Electro Chemical Machining in the Aid of Abrasive Flow Machining Process

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Abstract—*Performance of Abrasive Flow machining (AFM) process is usually marred by its low material removal capacity in the fine finishing of the surfaces, though the complexity of the surfaces which can be finished with this process is really astonishing. To enhance the performance of this process in the machining of internal holes or recesses, a new process namely Electro-Chemical Aided Abrasive Flow Machining (ECA2FM) process has been developed. It is a hybrid process of Electrochemical Machining (ECM) and Abrasive Flow Machining (AFM). In the present work, the intensified machining action has been observed due to the cooperation between the two above mentioned processes.*

Keywords: *Abrasive Flow Machining (AFM), Electro-chemical Machining (ECM), Electro-Chemical Aided Abrasive Flow Machining (ECA2FM).*

Introduction

Abrasive flow machining is a non traditional polishing process to polish metallic components using a semi-liquid paste, and with which complicated or miniaturised parts requiring high surface finish can be economically produced [1]. Abrasives laden media (made up of a liquid polymer with abrasive particles) is forced through a controlled passage for the simultaneous finishing of the required external/internal surface with a large number of randomly oriented cutting points. The abrasives laden media can be tailor made with different viscosities, abrasive types and sizes, concentrations of the constituents, etc.

In the recent times, work has been largely towards the hybridisation of AFM with other machining processes to achieve the higher material removal, faster and better surface finish for different shape/size work-pieces. Singh and Shan [2] developed Magnetic Assisted Abrasive Flow Machining (MAAFM) process by mixing the polymer base with ferromagnetic material for achieving more number of active grains in the cutting action. Walia et al. developed Centrifugal Force Assisted AFM (CFAAFM), by rotating the AFM media with different shaped rods [3&4] for improved machining. Sankar et al. developed Drill Bit-Guided Abrasive Flow Finishing (DBG-AFF) process, employing a drill bit for the simultaneous rotation of AFM media in place of prismatic rods [5]. Jones and Hull, developed Ultrasonic Flow Polishing (UFP) process, employing ultrasonically energised tool in addition to abrasives laden media flow for the polishing of complex dies and moulds [6]. Mulik and Pandey, concieved a new process, namely ultrasonic-assisted magnetic abrasive finishing (UAMAF), which integrates the use of ultrasonic vibrations and a magnetic abrasive finishing (MAF) process to finish surfaces to nanometre order within a short time span [7]. Dabrowski et al. developed Electrochemical Aided AFM (ECAFM) using polymeric electrolytes for the finishing of flat work-pieces. An increased material removal with deteriorating surface finish was noted [8 & 9].

In general, AFM is suitable for fine finishing of work-pieces with complicated intersections, complex inlet manifolds and ports, medical technology, hydraulic and pneumatic components, automobile, space and aeronautics industry [1].

In this paper, a new indigenous setup has been discussed for the finishing of internal surfaces of through holes or slots employing abrasive flow machining and electro-chemical machining processes simultaneously. This novel method of integrating AFM with Electro-Chemical Machining process has been termed as Electro-chemical Aided Abrasive Flow Machining (ECA^{2}FM). This hybrid finishing process improves the material removal from the internal surfaces and that too at very low pressures.

Schematic of ECA^{2}FM Process

It employs the Electro-Chemical aid along with the AFM, as has been experienced by Dabrowski et al. [8 & 9] for the fine finishing of flat surfaces. But the current process is a modified setup for the abrasive flow machining of hollow cylindrical surfaces (an advantage of AFM process over other finishing processes) and employs an axially concentric cylindrical cathode and work-piece as anode. The current setup employs the hydraulic system for the back and forth extrusion of the electrolytic abrasives laden media through the hollow cylindrical work-piece.

Electro-Chemical Aided Abrasive Flow Machining (ECA^{2}FM) process employs an axially held cylindrical electrode rod acting as the cathode, whereas the conductive material work-piece is made anode along with the usual abrasive flow machining. As the electrolytic salts-abrasives laden medium passes through the annular space between the stationary cathode rod and work-piece, it results in more machining due to the additional electrolytic machining along with the mechanical machining due to the cutting action of abrasives (Refer Fig. 1).

