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Research Article

Effect of Process Variables on Material Removal Rate during Finishing of Al-6061 alloy using Abrasive Flow Machining

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Abstract

Abrasive flow machining is a manufacturing technique that is flow of pressurized abrasive media to remove work piece material and improve surface roughness. AFM is very efficient and suitable for finishing of complex inner surface and difficult to reach surface. In the present study the effect of different input parameters on MRR has been investigated by using Taguchi analysis. An experimental study was carried out on Aluminium-6061 work piece. The abrasive size, properties of carrier, no of cycles and abrasive concentration are important parameters that affect the performance of AFM. The objective is to study the effect of process variables on material removal rate.

Keywords: *Abrasives, Machining, Finishing, Taguchi method*

1. Introduction

Abrasive Flow Machining

Abrasive flow machining is unconventional machining process. In this process machining of work piece is done by passing pressurized abrasive with carrier to the surface for attaining good surface finish. Basically there are three types of AFM processes. One way, Two ways and Orbital AFM. In Two ways AFM process there are two cylinder stocks, one from the lower cylinder pumping an abrasive laden medium throughout and one from the upper cylinder makes up one process[8]. For the finishing of the components which have complex unsymmetrical shape/profile, holes and undercut, a need is being felt to expand finishing operations which can produce parts with superior quality performance and higher productivity. The abrasive with carrier flows under pressure inside the work piece. The properties of carrier in AFM are very important. They should be visco elastic and non-sticky in nature. The polymer abrasive medium which is used in this process possesses easy flow ability, better self-deformability and fine abrading capability. Generally carrier belongs to silicon polymer. This is very viscous fluid in any blind recess. Commonly used abrasive grains are silicon carbide, aluminium oxide, boron carbide and diamond. Fixture design is important feature that affects the output responses. The type of abrasion and place where to abrade depends upon type of machine and fixture.

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2. Literature Survey

T.R. Loveless *et al*. presented the results of an investigation of the effects of AFM on surfaces produced by turning, milling, grinding, and wire electrical-discharge machining. The machining characteristics studied included material removal and surface finish improvement. The statistical analysis found that the type of machining process affected both metal removal and surface finish results. The initial surface condition significantly affected the amount of metal removal and was very close to meeting the significance requirement for surface finish improvement. In particular, all of the Wire EDM surfaces were improved greatly by AFM. Media viscosity significantly affected only surface improvement, while extrusion pressure did not have a significant effect in this experiment.

V.K. Jain *et al*. studied that Abrasive flow machining (AFM) process provides a high level of surface finish and close tolerances with an economically acceptable rate of surface generation for a wide range of industrial components. It is attempted to analyze the AFM process using finite element method (FEM) for finishing of external surfaces. To study the material removal mechanism of AFM, finite element model of forces acting on a single grain has been developed. Response surface method (RSM) is used to carry out an experimental research to analyze the effect of extrusion pressure and number of cycles on material removal and surface finish. Results obtained from finite element analysis for material removal have been compared with the experimental data obtained during AFM.

Jain and Jain proposed a generalized back propagation neural network model and a second network which parallelizes the augmented Lagrange multiplier (ALM) algorithm. The model determines optimal finishing parameters by minimizing a performance index subject to appropriate operating constraints.

Ramandeep Singh *et al*. presented that material is removed from the work-piece by flowing a semi-solid viscoelastic/plastic abrasive laden medium through or past the work surface to be finished. The present work is an attempt to experimentally investigate the effect of different vent/passage considerations for outflow of abrasive laden viscoelasic medium on the performance measures in abrasive flow machining. The results suggest that the work-piece surfaces having single vent/passage for media outflow have higher material removal and more improvement in surface roughness in comparison with work-piece surfaces having multiple vents/passages and the performance measures decrease with increase in the number of vents for media outflow.

