or dissolved, thus, surface finishing increases. It was also observed that the slope of the curve gets decreased gradually at 0.5 T of magnetic field. As the surface is subjected to repeated cycles, there occurs decrease in the no. of peaks and their respective heights on the workpiece surface. So, the surface finishing decreases after the certain value of magnetic flux density.
5. With the increasing percentage of SiC (10%-30%) and B4C (0.5%) in the Al/SiC/B4C MMCs, the MRR gets decreased. This is due to the addition of SiC and B4C that makes the workpiece harder. Therefroe, the MRR decreases with increase in the hardness of the material.
6. The surface finishing increases with increasing number of cycles initially, because initially there are more number of peaks and valleys to be finished but after a limit, the surface finishing gets decreased with increase in the number of cycles.
7. Mesh number and abrasives concentration have been observed as non significant parameters as per the ANOVA table.
8. The MRR varies from 1.66 µg/s to 9.66 µg/s. From the confirmation experiments, the optimum MRR was found to be 8.28 µg/s and predicted value is 8.77 µg/s. The percentage error between experimental and predicted value is 2.36% which shows experimental results are in good agreement with theoretical results.
9. Average surface roughness before experimentation was 3.2 µm and after machining, it was observed as 1.61 µm. From the confirmation experiments, the optimum surface roughness was found to be 1.86 µm and predicted value is 2.01 µm. The percentage error between experimental and predicted value is 2.10% which shows experimental results are in good agreement with theoretical results.
10. For surface roughness, the percentage contribution of magnetic field, extrusion pressure workpiece material and number of cycles are 46.1%, 14.9%, 25.2% and 11.4% respectively.
11. For MRR, the percentage contribution of magnetic field, extrusion pressure, work piece material and number of cycles are 42.6%, 18.6%, 20.8% and 16.3% respectively.

12. The SEM images showed that the defects on the surface that produced after EDM process were successfully removed and MAFM process has significantly improved the surface finish of the work pieces.
13. As per mathematical modeling, it has been found that increasing magnetic field leads to an increase in the velocity of abrasives flow. However, this increase in velocity only occurs up to a certain magnetic field, after which it starts to decrease.
14. The FEM model was successfully validated with the experimental results.

REFERENCES

[1]. J.Mohapatra, S.Nayak, M.Mohapatra, "Mechanical and Tribology properties of Al – 4.5% Cu – 5% TiC Metal Matrix Composites for light – weight structures", International Journal of Lightweight Materials and Manufacture, Vol. 3, No. 2, pp. 120 – 126, 2020.

[2]. S.Rawal, "Metal Matrix Composites for space applications", JOM – The Member Journal of the Minerals, Metals and Materials Society, Vol. 53, No. 4, pp. 14-17, 2001.

[3]. S.K.Amnieh, P.Mosaddegh, A.F.Tehrani, "Study on Magnetic Abrasive Finishing of spiral grooves inside of aluminium cylinders", International Journal of Advanced Manufacturing Technology, Vol. 91, No. 5, pp. 1-10, 2017.

[4]. I.Mingareev, T.Bonhoff, A.Sherif, M.Richardson, "Femtosecond laser post processing of metal parts produced by laser additive manufacturing", Journal of Laser Applications, Vol. 25, No. 5, pp. 1-4, 2013.

[5]. A.Sadiq, M.S.Shunmugam, "Investigation into magnetorheological abrasive honing (MRAH)", International Journal of Machine Tools and Manufacture, Vol. 49, pp. 554-60, 2009.

[6]. Groeger, F.Segel, E.Uhlmann, S.Robkamp, "Definition of edges in correlation to abrasive flow machining as a finishing process", Surface Topography – Metrology and Properties, Vol. 6 (3), pp. 1 – 11, 2018.

[7]. V.K.Jain, "Advanced Machining Processes", Allied Publishers Pvt. Ltd, 2002. T.Shinmura, K.Takazawa and E.Hatano, "Study on magnetic abrasive process application to plane finishing", Bulletin of Japan Society of Precision Engineering, Vol. 19, pp. 289-91, 1985.

[8]. M.Shabgard, F.Tabriz, A.Gholipoor, "Experimental study of the effects of abrasive particle size and workpiece hardness in magnetic abrasive flow machining", Modares Mechanical Engineering, Vol. 16 (8), pp. 131-138, 2016. 10.

[9]. S.Mittal, V.Kumar, H.Kansal, "Multi objective optimization of process parameters involved in micro-finishing of Al/SiC MMCs by abrasive flow machining process", Journal of Materials: Design & Applications, Vol. 232 (4), pp. 1-14, 2016.