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"EFFECT OF PROCESS PARAMETERS OF BEMRF ON EN-31 STEEL FOR SURFACE FINISH AN EXPERIMENTAL INVESTIGATION"

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ABSTRACT

With the current trends in developing the advanced processing technologies, manufactured components/products are expected to demonstrate superior quality and enhanced functional performance. Material removal processes continue to dominate among all manufacturing processes. The functional performance of components from material removal processes is heavily influenced by the quality and reliability of the surfaces produced. MRF is relatively a new technology that facilitates a better surface finish. MRF is based on Magneto rheological (MR) fluids. These are special class of fluid called smart fluid. Magneto rheological (MR) materials (fluids) are a class of smart materials whose rheological properties (e.g. viscosity) may be rapidly varied by applying a magnetic field. MRF has ability to improve micro-roughness, remove sub-surface damage, and reduce residual stresses, abrasive marks induced during lapping process. This study is divided in two phases. In first phase no. of experiment were conducted using Taguchi L9 orthogonal array and RSM experimental design. The results in terms of % improvement in surface roughness were analyzed to find the effect of process parameter by various approaches. With the help of RSM a regression model is developed and for various other set parameters the value of responses are predicted. In the second phase the result of the experiments from the RSM design are used to train feed forward back propagation neural network model. At the end both of the models is validated through conducting the experiment and effectiveness of both model is compared.

Keywords: Ball End Magnetorheological Finishing (BEMRF), Magnetorheological (MR), Artificial Neural Network (ANN), Analysis of variance (ANOVA)

1. INTRODUCTION

Ultra Precision Machining Manufacturing dominates world trade. Two current worries faced by manufacturing industry all over the world are, rising global competition and increasing demands from the soft manufacturing sectors. Lean manufacturing techniques and automation are used to deal with the former whereas precision manufacturing is the answer for the latter. Material removal processes continue to dominate among all manufacturing processes. The functional performance of components from material removal processes is heavily influenced by the quality and reliability of the surfaces produced both in terms of topography as well as metallurgical and mechanical state of the subsurface layers. Significant efforts were made by numerous investigators in the past few decades to investigate the nature of the surface and subsurface alterations produced by the various material removal processes and to correlate them with the product's functional performance.

However, the success in developing quantitative predictive models has been limited, yet the research community continues to gain new technical knowledge by developing new tools and techniques for designing products, modeling processes, and improving experimental techniques for use in manufacturing operations. The need for high precision in manufacturing was felt by manufacturers worldwide to improve interchangeability of components, improve quality control and longer wear/fatigue life. Taniguchi reviewed the historical progress of achievable machining accuracy during the last century. He had also extrapolated the probable further developments in micro technology and nanotechnology. The machining processes were classifieds into three categories on the basis of achievable accuracy viz. normal machining, precision machining and ultra-precision machining.

It has been predicted that the machining accuracies in conventional processes would reach 1μm, while in precision and ultra-precision machining would reach 0.01μm (10nm) and 0.001μm (1 nm) respectively. His predictions are in line with the current advances in manufacturing technology. New advanced finishing processes were developed in last few decades to overcome limitations of traditional finishing processes in terms of higher tool hardness requirement and precise control of finishing forces during operation. Techniques for Surface Finishing Surface finishing can be divided into two parts. 1. By conventional methods 2. By non-conventional methods. Conventional Methods Conventional methods like Lapping, polishing, grinding, buffing and honing are used for finishing of many optical and engineering components. Non-Conventional Methods Non-conventional methods includes Abrasive flow machining with SiC abrasive, Magnetic abrasive finishing, Magnetic float polishing with CeO_2, Magnetorheological finishing (MRF) with CeO_2, Elastic emission machining with ZrO_2 abrasives, Ion beam machining etc.

