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Investigation of Abrasive Flow Finishing While Machining Convergent-Divergent Nozzle of Different Engineering Materials

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Abstract— ***Abrasive Flow Finishing (AFF) is utilized for finishing the precision parts like die-mould, prosthetic joints, automobile and aviation components like convergent-divergent nozzles, engine manifolds, turbine blades, rocket engines and many more which have multifaceted profiles to achieve high degree of surface completion with required accuracy. Various researchers have researched to contemplate diverse aspects of abrasive flow finishing. An adaptable tool involving mixture of polymer medium and abrasive particles is utilized to carry out the analysis. The relative movement between the polymer medium and the workpiece surface gives the required finishing on the components. This paper deals with the application of AFF for finishing of convergent-divergent nozzles. Mathematical modeling is also used to model the finishing operation.***

Keywords— Abrasive Flow Finishing; MRR; surface roughness; abrasive media

I. INTRODUCTION

This document is a template. An electronic copy can be downloaded from the Journal website. For questions on paper guidelines, please contact the journal publications committee as indicated on the journal website. Accurate and Precise finishing of the machined part are critical and costliest part of the production process. The practical properties for example, corrosion resistance, wear resistance and power losses because of friction are affected by surface harshness of the mating parts. A need is felt to develop a finishing process which can create parts with predominant surface quality and higher productivity. To counter the issues stated above abrasive flow finishing methods are developed. Abrasive flow finishing is carried out with an extensive number of cutting edges which have indefinite orientation and shape along with carrier media. AFF process is used to deburr, radius, polish and remove recast layer of part. AFF technique contains three separate segments those are machine, fixture and medium. The machine includes base frame, abrasive media barrel, hydraulic cylinder and a control framework to operate the cylinders. The working pressure used, ranges from 1 MPa to 10 MPa. The fixture is used to hold the workpiece in its proper position and to control the flow of medium. The medium is a blend of polymer, rheological substances and abrasive particles. Particularly the internal sections which are hard to finish by different conventional methods are done by AFF efficiently. The AFF procedure is a viable finishing procedure for hard to machine materials, aviation and automobile sectors, and other precision manufacturing areas. The surface harshness qualities were measured parallel to the abrasive media stream lines for different operating cycles. The improvement in the surface quality of the workpiece materials were observed and compared. Various researchers have done distinctive studies about the diverse nature of AFF.

II. LITERATURE REVIEW

Zhang et al. [1] observed that the abrasive flow finishing process has both microcutting and furrowing and the viscoplastic deformation, where the microcutting steadily decreases as working cycle increments while the viscoplastic deformation, assumes the key part through the whole process. Sato et al. [2] developed numerical model on straight tubes of ellipsoidal cross-sections and the same was proved experimentally. The model was developed using a zero-order semi mechanistic approach. Sankar and Jain [3] reported that the material evacuation mechanism in alloys is not the same as that of composites in AFF. The work done by Singh and Shan [4] for the most part focused on improving the effectiveness of the abrasive flow finishing with a specific end goal to build the material evacuation rate, for this they applied magnetic field around the brass workpiece and suitable procedure parameters was established. Ulhmann et al. [5] investigated the modeling of the media by considering standard Maxwell model for elastomers and later was stretched to generalized Maxwell model with a presumption that material evacuation happens because of shearing force of abrasive particles on workpiece surface. Study on surface harshness was done by Swat et al. [6] for a characterized set of cylinder pressure and model for the axial forces in one-way abrasive flow finishing was given by them. Lin et al. [7] took a shot at finishing of micro channels on stainless steel. Results uncovered that higher concentration of coarser particles in the medium provided consistency and enhanced the surface finish at higher extrusion pressure. Kursad et al. [8] examined the impact of workpiece hardness on the machinability of abrasive flow finishing process. Results demonstrated a change in surface quality as hardness increased. Internal finishing of capillary tubes utilized as a part of biosensor applications was given by Yamaguchi et al. [9] Stainless steel capillary tubes of 400 µm breadth was effectively machined by them by utilizing magneto rheological abrasive flow finishing. Kavithaa et al. [10] generated nanometric finishing of prosthetic hip-joints which is important to forestall tedious corrective surgeries. The hip joint was made of business fashioned cobalt-chromium molybdenum alloy. It was observed that low working pressure created a superior surface finish with expanded material evacuation. The present paper concentrates on finishing of the machined convergent-divergent nozzles of different engineering materials to completely utilize the versatility of the adaptive silicone polymer with additives is taken as the carrier media impregnated silicon carbide as the abrasive particles. The volume fraction, extrusion pressure and inlet velocity are considered as the process variable parameters. Surface roughness is considered as core output parameter against the number of operating cycles.

