Investigations into Optimization of Abrasive Flow Machining Process Parameters: A Review

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***Abstract*— In the present work, different optimization technique used for Abrasive Flow Machining process is studied and after effects of various input parameter on some performance parameters of AFM generated component like surface finish have been reviewed. The aim of this work is to investigate the effect of process variable parameters like Extrusion pressure, Grain size, number of cycles, workpiece configuration, reduction ratio, and percentage concentration of abrasives on process performance parameters like surface finish, dimensional tolerance, material removal, active grain density, cutting forces, and residual stresses in AFM through different optimization technique. Considerable amount of work has been reported by the researchers on AFM and optimization of various in process variable parameters. Several approaches are proposed in the literature to optimize these parameters hence it is felt that a review of the various approaches developed would help to distinguish their main features and their relative advantages and limitations to allow choose the most applicable approach for a particular application. In view of above, this paper presents a review of development done in the area of optimization of process parameter of AFM component.**

Keywords*— Abrasive flow machining, process variables, process performance, optimization technique, surface roughness, material removal

I. INTRODUCTION

Abrasive Flow Machining (AFM) technique was developed by Extrude Hone Corporation (USA in 1960). AFM is a non-traditional finishing process that is used to deburr, edge contouring, surface finishing, and to generate compressive residual stresses even in inaccessible areas. The process of abrasive flow machining produces a smooth, polished finish using a pressurized abrasive media. The abrasive media is flown across the surface of workpiece either in a one way direction or two-way AFM. In case of one way system, the abrasive media is forced through the workpiece at an entry point and then exits on the other end. In two-way AFM process, the media flow is controlled by two vertically opposite hydraulic cylinders, push the abrasive media to and fro. This paper presents a comprehensive review of Abrasive Flow Machining process parameter optimization involving different method of optimization and identifies several research gaps where further research and development work can be directed to make this advanced finishing process deliver products with super finishing, better quality and desired properties.

AFM process conditions play an important role in improving surface finish, dimensional accuracy, intricate surface of workpiece is difficult to and such internal passages, edges, cavities and bends. Critical process parameters that affect the quality of processed workpiece have been discussed and extensive research on this topic focusing on experimental results and optimization process. Most of the researches on AFM process parameters have been directed toward optimizing process parameters to improve the surface roughness, material removal rate (MRR), dimensional accuracy and higher productivity.

II. VARIOUS TECHNIQUES FOR OPTIMIZATION OF AFM PROCESS PRAMETERS

There are the different predictive and optimization techniques. Which were applied by many researcher and after going through the literature the major optimization methods and tools utilized by the researchers are as follows:

- Full factorial design
- Genetic algorithm approach
- Design of experiment
- Neural network
- Computational fluid dynamics (CFD)
- XRD and SURFASCAN

III. VARIOUS PROCESS AND PERFORMANCE PARAMETERS

The parameters which play important role in AFM is as follows: abrasive mesh size, extrusion pressure, number of cycles, compressive residual stress, dimension accuracy and surface roughness, media viscosity.

IV. EXISTING RESEARCH EFFORTS

Williams et.al.[1] proposed a stochastic modeling and analysis technique used to study abrasive flow generated surface. This paper addresses preliminary results of an examination into some aspects of the AFM process performance, surface characterization, and process modeling. The influence of process input parameters such as extrusion pressure, media viscosity, and number of cycles on the process performance parameters material removal rate and surface finish are discussed. They describes that material removal and surface finish in AFM are significantly affected by the carrier media viscosity and extrusion pressure appear to be highly significant in improving surface finish.

Jain and jain et.al.[2] material removal and finished surface occurred to the interaction of abrasive particles have been analyzes and simulated in their work. They showed that if the active numbers of abrasive grains per unit volume of media flow increases with reduction ratio and percentage concentration of abrasives, change in surface roughness and higher material removal can be achieved.

Rajendra et.al.[3] this paper is to describe the use of neural network for modeling and an optimal selection of input parameters of AFM process. The authors present first, a generalized back-propagation and neural network had been use to establish the process model. A second network augmented Lagrange multiplier (ALM) method is used to provide optimize the machining parameters. It was concluded that appropriately trained network is successfully synthesizes optimal input conditions for AFM process and the optimal input conditions maximized the MRR and subjected to appropriate process constraints. The neural-network approach helps to get optimized value and coincide well with the results obtained from genetic algorithm (GA) and hence validate the neural network approach..

Jain et.al.[4] studied the effects of three parameters i.e. abrasive volume fraction, temperature, and abrasive mesh size have a valuable effect on medium viscosity. By conducting AFF experiments using medium of different viscosities, It is seen that there is an increase in material removal and getting decreased value of surface roughness as viscosity of the medium increases.

Sehijpal et.al.[5] this paper discusses the possible improvement in surface roughness and metal material removal rate(MRR) with help producing magnetic-field around the workpiece in AFM. They reports the media viscosity interacted with magnetic-flux density while affecting both material removal and surface roughness of workpiece.

