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Original Article

Influence of Magnetic Abrasive Finishing Process Parameters on Surface Roughness of SAE 52100 Steel Using a Hemisphere Pole Geometry Electromagnet

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Abstract - *Finishing is the last stage of the manufacturing of jobs that demand the utmost quality with regard to shape, precision, and surface integrity. Fine-finishing is a process that improves the surface of the workpiece, enhancing its functional and quality attributes. The automotive sector requires precise finishing to enhance the performance, appearance, and longevity of its components. 52100 bearing steel is widely utilized in the production of critical components for various bearings and other applications. However, conventional finishing methods can be difficult to apply when creating components of diverse shapes and sizes. To address this, advanced fine machining and finishing techniques are being employed. One such method is Magnetic Abrasive Finishing (MAbF), a precision technique that produces outstanding quality components. This process utilizes a Flexible Magnetic Abrasive Brush (FMAB) guided by a magnetic field to achieve the desired finish. Typically, the magnetic abrasives used in MAbF consist of two key components: ferromagnetic materials and abrasives, which work in tandem. In this study, 52100 steel bars undergo fine polishing using an MAbF technique, with various process parameters being examined. Aluminum oxide* (Al_2O_3) *serves as the abrasive, while a hemisphere-shaped DC electromagnet is employed for the finishing process. Key variables can be adjusted to achieve optimal surface finishes, including magnetic flux density, component rotation speed, and the ratio of abrasive to ferrous powder in the mixer. The effectiveness of the process is influenced by factors such as the abrasive particle content in the mixing ratio, the speed of the workpiece, and the input DC power source that determines the magnetic flux density. The results indicate that increasing the rotation speed and DC voltage enhances the surface roughness of the 52100-bearing steel rods. Specifically, experiments reveal that improvements in rotation speed and DC voltage can lead to a 57% increase in the maximum enhancement of surface roughness.*

Keywords - *Magnetic abrasives finishing, Hemisphere electromagnet, Flexible magnetic abrasives-brush, Magnetic abrasives particles.*

1. Introduction

Advanced fine and micro finishing techniques encompass polishing, buffing, lapping, super finishing, honing, Elastic Emission Machining (EEM), Abrasives Flow Machining (AbFM), and Magnetic Abrasives Finishing (MAbF), among others. Figure 1 illustrates an illustration of the MAbF process using hemisphere electromagnets. The MAbF technique operates on the principle of coordinated movement between the workpiece and a blend of ferrous and abrasive particles exposed to an electromagnetic field, creating a processing effect on the workpiece. In the MAbF process, the electromagnetic field is essential for determining how the workpiece interacts with the abrasive particles. The Direct Current (DC) electromagnetic field affects both the test piece surface and abrasive particles, and this interaction is what distinguishes the process. The efficiency of the material removal process is closely linked to the motion and force exerted by the electromagnetic field on the Al_2O_3 particles.

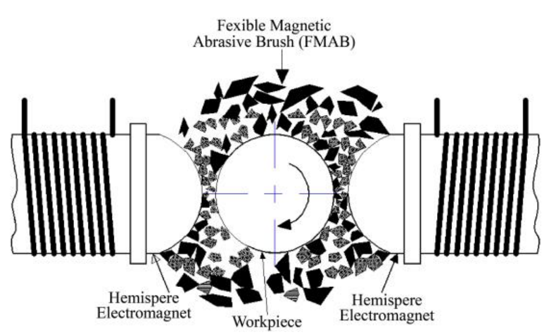

Fig. 1 Schematic of the MAbF

As the workpiece's spinning speed rises, the material removal rate also rises, influenced by the interaction among the abrasive particles and the test piece. Furthermore, when Al_2O_3 particles impact the workpiece, they perform cutting or polishing actions contributing to surface smoothing.

