INVESTIGATION OF SURFACE INTEGRITY DURING MAGNETIC ABRASIVE FINISHING OF AISI 307 STAINLESS STEEL

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Abstract : Magnetic abrasive finishing (MAF) is a polishing/finishing technique used primarily to achieve higher levels of surface finish. The process is widely used for finishing of very hard and brittle non magnetic materials. It utilizes magnetic force and ferromagnetic abrasive particles for finishing of work piece. Ferromagnetic particles are conglomerate of abrasives and iron particles. The work piece was a non-magnetic stainless steel (SS307 grade) tube. The magnetic abrasive particles were used in present work prepared by sintering of iron and silicon carbide particles. The input parameters which were considered for the study include rotational speed of poles (RPM), MAP size (μm), quantity of iron in abrasive particles.The effect of MAF parameters have been studied on Ra, Percentage Improvement in Surface Finish. The interaction of Rotational speed , MAP size and Percentage of iron in abrasive particles have shown predominant effect on the Ra, and percent improvement in surface finish. Then the SEM analysis of the finished work pieces was done which indicates that the tool marks are completely removed by the MAF process. The maximum PISF (58.55%) was obtained at, speed = 200.45 rpm, MAP size = 200μm and 85% of iron in abrasive particles.

***IndexTerms* - MAF, SS307, RPM, MAP, Ra, PISF, SEM**

1. INTRODUCTION

Rising demand for manufacturing of high performance parts made of very hard and high strength materials has taken the finishing to a very advanced level. Economic manufacturing of high quality precision parts is required in small batches and large variety. With the development in technology the parts have intricate geometries and a growing trend towards miniaturization of parts. Industries like aero-space, automobiles, electronics etc. require using high performance parts manufactured to very close tolerances and high surface finish.Magnetic abrasive finishing (MAF) is a famous super polishing technique used mainly to achieve higher levels of surface finish exclusively on the hard materials and non ferrous like stainless steel, ceramics and silicon. It utilizes a disciplined magnetic force of extreme small magnitude on ferromagnetic abrasive particles which are a conglomerate of abrasives and iron particles for the material removal. The process is widely used for ultrafine finishing of ferrous and non ferrous, hard and brittle materials.In magnetic abrasive machining or finishing, there is the need of magnetic strength as well as magnetic abrasives. The required magnetic strength is obtained either from both types of magnets, electromagnets or permanent magnets.

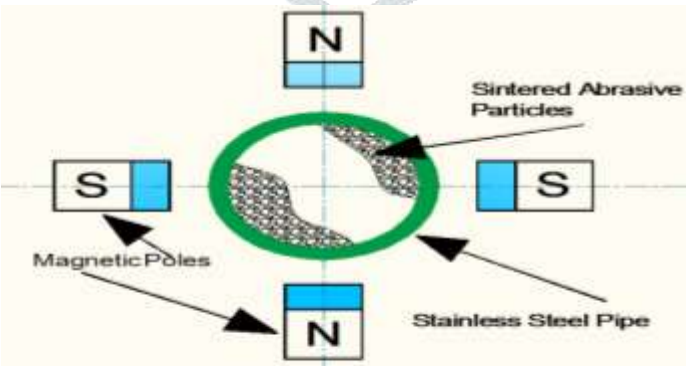

Fig.1 Schematic diagram of magnetic abrasive finishing process

2. PREPARATION OF MAGNETIC ABRASIVES

Sintered Magnetic abrasives were prepared in following 4 steps:

1. Uniformly mixing of silicon powder and iron metal powder

For getting magnetic abrasives it must be magnetized and have the ability of finishing. For this purpose iron metal powder (mesh number-300) and natural silicon powder (mesh number100-300) were mixed mechanically in three different ratios by weight.

2. Preparation of Compacts

The mixture is compressed into a cylindrical die and by applying a load of 100 kilo-newton on die using UTM.The dimensions of the compacts are 20mm diameter and 26mm length approximately.

3. Sintering of Compacts

Sintering is the process by which metal powder compacts (or loose metal powders) are transformed coherent solids at temperatures below their melting point. During sintering, the powder particles are into bonded together by diffusion and other atomic transport mechanisms, and the resulting somewhat porous body acquires a certain mechanical strength. After the preparation of compacts they were sintered in a specially designed furnace to a temperature of 1200˚C in H_2 gas atmosphere and kept at selected temperature for 2 hrs. During Sintering the silicon powder got cohered with the iron particles and is difficult to separate. The sintering temperature was selected on the basis of literature survey.

