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Regression Model and Optimization of Magnetic Abrasive Finishing of Flat Brass Plate

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Abstract

Magnetic abrasive machining is a surface finishing process in which a magnetic field is utilized to force abrasive particles against the work piece surface to remove the material as microchips. The aim of the present examination work is to investigate the effect of boron carbide abrasives on surface finishing and material removal rate of flat brass plate using magnetic abrasive finishing process. Four input parameters are taken in this research work which is rotational speed, quantity of magnetic abrasives, mesh number and machining time. Full factorial experimental design technique was used to investigate the effect of the input factors on the surface roughness and material removal rate. The analysis of variance (ANOVA) was investigated using statistical software to find optimal conditions for better surface roughness and material removal rate. Regression models have been developed by using MINITAB-17 statistical software for both surface roughness and material removal rate. Experimental results showed that rotational speed is the most important parameters on change in surface roughness and machining time for change in MRR. Minimum surface roughness (Ra) achieved 0.061μm and maximum material removal rate (MRR) 3mg/min.

Keywords: Analysis of Variance (ANOVA), Design of Experiments, FMAB, Magnetic Abrasive Finishing, Regression Analysis, Sintering, Surface Roughness

1. Introduction

In the period of nanotechnology, high precision finishing processes are utmost important. The requirement for high accuracy in manufacturing was felt by manufacturers worldwide to enhance interchangeability of parts, enhance quality control and more wear life. Magnetic abrasive finishing process is one of such processes which is utilized to manufacture parts with ultra-accuracy finishing processes which are produced for acquiring nanometer range surface finish. Final finishing operations in manufacturing of precise parts are dependably of concern due to their most basic and slightest controllable nature. With the progression of time tailor made, hard and soft or fragile materials are being developed for example titanium for aerospace and marine applications, stainless steel for surgical tools and sugar refineries, ceramics for disk brakes and bullet proof jackets, brass or copper for axial piston pumps, ammunition parts and radiators etc. It is extremely hard to machine these materials with conventional finishing and polishing operations used for obtaining high surface finish of the materials but these techniques may lead to smaller scale splits and burrs on the workpiece surface. Brass is soft, very ductile and soft materials are not so easy to machine as harder one. Conventional solid polishing tools exert high polishing force which may even damage the material surface, resulting in re-working and time-consuming. In order to overcome these defects, non-conventional techniques are required. Magnetic abrasive finishing is a non-traditional machining process which came in practice in 1938 in a patent by Harry P. Coats. In MAF process cutting power is basically controlled by the magnetic field. Magnetic field plays an exceptionally vital part in this finishing process. MAF can be used to produce efficiently good surface quality of some products such as bearings, port plates, precision automotive components, shafts. This method can not only be used to machine ferromagnetic materials

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such as steel, but can also to machine non-ferromagnetic materials such as brass. To perform magnetic abrasive finishing of plane surface a rotating magnetic pole system is used. The workpiece is placed on worktable and magnetic abrasive particles are dispersed on the surface of workpiece. Required machining force against the upper surface of workpiece is generated with the help of magnetic field that brings together the workpiece surface area and abrasive grains. Magnetic field attracts the magnetic abrasives and forces them against the work piece surface. These particles get collected and align themselves along the direction of magnetic field lines hence forms a flexible magnetic abrasive brush (FMAB). Indentations are formed on the surface of work piece due to finishing pressure. Two magnets are placed below the work piece. This flexible brush acts as a multipoint cutting tool for finishing operation. The required machining force is provided by the magnetic force acting on the abrasive grain. This force is responsible for the abrasion of the plate by magnetic abrasive particles.

Jain et al.,[1]carried out experiments on stainless steel with the use of unbounded abrasives by MAF process. They concluded that the parameters that significantly affect the material removal rate and the percentage surface finish improvement are working gap and the circumferential speed of the work piece. The maximum PISF was found to be 87.83%.

Dixit et al.,[3] performed magnetic abrasive finishing on alloy steel plate with unbounded silicon carbide and iron oxide abrasives. Input parameters were rotational speed, working gap, mesh number and voltage. The maximum change in surface roughness found to be 0.26µm.

