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A Study on Comparison of Abrasive Powders on the Basis of Productivity in Magnetic Abrasive Finishing

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Abstract - **Magnetic Abrasive Finishing (MAF) is a new non-conventional finishing process which has shown vast potentials to do finishing operation with the aid of magnetic force. Major studies concerning MAF have been done regarding the behavior of the process under the effect of various parameters like working gap, mesh number of abrasive, speed of relative motion and so on. In the present paper a comparative study has been done on life of abrasive powders taking die steel (EN31) with ferromagnetic behavior as work material to analyze the productivity of different abrasive powders.**

For this study, experiments are conducted on flat die steel (EN31) work-pieces. The results of the experiments are statistically analyzed for the responses generated during the process. Mesh number of abrasive powders and time of finishing are identified as most significant parameters on material removal rate. Whereas the abrasive type contribution is less significant in case of material removal rate

Index terms **- Abrasive Finishing, Productivity, Magnetic, Material Removal**

I. INTRODUCTION

Magnetic field-assisted finishing, sometimes called magnetic abrasive finishing, is a surface finishing technique in which a magnetic field is used to force abrasive particles against the target surface. Magnetic field-assisted finishing (MAF) processes have been developed for a wide variety of applications including the manufacturing of medical components, fluid systems, optics, dies and moulds, electronic components, micro electromechanical systems, and mechanical components. The magnetic abrasive grains are combined to each other magnetically between magnetic poles along a line of magnetic force, forming a flexible magnetic abrasive brush. MAF uses this magnetic abrasive brush for surface and edge finishing. The magnetic field retains the powder in the gap, and acts as a binder causing the powder to be pressed against the surface to be finished. 3D minute and intricately curved shape can also be finished along its uneven surface**.** [1]

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Yamaguchi et al [2] studied the in-process abrasive behavior in view of the magnetic field distribution and its effects on the finishing characteristics. Internal surface of SUS304 stainless tubes are finished using a pole rotation system with mixed type MAP consisting of iron particles (510 μm mean diameter) and WA magnetic abrasive (80 μm mean diameter) for machining time of 5 min. Jain et al [3] studied the performance of the MAF process under the effect of working gap and circumferential speed of the work-piece. They evaluated the performance in terms of change and percentage improvement of surface roughness and material removal. Khairy et al [4] established an analytical model for process kinematics, supported with experimental plan.

Chang et al [5] studied the potential of unbounded MAP using iron and steel grits as ferromagnetic particles and SiC as abrasive. Shaohui et al [6] studied to develop an efficient finishing process enabling unskilled operators to finish automatically the complicated micro-curved surface and edge surface of the magnesium alloy. Dhirendra et al. (2004) [7] reported the experimental findings about the forces acting during MAF and provided correlation between the surface finish and the forces. Park et al. (2005) [8] studied the Magnetic Abrasive Deburring method for Deburring the micro burr in electric gun parts used in TV monitor. To improve the Deburring performance, vibration table is used for increasing the relative velocity.

Ko et al [9] analyzed the MAF process for two strokes. The coolant (cutting oil) was periodically injected into the gap. Two sorts of powders were used: mechanical mixture of powders of iron CH2 (50% vol.) and Al_2O_3 (50% vol.); iron powder CH2. Wang et al. [10] used an oval abrasive medium, alongwith the silicone gel to mix the ferromagnetic particles and abrasive so as to reduce the disadvantages in MAF. Thus Magnetic finishing with gel abrasive (MFGA) was utilized.

Jain et al [11] studied a process on rotational abrasive flow finishing (R-AFF) process wherein complete tooling is externally rotated and the medium reciprocates with the help of hydraulic actuators with the help of viscoelastic abrasive medium. They further concluded that normal as well as tangential forces decrease with increase in working gap in magnetorheological fluid based finishing process however, both forces increase with increase in CIP concentration. Yamaguchi et al [12] observed that through selective heat treatment, a metastable austenitic stainless steel tool can be fabricated to exhibit alternating magnetic and nonmagnetic regions. Kanish [13] studied the process in micro domain on stainless steel SS316L material.

