The Effect of Operating Parameters of MAF Process on the Surface Roughness for Ferromagnetic Materials

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Abstract:-

Magnetic abrasive finishing (MAF) process, Taguchi design of experiments (DOE) is applied to find response parameters effecting the surface layer quality by using change in surface roughness generated. Important operating parameters effecting the surface layer quality generated during the MAF are identified as: (1) finishing time, (2) dose (volume of powder), (3) current (DC) applied to the electromagnet and (4) feed rate. Using response surface methodology(RSM) the predicated mathematical model, Experimental results show that for a change in surface roughness (ΔRa), feed rate and finishing time are found to be the most significant parameters followed by dose(volume of powder) and then current. Experiments are carried out with ferromagnetic (work piece) stainless steel 420 plate. The model sufficiency is very satisfactory as the Coefficient of Determination (R^2) is found to be 98.80% and adjusted R^2-statistic (R^2 adj) 97.60%.

Keywords; Response surface methodology (RSM), surface roughness, MINITAB software ,ferromagnetic, Magnetic abrasive finishing (MAF)

1. Introduction

Advanced technology of industries requires very ultraclean and smooth finished surfaces for their Complex and critical applications. The technology for super finishing needs ultra clean machining of advanced engineering materials such as silicon nitride, tungsten carbide, industrial diamond, and aluminum oxide which are used in high- technology industries and are difficult to finish by conventional grinding and polishing techniques with high accuracy, and minimal surface defects, such as micro cracks, in order to get the higher mechanical properties surfaces. A small amount of material is removed by producing a relative motion between the work surface and abrasive particles so that a mirror like surface can be obtained.

Magnetic abrasive finishing (MAF) process suitable to produce efficiently good surface layer quality on internal and external surfaces as well as flat surface work piece and complex shapes. In the machining pressure can be controlled by the input current. The

process can not only finish ferromagnetic materials such as stainless steel, but can also smoothing effectively non-ferromagnetic materials, ceramic, brass, plastic and glass. The specialty of MAF process was capability to control the flexibility of tool, ferromagnetic powder sealing by magnetic field, one can control the density and rigidity of the magnetic brush, that help to change the topography of magnetic flux in the working gap [1-6]. Shinmura et al.[7,8] studied the basic processing principle and abrasive characteristics of plane MAF and verified that the MAF have the ability to achieve precision finishing of flat surface. Shinmura et al.[9] They developed plane MAF process using high rotary speed magnetic pole, spindle-finish type MAF process and plane MAF experimental equipment of coil rotary style and coil fixed style. Jain et al.[10,11] have studied the MAF process on non-magnetic stainless steel work piece and concluded that the working gap and circumferential speed are the parameters which significantly influence the surface roughness value, proved forces and change in surface roughness (△Ra) increase with increase in current to the electromagnet and decrease in the working gap. Joshi et al.[12] analysis of MAF of plane surfaces and concluded that the surface

finishing may improve significantly with an increase in the grain size, feed rate and current .Zou et al.[13] proposed a plane MAF process using a constant-pressure magnetic brush.Singh and et al[14]. investigated the most important effective parameters on surface quality such as applied voltage on electric magnet, working gap, mesh size abrasive powders and rotational speed on stainless steel plates using Taguchi design of experiments. They found that applied pressure on electric magnet and working gap as the most effective parameters on surface quality. Ali H. Kadhum. et al [15] describes how Taguchi design of experiments is applied to find out important parameters influencing the surface quality generated during MAF method, there are various parameters, such as the coil current, working gap, the volume of powder portion and feed rate, that are known to have a large impact on surface quality .Baron et al. [16] analyzed the effectiveness of using Magnetic Abrasive Finishing (MAF) to remove burrs on drilled holes located on planes. By using X-ray diffraction analysis an electron-probe micro analysis. The previous researchers have concluded the main parameters affecting the performance of MAF process and find out the methods improving significantly efficiency of MAF. However, to processing quality, the MAF process is still considered to be difficult to obtain effectively few nanometer finish surface, especially in finishing on flat and micro complex surface work piece made of hard materials. This work aims to study the influence of operating parameters on the quality of surface by using experimental method then finding the mathematical models with the MINITAB software.

2. Experimentation

The schematic of the system used to implement the experiments is shown in **Fig.1.** The electromagnetic inductor has designed and manufactured using for finishing flat surfaces with some required modifications. The inductor was a steel rod wrapped around a coil of wires, magnetic force was generate on the working gap, between pole and work piece, the gap was filled with powder and the current was applied by (DC) power supply. See Fig 1.The characteristic of inductor are the following:

The materials of the core was low carbon steel C15, the diameter of copper wire was 0.9mm ,the number of turns was N=2000 turns ,the abrasive powder was (65%) oxide of the iron with (35%) ilicon nitride . **Fig. 2** Show vertical milling machine .

