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Magnetic field effect on Abrasive Flow Machining Process

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1. Abstract

Abrasive flow machining (AFM) is a generally most recent machining procedure among non-traditional machining processes. Particularly low material removal rate happens to be one of the limitations of the processes. Limited efforts have been directed towards improving the efficiency of these processes so as to achieve better results by applying different techniques. This paper talks about the conceivable improvement accomplishments in the surface finish by applying a magnetic field around a test specimen in AFM. An abrasive flow machining experiment set-up has been created to acquire a procedure termed magneto abrasive flow machining (MAFM), and the impact of key parameters on the general execution of the process has been considered. Relationships were developed between process parameters and the percentage improvement in surface finish of stainless steel 318 components when finish-machined by this process. Analysis of variance has been connected to distinguish critical parameters and to test the ampleness of the models. Experimental results indicated that performance of MAFM significantly improved over AFM. Leading to improve internal surface quality of products such as heat exchanger, plastic dies and others. Many of industries are concerned in MAFM produced surface quality such as army, aero-planes, atomic reactors and computers industry.

Keywords*:* Abrasive flow machining; Electromagnet; Magneto abrasive Flow Machining; Magnetic abrasives

2. Introduction

Abrasive flow machining (AFM) is a relatively new method of super finishing internal surfaces of complex shape parts, which can be considered as an excellent way for deburring, polishing, removing recast layers, and to produce fine surface with a compressive residual stress [1]. Very low levels of surface roughness and close tolerances have been achieved for internal surfaces of complex shape components [2]. Semi-solid medium consisting of a carrier which is a polymer-based and abrasive material in a typical percentage are extruded under pressure through the internal surfaces to be machined. The crossing media acts as a deformable grinding or polishing tool whenever it is subjected to any restriction. A special workpiece fixture is required to create restrictive passage to direct the crossing media to the desired locations in the work-piece.

Extrude Hone Corporation, USA, originally presented the AFM process and its machine tools in 1966. Since then, a few empirical studies [2–6] have been carried out and also modeling of generated surface and monitoring of process was conducted by Williams and Rajurkar [7] during the late 1980s. Their work [8] was mainly related to on-line monitoring of AFM with acoustic emission and stochastic modeling of AFM. Loveless et al. and Kozak et al. [9,10] investigated the effect of previous machining process on the quality of the surface produced by AFM and the flow behavior of the medium used in the process. Fleticher and others [11,12] have reported many studies on the rheological properties and the medium response Affected by temperature in AFM. Przyklienk [13] has led parametric investigations on AFM. Research work that concern math-ematical modeling, simulation of material removal and surface generation with the help of finite element and neural networks was presented by different researchers [14–15]. Steif and Haan [16] suggested the presence of 'dispersive stresses', which initiate wear of the surface during abrasive flow machining. The dispersive stresses are created as a result of the contrast between stresses acting on abrasive particles and stresses in the encompassing medium. Jonies and Hull [17] have reported a modification of AFM by applying ultrasonic waves in the media for machining cavities to improve results.

These procedures can be classified as hybrid machining processes, an ongoing idea in the headway of non-conventional machining. The purposes behind creating hybrid machining processes are to utilize or mutually enhanced advantages and to avoid or diminish some of the adverse effects the constituent processes produced when they are individually applied. Rajurkar and Kozak [19] have described around fifteen various processes under hybrid machining processes. In Egypt, Prof. M abdel Mohsen Mahdy originally created first process setup in 2002, since there a lot of researches had carried out in investigation of media behavior, analysis of flow force and process parameter analysis [20].

The present paper reports the starter consequences of a progressing research project being conducted with the aim of investigating techniques for improving material removal rate (MRR) and upgrading surface finish in AFM. One such technique studied conduct a magnetic field around the workpiece. In the past magnetic fields have been effectively exploited, such as machining force in magnetic abrasive finishing (MAF), utilized for micromachining and finishing of components, especially circular tubes. Shinmura and Yamaguchi [20] and more recently Kim et al. [21], Kremen et al. [22] and Khairy [23] have detailed examinations studies on (MAF). The procedure under investigation is the combination of AFM and MAF, and it is given the name (MAFM).

