Study of Process Parameters for the machining of Metal Matrix Composites (MMCs) using Magnetic Abrasive Flow Machining (MAFM)

Anil Jindal, Vijay Singh, Dr. Aman Bansal

Abstract: The magnetic abrasive flow machining (AFM) offers highly efficient machining of hybrid work pieces. The various intricate profiles and hard to reach areas of the work pieces are easily finished by the magnetic abrasive flow machining. The Al, SiC, B_{4}C abrasive particles and iron powder was taken as cutting tool. The fluid medium used in abrasive flow machining is hydraulic oil and liquid silicon. In this paper, the study of process parameters for the machining of hybrid work piece Al/SiC/B_{4}C MMCs using magnetic abrasive flow machining is investigated. The input parameters taken were magnetic flux density, extrusion pressure and number of cycles. The output parameters taken were MRR and surface roughness. The testing was investigated using Scanning Electron Microscope (SEM).

Index Terms: Material Removal Rate (MRR), Surface roughness, Magnetic Abrasive Flow Machining (MAFM).

1. INTRODUCTION

Abrasive flow machining (AFM) came into existence in 1960 and used for finishing difficult to reach areas of ferrous and non-ferrous metals. It is a non-conventional machining process for achieving an advanced finishing of tough and hard metals. Abrasive flow machining is defined as the process of finishing internal or external 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. In the micro-electric discharge machining (μEDM) and wire-electric discharge machining (WEDM) process, the problem of recast layer on the machined surface often occurs. The magnetic abrasive flow machining provides the solution to this problem by removing the recast layer on the machined surface and significantly improving the surface finishing of the work piece.

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1.2 Magnetic Abrasive Flow Machining of Metals and Metal Matrix Composites (MMCs)

Magnetic Abrasive flow machining (MAFM) provides a very good surface finishing and high material removal rate (MRR) for different metals and hybrid work piece such as Al/SiC metal matrix composites (MMCs). The metal matrix composites (MMCs) components are widely used in defence, automotive, aerospace and electronic industries. The abrasive particles such as carbonyl iron powder, Al_{2}O_{3}, 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.

1.3 Magnetic Abrasive Flow Machining

The magnetic abrasive flow machining uses a fix or variable magnetic flux around the work piece. The magnetic abrasive flow machining is shown in Fig. 1. The main purpose to use the magnetic field around the work piece is to enhance the material removal rate and surface finishing of the work piece. The magnetic/hybrid abrasive flow machining provides an excellent surface finishing and MRR for the ferrous/non-ferrous metals and hybrid work pieces such as Al/SiC metal matrix composites. In magnetic assisted abrasive flow machining, the common process parameters are: extrusion pressure, no. of cycles, magnetic flux density, applied voltage, tool feed rate and work piece material. Some research studies showed that the magnetic/hybrid abrasive flow machining significantly improved the surface finishing of Al/SiC metal matrix composites (MMCs) and also increases the material removal rate. In magnetic abrasive flow machining process, the abrasive powder is fabricated by sintering mixture of iron and abrasive powder.

The sintered mixture is crushed and sieved for getting suitable particle size. The fabrication of magnetic abrasive powder
may also be accomplished by mixing of iron powder with abrasive particles and adding lubricants to the mixture for providing strength between the abrasives and the ferro-magnetic particles.

2 LITERATURE REVIEW

Mittal et al. investigated the micro finishing of Al/SiC MMCs using abrasive flow machining process for multi-objective optimization of process parameters. Aluminium was taken as base material of Al/SiC MMCs. The abrasive particles such as SiC, liquid silicon and hydraulic oil as liquid medium were used as the cutting tool. The process parameters taken were extrusion pressure, percentage of oil in abrasive media, grit size of abrasive, concentration of abrasives, work piece material and number of cycles. The response parameters taken were Material Removal Rate (MRR) and Surface Roughness (R_a). The mathematical modeling was performed using Box-Behnken method of Response Surface Methodology (RSM). The testing was conducted using Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD) machine. It was found that extrusion pressure and number of cycles were the two most important factors affecting the MRR and surface finishing. The increase in extrusion pressure and number of cycles increases the MRR and surface finishing of the work piece. It was also found that the various surface defects on the work piece in the inner and outer sides were successfully removed after abrasive flow machining process.