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2. LITERATURE SURVEY

Anand Sharma al. [2023] explain that significant processes and parameters affect the residual stresses and roughness of surface on polishing of workpiece are obtained using ANOVA. The highest percentage of surface roughness reduction and residual stress has obtained at rotational speed of tool 550rpm, 2.3A current, and 0.5mm working gap. [1]

Md. Amir al. [2023] explain that at different carrier wheel speed shows that at high speed of wheel on throwing of MR fluid reduction of MR fluid ribbon thickness. Therefore the particle separated from the MR fluid at high speed of rotation. On increasing the carrier wheel speed firstly roughness of surfaces decreases initially and then increases. [2]

Nitesh Kumar Dubey al. [2023] their study is related to development of SPION based smart material of MRF and their variant processes, it enhance the finishing process of BEMRF technique and increase surface finishing on the BK-7 substrate up to the surface roughness (Ra) value of 22.3nm with Ra improvement of 88.14%. [3]

Himmat Singh al. [2022] in their study describe that Residual stress of EN-31 surface roughness measured before and after experimentation. Using Cosα method residual stress of EN-31 surface is measured with X-ray residual stress analyzer. It is observed that the residual stress reduced from 130MPa to 66Mpa also surface roughness reduced very fast with the use of pulse DC power supply in BEMRF process. [4]

Manjesh Kumar al. [2021] they discusses advanced finishing method for polishing different complex components made of various materials, different modes of operation and development of instruments which are based on advanced abrasive-based finishing methods, there is also detailed study related to MR polishing and AFM media. [5]

Anand Sharma al. [2020] they present study and reviews critically the BEMRF process for achieving finishing at nano-level finishing on different variety of materials like EN-31, copper, mild steel etc. and also explain the factors influenced this process so far which led to advancement in this process. [6]

Himmat Singh al. [2020] their study carried out to analyze the effect of the duty cycle on the response percentage reduction in surface roughness. They observed that the improved response percentage reduction in surface roughness has been obtained with pulsating DC power supply as compared to the response percentage reduction in surface roughness obtained with DC power supply without pulse at same parameter. [7]

Anand Sharma al. [2019] in their study they study critically reviews the MRF process used for soft material and the advancements made in this process for achieving nano-level finishing. [8]

Zafar Alam al. [2017] their work deals with theoretical investigation into modeling of surface roughness and material removal mechanism associated with ferromagnetic workpiece. Based on induced shear and normal forces on abrasive, the wear behavior during finishing operation on material removal process have been analyzed. [9]

Anant Kumar et al. [2012] had done performance evaluation of the ball end MRF process and achieve the final surface finish as low as 19.7 nm from the initial surface of the 142.9nm in the ferro workpiece. [10]

3. EXPERIMENTAL DEIGN AND PROCEDURE

A large number of theoretical and experimental studies on surface roughness of Nano finishing products have been reviewed where polishing conditions such as spindle speed, feed rate, gap between nozzle and work piece, current, magnetic field, various types of abrasive size and the material properties of both the fluid and work piece significantly influence surface finish of the machined parts. From the literature review it is observed that there are many factors which affect the surface quality. Factors which affect the surface quality are basically differentiated into two major types: Controllable and uncontrollable parameters like machine tool vibration, ambience and metrology practice are considered to be the uncontrollable parameters and the nozzle speed, feed rate, gap between nozzle and work piece, current (magnetic field), types of fluid, abrasives, time are considered to be the controllable parameters. The parameters chosen for optimization in the present study are as follows: Nozzle speed, Gap between nozzle and work piece, Current. Two set of experimental design were planned to perform for investigating the effects of finishing parameters on the surface quality and to predict the change in surface roughness by two different methods. 1. Taguchi parameter design (L9) 2. Response surface methodology (RSM)

Taguchi Parameter Design

The general steps involved in the Taguchi Method are as follows.

Step 1: Selection of the Quality Characteristic

Step 2: Selection of Levels of Control Factors

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Table 1: Levels of Control Factors

FactorsControllable Factors	Unit	Level 1	Level 2	Level 3
Current	Ampere	0.8	1.1	1.4
Nozzle Speed	Rpm	300	400	500
Gap	Mm	0.75	1	1.25

Step 3: Selection of Orthogonal Array: THREE factors for MRF are studied (viz: Current, Nozzle speed, Gap) in which three levels of each factor are considered.