Vahadati and Vahadati[7] performed magnetic abrasive finishing of aluminium pipes with silicon carbide based unbounded magnetic abrasives. Input parameters were quantity of abrasives, speed of work piece and process time. Initial surface roughness was 2µm and final surface roughness achieved 0.45µm.

Hamad[11] used stainless steel 420 plate for fine finishing using magnetic abrasive finishing. Bonded iron oxide and quartz abrasives were used for this purpose. Input parameters were working gap, coil current, feed rate and table stroke. Initial surface roughness was 0.316 µm and final surface roughness achieved 0.127µm.

Nazar[9] performed magnetic abrasive finishing on brass plate using iron oxide and quartz based magnetic abrasives. Input parameters were rotational speed, working gap, volume of powder and coil current. Initial surface roughness was 1.046µm and final surface roughness achieved 0.131µm.

Mithlesh & Rishi[6] performed magnetic abrasive finishing of SS304 stainless steel, cast iron and Brass by sing unbounded alumina based magnetic abrasives. The input factors were grain size, rotational speed, working gap, current, machining time Initial surface roughness was 0.4µm and final surface roughness obtained was 0.075µm. It was observed that maximum surface finish and material removal rate occurred for brass. The objectives of present research study to investigate the effect of Boron carbide based abrasives on finishing of a flat brass plate and establish regression equation for the response surface and material removal rate characteristics as a function of process parameters on responses and optimization of process parameters.

2. Experimentation

2.1 Experimental Setup

The experimental setup for finishing of plane surfaces using Magnetic Abrasives Finishing process consists of 2 rectangular shape silver permanent magnets having magnetic flux density 5000 Gauss each mounted on aluminium disk which acts as a carrier and insulator to separate them. This disk is placed below acrylic working table. Magnets are rotated by a D.C motor. The work piece is placed over the working table and sintered magnetic abrasives are placed upon the work piece. The speed of magnetic chuck is varied by changing the speed of D.C motor. To change the speed of magnetic chuck a step-down transformer is installed in the controller box. The direction of rotation of the magnetic chuck can be changed by using the controller. The photographic view of experimental setup is shown below (Figure 1)

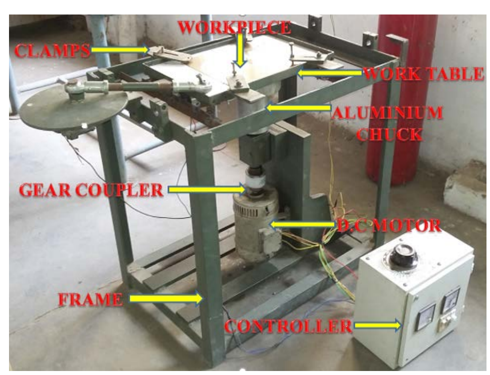


Figure 1. Setup of plane magnetic abrasive finishing.

2.2 Experimental Design

In the present research work a two level full factorial technique is employed for experimentation. Four input parameters (rotational speed, quantity of abrasives, mesh size and machining time) are selected and total number of experimentation runs came out to be 16. So to complete entire experimentation 16 experiments were performed in random order. Levels are selected based on trial experiments.

Table 1. Levels of process parameters

Symbol	Input Factors	Low level (-)	High level (+)
X1	Rotational speed (rpm)	100	200
X2	Quantity of magnetic abrasives (mg)	5	10
X3	Mesh number	140	270
X4	Machining time (min)	30	60

Constant parameters were magnetic flux density (6000 Gauss), working gap, current, voltage and percentage of iron in magnetic abrasives.

2.3 Experimental Procedure

The surface roughness of brass plate was measured before machining at different points. Then work piece was clamped over the work table above the two poles. Measured quantity of magnetic abrasive powder is then poured over the brass plate mounted on the work table. The machine is then switched ON. Different input parameters are varied in accordance with design of experiment. The rotary motion to the magnetic chuck was given by a D.C motor. As soon as power was provided magnetic abrasive particles aligns themselves along the direction of magnetic field lines and forms a flexible magnetic abrasive brush. This flexible magnetic abrasive brush acts as multi point cutting tool and shear off the peaks of irregularities on the surface of work piece being finished and hence improve its surface finish and material was removed from the finishing zone. The finishing operations were carried out for different time intervals as per experimental design After the completion of all experimental runs the workpiece was removed from the table and cleaned with methanol. The surface finish of brass plate after machining was measured by using the Mitutoyo SJ-410 Surface roughness tester(with least count of 0.001 μm and cut off length = 0.8 mm) and MRR calculated by dividing material removal by machining time. Material removal was measured by using wieght balance.