Liang Fang *et al*. presented that the influence of temperature on work efficiency is most critical. Media temperature increases with increasing cycles, which means media viscosity decreases with cycles increasing. AFM tests shows that increasing cycles extensively decrease materials removal and surface roughness decreasing efficiency. When media with different viscosity is used media with high viscosity has more effective material removal efficiency. The high viscosity media to surface roughness improvement is also better than the low viscosity media at the initial several cycle numbers. With further increasing cycles the roughness improvement difference among different media with different viscosity is reduced. It is found from Mooney viscosity–temperature relation of media that temperature rising directly results in the decrease of media viscosity. When work cycles are increased the media temperature is quickly increased. The media viscosity is also decreased dramatically. In order to understand the mechanism of decrease of material removal efficiency with temperature, computational fluid dynamics (CFD) approach is applied to predict the abrasive particles movement tendency. A two-dimensional model is constructed for AFM process. The simulation results show that the temperature rising of media results in increasing the rolling tendency of abrasive particles which causes work efficiency deteriorated.

Jose Cherain *et al*. studied abrasive flow machining (AFM) process is a non-traditional finishing process used for polishing and radius difficult to reach surfaces by the abrading action of the abrasives. The material to be machined is taken in the form of a cylinder. The abrasives are taken in the work piece and rotated at high RPM.AFM can be used to produce high surface finish. Various process parameters are abrasive size, Machining time, Hardness of abrasives and speed of abrasives. The experimental result reveals that the efficiency of the process strongly linked to the mechanical properties of the machined material and machining time. This technique offers good surface finish without affecting closesest geometrical tolerances of materials.

R.S. Walia *et al*. studied the abrasive flow machining was hybridized with the magnetic force for productivity enhancement in terms of material removal (MR). The magnetic force is generate around the full length of the cylindrical work piece by applying DC current to the solenoid, which provides the magnetic force to the abrasive particles normal to the axis of work piece. The various parameters affecting the process are described here and the effect of the key parameters on the performance of process has been studied.

M. Ravi Sankar *et al*. studies that abrasive Flow Machining was developed in 1960s as a method to deburr, polish, and radius difficult to reach surfaces like intricate geometries and edges by flowing a abrasive laden viscoelastic polymer over them. It uses two vertically opposed hydraulic cylinders, which extrude medium back and forth through passage formed by the workpiece and tooling. Abrasion occurs wherever the medium passes through the highly restrictive passage. The key components of AFM process are the machine, tooling and abrasive medium.

Process input parameters such as extrusion pressure, number of cycles, grit composition and type, tooling and fixture designs have impact on AFM output responses (such as surface finish and material removal). AFM is capable to produce surface finish (Ra) as good as 0.05 μm, deburr holes as small as 0.2 mm and radius edges from 0.025 mm to 1.5mm. AFM has wide range of applications in industries such as aerospace, medical, electronics, automotive, precision dies and moulds as a part of their manufacturing activities. For better surface integrity, texture and its performance, continuous developments are taking place for modifying the existing AFM process technology and AFM machine configuration. To overcome some of the draw backs such as low finishing rate and inability to correct the form geometry, researchers have proposed various versions of AFM machines abbreviated as M-AFM, DBGAFF, CFAAFM, spiral polishing and R-AFF.

3. Experimental Design

The photograph shows an assembly drawing of the table-top set-up for an AFM process. The machine has two cylinders each i.e. hydraulic and media. The medium is extruded, hydraulically or mechanically, from the filled chamber to empty chamber via the restricted passageway through or past the work piece surface to be abraded. Typically, the medium is extruded back and forth between the fixed chambers for the desired number of cycles. The cylindrical work pieces are placed in the work holder. When extrusion pressure is applied to the medium by the piston two types of forces are generated i.e. Radial and Axial forces. The medium used for experiment is silicon polymer. The initial positions of these pistons will decided the media volume. To and fro media movements are controlled by the hydraulic cylinders connected to the control unit. A flange is used for clamping the fixture between the media cylinder as shown in fig.-1