Mittal et al. reported the abrasive flow machining of Al/SiC MMCs using abrasive particles such as Al, SiC mixed with vinyl-silicone polymer (silicone rubber). The available literature work was analyzed and taken as a reference to conduct the experimentation. The hydraulic oil was used to act as liquid media. The process parameters taken were extrusion pressure, viscosity of medium, grit size of abrasive, concentration of abrasives, work piece material and number of cycles. The response parameters taken were Material Removal Rate (MRR) and Change in Surface Roughness (R_a) and Surface Topography. The mathematical modeling and testing was conducted using Taguchi method and RSM technique. It was found that MRR and surface finishing increased with increase in extrusion pressure. However, MRR decreases with decrease in viscosity of medium. Surface finishing was decreased with increase in mesh grit size of abrasive particles. Both, MRR and surface finishing increases with increase in number of cycles.

Cheng et al. reported the abrasive flow machining of integrally bladed motor (IBR) blade made up of Inconel 718 or Ti-6Al-4V alloys. The testing of the work piece and simulation of MRR was performed using computational fluid dynamics (CFD) simulation software. The process parameters taken were work piece material, abrasive flow media, extrusion pressure etc. The response parameters taken were material removal rate (MRR), surface roughness (R_a) and edge profile accuracy. The measuring of the work piece was performed using TESA-VISIO 200 optical system. The work piece was machined using abrasive flow particles made up of cubic boron nitride (CBN) and ceramic aluminium oxide mixed with hydraulic oil. It was found that the increase in extrusion pressure, abrasive concentrations increases MRR and surface finishing of the work piece. The edge profile of the work piece also gets smoother with increase in number of cycles.

Sharma et al. investigated the abrasive flow machining optimization using Taguchi based principal component analysis technique. The principal component analysis technique is a statistical procedure of finding the linear combination of a set of variables having maximum variance and removing its effect. The importance of abrasive flow machining was discussed for finishing difficult to finish internal cavities/holes of the work piece. The copper metal cylindrical work piece was used for experimentation. The Al and SiC abrasive particles mixed with hydraulic oil used as the cutting tool. It was found that increase in extrusion pressure, number of cycles increases MRR and surface finishing of the copper work piece. The abrasive flow mixture having high concentration of SiC offered good surface finishing.

Kumar and Hiremath investigated the abrasive flow machining through extensive literature review. The process parameters taken were extrusion pressure, number of cycles, abrasive grit size, abrasive concentration, volume flow rate. The abrasive particles SiC, Al_2O_3, B_4C mixed with visco elastic polymer and hydraulic oil were used as the cutting tool. The one way and two way abrasive flow machining were discussed. In one way abrasive flow machining, the machining was obtained using single hydraulic cylinder and in case of two way abrasive flow machining, the machining was obtained using double hydraulic cylinder. The mathematical modeling was performed using ANOVA and Taguchi methods. It was found that the abrasive flow machining is an advanced and efficient technique for super finishing the intricate profiles in case of automotive, aerospace and biomedical fields.

Bahre et al. reported the one way abrasive flow machining for machining internal geometries of the work piece. The work piece taken was automotive steel AISI4140 and the abrasive particles taken were Al_2O_3 mixed with hydraulic oil. In the experimentation, only one cylinder was used for machining the work piece. The testing was conducted using ZIESS Prismo 3D metrology machine and Mahr MarSurf XR20 surface metrology system. The Extrude Hone Vector AFM machine was used for the experimentation. The process parameters taken were number of cycles, work piece material, piston pressure and abrasive concentration. The response parameters taken were MRR and surface finishing. The mathematical modeling was done by plotting graphs/histograms between process and response parameters. It was found that surface finishing of the work piece was improved significantly after 15 numbers of cycles. The increase in piston pressure increases surface finishing of the work piece.

Kiani et al. investigated the hybrid abrasive flow machining through extensive literature review. The abrasive flow machining in combination with magnetic field assisted, ultrasonic assisted, centrifugal force assisted, rotational AFM, drill bit guided AFM were discussed. The process parameters
taken were work piece material, abrasive flow media, extrusion pressure etc. The response parameters taken were material removal rate (MRR), surface roughness ($R_s$). The work piece material taken were Inconel 718 and Al/SiC MMCs. The abrasive particles taken were mixture of $\text{Al}_2\text{O}_3$, SiC and hydraulic oil. The work piece was machined using ultrasonic assisted abrasive flow machining, magnetic field assisted abrasive flow machining, centrifugal force assisted abrasive flow machining, rotational abrasive flow machining and drill bit guided abrasive flow machining. It was found that hybrid AFM provides highly significant MRR and surface finishing of Inconel 718 and Al/SiC MMCs. The ultrasonic assisted abrasive flow machining provides higher MRR and surface finishing as compared with other hybrid AFM processes.

