MAGNETIC ABRASIVE FINISHING OF INCONEL 718 SUPER ALLOY USING PERMANENT MAGNET

Ankur Chaurasia[1], Vishal Wankhede[2]

[1]Lecturer, Dept. of Mechanical Engineering, Pandit Deendayal Petroleum University, Gujarat, India
[2]Lecturer, Dept. of Industrial Engineering, Pandit Deendayal Petroleum University, Gujarat, India country

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Abstract - *The demand of Inconel metal (Nickel based super alloy) has rapidly increased due to its better properties, light weight and variety of industrial application. In this present work, MAF setup is designed for finishing typical flat workpiece of Inconel 718 super alloy. The unbounded powder is prepared for experimentation by homogeneous mixing of ferromagnetic particle (Iron powder of 350# mesh size) and abrasive particle (Silicon carbide powder of 600# mesh size). In order to provide magnetic field Nd-Fe-B (Neodymium Iron Boron) magnet of 0.52 Tesla are used to carry out the experiment. Effects of working gap, circumferential speed and the mixing ratio of iron powder and abrasive powder on percentage change in surface in surface roughness (% ΔRa) have been studied. Series of experiments have been conducted using in-house fabricated setup by using Taguchi L9 orthogonal array. ANOVA table is used to find out the significant Process parameter. It has been observed that working gap and speed are significant process parameters.*

Key Words: **Magnetic abrasive Finishing, Analysis of variance, flexible magnetic abrasive brush**

1. INTRODUCTION

Magnetic abrasive finishing (MAF) process is advance abrasive super finishing process to produce highly finished surface of super alloy and advanced materials like Ceramics, Super alloys of Magnesium, and Nickel based Inconel materials. In this process, granular magnetic abrasives composed of ferromagnetic material (iron particles or steel grit) and abrasive powder (Silicon carbide) are used for finishing of Inconel-718. Finishing pressure is generated by a magnetic field due to formation of Flexible magnetic abrasive brush (FMAB). The FMAB is self-adaptable and controllable.

Several attempts have been made in the area of finishing of soft materials. Very few attempts have been made in the finishing of Inconel-718. Some of the researcher carried out the experiment of magnetic abrasive finishing of hard materials. Yamaguchi & Shinmura [1] conducted experimentation for surface finish of alumina ceramic components to examine the effects of volume of lubricant, abrasive grain size and ferrous particle size on the finishing characteristics. A permanent Nd-Fe-B magnet of magnetic flux density of 0.37 Tesla was used, they came up with the conclusion that as the volume of lubricant is increased, material removal rate is increased due to less friction generated and thus improved surface finish is obtained. The highest finish was observed with a lubrication volume of 0.35ml. This process achieves surface finishes as fine as 0.02 µm in surface roughness (Ra). Wang et al. [2] studied and conducted magnetic abrasive finishing for polishing inner surface of silicon nitride ceramic components. During experimentation chromium oxide abrasive were used with distilled water as lubricant for wet internal finishing of silicon nitride ceramic tubes. The experiment was performed under without and with use of distilled water (lubricant) conditions. It is reported that wet finishing is superior to dry finishing, thus use of distilled water found to be more efficient. Mulik & Pandey [3] used ultrasonic assisted magnetic abrasive finishing for AISI 52100 steel. They used SiC abrasives for finishing assisted by ultrasonic vibrations. Surface roughness as low as 22 nm was obtained in just about 80 seconds. Yamaguchi et al. [4] performed MAF mechanism for coated round tools cutting tools. The impact of brush contents on the brush actions and magnetic force were identified. The study reported extended tool life with the MAF as this process improves tribological properties of surface which reduces the friction between chip-tool interface.

The objectives of this present study are given below: to study the effect of process parameters on surface roughness during finishing of Inconel 718 alloy and also find out optimum process parameter to obtain minimum surface roughness value of the Inconel alloy plate.

2. Experimental set up and experimentation

In this section explanation of fixture design, fixture mounting and experiment setup installation have been discussed. The setup was able to produce magnetic force up to 0.52 Tesla. As there is no any direct contact between work pieces and rotating magnet so no forces except magnetic force are applied on the work piece. The whole set up was mounted on vertical milling machine. The magnetic force produced was quite high so that fixture for both plate as well as magnet should be of non-magnetic material for safety and ease purpose.

Working gap between magnet pole and plate was filled with homogeneous mixture of iron particles and abrasive particles. The design of plate fixture was done in that way so that flatness during experiment should maintain. The available speeds on the vertical milling machine ranges from 90 to 1500 rpm. Working gap was maintained 2.5,2 and 1.5 mm during the experiment. Wooden block is used to fix Inconel 718 plate. The wooden block clamped by using nut and bolts as shown in the figure 1.