III. AFF PROCESS

Figure 1 shown below is the schematic diagram of the developed experimental setup of one-way type abrasive flow machine which consists of abrasive media cylinder, hydraulic cylinder, valves, and hydraulic power pack. A flexible coupling is used to connect both hydraulic and abrasive cylinders. The linear motion of the hydraulic cylinders are given by the hydraulic power pack to push the hard slurry media present in the abrasive media cylinder through the workpiece that has to be machined.

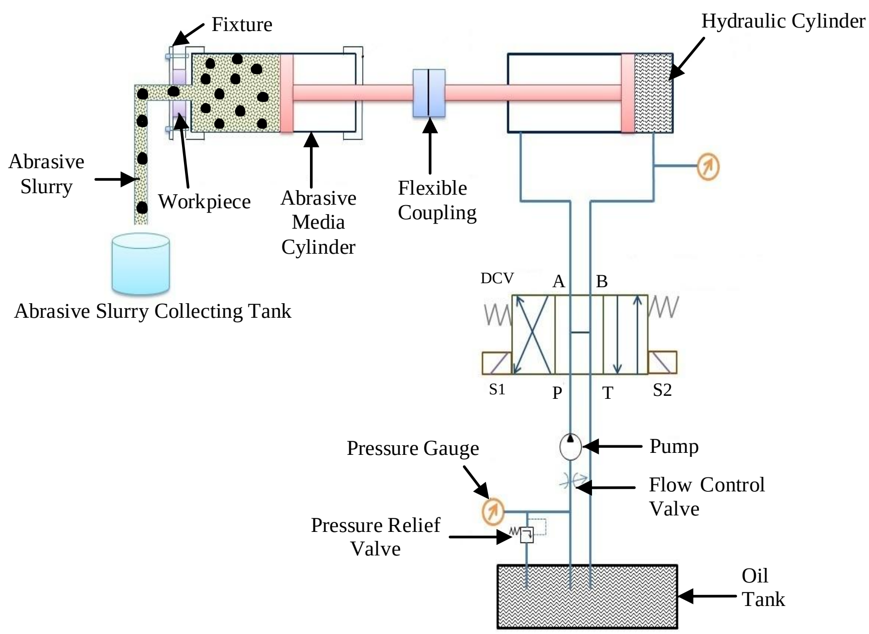

Fig. 1 Schematic diagram of abrasive flow machine

A. Mathematical Model

The following assumptions are made during AFM process.

- Abrasive grains are approximated to be spherical in shape
- Each grain consists of only one active cutting edge
- All abrasive grains are of the same size
- Maximum depth of penetration is restricted to the radius of the abrasive grain, above which cutting is not

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possible as it may cause a deeper scratch instead of cutting