Table 2: design of experiment

Runs	Current	Gap	Nozzle speed
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	3
5	3	1	3
6	3	2	1

Step 4: Conducting the Experiment: All these experiments are conducted under uniform conditions. It is assumed that the work-piece material is homogenous and tool (nozzle) wear effects are negligible. Each machined surface is scanned thrice at near identical locations to get repeated roughness values. Every set of parameters is also repeated for three times so finally 27 experiments should conduct.

Analysis of Variance (ANOVA): The significance of the variation components associated with factor effects is assessed by comparison with the residual. The usual F-test is utilized for this purpose for comparing variances. The ANOVA Table is shown to determine the significant parameters among the selected parameters.

Table 3: ANOVA

Parameters	DF	SOS	MSS = SS/df	F-ratio
Current	DF_C	SOS_C	$MSS_C=SOS_C/DF_C$	MSS_c/ MSS_e
Gap	DF_g	SOS_g	$MSS_g=SOS_g/DF_g$	MSS_g/MSS_e
Speed	DF_s	SOS_s	$MSS_s=SOS_s/DF_s$	MSS_s /MSS_e
Res(e)	DF_e	SOS_e	$MSS_e=SOS_e/ DF_e$	
Total	DF_{tot}	TSS		

4. RESPONSE SURFACE METHODOLOGY

In general all RSM problems use either one or the mixture of the both of these models Includes 1. A first-order model with 2 independent variables 2. The approximating function with 2 variables is called a second-order model. In order to get the most efficient result in the approximation of polynomials the proper experimental design must be used to collect data. Once the data are collected, the method of least square is used to estimate the parameters in the polynomials.

The response surface designs are types of designs for fitting response surface. Therefore, the objective of studying RSM can be accomplish by: Understanding the topography of the response surface (local maximum, local minimum, ridge lines), and, Finding the region where the optimal response occurs. The goal is to move rapidly and efficiently along a path to get to a maximum or a minimum response so that the response is optimized.

Steps of design of experiment using RSM: 1. A series of experiments were performed for adequate and reliable measurement of the response of interest. 2.

A mathematical model of the second-order response surface with the best fit was developed. 3. The optimal set of experimental parameters producing the optimum response value was determined. 4. The direct and interactive effects of the process parameters (factors) were represented through two and three-dimensional plots.

Table 4: Relationship between the coded and actual values of a factor

Code	Actual value of factor
-α	Xmin
-1	(-α+1)Xmax+(α+1)Xmin/2α
0	Xmin+Xmax/2
+1	(-α+1)Xmin+(α+1)Xmax/2α
+α	Xmax

Table 5: Coded level and actual value of process parameter according to RSM

Sr.No.	Parameter	Unit	Levels				
			-1.633	-1	0	1	1.633
1.	Magnetic Current (I)	A	0.6101	0.8	1.1	1.4	1.5899
2.	Working gap (D)	Mm	0.59175	0.75	1	1.25	1.40825
3.	Nozzle speed (N)	Rpm	236.7	300	400	500	563.3

Table 6: Response surface design (plan) for MRF experiment

Set order	Run order	Block	Coded values			Actual values		
			Current	Gap	Nozzle speed	Current (Amp)	Gap(mm)	Nozzle Speed(rpm)
2	9	1	1	-1	-1	1.4	0.75	300
4	13	1	1	1	-1	1.4	1.25	300
5	15	1	-1	-1	1	0.8	0.75	500
1	16	1	-1	-1	-1	0.8	0.75	300
8	17	1	1	1	1	1.4	1.25	500
3	18	1	-1	1	-1	0.8	1.25	300
7	19	1	-1	1	1	0.8	1.25	500
6	20	1	1	-1	1	1.4	0.75	500

Magnetorheological finishing Experiment is performed on the MRF set up according to the experiment design and then mathematical model is then developed that illustrate the relationship between the process variable and response.

Equipment Details In this section some details of instruments used for this project work with their technical specifications are provided, which are: MR Finishing Holmarc machine set up, Form Talysurf PGI 120 mechanical profiler. Form Talysurf CCI optical profiler.

Design of MRF Exercise

The objective of this effort is to study the behavioral aspects of MRF process parameters to obtain the optimum improvement in surface finish, ΔRa. Towards this objective and to analyze the surface quality of the surface profiles thus generated in terms of surface finish (Ra), a series of finishing exercises were planned and performed on a disc of 20 mm diameter and 15 mm thickness.

