

Mathematical Modelling of Magnetic Abrasive Machining Hybrid Operation: A Review

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Abstract

Magnetic Abrasive Finishing (MAF) or super finishing is a modern unconventional finishing technique to produce high quality of parts, which is controlled by a magnetic energy. Magnetic abrasive operation develops some of the mechanical properties such as the surface quality. Nowadays, many of the traditional finishing technique such as honing, polishing and grinding are now being replaced by this process. In this review, principles of the MAF process, processing factors and their influence on the responses, the process modeling and development of the MAF method for flat surfaces will be examined in details research work in the literature. Additionally, there is a new type of MAF connected with Electrochemical Machining (ECM) to produce Electrochemical Magnetic Abrasive Machining (EMAM). The performance of models and multi-optimizing for predicting the responses such as metal removal rate (MRR), surface finish (SF), heat affected zone (HAZ) etc. are found to comparable in terms of the prediction accuracy and speed.

Keywords: Magnetic Abrasive Machining, Mathematical Modelling.

1. Introduction

Finishing is among modern methods which are done on the workpiece. This operation considerably effects the performing and lifetime of the product. There is a direct relation between the surface roughness, machining accuracy, and life span of the produced part. The increasing development of the automation in industries and increase in robots and numerical control machines lead to the achievement of great accurate surfaces with extra fine surface roughness [1]. MAF is one of foremost practice which applies a measured magnetic force to surface roughness. In MAF, a tool which involves of abrasives and powder particles is bendable in nature. To minimal the damage of surface, mild/flexible final conditions are obligatory, specifically, a small level of controlled force. Magnetic field aided manufacturing operations are becoming operative in finishing, deburring, burnishing and cleaning of metal and advancing engineering materials parts. MAF is one of the unconventional machining operations that came to the surfaces in an obvious by H. Coats in 1938 [2]. MAF has a great potential to be used extensively by the industries as it can form a high quality mirror like finished surface for various simple and until complex surface forms. Nonetheless, it is fewer effective on difficult to machine [3]. A hybrid MAF approach is mixes the MAF process with another non-conventional machining NCM process such as ultrasonic assisted magnetic abrasive finishing (USMAF), electrochemical magnetic abrasive finishing (ECMAF) etc. in order to improve its response characteristics [4]. This paper reviews the research trends on various aspects of Hybrid MAF, Modeling & optimization in Hybrid MAF. The results are summarized and presented in the form of graphs.

2. MAF and its integration with NCM

2.1. Magnetic abrasive finishing

In MAF, the distance between the W.P and the magnet called gap which is filled with abrasive and magnetic particles. abrasives and magnetic particle can be employed as bonded (joined) or unbounded. Bonded (joined) abrasive and magnetic particle are organized through abrasive particles and ferromagnetic particles, unbounded abrasive and magnetic particles are combination of abrasive particles and ferromagnetic particle with a minimal quantity of lubrications. The abrasives can be employed like (Al_2O_3), (SiC), diamond and boron nitride. The abrasive particle and magnetic, after the use of magnetic field, joint each other lengthways the magnetic form a flexible magnetics abrasives brush and lines force between the pole and the W.P. The brush transmits on like a multi-points machining apparatus for finishing operation. At the point when the magnet turns, likewise grinding wheel like an adaptable crushing wheel and completing is carried out as per the powers following up on the abrasive particles [5].

2.2. Ultrasonic Machining (USM)

Regardless of the electrical conductivity of the W.P, the USM operation is generally used for brittle and/or hard materials frequently having hardness over than 40 RC. A slurry (It is a combination of soft water and particles) is placed in the gap between W.P and tool. At very high frequency (above 16 kHz), the tool vibrates. This frequency is formed by an ultrasonic transducer which transforms the great frequency electrical signal to a great-frequency linear mechanical movements. By mechanical amplifier, this vibration is transferred to the tool which is planned to vibrate at its resonance frequency with the aim of the extreme metal removal rate (MRR) can be attained. This operation has the benefit of machining brittle and hard materials into intricate shapes with sensible finishing and perfect accuracy [6].

2.3. Electrochemical Machining (ECM)

Depended on Faraday's law of electrolysis, ECM works. The remarkable characteristics of electrolysis is the electrical energy is utilized to form the reaction, hence the machining operation depended on this basis that is called as ECM. In ECM, a minor DC possible (5–30 Volt) is utilized through the W.P (anode) and the tool (cathode). Between these two electrodes, electrolyte flows in the gap as displayed in Fig. 1 [7].