4.Crushing and sieving of crushed compacts

The sintered compacts were crushed mechanically into desired size. Then the powdered abrasives were separated by sieves to get a single abrasive size by using sieve set for experimentation. The size of abrasives used in this study were 368,300,200,100 mesh size.

3. EXPERIMENTAL SET UP:

The experimental setup for finishing of internal surfaces using Magnetic Abrasive Finishing process consists of Four permanent magnets mounted on an silicon chuck, which act as a carrier and also acts as insulator to separate them. The work piece (Stainless Steel Grade 307) is held in the centre of the chuck by means of external clamps inside a PVC pipe.

Fig.2 MAF set up

3.1 RESPONSE VARIABLE FOR EXPERIMENTATION:

The response variables chosen for the present experiment is surface roughness. The initial surface roughness is not identical for all the work pieces (it varied between 1.70 µm to 1.90 µm Ra). A ratio of decrease of surface roughness to the initial roughness is considered as one of the response variables during this experimentation. It is called percentage improvement in surface finish and is given by :-

$$\text{PISF } (\mu m) = \frac{(\text{Initial Surface Roughness} - \text{Final Surface Roughness})}{\text{Initial Surface Roughness}} \times 100$$

SELECTION OF MAGNETIC ABRASIVE FINISHING PARAMETERS:

The Magnetic Abrasive Finishing parameters are selected based on literature review and the preliminary experimentation as discussed below:

Rotational speed:

Both the work piece and the poles can be rotated to obtain surface finish. Material removal increases with rotational speed and after some value of speed jumbling of abrasives starts which decreases surface finish. In the present study three levels ranging from 120 to 180 rpm were selected for poles of the permanent magnet as it is clear from the initial experimentation that the abrasives start rolling over the surface due to higher value of tangential force.

Size of MAP:

It refers to the size of Sintered Magnetic abrasive prepared for the experimentation. It is understood that smaller MAP grains tend to give better surface finish, whereas the larger grains apply excessive force on the work piece and tend to deteriorate the surface finish. In the earlier work, MAP grain size in the range 45µm–800µm was used. In the present experimentation, MAP grains with intermediate size were chosen so that the three levels of grain size of MAP lie between 100µm–300µm

Percentage of iron in magnetic abrasives:

In most of the cases iron percentage is varied from 60 to 90% of the abrasive volume. So in the present study the sintered magnetic abrasives were prepared by varying iron percentage from 75 to 95 % of the abrasive volume.

4. EXPERIMENTAL PROCEDURE:

Initially the Ra values of work pieces were measured. The work piece is clamped in the chuck between the magnetic poles as shown in figure 2. The quantity of abrasive powder in MAP's is fixed 15 gram by weight for experimentation. The sintered magnetic abrasive powder, which is prepared just before each test by adding the lubricant, was placed in the stainless steel tube mounted in the magnetic chuck. The working gap between the poles and the work piece had been fixed. The rotational motion to the magnets was given through the motor. The finishing operation was continued for 120 minutes and monitored with a stop watch (0.01s accuracy) after which the work piece was removed from the table. After cleaning the specimen with ethanol, its surface finish was measured using a Mitutoyo surface roughness tester having a least count of 0.001µm(cut off length = 0.8mm).

Magnetic abrasive powder introduced in the work piece surface join each other to form a flexible magnetic abrasive brush. The abrasive particles of the flexible magnetic abrasive brush shear off the peaks of the irregularities on the surface of work piece being finished thereby improving its surface finish. To hold work piece in the finish zone for a longer time period, lubricating oil (1ml for 5 gm weight) is added to the MAPS. The process was repeated with different parameters selected earlier.