Singh et al. reported the latest trends in abrasive flow machining using hybrid abrasive flow machining for achieving high MRR and surface finishing. The process parameters taken were work piece material, abrasive flow media, viscosity, extrusion pressure etc. The response parameters taken were material removal rate (MRR), surface roughness ($R_s$). The abrasive particles taken were $\text{Al}_2\text{O}_3$, SiC, $\text{B}_3\text{C}$ and diamond mixed with liquid polymer and hydraulic oil in the hydraulic cylinder. The work pieces used were steel, brass, gun metal and copper. The work pieces were machines using hybrid abrasive flow machining such as Electro chemical assisted abrasive flow machining. Ultrasonic assisted abrasive flow machining, magnetic field assisted abrasive flow machining, centrifugal force assisted, rotational AFM, drill bit guided AFM. It was found that the magnetic field assisted AFM provides high MRR and surface finishing at low extrusion pressure. The Ultrasonic assisted abrasive flow machining provides higher MRR and surface finishing as compared with other hybrid AFM processes. Electro chemical assisted abrasive flow machining offered very good MRR and surface finishing of copper work piece.

Pal and Jain investigated the abrasive flow machining through extensive literature review. The process parameters taken were work piece material, abrasive flow media, extrusion pressure, number of cycles, grain size, and percentage abrasives concentration. The response parameters taken were material removal rate (MRR), surface roughness ($R_s$), dimensional tolerance, residual stresses. The work piece materials taken were aluminium, mild steel, brass, stainless steel, hardened tool steel. The abrasive particles taken were boron carbide, silicone rubbers, mixture of silly putty and silicon carbides, carbonyl iron powder, $\text{Al}_2\text{O}_3$. The work pieces were machined using abrasive flow machining and EDM machine. The mathematical modeling was performed using ANOVA and Taguchi method. The simulation technique used was computational fluid dynamics (CFD) through ANSYS software. The testing was done using X-Ray diffraction (XRD) technique and SURFASCAN surface testing machine. It was found that the process parameters have significant effects on the response parameters in abrasive flow machining. The change in process parameters significantly improves the MRR, surface finishing, dimensional tolerance and residual stresses in the work pieces. It was also found that the various surface defects occurred after EDM machining process were successfully removed after abrasive flow machining process.

Soni et al. reported the abrasive flow machining using simulation software ANSYS for computational fluid dynamics analysis. The work pieces taken were titanium, aluminium alloys and abrasive particles taken were aluminium oxide and cubic boron nitride mixed with hydraulic oil. The work piece was machined using abrasive flow machining. The mathematical modeling was conducted using multiple regression model. The testing was conducted using 2D ANSYS simulation software. It was found that the MRR and surface finishing was significantly improved after abrasive flow machining of the work pieces. The deviations so obtained in the experimental results were within the prescribed limit. Further investigations to improve MRR and surface finishing were emphasized.

Mohit et al. investigated the hybrid abrasive flow machining through extensive literature review for nano finishing. The abrasive flow machining in combination with magnetic field assisted, ultrasonic assisted, centrifugal force assisted, rotational AFM, drill bit guided AFM, electrochemical assisted AFM were discussed. The work piece materials such as copper, aluminium were discussed. The abrasive particles such as $\text{Al}_2\text{O}_3$, SiC, CBN and diamond mixed with hydraulic oil were discussed. The work pieces were machines using hybrid abrasive flow machining. The mathematical modeling was performed using ANOVA and Taguchi method. It was found that the hybrid abrasive flow machining offered higher MRR and surface finishing in all the work pieces. It was also found that the various surface defects occurred after EDM machining process were successfully removed after abrasive flow machining process.

Azizi and Azami investigated the rotational abrasive flow machining for micro and nano-finishing. The work piece used for the experimentation was cylindrical bushing made up of cast iron. The abrasive particles used were SiC, polymers, wax and silicone oil mixture as a liquid medium. The work piece was machined using rotational abrasive flow machining. The medium inside work piece was rotated using four bladed stirring axis. The surface roughness of the work piece was measured before and after the machining. The testing of the work piece was done using Scanning Electron Microscope (SEM) machine. The mathematical modeling was conducted by plotting the graph between material removal and work piece rotational speed. It was found that MRR and surface finishing of the work piece was significantly improved after rotational abrasive flow machining. The high stirring speed increases the MRR and surface finishing. It was also found that the technology of rotational abrasive flow machining is an efficient and available at low cost for offering high MRR and surface finishing.