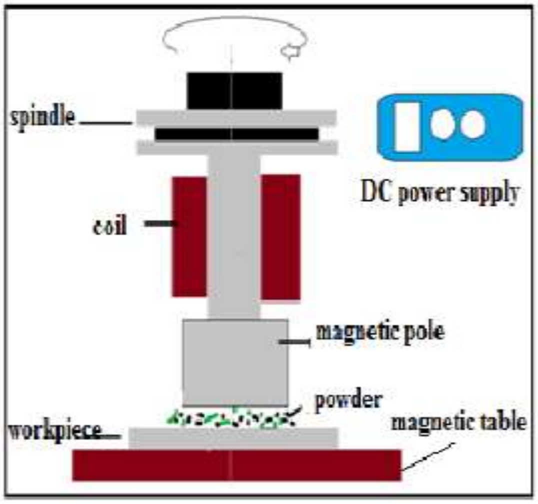


Fig.1 Electromagnetic inductor

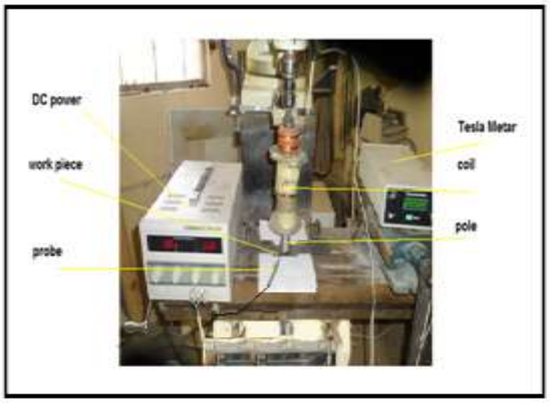


Fig.2 Photograph of Magnetic Abrasive Machine

The mechanism of MAF process requires filling the working gap between the electromagnetic pole and the work piece with the magnetic abrasive powder. The magnetic abrasives are generated magnetic force to form a flexible magnetic brush. The magnetic force lines generated power to apply pressure from the magnetic abrasives to the work piece, and the magnetic brush became a tool for finishing the work piece. Moreover, the magnetic abrasives in the magnetic brush stick to the work piece.When the magnetic pole rotates with moving the work piece relatively, the frictional force generated from MAF process causes the abrasives to finish the particles of the surface until it becomes smooth [18].

2.2 **Design of Experiments**

In the present study, four input operating parameters, each has three different levels were chosen which are: (1) finishing time, (2) dose (Volume of powder), (3current and (4) feed ra**te**. The ranges of operating parameters are listed in **Table. 1**.

Table .1 Input Parameters Values

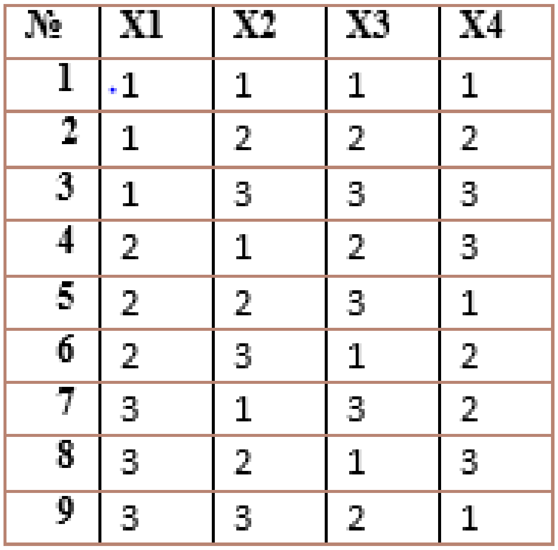
Input	Levels			
	Symbol	**Level 1**	**Level 2**	**Level 3**
Finishing time (min)	X1	5	10	15
Dose (Volume of powder) (cm^3)	X2	3	5	7
Current (Amp)	X3	1.5	2.0	2.5
Feed rate (mm/min)	X4	10	14	18

Table .2 Constant Parameters

Parameter	value
Gap	3mm
Cutting speed	250 (rpm)
Work piece	stainless steel 420 plate
Abrasives used in (MAF)	silicon nitride

Taguchi method (DOE) was used to design the experiment with L9 (34) orthogonal array Taguchi matrix (9 tests, 4 in depended variables, with 3 levels), **Table. 3**which leads to decreases the high required number of experiments to 9 influential experiments [17].The abrasive powder used is formed from 33%Fe (iron) and 67% (abrasive) silicon nitride of (300µm mesh size). .The work piece plate ferromagnetic material is grade stainless steel type 420, chemical composition its are listed in **Table. 4**

Table .3 Orthogonal Array L9(34).



