Experimental Investigation on Chemical assisted AISI 52100 Alloy Steel Using MAF

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Abstract. Surface finish is a crucial aspect to decide the quality of a manufactured product. With the technological advancement, alloy steel having high strength and hardness preferred over conventional materials. In some cases, an ultra-smooth surface of alloy steel is needed which cannot be done by conventional method. In the current investigation, surface finishing of AISI 52100 steel has done using magnetic abrasive finishing assisted by chemical oxidizer. Hydrogen peroxide is used as an oxidizing agent. The effect of input parameters such as voltage, spindle speed, finishing time has been investigated on surface roughness output parameter. Experiments have been performed and analyzed using response surface methodology (RSM) and to obtain the significant factors of ANOVA was used while empirical model has developed to examine the surface roughness (Ra) in terms of significant process variables.

Keywords: Response surface methodology (RSM), Chemically treated AISI 52100 alloy steel, ANOVA, Magnetic Abrasive Finishing (MAF).

1 Introduction

Due to advancement of manufacturing technology, the feasibility of fine surface finish with improved surface finish can be an attribute for a wide range of industrial applications [1]. It is very difficult to finish the advanced materials like steels, ceramics, and non-ferrous metal using conventional methods like honing, lapping and super finishing to a higher extent. This causes the advance finishing technology to came in existence. Magnetic abrasive finishing (MAF) is one of the dominant super finishing methods to produce a surface with minimum surface roughness [2].

In MAF, the surface of the work piece is finished by removing the materials in microchips forms with help of magnetic field in finishing zone. The working gap between tool and work piece is filled with a mixture of ferromagnetic and abrasive particles [3]. Chemical mechanical polishing (CMP) integrates the mechanical and chemical forces to finish the surface. In which combination of chemical etching over workpiece and abrasive polishing. During CMP process, an abrasive and chemical slurry is utilized along with free abrasive polishing. This abrasive Slurry was imposed on work material surface so that a soft oxide layer forms on the surface and can be easily removed in comparison to parent material due to softness [4].

El-Taweel used the combination of magnetic abrasive finishing along with electrochemical turning that leads to reduction in surface roughness and increase in material removal rate. 6061 Al/Al_2O_3 was used as work piece. After adding both processes results in increment of machining efficiency by 147% and 33% increment in surface roughness (R_a) in MAF [5].

Sihag et al. analyzed finishing characteristics for Tungsten work piece experimentally through chemical assisted magnetic abrasive finishing. The experimentation was planned by Taguchi L9orthogonal array [6]. Mulik and PM Pandey introduced a new hybrid process, called ultrasonic magnetic abrasive finishing (UAMAF). This technique combines the ultrasonic vibrations and magnetic abrasive finishing (MAF) method for finishing of the surfaces to nano range within a limited time period. The surface roughness observed as small as 22nm in 80 second on a (AISI 52100) hardened steel by UAMAF [7].

Thus the present article aimed to investigate the effect of process parameters such as voltage, finishing time and spindle speed on surface roughness for chemical assisted magnetic abrasive finishing of AISI52100 alloy steel.

2 Experimental Detail

A series of experiments have been done according to Response Surface Methodology(RSM). The particulars about the workpiece, experimental setup, selection of input process parameters and their working range, design of experiment has been discussed in following sections.

2.1 Work material

There is a growing demand for alloy steels which gives an excellent performance within severe conditions. Being a high carbon-chromium steel AISI 52100 have broad areas of applications. Thus in present work, AISI 52100 alloy steel has been selected as workpiece material in all the experiments, 60mm × 60mm × 3mm dimensions of workpiece have been considered. The properties of AISI 52100 are:

Table 1: workpiec composition of AISI 52100 [8]

Elements	Chemical composition
C	0.95-1.05
Mn	0.25-0.45
Cr	1.35-1.60
Si	0.15-0.35
Ni	0.25
Fe	Rest

2.2 Experimental setup

In the current study, all the experimental trials have been performed on the MAF setup. The set up comprises of an electromagnet mounted over drill machine to provide rotary motion to electromagnet. The electromagnet consists of copper windings wounded on a circular rod of mild steel having a diameter of 4 cm. The electromagnet generates a magnetic field instensity ranging from 0.2T to 0.9T between the tool and workpiece surface when it was connected to a DC power supply (1-5V). For the generation of oxide layer over the workpiece surface H_2O_2 was used as chemical oxidiser. Before the experimentation, the workpiece was dipped in oxidiser for half an hour. Finishing gap taken was 1.5mm. A blend of ferromagnetic (iron) particles(300 in mesh number) and the abrasive powder(400 mesh number) was filled in the working gap between magnet and workpiece surface which leads to formation of magnetic abrsive brush by which finishing action was achieved. The experimental setup and formation of brush has been shown in figure 1 and 2 respectively.

