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Research Article

Studying Material Removal in Abrasive Flow Machining by using SiC

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Abstract

Finishing of complex, miniaturized parts, especially of internal recesses is very difficult and time consuming process. Abrasive Flow Machining (AFM) is an appropriate finishing process for such finishing requirements. It uses abrasives laden polymeric putty with other ingredients to polish the surfaces. This medium is extruded back-and-forth over the surface employing the hydraulic pressure system through the low carbon steel as the workpiece and SiC as abrasive material. In this Paper, propose multiple regression model (MRM) by using response surface method (RSM) in Minitab program, to predict material removal. The R^2 (ability the Independent values to predict the dependent values) of the predictive model is 92.3%. From the applicant multiple regression model equation, the extrusion pressure (X_1) is the most significant machining parameter to influence material removal (MR).

Keywords: *AFM, MRM, SiC etc.*

1. Introduction

Abrasive flow machining (AFM) is a non-conventional finishing process, which is being used for deburring, polishing, radiusing, removing recast layers, and producing compressive residual stresses on difficult to reach surfaces. AFM has three major elements, namely, the machine, work piece fixture (tooling), and media. The machine in a typical two-way AFM flow process hydraulically clamps the work holding fixtures between two vertically opposed media cylinder. These cylinders extrude abrasive laden semisolid pliable substance known as the media back and forth through the workpiece(s). Two strokes are obtained, one from the lower cylinder and the other from the upper cylinder, making up one process cycle (Jain VK, 2002). In AFM, the media determines the aggressiveness of the action of abrasives, which is resilient enough to act as a self deforming grinding stone when forced through a passageway (Rhoades L, 1991). Production of extremely thin chips allows fine surface finish, closer tolerances, and generation of more intricate surface texture. Recently, diesel injector nozzles (Jung D *et al*,2008), microchannels, and spring collets have been finished by abrasive flow finishing (AFF) process, and the researchers claim that the AFF process directly improved the performance of their systems. Monolithic materials from soft aluminum to tough nickel alloys, ceramics, and carbides can be successfully micro machined by this process (H.S.Mali *et al*, 2010). This technique uses a liquid polymer containing abrasive particles as grinding media. This media is also known as an abrasive laden medium, not-so-silly putty (Rhoades L.J., 1987), or a liquid file. The abrasive media is extruded through the passages formed by the work-piece and tooling with the help of hydraulic pressure system employing hydraulic actuators. Abrasion occurs wherever the medium enters and passes through the most restrictive passages. The media act as a self-modulation abrasive medium with good fluidity and viscosity so the cutting tools are flexible (Tzeng *et al*, 2007). Consequently, the medium abrade the work-piece in the work holder and fixture. This study was focused to study extrusion pressure and number of cycles on the material removal for internal hole to aluminum alloy in abrasive flow machine.

2. Model for material removal

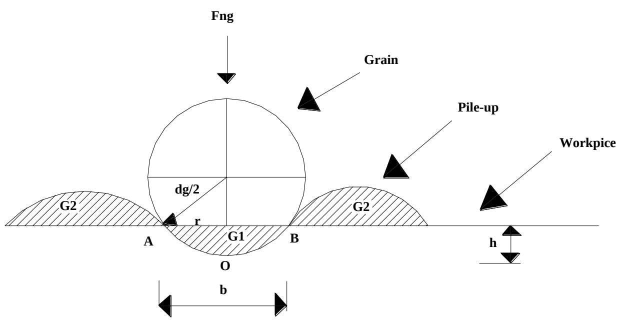

Figure 1: Sphere indenting a plane surface elastically with side pile up Material (V.K.Gorana *et al*, 2006)

The material removal in AFM process is assumed by indentation (caused due to normal force) of the abrasive particle in the workpiece surface followed by its linear movement along the length of the workpiece.