№	X1	X2	X3	X4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table. 4 Chemical composition of the flat stainless steel 420 plat work piece [wt. %].[ ]

Composition Ranges W%	
SER. NO.	1
Element	max
C	0.04
Si	1.00
Mn	1.0
Cr	14.0
Ni	0.05
P	0.04
Fe	Balance
S	0.03

The output (response) data measured is the change in surface roughness (Δ*Ra*) after all the experiments was completed, between the mean surface roughness (*Ra*) of the work piece before and after MAF process.**Fig.3** show surface roughness tester (SRT-6200) used to measure the values of *Ra* at three different places at same location in the work piece before and after MAF taking the average value and then we take the difference between the two cases from the average value of *Ra* ,which is obtained from 27readings of *Ra* at different places of the work piece .

Fig. 3 Surface Roughness Tester (SRT-6200)

3. Results and Discussion

The output ΔRa, dependent variable in regression models, while the predictor's factors were the finishing time ,dose (volume of powder), current (DC) applied to the electromagnet and feed rate. **Table.5** shows the result of experiment for stainless steel 420 plate ferromagnetic material.

Table .5 Results of experiments for stainless steel 420 and distribution parameters according to Taguchi matrix L9

№	X1	X2	X3	X4	ΔRa,E: pr-ement	ΔRa, Calcul-ted	Error
1	5	3	1.5	10	0.332	0.338	-0.00611
2	5	5	2.0	14	0.354	0.348	0.00538
3	5	7	2.5	18	0.353	0.359	-0.00611
4	10	3	2.0	18	0.371	0.367	0.00305
5	10	5	2.5	10	0.284	0.276	0.00755
6	10	7	1.5	14	0.299	0.295	0.00305
7	15	3	2.5	14	0.292	0.295	-0.00377
8	15	5	1.5	18	0.316	0.315	0.00072
9	15	7	2.0	10	0.220	0.223	-0.00377

3.1. Regression Model for Surface Roughness (ΔRa for stainless steel 420 plate) Versus x1; x2; x3; x4

By using Minitab 16 statistical software, finding the mathematical statistical regression models for MAF process between the surface roughness ΔRa and all four parameters are represented bellow.
The regression equation is

ΔRa = 0.328 - 0.00703 X1 - 0.0103 X2 - 0.00600 X3 + 0.00850 X4 ….. (1)

The regression analysis of variance (ANOVA) on to surface finish ΔRa for stainless steel 420 plate, the

results of analysis were show in **Table .6**

Table .6 Result of ANOVA (Analysis of Variance) for regression also show:

No.	Coefficient	P	Effect	Inductor
X1	-0.0070	0.000	significant	($p < 0.05$)
X2	-0.010	0.002	significant	($p < 0.1$)
X3	-0.0060	0.366	Insignificant	($p > 0.1$)
X4	+0.0085	0.000	significant	($p < 0.05$)

R-Sq = 98.8% R-Sq(adj) = 97.6%
F = 81.19 P =0.000

Fig .4 show plot of normal distribution probability for Δ (Ra**),** the R-sq showed that 98.8% and R-Sq(adj) = 97.6% of the observed variable in surface roughness for stainless steel 420 plate was independent variable. F- Value was high F = 81.19, P-value for regression equation was significant effect P =0.000. The coefficients (of output parameters) for regression are listed in the **Table .3**. For these coefficients, linear regressions (mathematical statistical model) for surface roughness with stainless steel 420 plate materials could be expressed in equation (1).

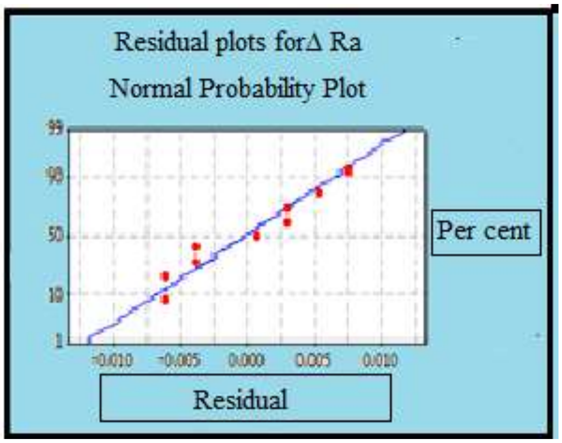


Fig .4 Plot of normal distribution probability for Δ (Ra)

3.1.1. The Effects of finishing time and feed rate on the surface roughness ΔRa for stainless steel 420 plate

However for the four input operating parameters, all coefficient of the linear regression equation 1, analysis of variance and main effect of process parameters curves **Fig .5** indicate some significant X1, X4, have a significant effect parameters on the surface roughness ΔRa . **Fig. 5.(a)** it is observed that the decreases in Δ(Ra) with increases number of finishing time X1from 5 to 15 min, the influence of finishing time (X1) that has a significant effect on surface roughness as follow increases in finishing time from 5 to 15 min lead to deceases in the ΔRa from 0.35 to 0.27 µm and improved to the ΔRa 43.82%.

