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MODELLING AND OPTIMIZATION OF ABRASIVE FLOW MACHINING OF AL ALLOY

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Abstract

Abrasive flow machining (AFM) is used for processing the precision parts with inaccessible area to accomplish very high amount of surface finish and accuracy. A number of researchers have investigated to study different aspects of abrasive flow machining. In the present investigation a CFD simulation of abrasive flow machining of aluminium alloy work piece with polyborosiloxane with grease as the media and silicon carbide as abrasive particles to determine velocity distribution, pressure distribution, stress and MRR. The optimization of the process parameters has been carried out using RSM.

Key words: AFM, RSM, CFD, MRR, Pressure

1. Introduction

Manufacturing of precision parts and ultra-finishing is a critical, uncontrollable and labor extensive methodology. Abrasive flow machining(AFM) is used to finish the precision parts with particular features with inaccessible area. It is carried out with countless edges with inconclusive orientation and geometry. These methods are utilized because of their capacity of finishing various geometries of structures(like flat, round and so forth) with fancied dimensional accuracies and surface finish.

AFM system comprises of three separate components i.e. machine, tooling and medium. The machine comprises of frame structure, medium cylinder, hydraulic cylinder and control system. By and large the working pressure ranges from 1 mpa to 16 mpa. The tooling is outlined in such a path to hold the work-piece in position and to guide the stream of medium. The medium is a mixture of polymer, rheological additives and abrasive particles. In AFM abrasion of work-piece happens because of the confinement of stream. The deburring and polishing of any out of reach and complex range is conceivable by driving the medium into it. It is conceivable to accomplish very high amount of surface finish and accuracy.

A number of investigators have carried out different studies about the different aspects of abrasive flow machining(AFM). Rhodes[1] observed that in AFM process depth of cut by abrasive particles depends on size, relative hardness, sharpness of abrasive particles and extrusion pressure. The medium flow design which influences finishing aspects depends on machine settings, medium formulation and tooling configuration. For abrading walls of substantial sections high viscosity medium was suggested. The low viscosity medium was found suitable for radiusing edges and for finishing thin entries. Experimental study by Przyklenk [2] proposed that the material removal limit of high viscous medium was around 300times more than that of low viscous base medium. The paramount variables that influence stock removal and medium speed are abrasive rate concentration, abrasive size and viscosity of the medium. Williams and Rajurker [3] conducted additional investigations to study the impact of extrusion pressure and medium velocity on material removal and surface finish. Jain et al.[4,5] suggested that the abrasive concentration and mesh size on medium viscosity at diverse temperatures played a crucial role in AFM process. It was observed that increase in medium viscosity enhanced the surface finish. Davis and Fletcher[6] depicted the relationship between the amount of cycles, temperature, weight drop and over the kick bucket. It is evident from the literature review that a great deal of experimental investigations on AFM has been carried out. But the work reported in the modeling of the process is not adequate.

In the present investigation, a CFD simulation of the abrasive flow machining of aluminum –alloy work-piece has been carried out to determine axial stress, radial stress, normal stress , depth of indentation and material removal rate.

Polyborosiloxane with grease is taken as the media and silicon carbide as the abrasive particles. The optimization of the process has been carried out using response surface methodology. The volume fraction, extrusion pressure and inlet velocity are considered as the process variable parameters. The axial stress, radial stress and depth of indentation are minimized with respect to the process parameters.

2. AFM Process

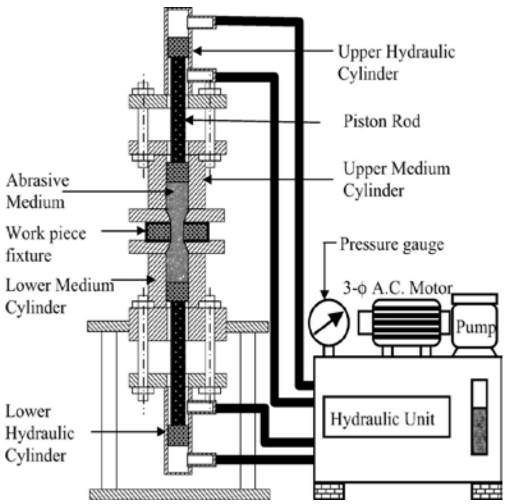


Fig.1 Components of AFM SET UP

The schematic diagram of AFM set up is given in Fig1. The work-piece in the form of pipe is held at the central position. Abrasive medium passes to and fro in the work-piece with the help of upper medium and lower medium cylinder. The length and diameter of pipe are 10mm and 55mm respectively.

3. Simulation of AFM

CFD simulation has been carried out of the AFM process(Fig.2). One quadrant of abrasive flow medium along with work-piece has been considered for CFD simulation because of symmetricity. The mathematical representation in the AFM process includes basic equations of momentum and continuity equations[7,8] as given in equation (1) and (2).

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad (1)$$

$$\rho \left[\frac{\partial u_i}{\partial x_i}\right] = \left[\frac{\partial \rho}{\partial x_i}\right] + \frac{\partial\left[\mu r\left(\frac{\partial u_i}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right)\right]}{\partial x_j} \qquad (2)$$

where ρ, u_i, p and μ are density, velocity, pressure, kinematic viscosity respectively.