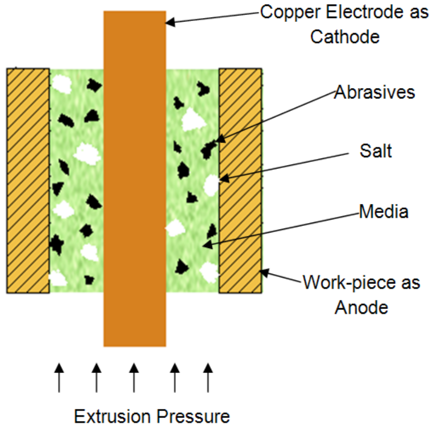


Fig. 1: Schematic of ECA²FM Process

The development of the ECA²FM encompasses of development of modified nylon fixture for the simultaneous holding of the hollow work-piece (working as anode) and axial-concentric cylindrical rod of copper (working as cathode) and developing a suitable electrolytic salts-abrasives laden polymeric media. A Scientech DC power supply with voltage range 0-30 V has been used on an already developed basic AFM setup [10] to supply the DC current to the electrodes (Figure 3). The fixture is made in two parts. The work-piece is held in seat, at the interface to two parts and the fixtures are clamped together with the help of screws. For the electro-chemical action, there is provision of fixing different diameter copper electrodes axially concentric with the hollow work-piece and the work piece is attached to the positive copper anode (Fig. 2).

Fig. 2: Nylon Fixture with Copper Electrodes

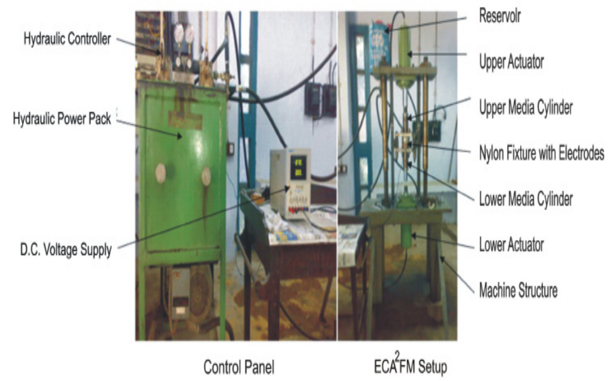


Fig. 3: Photographs of ECA²FM Control Panel and Setup

Media used for present investigation consists of silicon based polymer, hydrocarbon gel and Al_2O_3 abrasive particles with NaI salt. A Polymer-to-Gel (PGR) of 1:1 has been taken. Abrasives-to-media ratio has been kept constant at 1.25. Aluminium Oxide abrasives of grit size 600 have been used. The setup has the provision to extrude media at different pressures, media flow rates, media flow volume, stroke length, voltage, gaps between the electrodes and different number of cycles that are required to operate the system.

Experimental Design

The experimental design was according to One-factor-at-a-time approach. This method consists of selecting a starting point, or baseline set of levels, for each factor, and then successively varying each factor over its ranges with the other factors held constant at the baseline level. After all the tests are performed, a series of graphs are usually constructed showing how the response variable is affected by varying each factor with all other factors held constant [11]

The main process parameter for the present experimentation is Voltage (V, in volt), the other parameters of the experimentation have been kept constant. The quality characteristic under consideration is material removal (MR, in mg). The material removal signifies the amount of material that has been removed from a specimen in a specified number of process cycles. It is estimated by calculating the difference between initial weight of the specimen and final weight of the specimen after processing at a specified set of conditions by ECA²FM. For the present investigation, Work-piece material is Yellow Brass (65% Cu, 35% Zinc), having 156 BHN hardness [1, 2, 3 & 4]. The cylindrical hole has been machined in the test specimen by drilling operation followed by boring to the required size. Initial surface roughness of the specimens is in the range of 3.8 to 4.2

micron. The work-piece is a hollow cylindrical piece with I.D. 8mm, O.D. 10 mm and Length 16mm [3 & 4].