Fig. 5.(d) shows that the increases in Δ(Ra) with increases of feed rate X4 from 10 to 18 mm/min , the influence of feed rate (X4) that has a significant effect on surface roughness as follow increases in feed rate X4 from 10 to 18 mm/ min lead to increases in the ΔRa from 0.28 to 0. 34 µm and improved to the ΔRa 40.96%.

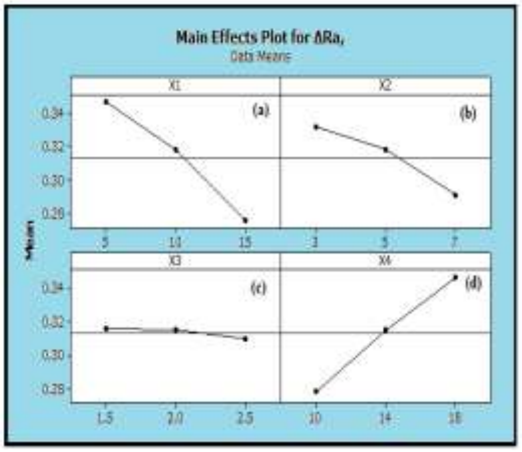


Fig .5 Main effect of process parameters in Δ (Ra)

3.1.2. The effects of dose (volume of powder), and current (DC) applied to the electromagnet on the surface roughness ΔRa for stainless steel 420 plate.

The dose(volume of powder) X3 has mildly significant effect on the ΔRa, compared with finishing time and feed rate , **Fig. 5(b)** shows if the dose(volume of powder) increases from 3 to 7 the ΔRa

deceases from 0.33 to 0.29 µm that means improved in the surface roughness 14.89%. Current applied X4 has insignificant effect on the ΔRa, **Fig .5(c)** shows if the current applied increases from 1.5 to 2.5 the ΔRa deceases from 0.31 to 0.30 µm that means improved in the surface roughness 0.3%.

4. Conclusions

This study shows the influence of operating parameters finishing time ,dose(volume of powder), current (DC) applied to the electromagnet and feed rate .on the MAF output process. Generate regression models for surface roughness, by using regression analysis of variance (ANOVA), the influence on the MAF process as follow:

1. The parameters X1, X4 (finishing time and feed rate) has significant effects on the

surface roughness ΔRa, which improved the surface roughness about 43.82%, 40.96% respectively.

2. The effect of parameter (X2,) has mild significant on the surface roughness which improved the surface roughness ΔRa about 14.89%.

3. The effect of parameter (X3,) has insignificant on the surface roughness ΔRa which improved the surface roughness about 0.3%.

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تأثير عوامل التشغيل في عملية الحك الممغنط على خشونة السطح للمواد المغناطيسية

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الخلاصة :-

الانهاء بالحك الممغنط هي من الطرق الحديثة والغير تقليديه في الانهاء عالي الجوده حيث يتم تطبيق تصميم تاجوشى للحصول على معلمات الاستجابة المؤثرة على جودة طبقة السطح باستخدام التغيير في الخشونة السطحية (ΔRa) المتولدة والتي تنتج نوعيه عاليه من الآداء للآجزاء كما ويتم تحديد معايير التشغيل الهامة على النحو التالي: (1) الوقت المستغرق في التشطيب (2) كمية (حجم مسحوق) (3) التيار الكهربائي (4) معدل التغذية ، وقد اظهرت نتائج النموذج الرياضي أونماذج الآنحدار المتعدد باستخدام منهجية استجابة السطح (RSM) مبينة ان أكبر تاثيرعلى خشونة السطح هو لمعلمات معدل التغذية والوقت المستغرق التشطيب ثم تليها المعلمات جرعة (حجم مسحوق) و التيار الكهربائي .وإجريت التجارب المغناطيسية على (قطعة العمل) من الواح الفولاذ المقاوم للصدأ نوع 420 وكانت نتائج النموذج الرياضي مرضية للغاية . حيث تم الحصول على معامل التحديد (R^2) 97.60٪ ومعامل التحديد المعدل (R^2) 98.80٪