In a recent study conducted by Rajendra E. Kalhapure and colleagues, 52100 steel bars were fine-finished using a magnetic abrasive finishing setup that incorporated various process parameters using two flat pole-shaped electromagnets. Aluminum oxide (Al_2O_3) was selected as the abrasive for this micro-finishing technique. Key variables such as magnetic density, workpiece rotational speed, and abrasive mixture can be adjusted to achieve superior surface finishes. The effectiveness of the process is influenced by factors including the mixing ratio of abrasive particles, the speed of the workpiece, and the input DC power source used to generate magnetic flux density. The results indicate that the surface roughness of 52100 bearing steel rods improved significantly at a voltage of 36V and a rotational speed of 1026 rpm. The experiments further demonstrate that increasing both the voltage and rotational speed leads to a notable enhancement in surface roughness [1]. In an earlier study by Ik-Tae Im and colleagues, a cylindrical workpiece made of STS 304 was processed using the MAbF technique at a very high speed. The research focused on evaluating the roundness, roughness, and variations in fine diameter. The results showed that the micro diameter and weights of the round workpiece may be efficiently controlled using a nearly linear technique. Additionally, applying vibration motion to the workpiece enhanced the surface's improvement. This upgrading was attributed to vibrational motion's ability to effectively eliminate irregularities both in the rotational direction and perpendicular to it [2].

The research paper of Baron et al. experimentally studied the effectiveness of MAbF for removing unwanted particles from holes on flat surfaces. The fundamental components of this technique include a magnetize inductor, a powder among both abrasive and magnetic properties that acts as a cutting tool, as well as a vibrating table and a face electromagnetic inductor made especially for flat surface finishing and deburring. Additionally, the effectiveness of commercially produced magnetic abrasive powders is assessed. A novel method has been created to compare the effectiveness of these magnetic abrasives and identify the most suitable one to polish and deburr holes that have been bored into a flat steel surface. The effectiveness of the deburring process for each magnetic abrasive can be assessed based on the outcomes of the magnetic abrasives experiment. Along with the powders experienced, Fe-TiC magnetic abrasives, characterized by granule sizes of 500 to 400 μm and abrasive sizes of 40 to 28 μm, which are situated on the plane of the composite granules, proved to be the most effective for taking out burr from steel pieces. Magnetic abrasive deburring has the potential to enhance the efficiency of deburring various precision components, including microelectronic parts, as its cutting power can be adjusted by regulating current [3]. Kanish T.C. et al. examine the impact of process parameters on enhancing Material Removing (MR) and %ΔRa, as well as surface roughness. Comprehensive scientific research was conducted on the mentioned work material utilizing the L27 Taguchi's investigational design. This paper presents an analysis using the S/N ratio and ANOVA, demonstrating that high input voltage, a tight machining gap, a bigger mesh size, a low feed rate, and a high rotational speed all substantially impact MR and %ΔRa. Their experimental results indicate a rise in volt, spinning speed, and ab. size positively influences MR and %ΔRa. Conversely, a rise in gap and feed rate negatively impacts %ΔRa and MR [4].

In the study of authors Pandey and Mulik, MAbF is a surface fine-finishing method that involves the removal of material in the form of fine chips through the act of magnetic as well as abrasive particles within an electromagnetic field. In this fine-finishing process, the finishing forces at play significantly impact the quality of the finished testing surface and the precision of the testing piece. Because it affects surface integrity, torque and force magnitude are important. In this study, a newly designed electromagnet was utilized for Magnetically Assisted Finishing (MAF), which produced lower torque and force compared to a traditional electromagnet. Measurements of finishing torque and normal force were taken under various processing conditions using a Kistlers dynamometer, yielding values of approximately 24 N for force and 8 Nm for torque. The experimental design was structured using Taguchi's L16 Orthogonal Array (OA), considering four process parameters: finishing gap, supply voltage to the electromagnet, abrasive weight % and electromagnet rpm.

The results indicated that the finishing gap and supply voltage were important factors impacting torque and finishing force. Additionally, analysis with Scanning Electron Microscopy (SEM) of fine-finished jobs revealed subsurface damage or no surface, recognized as the very low torque and fine finishing force applied [5]. Another review paper by Sinha, A., Singh, S., & Singh, L elaborates on the detailed study of abrasive particles and their processing for the MAF process. This paper explained several techniques for producing magnetic abrasives, including coated, Unbonded (UMA), Bonded (BMA), gel type, and plasma spray methods. Notably, 74% of research studies preferred the unbonded or simply mixed type of magnetic abrasives.