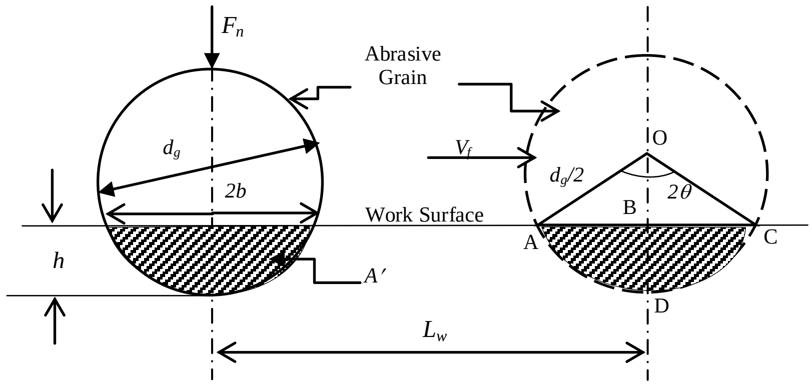


Fig. 2 Schematic diagram of a spherical abrasive grain

Indenting force (F_n) acting on an abrasive grain will cause it to penetrate the surface just as a Rockwell ball makes a dent during the hardness test and it is given by,

$$F_n = \sigma_r * A_g \quad (1)$$

Where, σ_r is normal stress acting on the grain and A_g is the area of the abrasive grain

From the geometry (Fig. 2) radius and depth of indentation (h) can be obtained as follows. By considering the Rockwell hardness of the work material on B – scale,

$$HRB = 130 - \frac{h}{0.002} \quad (2)$$

$$h = 0.26 - 0.002HRB \quad (3)$$

From the geometry (Fig. 2) in Δ OAB the radius 'b' of the indent made is given by

$$\left(\frac{d_g}{2}\right)^2 = b^2 - \left(\frac{d_g}{2} - h\right)^2$$

$$b = \sqrt{h(d_g - h)} \quad (4)$$

From triangle Δ OAB angle 'θ' can obtained

$$\theta = \sin^{-1}\left(\frac{2b}{d_g}\right) \quad (5)$$

Cross sectional area of indented zone A' (shaded portion of the grain in Fig. 2) can be derived from the geometry. Area of segment ADCA can be obtained by subtracting area of triangle Δ AOC from area of sector OADCO.

$$A' = \theta r^2 - b(r - h) \quad (6)$$

Substituting the value of 'θ' from Eq. (5) into Eq. (6) the cross sectional area of indented zone (A') is given as

$$A' = r^2 \sin^{-1}\left(\frac{b}{r}\right) - b(r - h) \quad (7)$$

Therefore, volume of the material removed (V_a) by an abrasive grain is given by,

$$V_a = A' L_i \quad (8)$$

$$V_a = \left[r^2 \sin^{-1}\left(\frac{b}{r}\right) - b(r - h)\right] L_i \quad (9)$$

From the assumption made the length of the abrasive grain in contact with the workpiece is,

$$l_i = \frac{Circumference\ of\ Abrasive\ Grain}{2} \tag{10}$$

$$l_i = \pi r \tag{11}$$

Substituting the value of 'l_i' from Eq. (11) into Eq. (9), the volume of the material removed per abrasive grain is given by,

$$V_a = \pi r \left[r^2 \sin^{-1}\left(\frac{b}{r}\right) - b(r-h) \right] \tag{12}$$

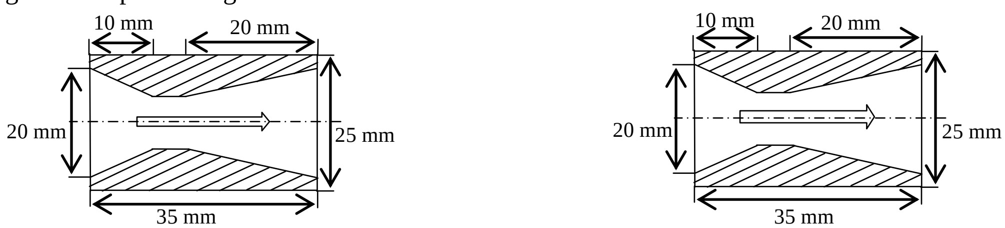
As the cycle is made up of 'n' such indentations of the abrasive grain and 'N' such cycles, volume of material removed is given as,

$$V = nN\pi r \left[r^2 \sin^{-1}\left(\frac{b}{r}\right) - b(r-h) \right] \tag{13}$$

This simplified model suggests that material removal rate per cycle depends on depth of indentation (h), size of abrasive grains (r), and total number of abrasive grains per stroke (n) for the given size of workpiece and media cylinder.