Fig.1. MAF setup

Fig.2. Formation of magnetic abrasive brush

2.3 Selection of input parameters and their range:

In the present work, the effect of several input factors such as voltage, spindle speed (RPM) and finishing time on the response namely surface roughness has been studied. The levels of the input variables have been chosen based on past literature, pilot experimentations and machine capability. The input variables and their levels are shown in the following table 1.

Table 1. Process Parameters & Levels for Design of experiments:

Symbol	Process Parameters	Level		
		-1	0	1
X_1	Voltage	1	3	5
X_2	Spindle speed	100	200	300
X_3	Finishing time	30	45	60

2.4 RSM for parameter design:

In current article, Response surface methodology's Box-behnken design has been utilised to carryout the experiments, and to develop emperical relationship between input process variables and output.Box and Wilson (1951) introduced RSM to study the statistical design in experimentations.In RSM,relationship is establised between the independent process variables and response which can be shown from equation 1.

$$Y_i = f(a_1, a_2, a_3, \ldots\ldots a_k) \pm e \qquad (1)$$

Where y_i is the output and f is the function of response. $A_1, a_2, a_3 \ldots.. a_k$ are input variables, e called as residual measures experiment error. A second order regression equation has been used to approximate response function.

The two methods of design in RSM are central composite design(CCD) and Box-Behnken design(BBD). CCD is used during sequential experimentations, it permits five levels of each parameters containing combinations with high and low level for factors simultaneously. While in BBD, it proposed three levels of parameters only and at same time with a fewer number of experimental runs as compared to CCD for same numbers of input variables. The uses of BBD is confined to a condition when predictions of ultimate response is not required. In the present article, a total of 15 experiments has been performed as per as experimental plan. MINITAB 18 software has been used to generate and analyse the design. The experimental plan with input variables along with output has been shown in table 2.

Table 2. BBD based experimental design matrix and response.

SNo	Input parameters			Response
	voltage	RPM	Finishing time	Surface Roughness(ΔR_a)
1	1	100	45	0.3834
2	5	100	45	0.2500
3	1	300	45	0.1867
4	5	300	45	0.1000
5	1	200	30	0.3800
6	5	200	30	0.3200
7	1	200	60	0.2000
8	5	200	60	0.3833
9	3	100	30	0.2534
10	3	300	30	0.4934
11	3	100	60	0.5800
12	3	300	60	0.1533
13	3	200	45	0.2300
14	3	200	45	0.1133
15	3	200	45	0.1833

2.5 Process variables

The difference in surface roughness has been taken as a process response for evaluation. The difference in surface roughness was calculated by the formula as given,

$$\Delta R_a = \text{Initial } R_a - \text{Final } R_a$$

Where,

ΔR_a = Difference in surface roughness. The initaial and final R_a was measured by Handysurf.

3 Result and discussions

The emperical model to correlate surface roughness and input variables i.e. voltage, rotaion of electromagnet and finishing time is shown by following regression equation in uncoded units.

$$\begin{aligned} \text{SR diff} = \; & 1.182 - 0.1129\, X_1 + 0.00208\, X_2 - 0.0420\, X_3 + 0.00066\, X_1 * X_2 \\ & + 0.000005\, X_2 * X_2 + 0.000634\, X_3 * X_3 + 0.000058\, X_1 * X_2 \\ & + 0.00203\, X_1 * X_3 - 0.000111\, X_2 * X_3 \end{aligned}$$

To check whether the model well fitted tha data or not ANOVA results are determined. The ANOVA result for surface roughness is shown in table 3.