Coated magnetic abrasives provide excellent finishing qualities; however, it has been noted that the coating on the abrasives wears away due to the magnetic particles during the process, which negatively impacts the finishing performance. Also, literature identifies various types of abrasives, including silicon carbide, aluminum oxide, boron nitride, diamond and chromium oxide. Of these, 45% of researchers prefer aluminum oxide, making it the most widely used abrasive [6]. Yuewu Gao and colleagues have carried out research on modeling of removal of material in this abrasive finishing process by examining various process parameters and concluded that removing of material increased as the feed rate, working gap of the job, and size of the MAPs were reduced also the considerable cutting force of diamond particles is capable of effectively removing a significant amount of material from the surface and for significant enhancement in surface finish by utilizing a low working gap, low feed, fine MAPs with high rotational speed [7]. Lida Heng et al. have used various shapes of magnetic poles for the experiments. The experimental findings revealed that the MAbF process effectively polished the internal surface of tubes with an oval shape.

This process utilized a freely movable magnetic pole arrangement along with iron-based composite abrasives / Al_2O_3 under the best possible conditions. An improvement in surface roughness of up to 79% is achieved under the following conditions: Higher rotational speed, D-shaped magnetic poles, lower grain size of abrasive, a wet processing method and a higher finishing time. Additionally, iron-based composite abrasives / Al_2O_3 successfully eliminated noticeable peaks and grooves from the oval-shaped tube's original inner surface, according to Atomic Force Microscopy (AFM) imaging of the surface conditions. The ANN model demonstrates potential as a valuable tool for assessing and predicting the results of the inner MAbF procedure [8]. In one more experimental study conducted by Singh, P., and Singh, L., SiC-based glued MAb were utilized for the inner surface completion of aluminum pipes that are cylindrical. These magnetic abrasives were produced by blending SiC (Silicon Carbide, 400 mesh) with iron powder (ferromagnetic, 300 mesh). The gap between the electromagnet and the workpiece is maintained at a steady distance of 1 mm for the experiments. The Magnetic Field Strength (MFS) for the experiments was adjusted using a variable DC power supply. Scanning Electron Microscopy (SEM) pictures were taken after the tests to compare the incomplete and finished workpieces.

The authors discovered that the interaction between Magnetic Field Strength (MFS) and speed significantly influenced both the Material Removing Rate (MRR) and % Improvement in Surface Finish (PISF). Consequently, surface irregularity was minimized, with PISF showing an enhancement ranging from approximately 27.6% to 81.5%. The optimal process parameters for achieving the maximum PISF of 81.5% included higher magnetic field strength, increased circumferential speed, a smaller abrasive mesh size, and a reduced quantity of magnetic abrasives in the mixture [9]. In the paper of Abdallha M et al., they studied and introduced innovative pole (shape) geometry to evaluate its effect during the MAbF process of the given alloy. Four process variables with three levels were taken, including pyramid-shaped pole (shape) geometry: input current, finishing time and rotational speed. The design of experiments was employed using an L9 orthogonal (Taguchi) array for analyzing the impact of all variables on results output i.e. response, which is given by surface roughness (Δ Ra). An ANOVA analysis of variance was conducted to determine the significance of these variables. A regression model was also developed to forecast the results, i.e., output response. The investigational findings indicated that rotational speed is the most influential factor, followed by input current, fine-finishing period, and the angle of the pole pyramid. The higher surface roughness is achieved at higher rotational rpm, a medium working clearance, a specific fine-finishing period, and a lower pole angle. It is noticeable that as the rotational rpm speed increases, the enhancement in surface roughness becomes more pronounced.

This suggests that higher rotational speeds help to minimize waviness and irregularities in the surface texture. Material removal occurs through chip formation, resulting from the correlative motion between the workpiece surface and the flexible magnetic abrasives brush. As a result, advancement in surface roughness grows with higher rotational speeds. Furthermore, increased rotational speeds facilitate greater material removal and contribute to a smoother surface improvement due to elevated temperatures with a decreased coefficient of friction. In contrast, lower rotational speeds produce less centrifugal force, leading to the accumulation of magnetic abrasive particles at the center of the workpiece. As the rotational rpm speed rises, the centrifugal force also rises, promoting a more effective distribution of abrasive particles that can efficiently eliminate surface peaks [10]. In the study article 'Evaluation of Parameters Affecting Magnetic Abrasive Finishing on Concave Freeform Surface of Al Alloy via RSM Method' by the authors M.Vahdati and Seyed Alireza R. explained the impact of magnetic abrasives process parameters on aluminum parts' free form surfaces is investigated. This technique is produced by combining the use of a CNC with a magnetic abrasive process.