During the experimentation, the abrasives laden electrolytic polymeric media is extruded through the recess between the copper cathode rod and the inner surface of the hollow cylindrical work-piece. A combination of upward and downwards stroke completes a cycle and for the present set of experimentation the media has been extruded for ten cycles. The stroke length has been kept constant at 100 mm. During the experimentation the required D.C. voltage is supplied and is switched on just before the start of extrusion and is also switched off in the middle of the last stroke of the experimentation to achieve final finishing due to abrasive flow machining. The internal cylindrical surface of the work-piece is finished by the abrasion process due to the cutting by the abrasives and also due to the electro-chemical action under the supplied voltage. The experiments, process parameters, run order were planned as per Table 1, to study the effect of only one factor of voltage on the response parameter of material removal. Each experiment was repeated three times and the responses of respective experiments are also enlisted in this table.

Table 1: Process Parameters and Experimental Results for Material Removal in the One-factor-at-a-time Approach

Exp No.	Run Order	Response for Material Removal, MR (in mg)				
		V	R_1	R_2	R_3	Mean MR
1	1	Nil	23.1	25.4	24.1	24.20
2	8	2	25.4	25.2	26.6	25.73
3	2	5	28.4	26.5	27.8	27.57
4	7	10	31.8	29.4	30.8	30.67
5	6	15	33.4	32.9	31.5	32.60
6	3	20	34.5	35.8	34.6	34.97
7	5	25	36.3	38.8	36.7	37.27
8	4	30	40.7	36.8	37.9	38.47

Polymer-to-Gel Ratio: 1:1, Abrasives-to-Media Concentration: 1.25, NaI Salt concentration: 1 M (mole/kg), Work-piece material: Brass, Abrasive type: Al_2O_3, Abrasives Grit Size: 600 (13-16 micron), Media Flow Volume: 290 cm^3, Reduction Ratio: 0.95, Extrusion Pressure: 5 MPa, Number of Cycles: 10, Temperature: 32±2°C, Initial Surface Roughness of Work-piece: R_a 3.8-4.2 micron, Media Viscosity: 810 Pa.s., Cathode rod diameter: 3.3 mm.

R_1, R_2, R_3 represent response value for three repetitions of each trial.

Analysis and Discussion

The main effects for the process parameter, voltage (V) are determined based on the average of the raw response data. The main effect for the voltage is plotted in the Figure 4. The analysis of variance (ANOVA) is performed to determine the significance of the voltage parameter (Refer Table 2).

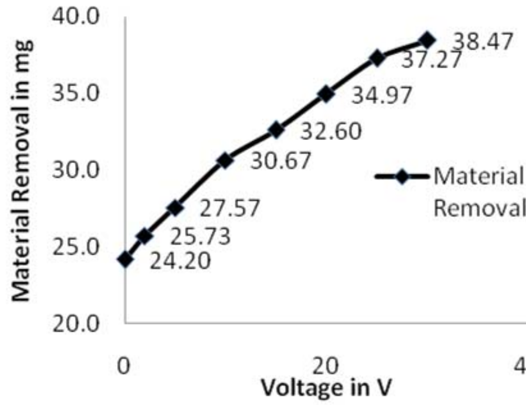


Fig. 4: Main Effects of Voltage on Material Removal

The main effects for the material removal for the process parameter of voltage show that the material removal increases almost linearly with the increase in the voltage for the electrochemical action along with the abrasive flow machining. The effect of the voltage was studied from nil-30V. From the ANOVA Table 3, it is observed that the effect of voltage on the material removal in the ECA^{2}FM process is significant for the quality characteristic of material removal (MR).

Dabrowski *et al.* [8&9] also observed similar results with a semi-liquid electrolytic paste with 1 molal concentration of NaI or KSCN salts and Al_2O_3/SiC abrasives in the machining of flat surfaces made of steel 1H18N9T with initial surface roughness of R_a = 0.81μm in the electrochemically assisted abrasive flow machining (ECAFM) process.

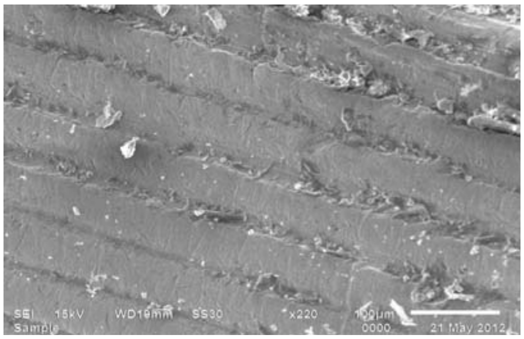
During the experimentation current of 0.1A amperage was noted. The noted increase in the material removal due to the electrochemical aid in the AFM signifies that the electro-chemical dissolution of the material helps in more abrasion during the abrasives cutting action.