The volume of the material removed (V_g) due to indentation by each grain from figure (1) is given by:-

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$$V_g = (\pi\, d_g/2)\, h^2 \quad (1)$$

Where d_g: Diameter of grain (mm)
R: Radius of grain (mm)

Total volume of material removal (V_t) in one stroke:

$$V_t = V_g N_a \quad (2)$$

Where N_a : The number of abrasives in contact with the workpiece in one stroke length
Total material removal after '*n*' number of cycles (2*n* strokes):

$$V_t = \frac{\pi}{2} d_g \left[\frac{F_n}{\pi\, d_g K_2 H_w}\right]^2 * K_1 \frac{3C\rho m L_s V_f}{2\rho a\, d^3{}_g V_p}\left(d^2 + 4d\, d_g\right) \quad (3)$$

Where:
ρ_a : density of the media around the internal diameter of workpiece (gm/mm^3).
ρ_m : density of the media (gm/mm^3).
Concentration (C) = $\frac{\rho_a V_a}{\rho_m V_m} \Rightarrow V_a = \frac{C\rho_m V_m}{\rho_a}$
L_s: stroke length.
V_p: piston velocity.
V_f: velocity of the medium near the workpiece.
K_1 :is the percentage of the active particles (K_1<1)
K_2 = 1 for brittle materials and K_2 > 1 for ductile materials (for steel, K_2 = 3.1).
F_n: Normal force acting on a grain.

3. Multiple Regression Model

The proposed multiple regression model is a two-way interaction and quadratic equation:

$$y_i= \alpha_i + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{1i} X_{2i} + \beta_4 X^2{}_{1i} + \beta_5 X^2{}_2 \quad (4)$$

Where;
yi= material removal (mg)
X_{1i}= Extrusion pressure (MPa)
X_{2i} = No. of cycles (cycle)
αi= constant value
β= *variable* coefficients

In this model, the criterion variable is the material removal (MR) and the predictor variables are Extrusion pressure and No. of cycles. Because these variables are controllable machining parameters, they can be used to predict the material removal in AFM which will then enhance product quality.

4. Experimental Set-up

An indigenously developed, hydraulically powered experimental machine for AFM process has been designed and fabricated as shown in Fig. (2).This set-up has been designed keeping in view the fundamental mechanism of the process and basic functional requirements of different types of parts. The AFM set-up consists of upper and lower media cylinders with pistons, workpiece fixture, hydraulic drive and supporting frame. The primary function of the abrasive media cylinders is to contain required quantity of AFM media and to guide the piston during up and down reciprocating motion for extruding the abrasive media. This setup has been designed for the maximum extrusion pressure of 25 N/mm². It employs two hydraulic actuators for the extrusion of media from one media cylinder to the other, through the work-piece during the forward stroke.

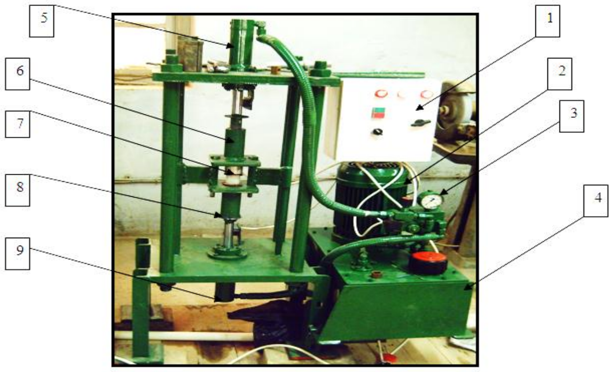

Figure 2: AFM setup:(1) control box,(2)electrical pump,(3) pressure gage,(4) hydraulic unit,(5) upper hydraulic cylinder,(6) upper media cylinder,(7) workpiece and fixture,(8)lower media cylinder,(9)lower hydraulic cylinder

The workpiece for the experimental studies was low carbon steel were made by turning machine with the following dimensions:-

Length = 60 mm
O.D = 50 mm
I.D = 20 mm

One of the major processes of abrasive flow polishing is to allocate abrasive materials. The media is composed of silicone gel, silicone carrier oil, and silicone carbide (150µm) as abrasive grains. Silicon oil was used in order to preserve the properties of the media as a result of the high temperatures during operation.

A Mettler Toledo AB 204-S/Fact instrument precision weighing balance of least count 0.01mg was used to measure the weight of specimen before and after each AFM operation.

Figure 3: Analytical balance

Figure (3) shows the analytical balance apparatus measurement for (MR).

The machining parameters, such as Extrusion pressure and number of cycles were varied to determine their effects on the material removal.

The experiments were designed to study the effect of these on response characteristics of AFM process. Table 1.shows the various levels of process parameters.