In this work, in addition to simulating and testing the magnetic flux density of the iron hemisphere and hemispherical magnet, the appropriate tool was manufactured for the MAbF procedure. It is utilized as an MAbF tool because of the improved distribution and accessibility of magnetic flux density on the hemispherical magnet surface. According to simulation studies, the ideal values can increase surface roughness by up to 75%. In order to test the experiments, a basic hemisphere is used for installation on the flat region of the magnets, and the magnets spark in the shape of a curve. Maxwell's finite element software determines the effect of magnetic field intensity.

According to the results, the surface roughness often drops from its initial 1.3 µm roughness to 0.2 µm in concave surface areas. Nonetheless, the lowest surface roughness of 0.08 µm was recorded in a few locations [11].

This paper examines the percentage improvement in surface roughness during MAbF, focusing on input DC voltage for the hemisphere-shaped electromagnets, workpiece rotational speed, and the percentage of Al_2O_3 abrasive in the mixing ratio as variables in the process. The input DC voltage and the workpiece's rotational speed are the main parameters influencing the enhancement of surface roughness, according to statistical analysis of the experimental data. The study explored the impact of these various process variables, utilizing the analytical data to assess the characteristics of the MAbF process.

This paper deals with the percentage improvement in surface roughness during MAbF (using hemisphere geometry electromagnet) using input DC voltage, workpiece rotating speed, and Al_2O_3 abrasive content (%) in mixing ratio as process variables. This study investigated the effects of various process variables, including input DC voltage, workpiece rotational speed, and the concentration of Al_2O_3 abrasive in the mixing ratio. The analytical data were utilized to evaluate the characteristics of the MAbF process.

2. Experimental Methodology

2.1. Experimental Configuration

For the purposes of this experimental study, the MAF setup is developed on a lathe machine (type of Lathe Machine: Centre Lathe Machine) using a DC power supply, as seen in Figure 2.

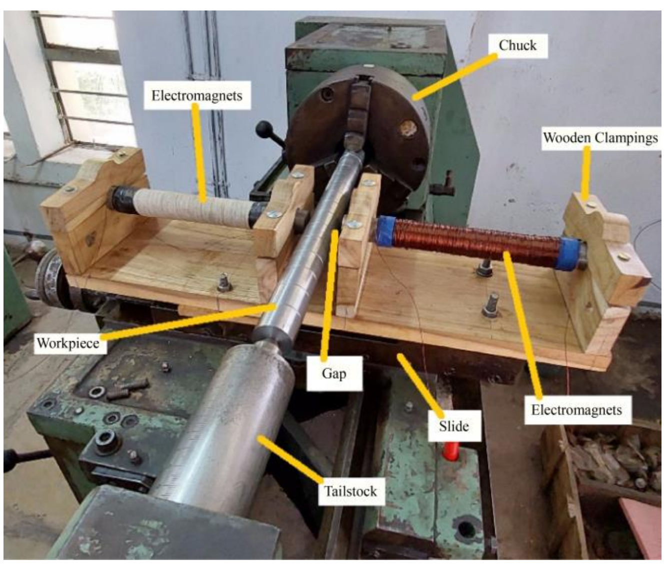

Fig. 2 Photograph of actual MAbF Setup

The cutting tools, FMAB, consist of a mixture of abrasive particles (Al_2O_3) and ferromagnetic material (iron powder). The workpiece (Dimensions of workpiece: Ø25*25mm length) is gripped in a three-jaw chuck and adjusted between electromagnetic poles. Two hemisphere-shaped electromagnets are made of copper wire coils, as shown in Figure 3, which were set to be mutually opposing.

Fig. 3 Hemisphere electromagnets

A DC current source (Specifications of DC power supply: 0 to 36V) from an AC to DC converter is utilized to power the electromagnet, which is coupled to a lathe slide. To prevent magnetic flux leakage onto the lathe slide, hardwood brackets and aluminium nuts and bolts are employed to clamp the electromagnet to the slide.