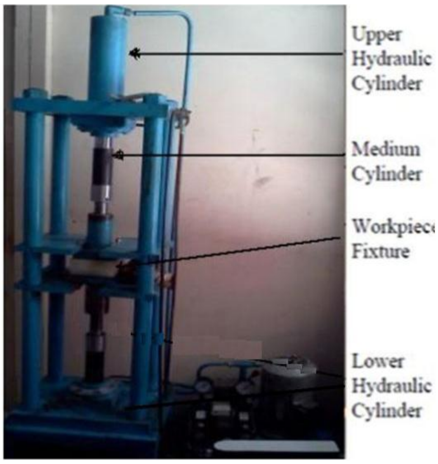

Figure 1 Experimental set up with fixture

3.1 Procedure

The experiments were performed by AFM process on cylindrical work-piece. The abrasives used in the media are silicon carbide. The mixture of media is mixed with the abrasive particles of particular mesh size in a definite proportion to achieve the desired percentage concentration of abrasive particles by weight. Before performing the real experiments, the intermediate was run for 20-25 cycles with the trial work piece, so as to get uniform mixing. Based on the conclusions from the preliminary experiments, three significant variables are the number of cycles, abrasive mesh size, abrasive concentration. Experiments are done by changing one variable and keeping others fixed. All experiments were conducted on work piece surfaces comprising of cylindrical part. Material removal rate was the output response calculated as performance indicators in each case.

3.2 Experimental Materials

The aluminium- 6061 alloy as a work-piece material is used. The hollow space to be machined in the work piece which is prepared by drilling operation and then followed by boring operation for necessary size i.e. Dimensions 7 mm internal diameter , 12 mm external diameter and 50 mm length. The internal cylindrical surface was finished by AFM process. The media formulation used for this study consisted a silicon based polymer, hydraulic oil and abrasive grains i.e. silicon carbide. Each work-piece was machined for a preset number of cycles. The work-piece was taken out from the setup and cleaned with acetone before any measurement is taken.

3.3 Fixure

The fixture is made up of Nylon with certain hole to hold the work piece having dimensions are shown in the sectional view of the given design as shown in fig-2.

Figure 2 Sectional view of Fixture design

4. Process Parameters

The selected parameters and their range for the detailed experiments as shown in the Table-1

Table 1: Selected Process Parameters and their Range

S. No	Process Parameter	Range	Unit
1	Abrasive particle size	150-250	Micron
2	No of cycles	50-150	No
3	Work piece material	Al-6061 alloy	No
4	Abrasive concentration	50-60	%

5. Experimental Observations

Abrasive concentration (%)	Mesh size	No of cycle	MRR(mg/s)
50	150	50	2.45
50	220	100	2.79
50	250	150	2.98
55	150	100	3.36
55	220	150	3.52
55	250	50	2.83
60	150	150	3.85
60	220	50	3.29
60	250	100	3.39

6. Experimental Analysis

The experiment results are analysed by using taguchi method. L9 orthogonal array is selected for the process. The input parameters are abrasive concentration (A), abrasive mesh size (B), no of cycle (C) and output response is MRR.

Table 3: Percentage composition of elements in work piece material

Element	Work piece (Al-6061)
Cu	0.0180
Mg	0.433
Si	0.512
Fe	0.530
Ni	0.0059
Mn	0.165
Zn	0.0146
Pb	0.0216
Sn	<0.0100
Ti	0.0198
Cr	0.0071
Al	98.24

Table 4: Input parameters and their levels

Symbol	Factor	Level 1	Level 2	Level 3
A	Abrasive concentration	50	55	60
B	Mesh Number	150	220	250
C	No of cycles	50	100	150

Table 5: L27 Orthogonal array, MRR after each experiment

	Factors				
Exp. No.	A	B	C	MRR1 10^{-3}g/s	S/N Ratio
1	1	1	1	2.45	7.7833
2	1	2	2	2.79	8.9121
3	1	3	3	2.98	9.4843
4	2	1	2	3.36	10.5268
5	2	2	3	3.52	10.9309
6	2	3	1	2.83	9.0357
7	3	1	3	3.85	11.7092
8	3	2	1	3.29	10.3439
9	3	3	2	3.39	10.6040