Gorana et.al.[6] studied the effects of two parameters i.e. cutting force and active grain density, on the surface roughness. Using a dynamometer for measuring radial force and axial force component. It was concluded that abrasive concentration, extrusion pressure and grain size would affect the cutting forces, active grain density and finally reduction in surface roughness value is approximately directly proportional to force ratio. Scanning electron microscopy (SEM) shows that rubbing and ploughing are the feasible mechanisms of material distortion.

Jain et. al.[7] An analytical model is projected to simulate and predict the surface roughness for dissimilar machining conditions in abrasive flow machining (AFM). They performed experiments for various sets of process variables, i.e., extrusion pressure (4 to 8 MPa), abrasive mesh size (80 and 220), abrasive concentration (40 to 60%). The analysis based on kinematics is used to model the interaction between grain and workpiece. An experimental value of average active grain density is approximately directly proportional to the extrusion pressure up to 7 MPa and the percent reduction in surface roughness value is also increased with an increase in percent abrasive concentration.

Sunil et.al.[8] experimentally investigated the effects on surface roughness caused by number of finishing cycles and extrusion pressure in magnetorheological abrasive flow finishing process. They reported that the maximum improvement in surface roughness was observed at an extrusion pressure (3.75 MPa) and also reported that the actual finishing takes place only after two hundred cycles when all loosely held material left after grinding is removed then the value of surface roughness decreases progressively with a further increase in cycles, limited by abrasive grain size and extrusion pressure.

Fang et.al.[9] considered the important governing factors in abrasive flow machining like temperature, viscosity, abrasive hardness, particle sharpness, pressure, piston moving speed, etc. According to their experiment, the effect of temperature is very critical. They conducted the experiments for different grades of steel and it was observed that with the increase of temperature, the viscosity of media decreased. Increase in number of cycles extensively decreased the material removal and surface roughness. With high viscous media, the material removal efficiency increases initially, but decreases with substantial increase in the number of cycles. The impact of temperature on media viscosity is study with Mooney-viscosity relationship with temperature. In order to study the mechanism, a computational fluid dynamics (CFD) approach into the experiment was done to predict the abrasive particle-moving tendency. A two-dimensional model was constructed to study the effects of viscosity at different extrusion pressures

Wang et al. [10] used a CFD simulation method for getting smooth roughness in passage holes in AFM. The shear forces in the polishing process and the nature of the media plays a vital role in controlling the roughness of the wall. In this case, a power law model was established first by using the effects of shear rate in media viscosity and the coefficients of power law were found out of the algebraic equations from the relation between viscosities and shear rate. Applying the equations, the velocities, the wall shear and the strain rate was obtained. The CFD simulation was considered with and without the mould. Different parameters gave the optimal results for the material removed

Kenda et.al.[11] investigated the influence of the process parameters on surface integrity, i.e. induced residual stress and surface roughness. It is found that AFM is adequate to remove work-piece defected surface which is formed by electrical discharge pre-machined (EDM). X-ray diffraction method (XRD) is used to measurements of residual stresses with two components, along and transverse to the workpiece which is hardened tool steel AISI D2. Results suggest that surface roughness value along the job is lower than the transverse one that corresponds to flow direction of media. The specimens have been investigated by means of SURFASCAN profileometer to study 3D roughness.

Kursad et.al.[12] studied the effect of work-piece hardness on AFM process. The work-piece had been cut by wire EDM and roughness measurement was done before and after AFM process. The improvement of surfaces with respect to hardness was observed. It was noticed that the white layer formed by WEDM process was successfully remove by AFM process and the surface cracks were also removed with increases in fatigue strength. Harder materials have more surface improvement than softer materials.

Apurbba et al. [13] used ultrasonic assisted abrasive flow machining as a new variant of AFM in which the work piece was subjected to a vibration in orthogonal direction to the media flow. A special type of fixture was designed for the process and piezoelectric actuator provided the vibration. Commercially available simulation tool was used for the analysis of media responses in different machining parameters in terms of pressure, velocity distribution and temperature. The abrasive particles hit the wall at an angle, which affected the basic mechanisms involved, and the effectiveness of the process was increased. The high frequency assisted AFM mainly affected the wall shear more in comparison to the pressure and velocity profiles. It also stated that the temperature had no effect on the stability of the media.

Subramanian et.al.[14] describes the finishing of a hip joint which is made up of ASTM-grade (Co–Cr alloy) by AFM process. They reported that the extrusion pressure is the most significant process parameter to optimize and achieve nanometric surface finishing of a biomedical implant(medical device) employing a designed and fabricated abrasive flow finishing (AFF) system. Result suggested that lower working pressures are recommended for getting a better surface finishing and higher material removal rates. They emphasize the importance of AFF technique for nanometric surface finishing hip implants thereby promising significant cost benefits.