Iron and Al2O3 particles are combined to make a flexible abrasive brush, held together by the electromagnetic field generated by DC electromagnets, which provides the required finishing force. The surface finish obtained is mirror-like since this technique is always carried out with very delicate forces.

Figure 4 shows a photograph that demonstrates how a Flexible Magnetic Abrasive Brush (FMAbB) is created when particles align along magnetic field lines. The same brush applies pressure to the workpiece's surface, generating finishing pressure that leads to micro indentations.

The required force, which the FMAB tangentially produces, serves as the primary cutting power that leads to fine chipping. In this abrasive finishing method, the workpiece is positioned between two electromagnets. The required distance between the surface of the workpiece and the electromagnets must be set using properly sized slip gauges.

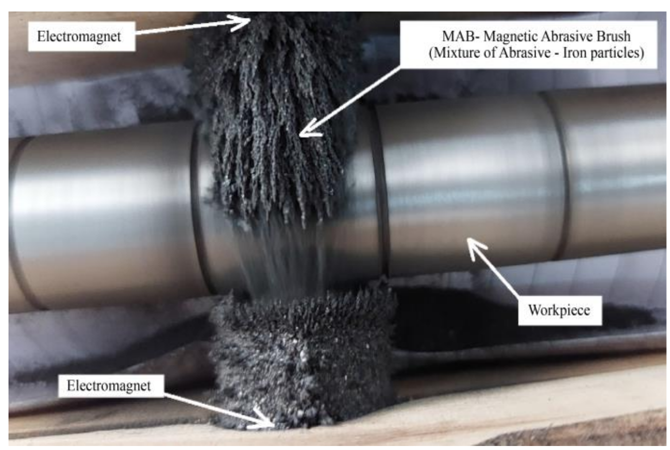

Fig. 4 Actual photograph of FMAbB

Al_2O_3 abrasive particles may be utilized in various forms: unbonded, lightly bonded and or fully bonded. A combination of Al_2O_3 abrasives and iron particles has been applied to SAE 52100, also known as ASTM 52100 steel bars in the finishing area, where the electromagnetic field generates the final force applied to the steel bars' surface. ASTM 52100 steel, also known as bearing steel, is a high-carbon, chromium alloy steel prized for its exceptional hardness, wear resistance, and fatigue strength, making it ideal for bearings, gears, shafts, and other high-stress.

Throughout the process, the mixture of iron and abrasive particles placed at the surface of the workpiece are attracted to the electromagnetic field that presses against its outer surface. As the workpiece rotates and a DC voltage is used to the electromagnet, a magnetized field is generated at the poles of the electromagnet. This magnetized field draws in a mixture of powders applied to the workpiece. The same mixer is positioned within the gap of the workpiece, where electromagnets are employed to achieve a precise polishing of the surfaces.

2.2. Work Material

In this study, Al_2O_3-based magnetic abrasives were employed to polish cylindrical ASTM52100 steel rods, each measuring 25mm in diameter and 25mm in length, to accomplish a good finish. Prior to the final finishing of the MAbF setup, the workpieces are initially ground, and their surface roughness is subsequently assessed.

2.3. Mixture of Abrasives and Iron Particles

A simply mixed mixture of magnetic abrasives was formed by mixing Al_2O_3 and iron powders in different proportions, as shown in Table 1.

2.4. Selection of Process Parameters and Experimental Design

Actual experimentation was carried out using the design of experiments, Taguchi's orthogonal array L9 (3^3) (3 levels, 3 factors), to estimate the effects of factors as process variables that influence performance (finishing of the surface). Distance between the electromagnet and the workpiece is maintained at 2 mm using slip gauges, and a consistent fine finishing time of 20 minutes is applied across all experiments. For this study, 3 factors are speed in rpm, Input DC voltage and Mixing Ratios. Also, the 3 levels, low, medium and high, were examined.

Table 1. Experimental conditions low medium high

Process Parameters	Levels		
	Low	Medium	High
The rotational speed of the workpiece	226	649	1026
Input voltage	24	30	36
Abrasive content in Mixing Ratio (Abrasive: Fe)	1:2 (1)	1:1 (2)	2:1 (3)

2.5. Measurement of Response Variables

Table 2 shows the respective input data and output measured data.