3. Experimental set-up

3.1. MAFM set-up

An experimental set-up was designed and fabricated as shown in (Fig. 1). It consisted of two cylinders, fixed and movable one (1) containing the media. The flanges facilitate clamping of the fixture (7) that contains the specimen (2). Two stud bolts (8) also support the movable cylinder. The set-up is integrated to a hydraulic circuit (10) that consist of pump pressurizing two hydraulic cylinders (6) through a number of hoses and hydraulic filter and being controlled via control unit (9). The media flow rate acting on piston of the press was made adjustable by controlling in hydraulic flow rate. Right and left movement (one complete cycle) is controlled by two limit switches. Hydraulic pistons acting towards media cylinders pressurizing media into specimen passage, therefore making machining action at the end of the stroke the right cylinder completely transfers the media through the workpiece to the left cylinder. Two strokes make up one cycle.

3.2. The fixture

The test specimen installation fixture was made of stainless steel, a non- magnetic material. It was designed to suit electromagnet poles such that the extreme magnetic pull occurs near the inward surface of the specimen. It consists of two halves containing specimen shaped cavity to ensure the fixation of the specimen in a horizontal direction. The cylinder restrictor is designed of tapered end making a gap in the inner side of the specimen to enforce the media flow towards the inner side of the specimen.

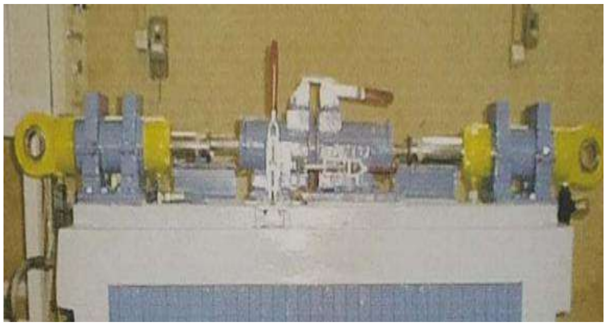

Figure 3-1 the real arrangement of the magneto abrasive flow machining process

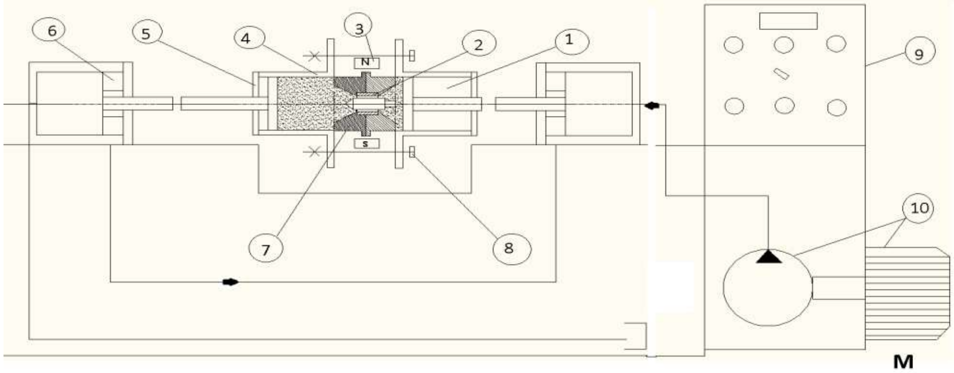

Figure 3-2 arrangement of the magneto abrasive flow machining process

3.3 The electromagnet

The electromagnet was created and fabricated for its location around the barrel-shaped specimen. It consists of two poles that are encompassed by copper coils arranged in such a manner as to provide the maximum magnetic field near the whole inward surface of the specimen. Table 1 gives the used electromagnet specifications.

Table 1
Specification of the electromagnet

Pole and yoke material	M. S. 0.25% C
Each pole size	35 mm diameter
Coil	Copper wire, ∅ 1 mm, 1500 turns
Power supply	0–50 V, 0–6A
Maximum flux density	0.9 T at 3.5 A

3.3. The abrasive medium

The medium used for this study consists of anon-magnetic carrier like silicon-based polymer, carbonyl iron and the abrasive grains. The abrasive used for this experimentation has essentially to be magnetic in nature. An abrasive called Brown Super Emery (trade name), supplied in the Egyptian market, was used and it consist of 40% ferromagnetic particles, 45% Al_2O_3 and 15% Si_2O_3.