Table 1: Process Parameters and their Values at Different Levels with constant length of stroke at 60mm, abrasive concentration 60%and abrasive grain size 150μm

No.	**Extrusion pressure(MPa) (A)**	**No. of Cycle (C)**
1	3	15
2	6	20
3	9	25

5. Results and Discussion

The results in terms of the effect of machine conditions on material removal have been calculated and discussed based on both experimental and theoretical results. Material removal is calculated by measuring weight of the workpiece before and after finishing operation. The workpiece was thoroughly cleaned with acetone and air before any measurement was taken.

The results depicted in Fig.4 show the generalization capabilities of prediction of the proposed multiple regression models. All the data taken from the experiment are shown in Table 2. A statistical model was created by regression function in (RSM) from the Minitab program .The material removal from the experiment has been established, to obtain regression coefficients (β_0,β_1,…..etc.) from applied RSM in Minitab program which entered in equation (4) . By using this equation to predict material removal, the following prediction function was derived to represent the predictive material removal (MR) as a function of the tested control factors:

$$y_i = 21.4756 - 1.77389X_1 - 1.50967X_2 + 0.160185X_1^2 + 0.0501X_2^2 + 0.03233X_1X_2 \quad (5)$$

Where (y_i) was the predicted material removal (MR). It was also apparent that extrusion pressure (x_1) was the most significant machining parameter to influence material removal (MR) in equation (5).

The R^2 (ability the Independent values to predict the dependent values) of the predictive model is 92.3%.

Table 2: Material Removal Obtained from the experiments

No.	Extrusion pressure (MPa)	Number of Cycles	Material removal Measured (mg)	Material removal Predicted
1	3	15	7.32	7.67
2	3	20	9.89	9.37
3	3	25	13.40	13.57
4	6	15	8.60	8.13
5	6	20	9.73	10.31
6	6	25	15.11	14.99
7	9	15	11.35	11.47
8	9	20	14.20	14.14
9	9	25	19.37	19.31

The relation between measured and predicted material removal as shown in Fig.4, it is clear there are agree in more points between two curves , this shows the efficiency (RSM) to predict the variables by multiple regression model.

In Fig.5, show the normal probability plots of the residuals response for surface roughness, a check on this plot in Figure reveal that the residuals generally fall on a straight line implying that errors are distributed normally.

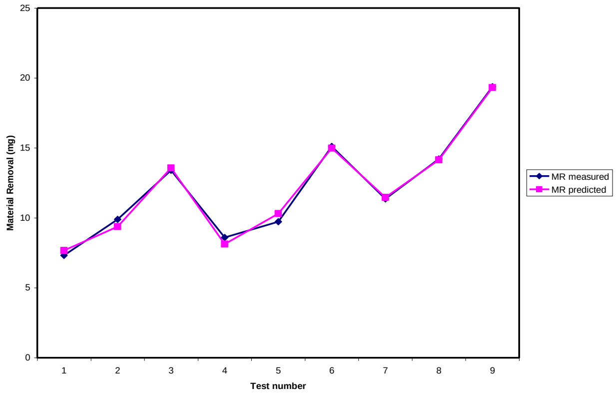

Figure 4: the diagram of the measured and predicted material removal for the experimental data

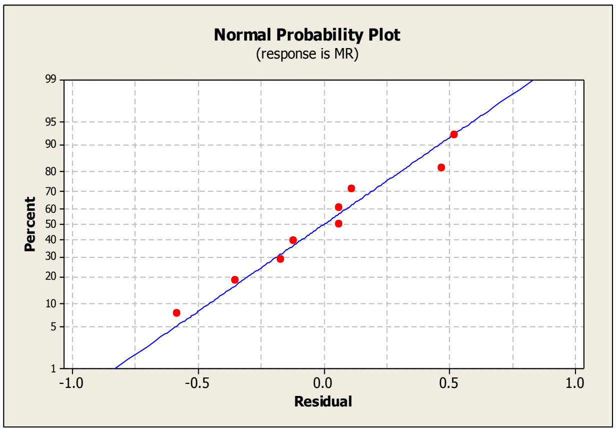

Figure 5: Normal Probability Plot response for improvement of average material removal

Conclusion

The present work has reached to the following conclusions:

1. The material removal (MR) could be predicted effectively by applying extrusion pressure, number of cycles and their interactions and quadratic in the multiple regression model, by using (RSM) in Minitab program.
2. The R^2 (ability the Independent values to predict the dependent values) of the predictive model is 92.3%.
3. The extrusion pressure (X_1) is the most significant machining parameter to influence material removal (MR).

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