Table 2. Experimental input data and response

Expt. No.	Workpiece Rotational Speed	Input DC Voltage	Mixing Ratio	% Improvement	S/N
1	226	24	1	21.310	26.5717
2	226	30	2	24.799	27.8887
3	226	36	3	32.653	30.2785
4	649	24	2	33.149	30.4094
5	649	30	3	39.366	31.9024
6	649	36	1	46.321	33.3156
7	1026	24	3	47.656	33.5624
8	1026	30	1	51.840	34.2933
9	1026	36	2	57.362	35.1725

3. Results and Analysis

This section outlines the outcomes of the statistical analysis carried out on experimental data. Inferential statistical techniques are employed to assess the signal-to-noise ratio (S/N ratio) and conduct an Analysis of Variance (ANOVA) to determine process variables that influence percentage improvement in surface finish.

3.1. Response Table - Signal-to-Noise Ratios

To attain an increased percentage enhancement in surface finish (% change in Ra), the "Larger is better" quality feature was selected for this study. Speed and voltage are more contributing factors.

Table 3. Response table for S / N ratio of percentage change in Ra

Level	Speed	Input Dc Voltage	Mixing Ratio
1	28.25	30.18	31.39
2	31.88	31.36	31.16
3	34.34	32.92	31.91
Delta	6.10	2.74	0.76
Rank	1	2	3

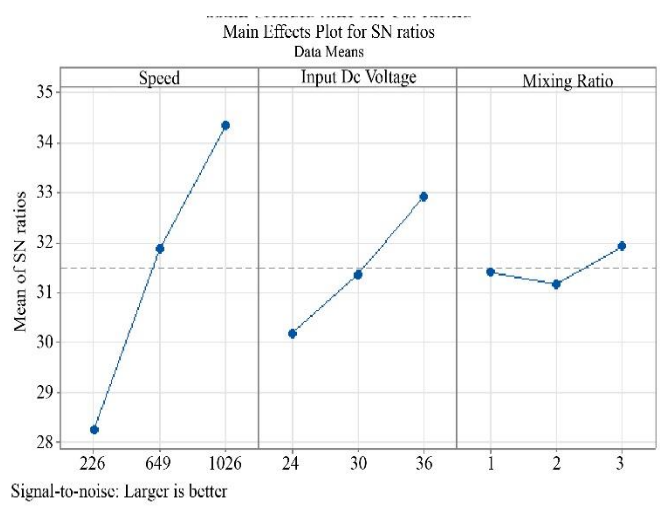

Fig. 5 Process parameters

In terms of Speed (Level 3), a value of 1026 has a greater impact; for Input DC Voltage (Level 3), a value of 36 is more important; and for Mixing Ratio (Level 3), a ratio of 2:1 is the most effective for achieving the desired output.

To assess how individual process factors influence %ΔRa, the delta value is determined by calculating the Signal-to-Noise (S/N) ratios. Table 6.4 ranks parameters based on delta values found for %ΔRa. The factor with the greatest delta value was assigned the top ranking, and so on. The Figure illustrates the S/N ratios for process parameters in relation to the percentage enhancement in surface roughness, denoted as %ΔRa. From Signal to Noise Ratio- Optimum levels are obtained. i.e. Best experiment levels to get maximum percentage Improvement: Workpiece input speed 1026 rpm, Input DC Voltage- 36 V, Mixing ratio- 1:1.

3.2. ANOVA, Analysis of Variance

Workpiece speed has the highest impact on the process because the F value is the largest compared to others. ANOVA was used to identify significant process characteristics influencing %ΔRa. Table 5 shows the ANOVA results for %ΔRa.