2.4 Experimental Data

The aim of the experimentation was to investigate the relation between input and output process parameters. The experimental results are shown in the Table 2.

Where X1, X2, X3, and X4 are in actual levels values of rotational speed, quantity of magnetic abrasives, mesh number, machining time respectively

Table 2. Design of experiments and responses

StdOrder	X1	X2	X3	X4	Ra (μm)	MRR (mg/min)
9	100	5	140	60	0.140	1.25
14	200	5	170	60	0.066	1.05
13	100	5	270	60	0.096	1.00
10	200	5	140	60	0.089	1.30
7	100	10	270	30	0.121	2.47
4	200	10	140	30	0.090	3.00
1	100	5	140	30	0.161	2.41
2	200	5	140	30	0.097	2.50
5	100	5	270	30	0.120	1.92
15	100	10	270	60	0.085	1.26
8	200	10	270	30	0.076	2.58
16	200	10	270	60	0.063	1.32
3	100	10	140	30	0.158	2.90
12	200	10	140	60	0.085	1.55
11	100	10	140	60	0.133	1.48
6	200	5	270	30	0.079	2.04

3. Results and Discussion

3.1 Modelling of Process Parameters

In the present work regression model has been developed and Experimental results obtained were subject to analysis by using MINITAB-17 statistical software to evaluate the relationship between input and output process parameters. Based on the experimental findings of 16 runs the following regression models have been evolved:

Regression Equation for surface roughness is given by-

$$Ra = 0.3297 - 0.001090\ X1 - 0.00057\ X2 - 0.000442\ X3 - 0.000924\ X4 + 0.000001\ X1*X2 + 0.000002\ X1*X3 + 0.000006\ X1*X4 + 0.000002\ X2*X3 - 0.000022\ X2*X4 - 0.000002\ X3*X4$$

Regression Equation for material removal rate is given by-

$$MRR = 3.4402 + 0.001246\,X1 + 0.14246\,X2 - 0.005519\,X3 - 0.035622\,X4 + 0.000020\,X1{*}X2 + 0.000000\,X1{*}X3 - 0.000015\,X1{*}X4 + 0.000054\,X2{*}X3 - 0.001767\,X2{*}X4 + 0.000054\,X3{*}X4$$

Table 3. Analysis of variance (ANOVA) of regression for Ra

Source	DF	Adj SS	F-Value	P-Value	%
Regression	10	0.014602	219.17	0.000	99.77
Error	5	0.000033	-	-	0.23
Total	**15**	**0.014635**	-	-	**100**

These statistical terms i.e., variance ratio (F) and P value are used to measure the significance of the regression under investigation. Model explains 99.77% of variations in the data for surface roughness. The value of R-sq. represents that our model better fits the data. More the value of R-sq, better the model fits our data and prediction of response is more accurate.

Table 4. Analysis of variance (ANOVA) of Regression for MRR

Source	DF	Adj SS	F-Value	P-Value	%
Regression	10	6.95945	13948.9	0.000	99.56
Error	5	0.00025	-	-	0.44
Total	**15**	**6.98970**	-	-	**100**

Since the P-value < (0.05) in both analysis, hence observed relationship is statistically significant at 95% confidence interval. Model explains 99.93% for MRR of variation in the data On the basis of these F and P values, it can be concluded that both models are highly significant. Therefore, the Regression Equation for Ra and MRR can be used to predict the responses of the MAF process.

3.2 Effect of Process Parameters on Ra

3.2.1 Effect of Rotational Speed

It was observed that surface roughness decreases as the speed increases from level 1 to level 2. This may be due to the fact that at high rotational speed, rate at which magnetic abrasive particles hits the work piece surface increases. Therefore, more peaks sheared at high rpm which results in high surface finish. Moreover, at low rotational speed, centrifugal force acting on magnetic abrasive particles was less so particles accumulated at center of FMAB results in improper brush formation. With increase in speed centrifugal force also increases and forced abrasive particles to move outwards results in formation of proper abrasive brush.