Preparation of component for BEMRF process: BEMRF is a nano finishing process which removes the material in the form of very small nano or micro size of chips and can finish the components up to 15-20 nm so for better. In this study initially a rod of 20 mm diameter is taken and then it is cut down in to various disks of 15 mm thickness and 20 mm diameter by hand hexa. Then with the help of facing operation in the conventional lathe machine using carbide tool surface is improved. Then next the grinding process is applied on these work pieces. After the grinding process the surface finish is achieved up to 800 nm. Then Component is taken for the lapping operation. Lapping is done by using alumina oxide as abrasive of size 303.5 (ma3) sizes 11µm and water as a base medium. After the lapping the surface finish was measured. After lapping the final surface roughness in all the components are around 210- 290 nm. The surface roughness of all the components is not same so % change in surface roughness is taken as output in this study.

5. RESULTS AND DISCUSSION

Table 7: Analysing the Results Using Taguchi Method

Sr. no.	Set 1		Set 2		Set 3	
	After MRF Ra (µm)	Before MRF Ra (µm)	After MRF Ra (µm)	Before MRF Ra (µm)	After MRF Ra (µm)	Before MRF Ra (µm)
1	0.070	0.292	0.075	0.290	0.059	0.283
2	0.074	0.225	0.067	0.245	0.081	0.234
3	0.13	0.267	0.145	0.277	0.113	0.276
4	0.056	0.254	0.059	0.251	0.060	0.247
5	0.067	0.217	0.081	0.226	0.074	0.228

Analysis of the S/N Ratio

Percentage change in Surface roughness and its S/N ratio for each level of input factor was taken and plotted to check their effects on process.

Table 8: Percentage improvement Table with s/n ratio and mean response

Sr. no.	Current (Amp)	Gap (mm)	Speed (rpm)	Average. % Change in surface roughness			S/N (db)	Mean response (% Improvement)
				% Improvement				
				Set 1	Set 2	Set3		
1	0.8	0.75	300	75.9247	73.9340	78.8563	37.6344	76.2383
2	1.1	0.75	400	77.9394	76.3347	75.5870	37.6848	76.6204
3	1.4	0.75	500	82.7402	82.2260	82.6648	38.3336	82.5437

Based on average response (% change in surface roughness) and SN ratios, plots are taken with the help of Minitab software.

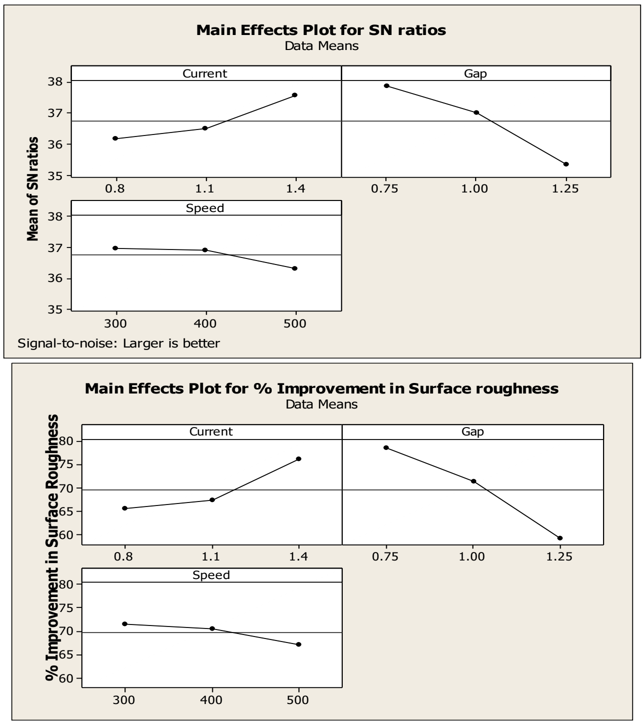

Figure 1: Main effect and S/N ratio plots of various parameters

From the Fig. 1 it can be observe the roughness has the tendency to increases with increase in gap between the tool and workpiece. As the gap increases from 0.75 mm to 1.25, the % improvement in Ra decreases. At the small gap the strength of magnetic field is high so improvement will be more.