Table 4. Analysis of variance

Source	DF	Adj SS	Adj MS	P-Value	F-Value	Percentage Contribution
Regression	3	1211.59	403.86	0.000	292.90	-
Workpiece Speed	1	1016.40	1016.40	0.000	737.15	83.42
Input DC Voltage	1	195.18	195.18	0.000	141.56	16.02
Mixing Ratios	1	0.01	0.01	0.946	0.01	0.00082
Errors	5	6.89	1.38	-	-	0.57
Total	8	1218.48	-	-	-	-

It is clear that the primary factor affecting the rate of improvement in surface roughness is rotational speed, followed by input DC voltage and mixing ratio. The highest value of ΔRa is 57.4%. These results were achieved at a high rotational speed, input DC voltage and a medium mixing ratio.

3.3. Percentage Contribution of Factors on the Process

The following Figure illustrates the percentage contributions of various variables to the outcome of percentage change in Ra, highlighting that the workpiece rotational speed has the most notable impact on the improvement in surface roughness of a given component. Additionally, the input DC voltage of the electromagnet has been recognized as a key factor.

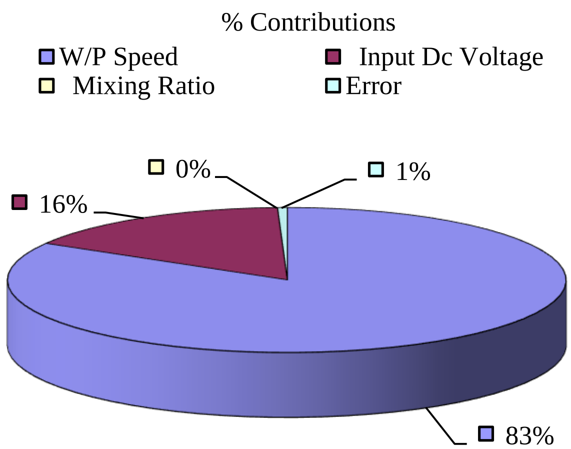

Fig. 6 Percentage contributions of process variables to %ΔRa

3.4. Regression Equation

Following Table 5 shows various coefficients,

Table 5. Coefficients

Terms	Coef.	SE Coef.	P-Value	T-Value	VIF
Constants	-9.81	2.72	0.015	-3.61	
W/P Speed	0.03252	0.00120	0.000	27.15	1.00
I/P DC Voltage	0.9506	0.0799	0.000	11.90	1.00
Mixing Ratio	0.034	0.479	0.946	0.07	1.00
		S 1.17423	R- sq (adj) 99.09 %	R- sq 99.43 %	R- sq (pred) 97.71 %

From the coefficients in Table 5, following is the following regression Equation (1) is formed.

$$\text{\% Improvement in Surface Roughness} = -9.81 + 0.03252\text{ Workpiece Speed} + 0.9506\text{ Input DC Voltage} + 0.034\text{ Mixing Ratio} \quad (1)$$

From Table 5, as R-Sq (Pred) is 97.71%, the regression model can be accepted statistically. The regression model is best fitted as the R-squared value is 99.43% and the R-adjusted value is 99.09% under 95% confidence level.

Table 6 displays the experimental and expected (predicted) ΔRa and the absolute percentage error, determined using Equation (2).

$$\% \text{ error} = \frac{\text{Experimental Ra} - \text{Predicted Ra}}{\text{Experimental Ra}} * 100 \quad (2)$$

Table 6. Experimental and predicted ΔRa with absolute % error

Expt. No.	Workpiece Rotational Speed	Input DC Voltage	Mixing Ratio	% Improvement Experimental	% Improvement Predicted	Absolute % Error
1	226	24	1	21.310	20.388	4.326983
2	226	30	2	24.799	26.126	5.349087
3	226	36	3	32.653	31.863	2.419012
4	649	24	2	33.149	34.178	3.103804
5	649	30	3	39.366	39.915	1.395824
6	649	36	1	46.321	45.551	1.66214
7	1026	24	3	47.656	46.472	2.48464
8	1026	30	1	51.840	52.108	0.516049
9	1026	36	2	57.362	57.845	0.84223
	Average					**2.45553**