Table 1 Experimental Plan and Results

Run	Factor 1 A:Abrasive size	Factor 2 B:RPM	Factor 3 C: % of Fe	Response 1 Ra	Response 2 Rz	PISF (%)
1	300.00	180	95.00	0.34	2.36	24.44
2	200.00	150	85.00	0.3	2.73	48.27
3	368.179	150	85.00	0.58	8.24	37.63
4	200.00	150	85.00	0.33	2.52	50.11
5	100.00	180	75.00	0.37	4.64	49.61
6	200.00	150	68.18	0.31	2.14	39.33
7	100.00	180	95.00	0.32	2.29	32.63
8	200.00	150	95.00	0.37	2.79	33.49
9	200.00	150	85.00	0.31	2.76	51.32
10	300.00	120	95.00	0.36	3.96	23.32
11	300.00	120	75.00	0.39	5.90	42.54
12	200.00	99.544	85.00	0.37	3.89	47.97
13	300.00	180	75.00	0.32	3.13	46.58
14	100.00	150	85.00	0.30	2.38	54.37
15	100.00	120	95.00	0.45	4.48	29.42
16	200.00	150	85.00	0.33	3.16	53.44
17	200.00	200.45	85.00	0.28	2.68	58.55
18	100.00	120	75.00	0.55	4.42	49.69

RESPONSE- 1: Ra

In the present study the measured value for Ra for different experiments are given in tables ANOVA results are shown in tables 6.3

ANOVA Analysis for Ra

Table 2 Analysis of variance table of Ra

Source	**Sum of squares**	**DF**	**Mean square**	**F value**	**P value prob>F**	
Model	0.108317852	9	0.012035137	16.50218837	0.0014	significant
A-Abrasive size	0.008136155	1	0.008136155	11.1558637	0.0156	Significant
B-RPM	0.022259837	1	0.022259837	30.52150774	0.0015	Significant
C-% of Fe	0.005231561	1	0.005231561	7.173238845	0.0366	Significant
AB	0.00605	1	0.00605	8.295439246	0.0281	Significant
AC	0.00245	1	0.00245	3.359310108	0.1165	
BC	0.00125	1	0.00125	1.713933729	0.2384	
A^2	0.074547575	1	0.074547575	102.215683	<0.0001.	Significant
B^2	2.42336E-05	1	2.42336E-05	0.033227864	0.8614	
C^2	0.004402465	1	0.004402465	6.036426566	0.0493	Significant
Residual	0.004375898	6	0.000729316			
Lack of fit	0.003700898	3	0.001233633	5.482812565	0.098	Not Significant
Pure error	0.000675	3	0.000225			
Cor Total	0.11269375	15				

The Model F-value of 16.50 implies the model is significant. There is only a 0.14% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, A^2, C^2 significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The "Lack of Fit F-value" of 5.48 implies there is a 9.80% chance that a "Lack of Fit F-value" this large could occur due to noise.

ANOVA statisics for Ra

Table 3 ANOVA statistics for Ra

Std. Dev	0.027005859	**R-Squared**	0.961169999
Mean	0.369375	**Adj R-Squared**	0.902924996
C.V. %	7.311230829	**Pred R- Squared**	0.514057251

Press	0.054762711	**Adeq Precision**	14.62537644

The "Pred R-Squared" value approaches to 1 reflects about the accuracy and reliability of conducted experiments.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 14.625 indicates an adequate signal. This model can be used to navigate the design space.

EFFECTS OF INPUT FACTORS ON Ra

The figure shows 4 shows about the graph of normal plot of the residual for Ra. The data points in the graph looks near to the straight line, thus the validates the accuracy of the results obtained .