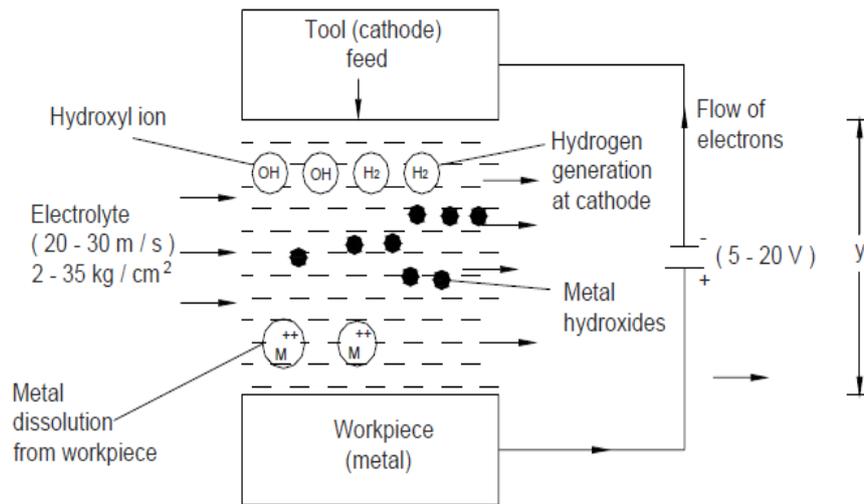
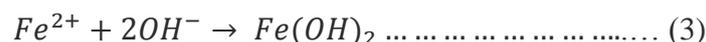


Fig. 1. Diagram of ECM [7].

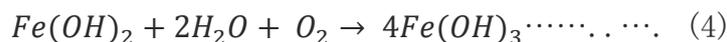
The electrical circuit is completed when the electrons move between the ions and electrodes. During the current flow in the electrical circuit, the metal is separated into the form of atoms (atom after atom) from the anode and shows as ions (Fe^{+2}) in the electrolyte. These ions form the metal hydroxides precipitate ($Fe(OH)_2$) (Fig. 1). water molecules get electrons during the water electrolysis from the cathode so that they detach into hydroxyl ion and hydrogen gas (free) as [7]:



The charged ions (positively) evidence in the electrolyte because the anode dissolves and in turn binds with hydroxyl ions that are negatively charged to produce metal hydroxides



Hydroxides show as precipitate and therefore do not affect reactions.



The change formed quantity by the same charge amount is commensurate with the chemical equivalent weights of the metal. It can be written with the following formula:

$$m = \frac{AIt}{ZF} \dots \dots \dots (5)$$

Where m is the metal deposited mass (gm), A is gram atomic weight, I is the current (A), t is the time (s), Z is the valiancy dissolution and F is constant of Faraday (96500 as).

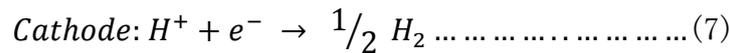
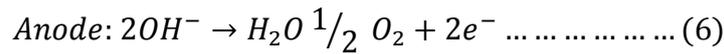
2.4. Ultrasonic assisted Magnetic abrasive finishing (UAMAF)

An UAMAF is a mixture finishing operation. In UAMAF, ultrasonic vibrations are inserted in the finishing region of MAF operation to finish the W.P surface high effectively as compared with MAF (usually expressed in nano-meters uint) [8]. In a finishing operation there are two kinds of forces that act through the surface finish of

the W.P especially with UAMAF, specifically, cutting force and normal force. The cutting forces have frontal effect on the creation of the accuracy while finished surface influence on the W.P [9].

2.5. Electrochemical Magnetic abrasive finishing (ECMAF)

The ECM happen in the existence of an electrolyte and current supply between W.P (anode) and tool (cathode), which develops Al₂O₃ on the W.P internal surface. Both cathode and anode can be expressed by the electrochemical equation as following: [10].



From (6), we comprehension that the O₂ gas is emitted at the anode. The O₂ interact directly with Al to produce Al₂O₃ film which is generates pit on the surface. Beside the ECM, MAF happen to eliminate the Al₂O₃ film. The slurry (Fe powder, polishing agent and white Al₂O₃), be magnetized on the magnet side of the mixture tool to produce magnetized particles. The machining influence caused by white Al₂O₃ abrasives that moving with particles which is magnetic finishing the tube surface during this operation [11].