Now γ (deformation tensor) can be represented as

$$\gamma = \sqrt{2 * D_{ij} D_{ij}} \qquad (3)$$

$$D_{ij} = 0.5 * \left(\frac{\partial u_i}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right) \qquad (4)$$

The energy equation is as follows:

$$\rho * \frac{dh}{dt} = \frac{dp}{dt} + \nabla (k \nabla T) + \varphi \qquad (5)$$

where h, T, k and φ are enthalpy, temperature, thermal conductivity and viscous dissipation function respectively.

In this modeling, quasi steady state is considered. The fluid is considered incompressible. The continuity, momentum and energy equation are solved for more precise modeling. Heat generation is not considered.

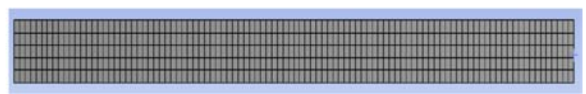


Fig. 2 Modelling and meshing of pipe using ANSYS 14.0

Boundary conditions

1. Velocity at inlet must be uniform and constant pressure is ensured at the outlet.
2. There should not be any slip along the boundary walls.
3. Work-piece is axisymmetric
4. Inlet pressure is maintained at 35bar
5. Volume fraction is kept at 40%

All abrasive particles used in AFM process are assumed to be spherical. Their average diameter can be determined as

Dg = 15200/Me = 25.33 micrometer

where Me value is 600. Each abrasive particle is assumed to have a single cutting edge. The constant load is considered on the abrasive particles and it is assumed that each abrasive particle has same depth of indentation.

4. Mechanism of material removal

Radial or normal force and the axial force are generated when extrusion pressure is applied on the medium by the piston. Normal force is responsible for the indentation of the abrasive grain on the work-piece surface while axial force is responsible for material removal from the workpiece[9].

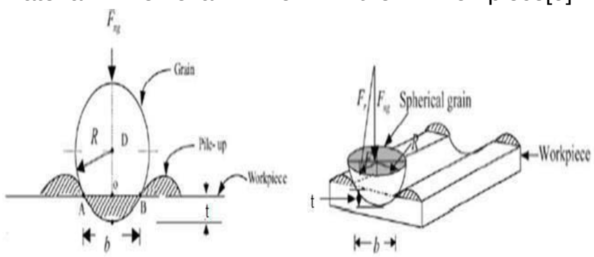


Fig. 3 Normal and axial force with depth of indentation

At the point when the normal force is connected on the work-piece throughout AFM, it will indent to a profundity into the work-piece. The normal force can be computed as

$$F_n=\sigma_{rad}.A \quad (6)$$

where $A=\pi.\frac{dg^2}{4}$, $\sigma_{rad.}$ = radial stress

5. Results and discussion

The simulation results of poly-borosiloxane medium flow analysis at different volume fraction and extrusion pressure have been obtained. The various responses like axial force, radial force, normal force, depth of indentation and volume of material removal are determined.

The velocity distribution is shown in Fig.4 (a) and 4(b) respectively. It is clear that the velocity changes when the medium flows through the narrow pipe. The velocity magnitude will always be maximum at the center or axis and minimum near the walls. The pressure distribution is shown in Fig.5 (a) and 5 (b). From the figure it is clear that static pressure remains constant up to the narrow pipe. The axial and radial stress was shown for different position in Fig.6(a) and 6(b). From the fluent, the radial stress was found to be 0.069P_a. Using the radial stress, the normal force is obtained as $F_n=3.476\text{X}10^{-11}$N. The indentation diameter is determined as D_i = $4.33\text{X}10^{-7}$m. The depth of indentation is obtained as t = $1.07\text{X}10^{-8}$m. The projected area is $3.07\text{X}10^{-10}m^2$. Reaction force is predicted as F_r = $1.022\text{X}10^{-13}$N. Axial stress on the work-piece material is obtained as =30.04Pa. Axial force is determined as F_a =$4\text{X}10^{-9}$N.

The axial force is much larger than radial force. It is quite clear that the material removal is taking place in this case due to axial force. So volume of material removed in this case is v_a = projected area X length = $3.8068\text{X}10^{-15}m^3$. The density and dynamic viscosity are 1219kg/m^3 and 789Pas. With increase in dynamic viscosity, MRR increases. With increase in density, MRR decreases and surface finish increases.