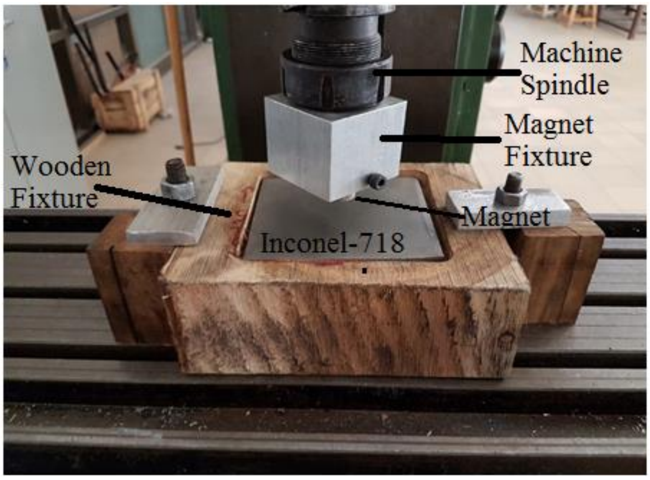

Fig -1: Photograph of Experimental Set up and wooden fixture.

As in the above figure magnet was fitted in spindle by means of magnet holder which is made of aluminum block. Magnetic line was passing from North Pole to south. Before and after starting experiment the surface roughness reading was take measured by surface roughness tester. Total nine experiments have been carried out according to L9 orthogonal array. Preparation of magnetic abrasive powder has been done manually by mechanical mixing of silicon carbide powder (Abrasive powder of 600# mesh size) and ferromagnetic particle (iron particle of 320# mesh size) in various proportionate. Based on literature review, rotational speed of magnet, working gap and mixing ratio was decided to be main process parameter. The available range of speed on vertical milling machine was 90-1500 rpm.

Table -1: Sample Table format

Factor	Value		
	Level 1	Level 2	Level 3
Rotation of Magnet (rpm)	765	1070	1500
Working gap (mm)	1.5	2	2.5
Mixing ratio	1	0.5	0.67
Response			
Percentage change in surface roughness (%ΔRa)			

Based on L9 orthogonal array we have to designing the experiment. Using the Minitab software, we have designing the experiment and arrange the process parameter in sequence that we use during the experiment. Calculate the percentage improvement in the surface roughness by the equation 1.

$$\Delta Ra = \frac{SRBF - SRAF}{SRBF} \times 100 \qquad \text{-------1}$$

Where, SRBF is Surface roughness before finishing
SRAF is Surface roughness after finishing

Table -2: Experimental design based on orthogonal array L_9

Trial number	Speed (rpm)	Working gap (mm)	Mixing ratio	Average surface roughness before exp. (µm)	Average surface roughness after exp. (µm)	Percentage improvement (ΔRa)%
1	765	2.0	0.50	2.055	0.918	55.32
2	1070	1.5	0.50	2.192	1.626	25.82
3	765	2.5	0.67	1.571	1.263	19.60
4	1070	2.0	0.67	2.449	0.316	87.10
5	765	1.5	1.00	1.419	0.971	31.57
6	1070	2.5	1.00	1.704	1.619	4.98
7	1500	2.0	1.00	1.433	1.127	21.35
8	1500	2.5	0.50	1.864	1.582	15.12
9	1500	1.5	0.67	1.759	1.578	10.28

Here in the above equation ΔRa is the percentage change in surface roughness and speed is rotational speed of magnet. From the above equation we can predict the values of the percentage change in surface roughness. The above equation generate on the basis of general regression model using MINITAB 2017 software. The following ANOVA table generated in the MINITAB 2017 has given below.

Table -3: Analysis of variance (ANOVA) for percentage change in surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution %	Remark
Speed	2	973.5	468.7	1.03	0.04	18.228	Sig.
Working gap	2	2823.4	1411.7	2.99	0.02	52.86	Sig.
Mixing ratio	2	599.0	299.5	0.63	0.04	11.215	Sig.
Error	2	944.6	472.3			17.68	
Total	8	5340.6				100.0	

Analysis of Variance is presented for the percentage change in surface roughness in the above table. The P value in the ANOVA table has less than 0.05 for all process parameter so all the parameter are significant.