Ya et al. reported the abrasive flow machining involving high visco elastic medium for surface finishing. The work piece material taken was circular steel tube. The abrasive particles used were $\text{Al}_2\text{O}_3$, SiC mixed with polymers and hydraulic oil as a liquid medium. The work piece was machined using abrasive flow machining. The various sensors such as pressure sensor, force sensor and temperature sensor were fitted with work piece and cutting tool. The mathematical modeling was done using MATLAB software. The testing of
the work piece was done using Scanning Electron Microscope (SEM) machine. It was found that the MRR and surface finishing was significantly improved after the abrasive flow machining of circular steel tube. The MRR and surface finishing was greatly improved using visco elastic medium for machining the work piece.

Zhang et al. investigated the abrasive flow machining of T-pipe for optimizing the process parameters and controlling quality of the work piece. The abrasive particles taken were SiC mixed with hydraulic oil. The work piece material taken was carbon steel. The work piece was machined using abrasive flow machining. The mathematical modeling was performed using six sigma model and regression analysis. The testing was conducted using simulation software ANSYS for computational fluid dynamics. The distribution of turbulent velocities was analyzed for the given abrasive flow medium. The surface roughness was detected using simple roughness testing machine. It was found that the volume fraction of SiC is an important factor in controlling quality of the work piece. The increase in the volume fraction of SiC significantly improved the MRR and surface finishing of the work piece.

Tan et al. reported double inlet abrasive flow machining on irregular geometry of work piece such as automobile part with tiny slots and complex geometry based on theory of fluid collision. The SiC abrasive particles and water were used for machining the work piece. The work piece was machined using single inlet and double inlet channel apparatus. The mathematical modeling was performed using incompressible continuity equation and navier-stokes equation of fluid mechanics. The numerical simulation was performed using ANSYS software fluent. The testing was performed using photo micrographic apparatus. It was found that the double inlet channel improved the surface finishing of the work piece. It was also found that the ultrasonic assisted abrasive flow machining can significantly reduce the machining time.

3. EXPERIMENTAL SETUP
Abrasive medium (Al, SiC, B₄C and Iron powder) was prepared using hydraulic oil and liquid silicon. The specimens were prepared using micro EDM machining. Nylon fixtures used for holding the work piece. Hydraulic oil number 46 was used. The cast iron made hydraulic cylinder was used. The stroke length was 240 mm.

4. EXPERIMENTATION
The various process parameters used for the experimentation are as following:
1. Magnetic flux density (T).
2. No. of cycles.
3. Extrusion pressure (MPa).

The response parameters taken are as following:
1. Material removal rate (MRR in gm/sec.).
2. Surface roughness (Ra).

The experiments were conducted on the work piece Al/SiC/B₄C metal matrix composites by varying the process parameters. The aluminium was taken as the base material for experimentation.

| S. No. | Process Parameter | Range  | Unit  |
|--------|-------------------|--------|-------|
| 1.     | Magnetic flux density | 0.2 – 0.4 | Tesla |
| 2.     | No. of cycles     | 100 – 300 | ______ |
| 3.     | Extrusion pressure | 5 – 7  | MPa   |

Material Removal Rate (MRR):

Material Removal Rate (MRR) was calculated as following:

\[
MRR = \frac{\text{Initial weight} - \text{Final weight}}{\text{time}}
\]

Surface roughness (Ra):

Surface roughness is calculates as following:

\[
\text{Improvement in surface roughness (Ra)} = \text{Initial roughness (Ra)} - \text{Final roughness (Ra)}
\]
CONCLUSIONS

1. It was found that with the application of magnetic field around the work piece, the Material Removal Rate (MRR) was increased significantly. At 0.4 Tesla, the material removal rate is maximum. However, after 0.4 Tesla, the MRR goes on decreasing.

2. It was also found that with the application of magnetic field around the work piece, the Surface Roughness (Ra) was decreased significantly. At 0.4 Tesla, the surface roughness is minimum. However, after 0.4 Tesla, the surface roughness goes on increasing.

3. It was found that with the increase in the extrusion pressure, the Material Removal Rate (MRR) was increased significantly. At 7 MPa, the material removal rate is maximum. However, after 7 MPa, the MRR goes on decreasing and surface roughness goes on increasing.
4. It was found that with the increase in the number of cycles, the Material Removal Rate (MRR) was increased significantly and the surface roughness decreased considerably.

5. The SEM image showed that the surface defects that occurred after micro-EDM are removed with the recast layer on the machined surface and significantly improving the surface finishing of the work piece.

6. From the present research work, It is suggested that the Magnetic abrasive flow machining is very useful for machining tough/hard work pieces such as Al/SiC/B$_4$C hybrid MMCs.

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