Table 2: ANOVA (Material Removal)

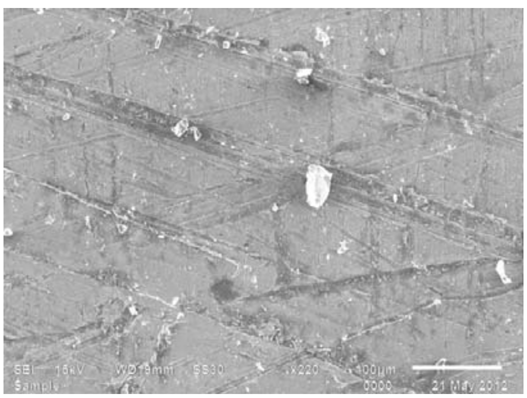
Source	SS	DOF	V	F-Ratio	P %
Voltage	593.07	7	84.72	58.23*	96.22
Error	23.28	16	1.45	--	3.78
Total	616.35	23	--	--	100.0

*Significant at 95 % confidence level
$F_{critical}$ = 2.66
SS–Sum of Squares, DOF–Degree of Freedom, V–Variance, P–Percentage Contribution of the treatment

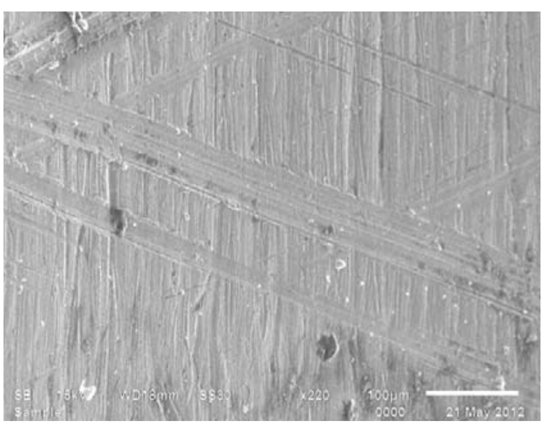
The influence of presence of electrochemical dissolution on the abrasion of the inner surface of the hollow cylindrical work-piece in the ECA^{2}FM process is evident from the set of representative SEM photographs as shown in Figure 5(a)–(c). SEM photographs of (a) finished work-piece (x220) without the electrochemical aid and having average finished surface roughness of R_a-0.85 microns corresponding to the first experiment, (b) finished with the electrochemical aid (x220) corresponding to the experiment no. 4 at 10V with the average finished surface roughness of R_a-0.49 microns, (c) finished with the electrochemical aid (x220) corresponding to experiment no. 8 at 30 V having the average finished surface roughness of R_a-1.07 micron.



(a)



(b)



(C)

Fig. 5: SEM Photographs of Finished Brass Test Pieces (X220): (a) without Electrochemical Aid (b) With the Electrochemical Aid at 10V, (C) With Electrochemical Aid at 30V

It can be seen from Figure 5(a) that the surface finish is less with the AFM process alone, as the boring tool marks are still visible signifying that lesser machining action has taken place. In the Figures 5(b &c) the surfaces are smooth and complete elimination of the boring tool marks is observed with the electrochemical action at voltages of 10V and 30V respectively. So with the ECA^2FM process more machining takes place and the surface first smoothens with the increase in the voltage (up to 10V for the present set of experimentation) and afterwards at higher voltages (say of 30V) it becomes a little rough due to the deeper scratches by the abrasives on the surface as is visible in the figure 5(c). At higher voltages the scratches are deep because of the more softening of the surface due to enhanced electrolytic dissolution.

Conclusion

The important conclusions of this research work are:

- The abrasion of the material is intensified due to the cooperation of electrochemical dissolution with the abrasives cutting in the Electro-Chemical Aided Abrasive Flow Machining (ECA^2FM) process.
- The material removal goes on increasing with the increase in the applied voltage.
- Better surface finish is achieved with this process, but at the higher operating voltages the surfaces are rough due to more material electrolytic dissolution resulting in the deeper scratches on the surface.

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