Analysis of Variance

Analysis of variances is performed to check the significance and contribution of input parameters on % improvement in surface quality. In current analysis pooled way ANOVA is applied. In one way ANOVA the contribution of error is less than 10% so the effect of interaction of parameters very much less. The effect of interactions of parameters are pooled to the error and pooled one-way ANOVA is applied for the analysis of the results. Further contribution of each input factor on output was calculated and it is observed that gap is most significant factor responsible for improvement in surface finish having contribution 66.59%, followed by current 22.65% and Nozzle speed is having least contribution only 3.63%. All these parameters are found to be significant at 95% confidence level in the magneto rheological finishing of EN-31 material.

Table 9: ANOVA

Source	Sum of Square	DOF	MSE	F-Ratio	F-Ratio Table	Pooling	Contribution in %
Current	586.51	2	293.25	31.78	3.4928	Significant	22.65698
Gap	1723.94	2	861.97	93.42	3.4928	Significant	66.59634
Nozzle speed	93.67	2	46.84	5.07	3.4928	Significant	3.618661
Error	184.52	20	9.23				7.128028
Total	2588.63	26					

It is found that for this particular material the working gap has more influence when compared to the other process parameters.

Table 10: Response Surface Methodology in MRF

Exp. No.	Current (A)	Gap (mm)	Nozzle speed (rpm)	Initial average roughness value (µm) Rai	After finishing average roughness value (µm) Raf	% Change in roughness value ∆Ra (%)
1	1.1	1.408	400	0.257	.1084	57.8
2	1.1	1	563.3	0.250	.103	58.78
3	1.1	1	400	0.2438	0.07789	68.05
4	1.1	1	400	0.2398	0.06589	72.52
5	1.1	1	236.7	0.2378	0.05954	74.96
6	0.61	1	400	0.2448	0.0878	64.12

Response Surface Regression Analysis: The regression coefficient of second order equation generated by response surface model is 0.9596. The generated model is having best fit for experimental and predicted values; there is only very small difference. This value shows that the model is capable for predicting the response for various input parameters very closely to the actual experimental value.For the model adequacy checking includes the test for significance of the regression model, test for significance on model coefficients, and test for lack of fit. For this purpose, analysis of variance (ANOVA) is performed.

Table 11: ANOVA Table for the fit of model

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	1588.02	1588.02	176.447	26.37	0
Linear	3	1405.57	468.524	468.524	70.01	0
Square	3	61.39	61.29	20.463	3.06	0.078
Interaction	3	121.06	121.06	40.354	6.03	0.013
Residual Error	10	66.92	66.92	6.692		
Lack of Fit	5	47.75	47.75	9.55	2.49	0.17

Pure Error	5	19.17	19.17	3.835		
Total	19	1654.94				

Validation: The developed empirical model for magneto rheological finishing (output percentage improvement in average Ra) was validated against the experimental observations. In order to verify the goodness of the predicted model, the error percentage between the observed value (percentage improvement in average Ra value) and the predicted percentage improvement in average Ra value was evaluated 6.6 represents the error percentage between the predicted and the actual percentage improvement in average Ra for different parameters of the MRF process.

Table 12: Validation Table of RSM Model

Sr. No.	**Parameters**			**Predicted value**	**Experimental value**	**Error %**
	Current (A)	**Gap (mm)**	**Nozzle speed (rpm)**			
1	0.8	1	400	64.62434	68.1603	-5.18772
2	0.8	1.25	500	44.35936	52.0196	-14.7257
3	1.1	1	500	63.48171	66.89	-5.09537
4	1.4	1	300	79.67421	79.3133	0.455038
5	1.4	1.25	400	72.89673	66.6289	9.40708

It has been observed that the error percentage for improvement in average Ra is negligible for various parameters. It is also clear from the graph between the predicted value by RSM model by red line and experimental value by green line. These lines are very close to each other which indicate the effectiveness of the developed model. Main objective is to obtain the better surface roughness with low prediction error percentage during MRF.