Table 3. ANOVA result for surface roughnes.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.247129	0.027459	5.25	0.041
Linear	3	0.038855	0.012952	2.47	0.176
Voltage	1	0.001171	0.001171	0.22	0.656
RPM	1	0.035564	0.035564	6.79	0.048
Time	1	0.002119	0.002119	0.40	0.553
Square	3	0.081808	0.027269	5.21	0.054
Voltage*Voltage	1	0.000026	0.000026	0.00	0.947
RPM*RPM	1	0.009925	0.009925	1.90	0.227
Time*Time	1	0.075130	0.075130	14.35	0.013
2-Way Interaction	3	0.126466	0.042155	8.05	0.023
Voltage*RPM	1	0.000545	0.000545	0.10	0.760
Voltage*Time	1	0.014799	0.014799	2.83	0.154
RPM*Time	1	0.111122	0.111122	21.23	0.006
Error	5	0.026172	0.005234		
Lack-of-Fit	3	0.019272	0.006424	1.86	0.368
Pure Error	2	0.006900	0.003450		
Total	14	0.273300			

3.1 Model summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0723487	90.42%	73.19%	0.00%

From the ANOVA table, it is intrepreted that the developed model has f- value of 5.25 and p-value of 0.041(less than 0.05) which shows that the model is significant. The adequacy of the model was confirmed further by high value of determination coefficient i.e. R^2 equals to 90.42%. The p- value for lack-of-fit is 0.368 which shows that it is insignificant at 95% confidence interval.

3.2 Interactive effects of inputs parameters on surface roughness

3D response surface plots were drawn to depict the effect of variation in input parameters on surface roughness. From figure 3(a)it is concluded that surface roughness decreases as spindle speed increases up to a certain value of 250 rpm and thereafter it starts increasing. Also at lower value of spindle speed surface roughness increases linearly with increase in voltage and at the higher value it increase at a very low rate linearly.

From fig 3(b), it is inferred that at lower value of spindle speed surface roughness decreases with increase in finishing time up to a certain value of 55 min and then start increasing also at higher value of spindle speed surface roughness decreases upto around 40 min and thereafter start increasing with time. At lower value of finishing time surface roughness decreases with increase in spindle speed and at higher value of finishing time roughness increases linearly with spindle speed. From fig 3(c) it is concluded that surface roughness firstly decreases with finishing time up to a certain value of 40 min and then starts increasing and at lower value of finishing time, surface roughness increases linearly with voltage and at a higher value of finshing time it shows slight linear decrement.

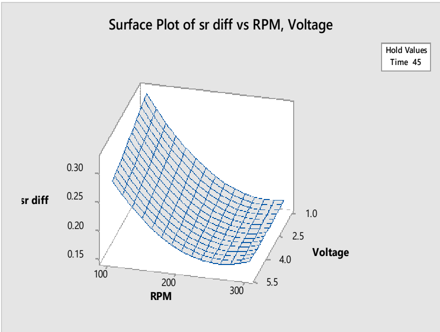

Fig.3 (a) Effect of RPM and voltage on Ra

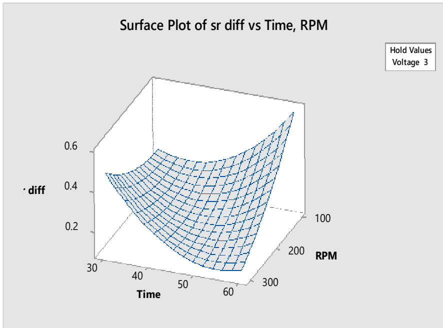

Fig.3 (b) Effect of Time and RPM on Ra

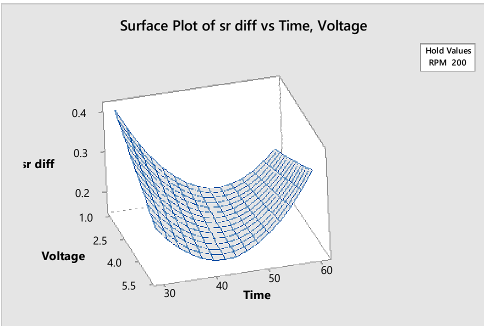

Fig.3 (c) Effect of Time and Voltage on Ra

4 Conclusions

The predicted values and the experimental values match reasonably well with R^2 of 90.42% for surface roughness which shows that the model is fitted well. For modelling of machining process variables, Response Surface Methodology can be applied successfully to achieve information with a fewer number of experiments. 3D surface plots drawn explain the better understanding of interactions of input factors on the response.

The surface roughness value decreases with an increase in tool rotation with any value of voltage. Surface roughness shows a linear increase with tool rotation at higher finishing time while at lower finishing time it shows a slight decrement with tool rotation. At any value of voltage, surface roughness firstly decreases up to 40 min and then shows an increasing trend. At a lower value of finishing time and tool rotation, surface roughness increases linearly following a straight line.

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