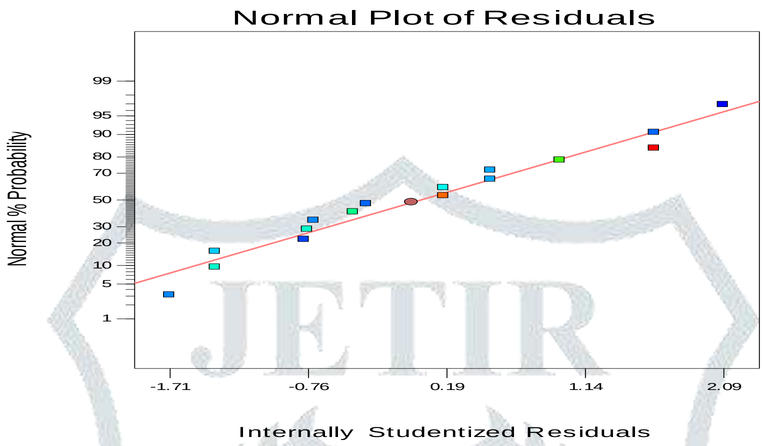

Fig.3 Normal probability plot of the residuals

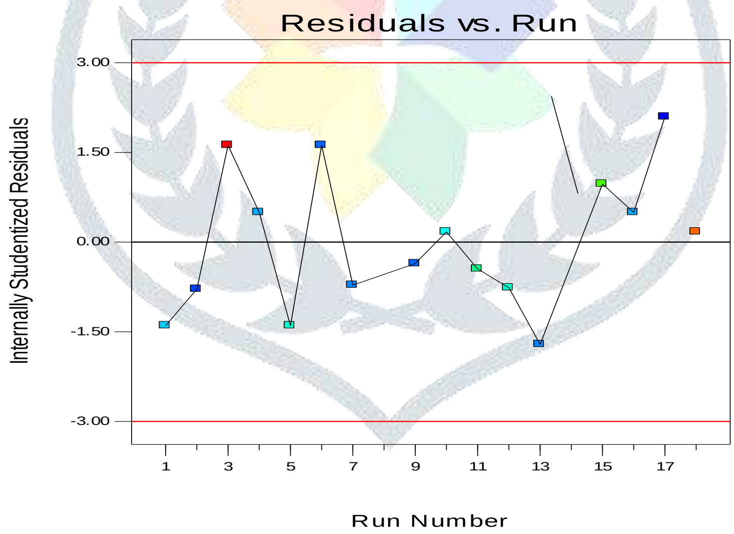

Fig.4 Depicts the residuals act random as desired

EFFECT OF RPM AND ABRASIVE SIZE

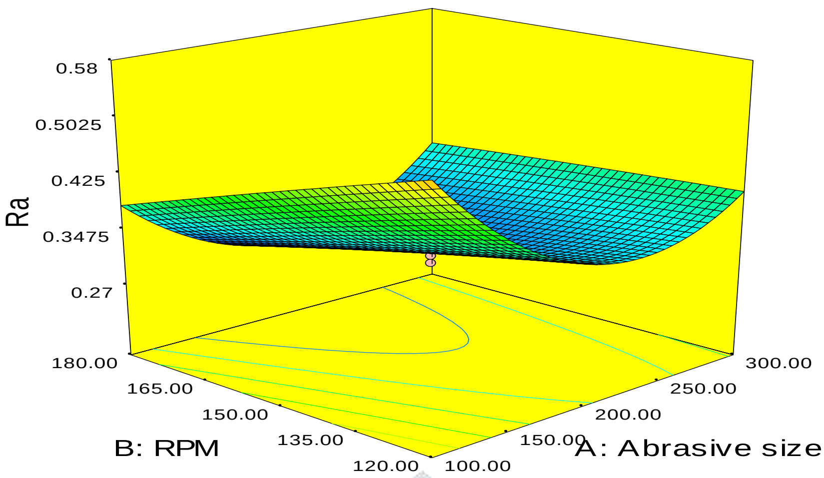

Fig.5 Interaction effect of RPM and Abrasive size

Fig.6 shows interaction effect of quantity of rotational speed and magnetic abrasive particles by using any grain size particles with decrease in rotational speed there is a massive improvement in Ra. At 100µm, value of Ra slightly decreasing with increasing in RPM ,and from 120-180 RPM and size of abrasive at 300µm, Ra decreases marginally with increases in rpm from 120-180. Whereas with increase in speed the PISF decrease .Further at lowest speed, with decrease in abrasive size there is a slight decrease in Ra.

EFFECT OF C: % OF Fe AND ABRASIVE SIZE

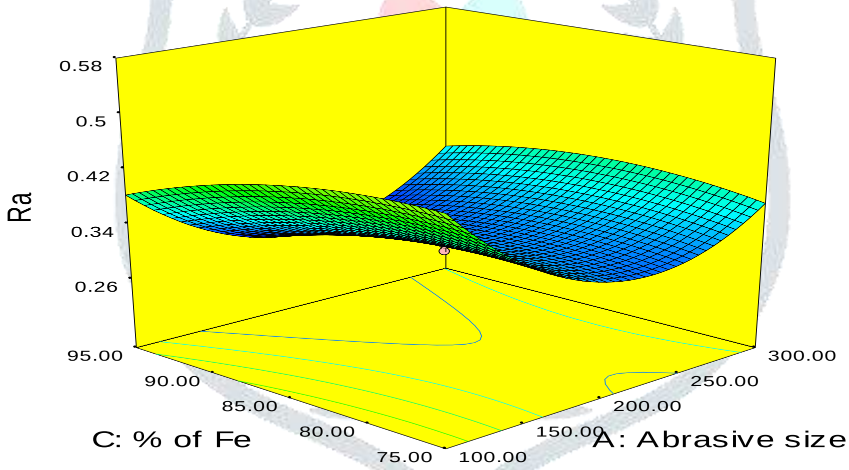

Fig.6 Interaction effect of C% of Fe and Abrasive size

The figure shows the interaction effect of At 75% of Fe, the value of Ra starts decreasing with increase in abrasive size from 100 to 200µm. However with further increase in abrasive size from 200, the value of Ra starts increasing, similarly decrease and of variation of Ra is observed corresponding to 95% iron (Fe).