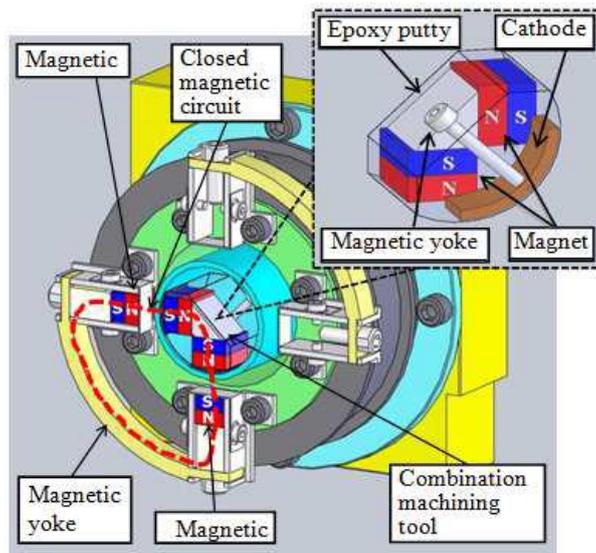


Fig. 2. Processing principle of ECM [11].

Fig. (2) shows the processing principle of MAF with integrated electrochemical finishing and tool structure. The tool has two purposes; electrochemical finishing and MAF.

3. Process Parameters

Many process parameters of MAF combined with ultrasonic such as ultrasonic vibration from one side and electrochemical such as electrolytic current, rotational speed of W.P, frequency of vibration, particle size, working gap etc. from other side.

4. Important literature

Several authors worked to enhance the conventional MAF operation and attempted to integrate other nonconventional operations to beat the restriction. Some of the chief literatures is discussed below.

Nanz and Camilletti [12] associated model of CMP to realize and examine assumptions of the model. They stated that both prime removal mechanisms (chemical and mechanical) depend on the passive removable layer and hence accurate the model of the operation is crucial to realize the operation.

Kim and Choi [13] analyzed the finishing specific of a Cr coated roller with anew improved magnetic electrolytic abrasive polishing (MEAP). The authors concluded that the finishing effectiveness was improved by adding the magnetic field.

Wrschka et al. [14] assessed performance of two Al_2O_3 and two silica based slurries in CMP of Cu specimen. Finished Cu specimens were examined utilizing SEM. The authors showed that low etch rates of the slurry chemistry is favorable for better removal.

Yan et al. [15] incorporated electrolytic operation with MAF to get a passive oxide film on the work piece which is easier to eliminate as compared to base metal. They showed that at current of higher electrolytic the finishing features were enhanced as compared to MAF. Rising both RPM of W.P and the electrolytic current improved finishing effectiveness, and the Ra enhanced quickly.

Yin and Shinmura [16] investigated the effect of vibration on the finishing process of the surface with low curvature. Workpiece in horizontal and vertical and combined orientations was vibrated in high amplitudes and low frequencies and its influence was investigated on magnetic field, finishing pressure on abrasive particles, and process performance. Vibration in vertical and horizontal directions had the highest influence in reducing of the surface roughness.

El-Taweel et al [17] considered RSM for molding and analysis of MRR and reduces Ra in a hybrid Electrochemical Turning (ECT) operation and MAF of Al/10% wt Al_2O_3 composite bars in terms of applied voltage, magnetic flux density, RPM of W.P and tool feed rate. The author highlights the characteristics of the enhancement of global mathematical models for linking the higher-order and interactive and highlights the several test results that prove the verity and correctness of the confirmed mathematical model for in-depth study of the influences of hybrid ECTMAF parameters on the output (MRR and Ra). Additional, optimum integration of these parameters has been assessed and it can be utilized to increase MRR and decrease Ra. The results evidence that aiding ECT with MAF give an increase in resultant surface nature significantly and machining effectiveness, as compared to that accomplished with the conventional ECT of some 0.147 and 0.33, respectively.

Im et al [18] studied the finishing of stainless steel rod of $\Phi 3$ by using diamond based UMA and achieved a R_y as fine as $0.06 \mu\text{m}$ and roundness as fine as $0.12 \mu\text{m}$.

Mulik and Pandey [19] used ultrasonic vibration with MAF on a AISI 52100 specimen. With the help of experimental outputs, the authors stated that with use of

ultrasonic vibration with MAF tangential force enlarged, which aided in getting well surface finish.

Mulik and Pandey [9] investigated and modelling of torque and finishing force in UAMAF process. the finishing torque and normal force have been estimated at several process conditions. Finishing gap and amount voltage to the electromagnet have been showed to be the major factors affecting the torque and finishing forces. Mathematical models built on process physics have been enhanced to predict the torque and finishing force. The enhanced model predicts torque and force as a function of W.P hardness, machining gap, and supply voltage. The enhanced mathematical model for finishing torque and normal force have been established and were found to be in perfect concord with experimental results.

Kala et al. [20] executed experiments with USMAF to polish Cu alloy and analyzed the output. The authors stated that adding of ultrasonic vibration with MAF lead to great improvement in finishing of paramagnetic W.P.

Judal et al [21] presented the machining output of cylindrical electrochemical MAF [EC MAF] for great effectiveness machining of AISI SS cylindrical surfaces by using SiC-based UMA and found that electrolytic current and rotational speed of workpiece have a major effect on surface finish and metal removal rate.