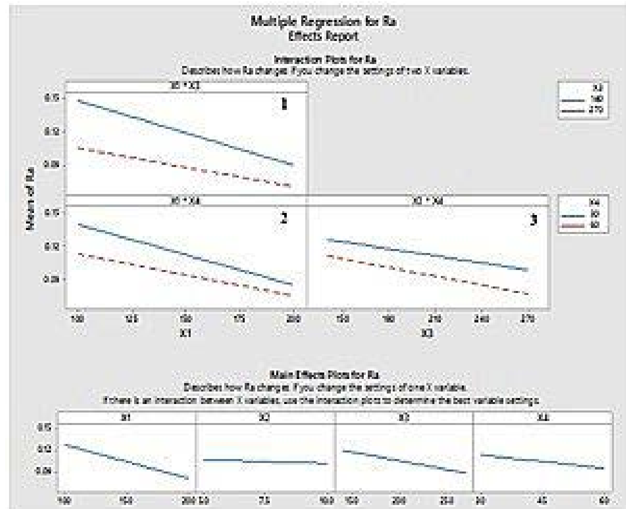


Figure 2. Interaction plots for Ra.

3.2.2 Effect of Quantity of Abrasives

Increase in quantity of magnetic abrasives has not much significant effect on surface roughness but slight decrease in surface roughness was achieved with increase in quantity of abrasives. This may be due to fact that more number of abrasives comes in contact with workpiece surface during finishing.

3.2.3 Effect of Mesh Size

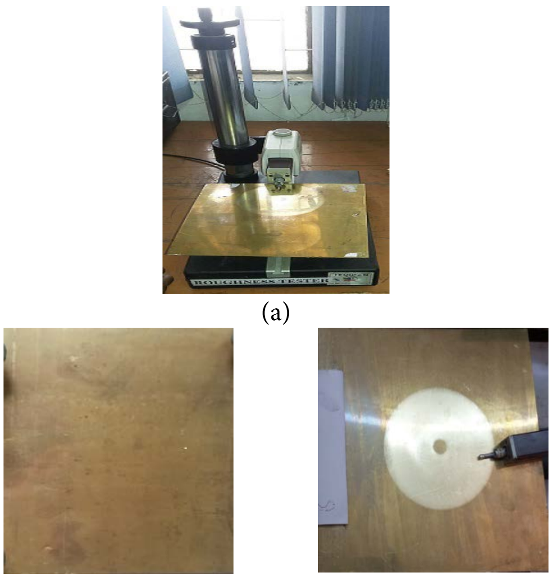
It was observed that with increase in mesh number from level 1 to level 2 there was decrease in surface roughness. More the mesh number lesser is the abrasive particle size. Fine abrasives cause high surface finish while coarse abrasives cause low surface finish. This may be due to fact that with increase in mesh number, there are more number of cutting edges in the same machining area if fine abrasives were used.

3.2.4 Effect of Machining Time

Increase in machining time has positive effect on surface finish as it was observed (Figure 2) that surface roughness decreases with increase in machining time from level 1 to level 2. This may be due to the fact that magnetic abrasives remain in finishing zone for more time and sharp cutting edges of the abrasives removes the material form work piece surface, hence smoothening micro-unevenness which results in high surface finish.

3.3 Surface Roughness Tester Results

Mitutoyo SJ-410 surface roughness tester was used to measure the surface roughness values at the different points on workpiece surface after machining. The average of all measurements is taken as surface roughness value for that particular combination of input parameters



(a) (b) (c)

Figure 3. (a) Mitutoyo SJ-410 surface roughness tester (b) Brass plate before MAF (c) Brass plate after MAF.

The surface roughness tester result after magnetic abrasive finishing is shown in Figure 4. The profile indicates that peaks and valleys are reduced to a large extent which results in higher surface finish

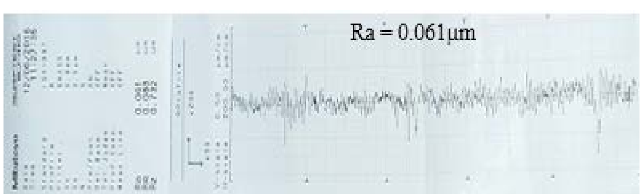


Figure 4. Surface roughness result after MAF.