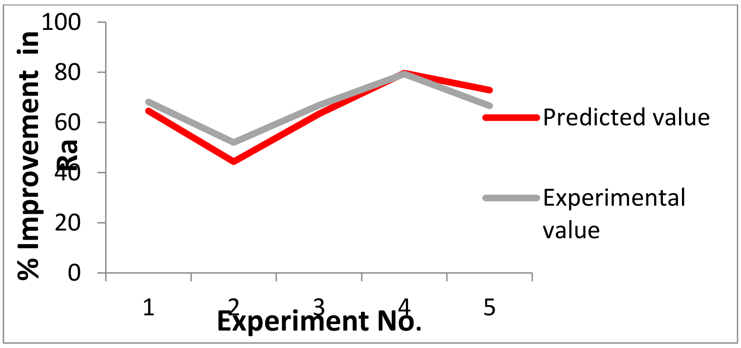

Figure 2: Graph between experimental value and predicted values of % change in Ra in validation trial

Artificial Neural Network

To make more predictable of parameters response we use ANN based FFBPN. We train the model with the help of the RSM experimental design. A generic model is developed which is able to find value of response (% change in surface roughness) for any data set of input parameters as discussed in chapter 5. To validate the neural network model the data is train for the various input parameters and then it verified by conducting actual experiment. 5 no. of experiment at various parameters are conducted and same set of parameters are used to predict the response. The Table 12 shows the experimental result and predicted result and the % error in the actual and the predicted value.

Table 13: Validation of ANN Model

Sr. No.	**Parameters**			**Predicted value**	**Experimental value**	**Error %**
	Current (Amp)	**Gap (mm)**	**Nozzle speed(rpm)**			
1	0.8	1	400	71.50	68.1603	4.89
2	0.8	1.25	500	49.16	52.0196	-5.49
3	1.1	1	500	65.47	66.89	-2.16
4	1.4	1	300	80.48	79.3133	1.4
5	1.4	1.25	400	66.27	66.6289	-.005

Table shows that ANN model is highly capable for predicting the response for a given set of parameter to the actual experimental value with less amount of error. In this case the value of minimum error is -0.005 % and maximum error is -5.49%.

6. CONCLUSION

The aim of this study was to identify the effect of process parameters of the magnetorheological fluid for surface finish. This exercise helps in identifying the optimum MRF conditions and thereby helps in improving the performance of product. Taguchi's design of experiment and Analysis of variances is used to explore the effects MRF process parameters on surface roughness. In this study two models are developed for prediction of the improvement of the surface roughness in terms of percentage. From this study, main conclusions are:-

1. It was found that working gap is a one of the important parameter in the finishing of EN-31 steel having contribution 66.59%.

2. Magnetizing current and nozzle speed are found significant factors for surface roughness with their contribution on surface roughness as 22.65% and 3.61% respectively.

3. Higher magnetizing current has higher value of % improvement in Ra for all combination of machining parameters.

4. Lower working gap is better for the better surface. Nozzle speed is not much affecting the improvement in the surface roughness during the MRF polishing.

5. Optimum combinations for MRF finishing are 0.75 mm gap, 300 rpm nozzle speed, 1.4 A magnetic current.

6. In the best set of parameters the maximum improvement in the surface roughness of the EN-31 steel sample is 82.92% from initial 245 nm to final 43.79 nm and minimum change is 44.16 %.

6. The MRF process was able to remove the abrasive marks left over from lapping process.

7. A second order mathematical equation is generated based on bases of RSM experimental design and confirmation tests are performed for validation of empirical equation. It is found from the conformation test that minimum error in case of mathematical model developed by RSM is 0.455% and maximum error is -14.72%.

8. The error in predicted value in case of ANN model is minimum -.005% and maximum error is -5.59 % in the MRF polishing operation.

9. Confirmation test shows that the predicted values from both the model are very close to the actual experimental values. But in case of artificial neural network it is more accurate than RSM model. The value of regression coefficient in case of ANN model is 0.97 and in case of RSM model is 0.95 which shows the effectiveness of the models.

10. RSM model is very easy to develop and understand but in case of use it is difficult than ANN model.

11. ANN model is time consuming for getting good result, but it is very easy to use.

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