Table 6: Analysis of variance (ANOVA) for SN Ratio for material removal rate

Factors	DOF	Seq SS	Adj MS	F	P	Remarks
A	2	7.2496	3.62478	33.9	0	Most Significant
B	2	0.2177	0.10884	1.77	0.46	
C	2	4.138	2.06902	22.2	0.04	Significant
Error	2	0.1863	0.09317			
Total	8	11.7916				
R-square = 98.4						

Table 7: Analysis of variance (ANOVA) for Means for material removal rate

Factors	DOF	Seq SS	Adj MS	F	P	Remarks
A	2	0.91429	0.457144	74.4	0.013	Most Significant
B	2	0.041169	0.020844	3.39	0.228	
C	2	0.52949	0.264744	43.09	0.023	Significant
Error	2	0.01229	0.006144			
Total	8	1.49776				
R-square = 99.2						

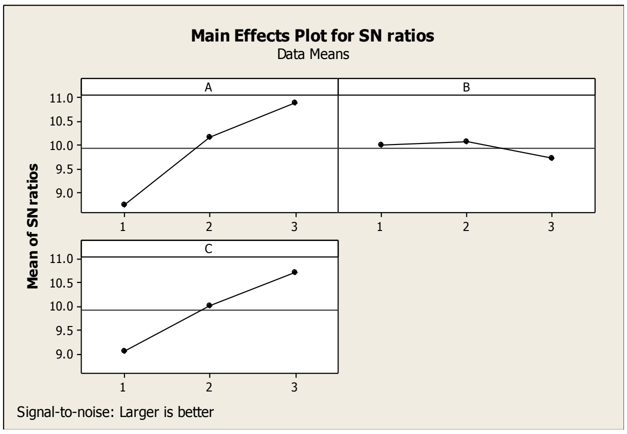

Figure 3 (a): Main effects plot for SN Ratios of MRR.

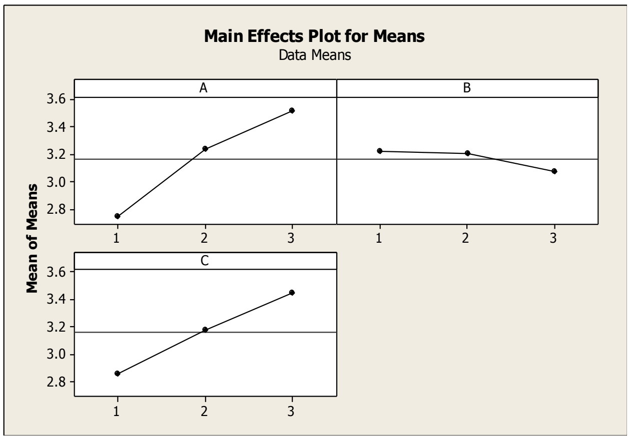

Figure 3 (b): Main effects plot for Means of MRR.

7. Results and Discussion

The analysis of present work is done using Taguchi method on MINITAB software. Abrasive concentration is found more significant factor, then no of cycles and then abrasive mesh size for material removal rate. It is observed that as abrasive concentration increases MRR increases. On increasing abrasive mesh size MRR decreases. As the no of cycle increases, MRR increases.

7.1. Material Removal Rate

Weight of the workpiece was measured before and after the machining operation has been noted. Material removal rate was calculated by using the formula.

$$\text{MRR} = \frac{(\text{Initial weight} - \text{Final weight})}{\text{time}}$$

Conclusion

In the present work Al-6061was drilled and bored by conventional machining operation and surface finishing was done by using abrasive flow machining. Experiment was carried for input parameters like abrasive concentration, abrasive mesh size and no of cycles. The output response is material removal rate. On the basis of results the conclusion is:

1) Finishing of difficult to reach surface can be done by using abrasive flow machining.
2) On the basis of Taguchi method, it is observed that abrasive concentration is significant factor for MRR. MRR increases with increase in abrasive concentration.
3) As the no of cycle increases, the MRR also increases.
4) MRR decreases with increase in abrasive mesh size.

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