Judal et al [22] developed vibration assisted cylindrical MAF (VAC–MAF) set up also investigated various process parameters by using Al_2O_3 based UMA for finishing of Aluminum cylindrical surface.

Liu et al [23] developed EMAF set up and carried out finishing of Al 6061 plane surface by using SiC-based UMA and found that EMAF operation is capable to get superior surface quality and greater material removal compared to conventional MAF.

Sihag et al [3] concentrated on fabrication and designing of experimental set up to achieve Chemo-Ultrasonic Assisted Magnetic Abrasive Finishing (CUMAF). Using this technique have been carried out on Cu alloy W.P and the influences of several process conditions on $\% \Delta Ra$ was noted. Design of experiments using RSM and ANOVA were used to realize contribution of several conditions and interactions on $\% \Delta Ra$. Regression model was enhanced to fit the $\% \Delta Ra$ in terms of major process conditions and interactions. Additional the enhanced model was conformed and was optimized using genetic algorithm to increase the performance of the enhanced process.

Amineh et al [24] developed a new setup by integrating ultrasonic floating abrasion and MAF operation. Ultrasonic vibrations are provided to the permanent magnet, attached to the horn and put inside the tube for finishing. The finishing region parts are obscured in water to gather advantage of cavitation collapse pressure. Workpiece of smaller diameter While finishing rods of smaller diameter it becomes imperative to retain its roundness.

Misra A. et al [8] presented model for surface finish through UAMAF operation. The authors assume that there is an instantaneous rate of surface roughness proportional to the quantity of irregularities existing on the surface and MRR. The model of the productivity (MRR) was existed, it to be referred to two immediate and independent phenomena a transient material removal and a steady state material removal. The productivity model has additional been utilized to model the immediate arithmetical mean value during surface finish. The arithmetical mean value model not only incarnate

the effect of original Ra value but also ingest a critical Ra value less which no dropping in roughness is conceivable. The inverse method was used to predict the constants in the model. A simulation of 3-D Ra profile has also been offered to see the influence of finishing numerically. The enhanced model fitted the Ra in UAMAF as a function of working gap, amount voltage, rpm of the electromagnet, frequency and amplitude of ultrasonic vibration, initial Ra and hardness of the W.P. The fitted value shows a pretty approval with the experimental output with an extreme error of 7.35%. The model confirms that an exponential correlation exists between finishing time and instantaneous surface roughness value during finishing.

A. Singh et al [25] prepared review about Mathematical Modelling and Prediction Perspectives for EMAM Hybrid Machining Process. The authors were highlight mathematical modelling of operation parameters and recital parameters for EMAM process. The untapped recital potential of EMAM process at implementation levels is in the study to a specific experimentals machine. Consequently, mathematical modelling has been summarized toward ensure superior recital of machining experimental setup.

4. Conclusions

1. Most of authors used Taguchi method and RSM to model, predict and optimize the response expect some of authors used ANN.
2. Many authors used current, rotational speed, type of particle, particle size and workpiece as process conditions.
3. Surface roughness, torque, finishing forces, MRR and hardness were used as output parameters.
4. A few of authors were used Finite Element Method to get mathematical model in hybrid MAF.

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النموذج الرياضي لعملية التشغيل بالحك الممغنط الهجين: مراجعة

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الخلاصة

الانتهاء بالحك الممغنط هو طريقة انهاء سطحي غير تقليدي لإنتاج اجزاء ذات نوعية عالية والتي يسيطر عليها بالطاقة المغناطيسية. طورت عملية الحك الممغنط بعض الخواص الميكانيكية للسطح. بعض طرق الانتهاء السطحي التقليدية مثل تنعيم السطح الداخلي، التجليخ والتنعيم الخارجي بدلت الان بهذه الطريقة. في هذا البحث (مراجعة) سنتناول بالتفصيل اساس عملية الانتهاء بالحك الممغنط، متغيرات العملية وتأثيرها على المخرجات (الاستجابة)، نمذجة العملية وتطورها للسطوح المستقيمة. اضافة الى ذلك هناك نوع جديد من الانتهاء بالحك الممغنط المندمج مع التشغيل الكهروكيميائي لإنتاج التشغيل بالحك الممغنط الكهروكيميائي. اداء النموذج الرياضي والامتلية المتعددة لتتبا المخرجات مثل معدل الازالة المعدنية، الانتهاء السطحي والمنطقة المتأثرة بالحرارة... الخ وجدت للمقارنة بدلالة دقة وسرع التنبؤ.

الكلمات الدالة: التشغيل بالحك الممغنط، النموذج الرياضي.