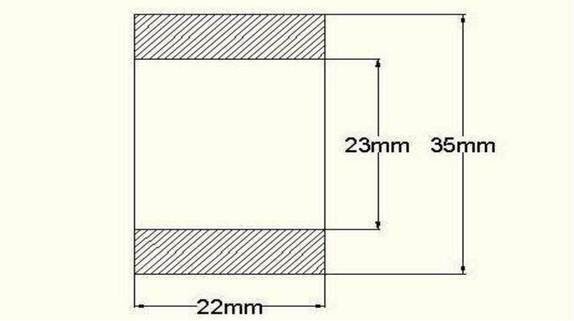

Figure 3-3 test specimen

4. Modelling

4.1. Process parameters

The following process parameters were hypothesized to influence the performance of MAFM process:

1. flow rate (volume) of the medium;
2. applied magnetic flux density;
3. number of cycles conducted;
4. extrusion pressure in abrasive cylinders;
5. viscosity of the medium;
6. grain size and concentration of the abrasive; and
7. workpiece material.

4.2 Design of experiments

With the help of design of experiment techniques, the effect of process effects has been determined within a specified range of process factors. Independent process parameters represented in quantitative form as:

$Y = f(X_1, X_2, X_3, \ldots, X_n)$ □ e, where Y is the response , f is the response function, e is the experimental error, and $X_1, X_2, X_3, \ldots, X_n$ are independent parameters of the process.

MR and percentage improvement in surface roughness value (%R_a) were considered as the response parameters. Cylindrical workpieces made of stainless steel 318 were chosen as test specimen. The size of the test specimen, shown in Fig. 2, was based on the guidelines given in [10]. An electronic balance (Metler, LC 0.001 g) and a Mitutoyo (Serftest, 301) were employed for the measurements of MR and surface roughness, respectively. The roughness was measured in the direction of flow of the abrasive media. The test specimens were chosen from a large set of test specimens in such a way that selected specimens had inherent variation in their initial surface roughness values in a tight range. It was not possible to remove this variability completely; hence percentage improvement in surface roughness (%R_a) has been taken as the response parameter in surface finish measurement. The roughness values were recorded by averaging the readings of five points on the internal surface of test specimen. Independent parameters real levels and constant parameters are introduced in Table 2.

5. Results and discussion

5.1 Effect of parameters on response

The response equations for MR and % Ra obtained from the experimental data are as follows:

MR = 59.687 - 12.19 No. of cycles_1
- 3.69 No. of cycles_2
+ 4.56 No.of cycles_3+ 11.31 No.of cycles_4
+ 0.81 Media Flow Rate_1+ 0.56 Media Flow Rat
e_2
- 0.44 Media Flow Rate_3
- 0.94 Media Flow Rate_4
- 18.19 Magnetic Flux Denisty_1- 9.69 Magnetic
Flux Denisty_2
+ 9.56 Magnetic Flux Denisty_3+ 18.31 Magnetic
Flux Denisty_4

And %Ra =0.63771 - 0.2032 No. of cycles_1
- 0.0904 No. of cycles_2+ 0.0699 No. of cycles_3
+ 0.2236 No. of cycles_4
- 0.0534 Media Flow Rate_1
- 0.0609 Media Flow Rate_2
+ 0.0585 Media Flow Rate_3
+ 0.0557 Media Flow Rate_4
0.1351 Magnetic Flux Denisty_10.078
Magnetic Flux Denisty_3+ 0.1393 Magnetic Flux Denist
y_4. Magnetic FluxDenisty_2+ 0.0716 Magnetic Flux

Table 2
Levels of independent parameters

Parameter	Symbol	Level			
		−2	−1	0	1
Magnetic flux density (T)	*A*	0	0.3	0.6	0.9
Volume flow rate (cm^3/min)	*B*	15700	20935	26170	31405
Number of cycles	*C*	2	4	6	8
Medium flow volume	1570 cm^3				
Abrasive grit size	355 µm (80%)+53µm (20%)				