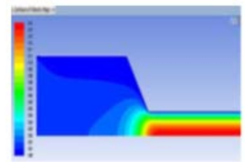


Fig. 4 (a) Velocity distribution

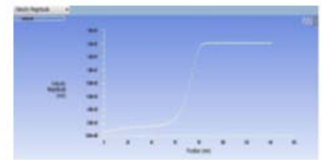


Fig. 4 (b) Velocity magnitude versus position

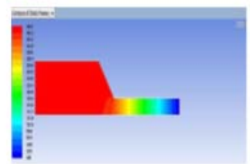


Fig. 5 (a) Static pressure distribution

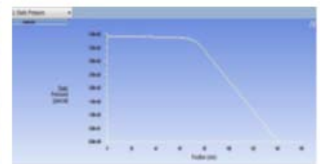


Fig. 5 (b) Static pressure vs position

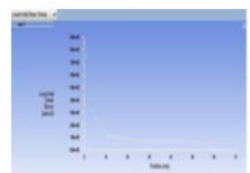


Fig. 6 (a) Axial stress vs position

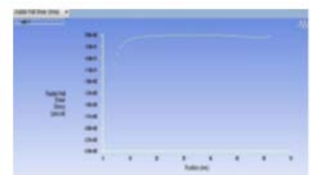


Fig. 6 (b) Radial stress vs position

6. Optimisation of AFM process using RSM

The optimization of the process has been carried out taking volume fraction, pressure and velocity as the process parameters. The axial stress, radial stress and depth of indentation are taken as the responses. The process parameters are varied at three levels. The levels of the process parameters are given in Table1.

Table 1 Values of inputs

Inputs	Unit	Code	Low	High
Volume fraction	%	A	40	50
Pressure	Bar	B	35	60
Velocity	m/sec	C	0.009	0.025

The output responses are given in Table 2. The regression analysis is carried out for axial stress, radial stress and depth of indentation. The regression co-efficients for axial stress are shown in Table 3. The values of the pressure, the square term of pressure and the interaction between volume fraction and pressure have significant value. Here R-square value comes 99.94% which is acceptable. The regression analysis for radial stress has been studied, here R-sq quality becomes 94.46% which is satisfactory.

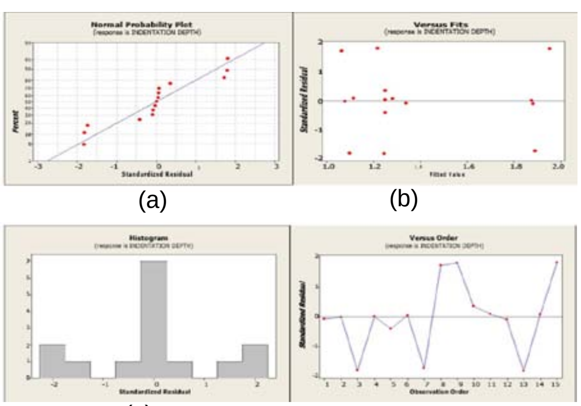
Table 2 Responses

Run Order	AXIAL STRESS	RADIAL STRESS	INDENTATION DEPTH
1	41.064	0.236	1.340
2	30.142	0.092	1.080
3	30.052	0.069	1.070
4	46.987	0.286	1.876
5	40.764	0.219	1.241
6	40.981	0.221	1.253
7	45.894	0.275	1.864
8	30.239	0.108	1.092
9	47.234	0.296	1.982
10	40.542	0.241	1.261
11	30.438	0.139	1.116
12	45.564	0.261	1.881
13	40.763	0.209	1.219
14	40.439	0.275	1.283
15	40.018	0.237	1.249

Table 3 Regression coefficient of axial stress

TERM	COEFFICIENT	SE COEFFICIENT	T	P
CONSTANT	-26.52	11.77	-2.254	0.074
PRESSURE	1.80	0.12	15.017	0.000
VOLUME FRACTION	0.25	0.47	0.530	0.619
VELOCITY	157.81	165.33	0.954	0.384
VOL.FRACTION*VOL.FRACTION	-0.00	0.01	0.721	0.503
VELOCITY*VELOCITY	-1545.57	2001.44	-0.772	0.475
PRESSURE*PRESSURE	-0.02	0.00	-18.330	0.000
VOL.FRACTION*PRESSURE	0.01	0.00	2.608	0.408
PRESSURE*VELOCITY	2.49	1.23	2.023	0.099
VOL.FRACTION*VELOCITY	-4.51	3.08	-1.467	0.202

The normal probability plot of radial stress (Fig.7 (a)) falls on the straight line. This indicates the accuracy of the result. Since no pattern of the fitted value vs. standardized residual value (Fig.7 (b)) is obtained, the inputs are fitted well in 95% of confidence interval. The histogram of radial stress is formed into normal probability distribution. The minimum radial stress occurs at 13th run (Fig.7 (d)).



(a) (b) (c) (d)

Fig. 7 (a) normal probability plot of radial stress (b) fitted value vs. standardized residual value (c) histogram of radial stress (d) minimum radial stress

7. Conclusion

The axial stress, radial stress and velocity contour are developed using CFD simulation. The velocity is maximum at the center and minimum near the walls. The velocity is low before entering into the narrow pipe and suddenly increases because of sudden change of area of cross section. The static pressure remains constant in the media cylinder and decreases gradually in the pipe. The axial forces and normal forces are also determined. The axial force is larger than radial force which accounts for the material removal. The optimal values obtained from Response Surface Methodology for maximum output are 45% volume fraction, 47.5 bar pressure and 0.009m/s velocity.

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