B. Experimentation

To understand the efficiency of the AFF engineering materials like Aluminum and Mild Steel are considered as workpiece with pre-machined complex internal geometries as shown below in Fig 3. The various parameters used for finishing the workpiece are given in the Table 1.



(a) Workpiece: Aluminum (b) Workpiece: Mild Steel

Fig. 3 Convergent-Divergent Workpiece

TABLE I: Parameters Used for Finishing Aluminum and Mid Steel Convergent-Divergent Components

Parameters	Values
Volume fraction	50%
Abrasive size	220 mesh
Pressure inlet	7.5 MPa
Media velocity	0.002 m/s
Stroke Length	0.4 m

C. Results and Discussions

The details of finishing of the convergent-divergent workpiece which was machined using the traditional turning process are given in the Table 2 below. The zeroth reading of the roughness is the initial value taken after initial machining. The plot shown in Fig.4 conveys the satisfactory result that is, an observable decrease in surface roughness as number of pass increases. It can be observed that as the number of pass increases the average roughness of the surface decreases which is due to the abrasion between abrasive media and work surface to remove the burrs and other undesired surface asperities. Also the percentage reduction in average roughness is high initially and reduces later which is due to blunting of sharp roughness peaks, which initially gets sheared off rapidly and after few pass of abrasive media it decreases which in turn reduces the material removal rate. Hence in the AFF material removal rate is not a major output parameter as the removed material is quantitatively less compared to the traditional finishing process. Also at the end of the 12th pass a uniform surface finish at both ends in Al, and almost close in case of MS was seen.

TABLE 2: EFFECT OF NUMBER OF PASSES ON AVERAGE SURFACE ROUGHNESS (R_A) AT DIFFERENT SECTIONS OF AL AND MS CONVERGENT-DIVERGENT WORKPIECE

Number of Pass	Average Surface Roughness in µm			
	Aluminum Workpiece		Mild Steel Workpiece	
	Convergent Side	Divergent Side	Convergent Side	Divergent Side
0	0.57	0.52	1.43	1.206
3	0.51	0.45	1.18	1.17
6	0.44	0.36	1.03	0.99
9	0.33	0.31	0.94	0.967
12	0.25	0.27	0.85	0.73