3. Result and discussion

To verify the effect of process parameter on percentage change in surface roughness, all the selected process parameter (speed, working gap and mixing ratio) have been varied from lower level to higher level as given in table 1. Taguchi L_9 was used to decide the variation in process parameters. Nine points with different parameters for each point were studied and observed. It is observed from the table 2 that the percentage change in surface roughness varied from 4.98% to 87.1% during the experimentation. From table 3 we can see that working gap has the highest contribution and effect towards the change in surface roughness. Thus we can say that working gap is the most significant parameter also shown in % contribution pie chart. At lower speed the change in surface finish is low and at higher speed the friction value tends to be higher which reduces surface finish. These results were proven through experiment as the optimum surface finish was observed at 1070 rpm, which is in-between the lowest and highest surface finish.

Similarly when using the mixing ratio of 1 (1:1), it is observed that the formation of FMAB is not strong enough to hold the abrasives in place. Using mixing ratio of 0.5 (1:2) gives a stronger brush but less abrasive particles present in the FMAB. With mixing ratio of (2:3) more iron particles gives a stronger brush with sufficient abrasive particles for finishing thus providing optimum performance.

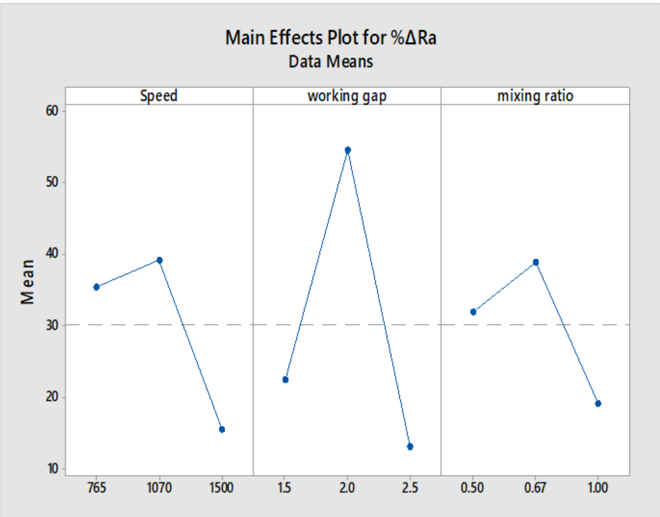

Fig -2: **Fig -1**: Photograph of Experimental Set up and wooden fixture.

It is found out percentage change in surface roughness decreases at high values of rotational speed as shown in the Figure. 2. At higher rotational speed, large amount of outward force acts on the each abrasive particle of the FMAB resulting decrease in percentage change in surface roughness [5]. Working gap has greater impact on percentage change in surface roughness (shown in figure 3) due to magnetic flux density at the working surface decreases while increasing the working gap.

The graph above shows us that trial number four has the optimum surface roughness change with parameters as shown in table 2 and thus verifies our experimentation to be successful and correct.

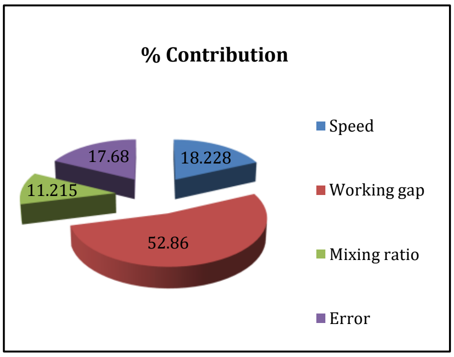

Fig -3: Contribution of process parameter on percentage change in surface roughness.

4. Conclusion

The experimental set up was successfully developed Magnetic abrasive finishing using a permanent magnet. The experiment has been successfully conducted and result obtained from the experiments is critically analyzed to check the performance and effect of change in parameters for change in surface roughness. Based on result presented above, following conclusions have been made.

- Effect of process parameter on percentage change in surface roughness (%ΔRa) has been studied using L_9 orthogonal array for INCONEL-718 super alloys.
- Surface roughness have been successfully measured by using handheld profilometer and percentage change in surface roughness (%ΔRa) are found to be in range 4.98% to 87.1 % and minimum surface roughness achieved up to 0.0316 micron.
- As per ANOVA table, it is observed that current and working gap is the most significant process parameters.
- It is observed that the optimum value of process parameters i.e. speed, working gap and mixing ratio is 1070 rpm, 2.0 mm and 0.67 (2:3) respectively for the maximum percentage change in surface roughness (%ΔRa).
- Percentage contributions of effect of process parameter on %ΔRa are 18.28% for speed, 52.86% for working gap and 11.2% for mixing ratio.

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BIOGRAPHIES

Ankur Chaurasia,
lecturer in Department of Mechanical Engineering, Pandit DeenDayal Petroleum University, Gujarat

Vishal Wankhede,
lecturer in Department of Industrial Engineering, Pandit DeenDayal Petroleum University, "
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