EFFECT OF C: % OF FE AND RPM

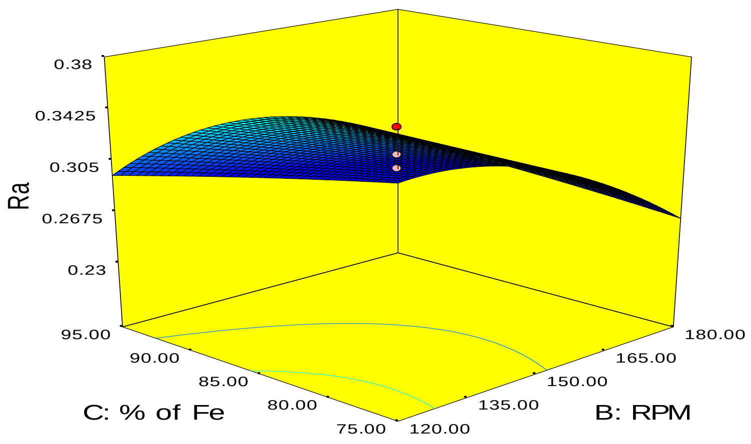

Fig.7 Interaction effect of C% of Fe and RPM

In this fig.8Graph plot in between of RPM and % of iron, at 75% of Fe, Ra decrease linearly with increase in RPM from 120-180.At 95% Ra starts increasing and after an optimum value it further stars decreasing.

5. CONSTRAINTS OPTIMIZATION

Desirability numerical optimization method can applied to find optimum setting of parameters to achieve lower value of Ra, The various constraints is applied in the optimization process is given in Table 6.5 . The optimization solution for minimizing of Ra was found as Abrasive size =199.91,RPM=174.97, and % of Fe=90.06 and predicted Ra=0.27 at Desirability level of 1

Table 4 Constraints Optimization

NAME	GOAL	LOWER LIMIT	UPPER LIMIT
Abrasive Size	is in range	100	300
RPM	is in range	120	120
% of Fe	is in range	75	95
Ra	minimize	0.28	0.58

OPTIMIZATION SOLUTION

Table 5 Optimization Solution

Number	Abrasive size	RPM	% of Fe	Ra	Desirability	
1	199.91	174.97	90.06	0.270278576	1	Selected
2	214.11	139.27	94.87	0.27849467	1	
3	209.35	179.47	81.92	0.278820437	1	
4	201.67	178.71	83.58	0.279656303	1	
5	222.77	155.67	94.66	0.269422346	1	
6	201.54	172.03	90.8	0.270709713	1	

7	223.5	174.84	76.53	0.278383189	1	
8	174.91	154.98	94.1	0.279572756	1	
9	196.07	174.64	76.74	0.279978739	1	
10	200.84	150.9	94.18	0.277875123	1	
11	213.12	176.8	89.91	0.27073695	1	

6. VALIDATION OF RESULTS

Experiments were performed at optimum condition's of machining and repeated 3 times. Percentage error is less than 5% for predicted and experimental value of surface roughness which validate the statistical results.

Table 6 Percentage error for predicted and measured value

S.no	Abrasive size	RPM	C% of Fe	Predicted value	Experimental value	Percentage Error
1	199.91	174.97	90.06	0.27	0.28	3.57

7. CONCLUSION

1.ANOVA shows Abrasive size, RPM and percentage of iron in abrasive are significant factor for surface finish.

2.Optimum value for input parameters are: Abrasive size =199.91, Rotation speed=174.97, Percentage of Abrasive in iron metal powder =90.06 and Ra(Surface Roughness)=0.27µm.

3.Confirmation experiment shows 3.57% error between predicted value and experimental value, thus validates statistical results.

4.The Abrasive percentage in iron powder and size of abrasives have predominant effect on the percent improvement in surface finish

8. REFERENCES

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