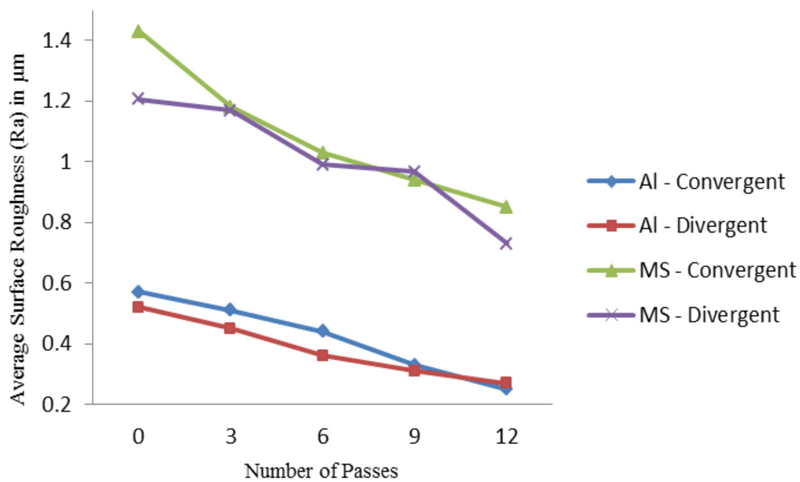


Fig. 4 Number of Passes Vs Average Surface Roughness

The detail of finishing of the convergent-divergent workpiece which was machined using the conventional turning process is given in the Table 3 below. The zeroth reading of the roughness is the initial value taken after initial machining. The plot shown in Fig.5 shows the variation of the skewness against number of machining cycles. Skewness is a parameter which gives the symmetrical variation of the roughness profile about a mean line. This parameter is most important because it is practically used for the evaluation of gloss and lusture of the surface and also helpful in evaluation of corrosion strength. Negative skewness indicates that valley plays an important role in determining the surface strength similarly positive value indicates the importance of peaks. At the end of the 12th pass from Fig. 5 we can observe that skewness at both sides of Al is same but in case of MS it is almost close at the end of finishing cycle.

TABLE 3: EFFECT OF NUMBER OF PASSES ON SKEWNESS (R_{SK}) OF THE ROUGHNESS PROFILE AT DIFFERENT SECTIONS OF AL AND MS CONVERGENT-DIVERGENT WORKPIECE

Number of Pass	Skewness of the Surface Roughness profile			
	Aluminum Workpiece		Mild Steel Workpiece	
	Convergent Side	Divergent Side	Convergent Side	Divergent Side
0	0.7	0.95	1.84	1.523
3	0.63	0.46	1.5	1.497
6	0.64	0.42	1.31	1.257
9	0.41	0.42	1.27	1.212
12	0.36	0.34	1.06	0.965

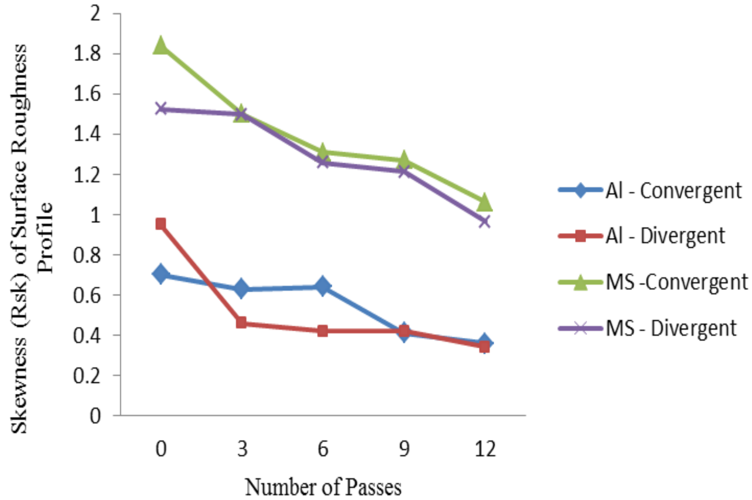


Fig. 5 Number of Passes vs Skewness of Roughness Profile

IV. CONCLUSIONS

In this paper, the surface characteristics imparted by the AFF process on various engineering materials with complex geometries have been examined. The Al and MS nozzles that were finished with abrasive media have been pre-machined by conventional CNC machining process. It can be concluded that,

- It is known that the traditional machining gives rise to undesired residual stresses in the machined surface. These are visible in the form of rings, smaller cracks and cavities along the surface which adversely influences the feebleness of the component. With use of AFF, high recovery stresses are imparted in the material surface layer which is similar to shot peening process.
- The increase in surface finish of the surface is a direct result of polishing or glazing and shearing impacts created by the abrasive particles because of the radial force applied by the media stream.
- Strain hardening caused by the abrasive particles on the surface of the workpiece is one of the constraints for further change in the surface roughness with increase in the quantity of cycles and machining time.
- Workpiece material is a significant element which contributes to finishing.
- From the experiments carried out on different workpiece material shows that at the end of 12th pass about 56.14 % of reduction in Ra value for Al and about 40.55 % of reduction in Ra value for MS along the convergent side respectively. Similarly for divergent side about 48.07 % and 36.63 % of reduction in Ra respectively for Al and MS.
- It can be concluded that AFF process can be efficiently used for finishing the convergent-divergent surface of different engineering materials.

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