Table I summarizes above research efforts

Table I: Existing research efforts

S.N	Author and published Year	Contribution	Workpiece material	Technique/Model	Abrasive Media	Process Variables	Process Performance
1	Williams et.al (1992)	Stochastic modeling and analysis of abrasive flow machining	AISI 4140	Scanning Electron Microscopy (SEM), Data Dependent Systems (DDS) methodology and SAS	Medium-high viscosity with SiC	Extrusion pressure, media viscosity number of cycles	Metal removal and surface finish
2	Jain and jain et.al (1999)	Simulation of surface generated in abrasive flow machining process	Mild steel (0.25%C)	response surface analysis (RSA)	–	Extrusion pressure, abrasive mesh size, abrasive concentration, and initial workpiece roughness	Surface roughness
3	Rajendra et.al (2000)	Optimum selection of machining conditions in abrasive flow machining using neural network	Aluminium	ALM and GA	Mixture of putty and silicon carbide abrasive particles	–	–
4	Jain et.al (2001)	Evaluation of rheological properties of medium for AFM process	Brass and Aluminium	–	Bingham Plastic	Abrasive concentration, abrasive grain size and medium temperature	Metal removal and surface roughness
5	Sehijpal et.al (2002)	Development of magneto abrasive flow machining process	Brass	Response surface methodology and design of experiment	Silicon based polymer, hydrocarbon gel and the abrasive grains.	Magnetic flux density, Volume flow rate, Number of cycles, Abrasive grit size, Reduction ratio	Surface roughness and material removal rate
6	Gorana et.al (2003)	Experimental investigation into cutting forces and active grain density during abrasive flow machining	Mild steel	Scanning electron microscope and DOE (design of experiment)	Silly putty (Dow Corning 3179 dilatant compound), Abrasive grain-SiC	Extrusion pressure, Grain size, Abrasive concentration	Cutting forces (axial and radial), material removal, reduction in surface roughness (Ra value) and active grain density)

7	Jain et.al (2006)	Prediction of surface roughness during abrasive flow machining	Mild steel	–	Mixture of silly putty and silicon carbide abrasive particles	Extrusion pressure, abrasive mesh size, abrasive concentration, and initial workpiece roughness	Surface roughness
8	Sunil et.al (2007)	Effect of extrusion pressure and number of finishing cycles on surface roughness in magnetorheological abrasive flow finishing (MRAFF)process	Stainless steel	–	Carbonyl iron powder and silicon carbide abrasives dispersed in a viscoplastic base of grease	Extrusion pressure number of cycles	Surface roughness
9	Fang et.al (2009)	Temperature as sensitive monitor for efficiency of work in abrasive flow machining	AISI 1045, 1080 and A36 steels.	CFD software FLUENT 6.3 and Mooney viscosity meter	boron carbide abrasive particles and silicone rubbers with different viscosity	number of cycles, media viscosity	Material removal efficiency and surface roughness.
10	Wang et al. (2009)	Uniform surface polished method of complex holes in abrasive flow machining	Steel	CFD software	silicone gel and silicon carbide abrasive	Temperature, Extrusion pressure and number of cycles	surface roughness, strain rate and shear force
11	Kenda et.al (2011)	Surface Integrity in Abrasive Flow Machining of Hardened Tool Steel AISI D2	Hardened tool steel AISI D2	SURFASCAN and XRD	polishing media with silicon carbide abrasive and mesh size 80	Pressure(3.5 MPa, 6.0 MPa),volume flow, machining time(1800 s)	Surface roughness and residual stress
12	Kursad et.al (2013)	Hardness Effects on Abrasive Flow Machining	AISI D2 tool steel	wire electro discharge machining (WEDM)	mixture of a polymer-based carrier and Al_2O_3abrasive	Extrusion pressure, No. of cycles	Surface roughness
13	Apurbba et.al. (2015)	Simulation of media behaviour in vibration assisted abrasive flow machining	-	ANSYS FLUENT 14.1 software piezo actuator and a specially designed fixture.	Polyborosilaxane silicon carbide	Ultrasonic frequency Extrusion Pressure Processing time	Surface finish and material removal rate
14	Subramanian et.al (2015)	Nanometric Finishing on Biomedical Implants by Abrasive Flow Finishing	ASTM 1537-08 wrought Co-28 Cr-6 Mo alloy	Analysis of X-rays (EDAX), Atomic Force Microscopy EnergyDispersive and SEM	Mixture of a polymeric material and suitable abrasives.	Extrusion pressure, No. of cycles	Surface finish and material removal rate

V. CONCLUSION

AFM plays a vital role in manufacturing industries and from literature survey find that the manufacturing of precision jobs involves last stage finishing operations which account for approximately 15 % of the total manufacturing cost. This article presents a review of research work carried out in the investigations into optimization of AFM process parameters a review of research work on various optimization techniques indicated that there are successful industrial applications of Taguchi method, RSM, GA, DDS and SEM. Computational method is very effective to optimize the machining parameters to help reduce the cost and predict the desirable conditions. These are robust optimization techniques which make experimental design insensitive to uncontrollable factors such as environmental parameters to predict responses and optimize the AFM process parameter for good surface finishing and MRR. The literature review shows that process parameters including number of cycles, media temperature, and extrusion pressure, rheological properties of medium and abrasive concentration are the critical factors and these must be studied and analyzed for doing research in the proposed area of work.

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