Figures 1 and 2 show the simultaneous effect of magnetic flux density and medium flow rate on MR and % R_a respectively, at a constant number of cycles. The response surfaces for % Ra and MR obtained by the variation of cycles at a constant medium flow rate are shown in Figures. 3 and 4, respectively. From these figures, it can be clearly observed that material removal and percentage improvement of surface roughness both increase with the increment of applied magnetic flux density. The impact of the magnetic field is typically more ordinarily beyond a magnetic flux density of 0.2 T. The concurrent increment in MR and % Ra indicates a unique behavior of AFM when compared with other machining processes. This outcome supports the findings reported in [6]. One conceivable reason could be that, in AFM, the material removal takes place first from hills or surface profile peaks. More material removal creates a smoother surface. In other words, the more material removal the littler is the height of hills or peaks on the surface, and subsequently, the lesser is the roughness of the surface. This holds great until all of the high hills are removed and a significant smooth surface is produced. It is likewise clear from the trend of the surface obtained in Figures 1 and 2 that the magnetic field interacts with the medium flow rate in both the material removal and surface roughness investigations.

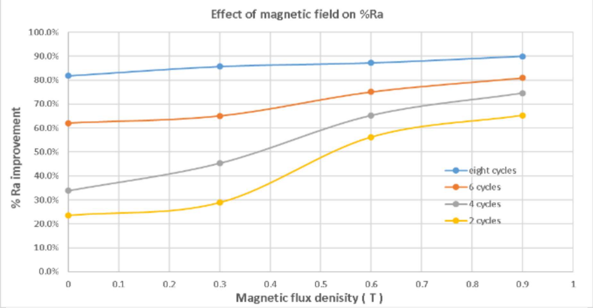

Figure 5-1 Effect of magnetic flux density and medium flow rate on %Ra

At higher flow rates, low significant of the magnetic field appears. This is probably due to the fact that, at the lower medium flow rate, the abrasive grains are pulled to the surface by the magnetic field for a longer period, bringing about a more concentration on the workpiece walls. On the other hand, the abrasive particles may not get pulled out to the wall by the magnetic field when the medium is moving fast. Further, the fast-moving medium takes the abrasives out of the influence of the magnetic field before they are able to strike the surface, and hence the magnetic field becomes somewhat ineffective at high medium flow rate with regard to its utility to enhance MR.

Figures. 3 and 4 indicate that whereas the material removal continues to improve with an increase in the magnetic field, %Ra appears to start stabilizing at higher densities of the magnetic field

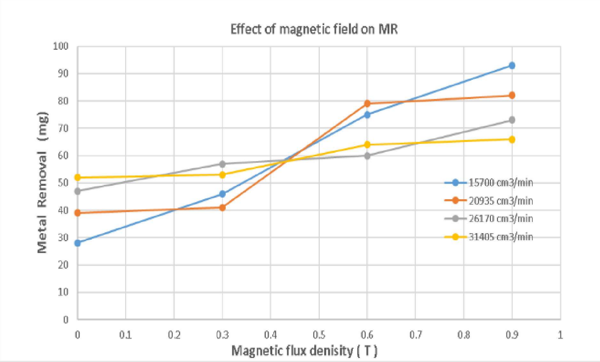

Figure 5-2 Effect of magnetic flux density and medium flow rate on MR

This type of trend may be noted from Fig. 4 also, where the %R_a is getting stabilized especially at higher flow rate. This result further confirms the material removal mechanism (from peaks. of this process discussed earlier. However, further work is being undertaken to find the upper limit of magnetic field that is effective for enhancement of both MR and % R_a as a function of medium flow rate. It is expected that once all of the peaks are removed from the surface, the enhanced MR due to applied magnetic field may not further improve the surface roughness.