3.4 Effect of Process Parameters on MRR

3.4.1 Effect of Rotational Speed

It was observed that with increase in rotational speed of magnetic pole material removal rate increases as shown in Figure 5. This may be due to the fact that on increasing rotational speed, striking of magnetic abrasives with plate surface occurs again and again as a result hardness of the plate may get reduced and due to which material removal rate takes place.

3.4.2 Effect of Quantity of Abrasives

On increasing quantity of abrasives from 5gm to 10 gm, material removal rate from work piece surface increases. This may be due to fact that more the quantity of abrasives, more number of abrasives comes in contact with work piece surface during finishing and hence more material removal rate occurs.

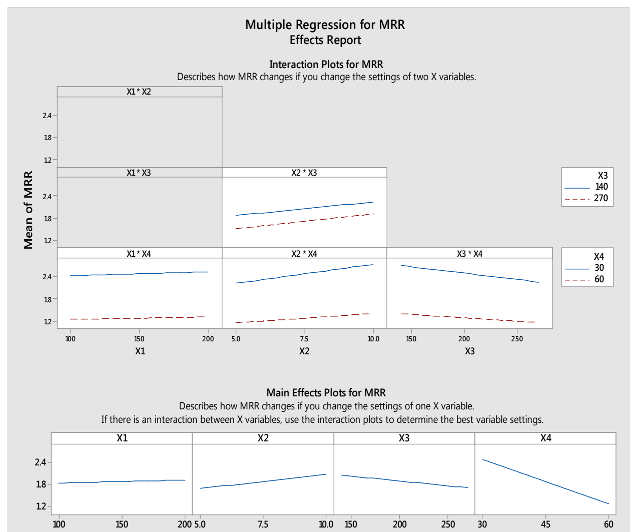


Figure 5. Interaction plots for MRR.

3.4.3 Effect of Mesh Size

It was observed that on increasing mesh size, material removal rate decreases. More the mesh number smaller is the grit size. This may be due to the fact that coarse abrasive has more area in contact with work piece surface irregularities compared to fine abrasives. So more material was removed in case of lower mesh number and less material removal occurred for abrasives having high mesh number.

3.4.4 Effect of Machining Time

It was observed that material removal rate increases with increase in machining time. This may be due to the fact that FMAB performs finishing for longer time and hence more material was removed. But material removal rate decreases with increase in time, because abrasives get blunt due to which their cutting ability decreases. With the passage of time, the amount of removed material from the workpiece increases. Also the density of abrasive particles decreases due to addition of removed material into abrasive powder. In fact, the number of effective abrasive grains decrease which may lead to a decrease in metal removal even though the process continues.

4. Conclusion

In this study, MAF was performed on the brass material and design of experimental method was applied to evaluate the effect of selected parameters (rotational speed, quantity of abrasives, mesh number, machining time) on output parameters (surface roughness and MRR) with the use of boron carbide based magnetic abrasive. The results can be summarized as follows:

On the basis of results obtained, following conclusion has been drawn

1) With increase in Rotational speed, quantity of abrasives, mesh size and machining time the surface roughness decreases. Whereas with increase in rotational speed and quantity of abrasives material removal rate increases but it decreases on increasing mesh size and machining time.

2) The optimal settings for surface roughness found to be rotational speed 200 rpm, quantity of abrasives 10mg, mesh size 270 and machining time 60min, whereas for MRR rotational speed 200rpm, quantity of abrasives 10mg, mesh size 140 and machining time 30min.

5. Scope for Future Work

Further efforts on magnetic abrasive finishing can be made in following ways:

- Other materials like stainless steel, copper, gun metal, ceramics and aluminium can be finished using magnetic abrasive finishing process.
- Microwave sintered magnetic abrasives can be used instead of sintered magnetic abrasives for finishing purpose.
- Different types of abrasive materials like aluminium oxide, silicon carbide, cubic boron nitride and diamond based abrasives can be used.
- Other geometrical shapes like tube, bent etc. can be finished using magnetic abrasive finishing process.
- Instead of permanent magnets an electromagnet of varying magnetic flux density may be installed on plane magnetic abrasive finishing setup.

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