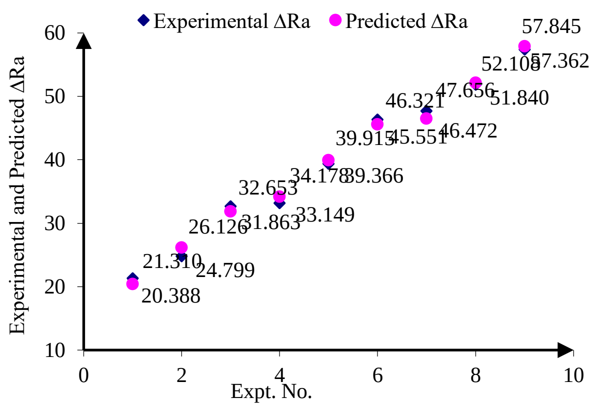

Fig. 7 Experimental vs. Predicted ΔRa

Between the experimental and projected ΔRa, the average absolute error was 2.4555. (Accuracy 97.5%) is within acceptable value considering 95% confidence interval level. Consequently, the value is appropriate for the linear statistical model. The Figure illustrates a significant relationship between the predicted and actual surface roughness.

3.5. Confirmatory Test

To validate regression Equation (1), confirmatory tests were performed for ΔRa by calculating various parameters. The workpiece rotation speeds considered were 250, 450, 550, 750, and 950 rpm, while the input DC voltages were set at 25, 27, 29, 31, and 33 volts. Additionally, mixing ratios of 2:1, 1:1, 1:2, 2:1, and 1:2 were used. The ΔRa was predicted for the same combinations of workpiece rotation speeds, input DC voltages, and mixing ratios.

Table 7. Experimental and predicted ΔRa for confirmatory tests

Expt. No.	Workpiece Rotational Speed	Input DC Voltage	Mixing Ratio	% Improvement Experimental	% Improvem ent Predicted	Error
1	250	25	1	22.078	22.119	0.001857
2	450	27	2	31.812	30.5582	0.039413
3	550	29	3	36.317	35.7454	0.015739
4	750	31	1	45.116	44.0826	0.022905
5	950	33	3	54.712	52.5558	0.03941
Average						0.023865

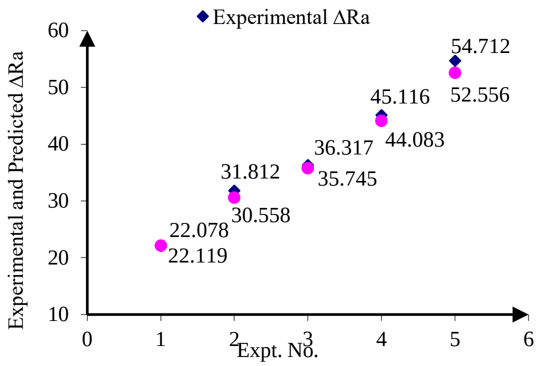

Fig. 8 Confirmatory tests, experimental vs. Predicted ΔRa

The mean absolute error between the experimental and predicted ΔRa was 0.023865. In other words, the correctness of the created model is approximately 97.6%, which is considered an acceptable value for a linear statistical model.

4. Conclusion

Optimizing the process parameters in MAbF plays a crucial role in improving the surface quality (%ΔRa). This research aims to develop an MAF process specifically for finishing 52100 bearing steel and determine the perfect conditions to boost surface finish and material removal. Through experimental investigations into the MAF process, this current study has led to the following conclusions:

It is clear that as the rotational speed rises, there is a corresponding enhancement in surface roughness. The surface texture's waviness and imperfections are reduced with higher rotating speeds. This improvement occurs because material removal is achieved through chip formation resulting from the relative movement of the FMAbB and the workpiece surface. The most influential input parameters are as follows: for Speed (Level 3), a value of 1026 has a significant effect; for Input DC Voltage (Level 3), a value of 36 is crucial; and for Mixing Ratio (Level 3), a ratio of 2:1 is necessary to achieve the desired output. Signal-to-Noise (S / N) ratios and ANOVA study indicate that a high-level voltage of 36V and superior workpiece rotation speed of 1026 rpm substantially impact %ΔRa. Experiments show that increasing rotating speed and DC voltage has a favourable influence on %ΔRa. The abrasive content in the mixing ratio has been shown to affect the least.

4.1. Future Scope

This process can be examined by utilizing different artificial abrasive powders in various grain sizes and a range of electromagnet shapes such as conical, flat conical, prismatic, and pointed. Additionally, the process can be analyzed under different working conditions, including wet and dry environments, while varying the process parameters.

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