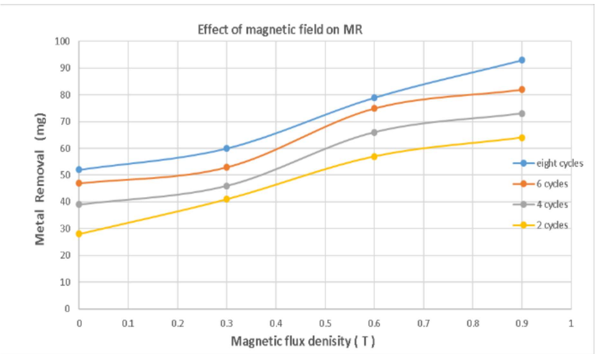

Figure 5-3 Effect of magnetic flux density and medium flow rate on%Ra

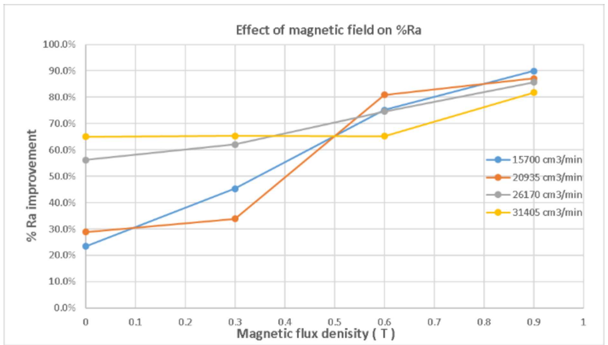

Figure 5-4 Effect of number of cycles and magnetic flux density on %Ra

In Figures 5 and 6, the variation of MR and % R_a with medium flow rate and number of cycles is depicted in the case of keeping the applied magnetic field constant. The effect of medium flow rate on MR and % R_a for any number of cycles remains insignificant. These findings do not match those reported in [13], where, with increase in medium flow rate, the material removal and improvement in surface finish increase. This is probably due to the media flow rates difference in the two used experiments. However, the findings of the present study confirm the reported results of Williams and Rajur-kar [6] in that the effect of medium flow rate on MR is insignificant;

almost the same ranges of media flow rates were conducted in the two studies. Figures 5 and 6 show that the abrasion rate is greater during the initial few cycles, after which it slows down. This is a consequence of the fact that, initially, the total peaks available upon the surface of the workpiece are more. The greater the number of peaks, the more will be the material removal. However, as the surface is subjected to repeated cycles, the number of peaks and their heights continue decreasing, and hence the material removal declines after a few cycles

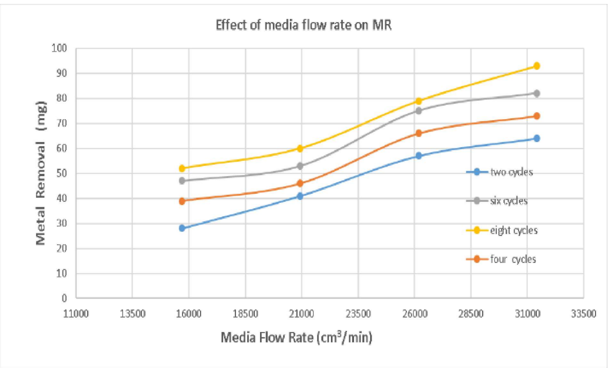

Figure 5-4: Effect of medium flow rate and number of cycles on MR

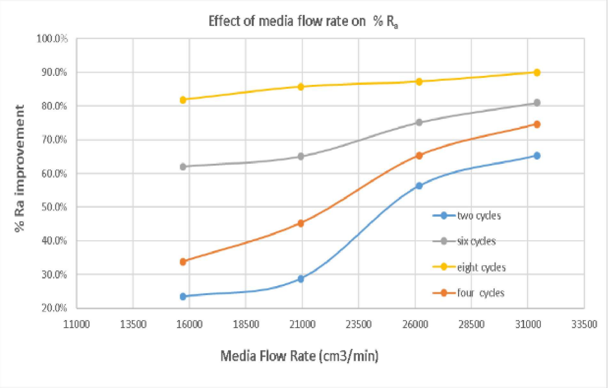

Figure 0-6 Effect of magnetic flux density and media flow rate on %Ra

1. Conclusions

The magnetic field applied to abrasive flow machining process around the specimen has led to enhancement of material removal rate and surface finish listed below:

1. Magnetic field application significantly affects both MR and %R_a. and slope of the curve indicates that MR increases with magnetic field more than improvement in %R_a does. Therefore, more improvements in MR are expected by increasing magnetic field density.
2. For a given number of cycles, MR and surface finish are significantly improved. Fewer cycles are required for getting the same results of metal removal from the component, if processed in the magnetic field existence.
3. Magnetic field and medium flow rate interact with each other. The combination of low flow rates and high magnetic flux density yields more MR and higher improvement of %R_a.
4. Medium flow rate has a significant effect lower than number of cycle and magnetic flux density on MR and %R_a in the presence of a magnetic field
5. MR and %Ra both level off after a certain no. of cycles

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