In today's industry 15% of total cost is finishing cost. Costly abrasive powders are used for finishing of hard materials. Therefore it is imperative to know about the life of abrasive powder, in order to optimize its usage. However fewer researches have studied to explore the productivity and life of abrasive powder. This paper presents the comparison of different abrasive powders like SiC, Al_2O_3 by their productivity in the field of magnetic abrasive finishing.

II. EXPERIMENTAL SETUP

In the present study an experimental set-up for MAF process had been designed and fabricated keeping in mind the fundamental requirements of this process. The fundamental requirements of the experimental set-up are as follows-

1. Magnetization unit
2. Magnet rotary motion unit
3. Motion control unit.
4. Work piece fixture, work piece size & material

To energize the electromagnet a constant voltage/current D.C. regulated power supply of output voltage from 0 to 30 V and output current from 0 to 5 A was used. By controlling the induced current from D.C. power supply the generated magnetic field can be controlled.

A Electromagnetic Inductor

A round flat faced electromagnet (Figure 3.2.) with diameter of 100 mm and height 57 mm was used for experimentation. Electromagnet has a centered N-Pole (diameter 42 mm), surrounded with a coil (thickness = 24 mm), further surrounded by an outer S-Pole. (Thickness=6mm). On energizing this electromagnet by D.C. power supply, the magnetic lines of forces will originate from the N-Pole and after covering the shortest distance between N-Pole and S-Pole, they will terminate at S-Pole completing the magnetic circuit. The path which magnetic lines of force follow, and the magnetic flux density, depends on the magnetic properties of the work piece material.

B Magnet Rotary Motion Unit

To get the finished surface, it was necessary to get relative motion between FMAB and work piece. This unit was used to rotate the magnet and consequently to get the relative motion between work piece and FMAB. This facility already exists in vertical milling machine available in our machine tool lab.

C Motion Control Unit

The machine is equipped with a precise motion control unit (MCU). The work piece can be easily and accurately positioned to get the finished surface. There are three different lead screw attachments to accurately position the work piece with respect to the electromagnet in three mutually perpendicular directions viz. X, Y, and Z, respectively. The work piece can be controlled in X, Y and Z direction. The X and Y directions are automatic controlled and Z direction is manually controlled.

D Fixture and Work Piece

In current scenario die steel (EN31) has a wide range of applications in every type of manufacturing industry due to its high hardness, high tensile strength and some other important mechanical properties. It is high carbon and high chromium steel which is very hard to cut and finish with conventional processes. Based on their crystalline structure die steel has three grades namely, ferrite, marten site and austenite. Ferrite and marten site are magnetic in nature but austenite is non-magnetic. Magnetic die steel material was chosen as work piece material. The work pieces were made of rectangular shaped. The length of the work piece was 420 mm and width is 105 mm which is slightly greater than the diameter of the electromagnet which was 100 mm in diameter. Second work piece was 115 mm wider and length is 410 mm . It was taken wider than the magnetic brush so as to collect the abrasive powder after the experiment. There were 54 experiments taken and the work pieces initially finished with surface grinder. During experiments the work pieces were mounted on the table with a base plate without the fixture.

III. EXPERIMENTAL PROCEDURE

The experiments were conduct according to following steps-

1. Work pieces were initially ground by surface grinder to give all the work pieces almost same initial surface roughness value.

2. Initial Surface roughness of cleaned workpieces was measured. by using 'Mitutoyo SJ-400 surf analyzer' with least count up to 0.01µm. Initial surface roughness should be approximately same in all experiments which lies between 140-150 µm.

3. The body of the inductor was fixed on the mandrel having the cone shank. The inductor is fixed with the help of this mandrel into the hole of a milling machine spindle. The coil is located inside the inductor body, and collector ring are placed on the top plane of the body. They are intended to connect the coil with a constant-current source. Besides the sliding contact device is fixed on the spindle block of the milling machine to transfer a constant current to the coil. The magnetic poles are located on the bottom plane of the inductor. They represent area elements of the external and internal rings: external pole S and internal pole N.

4. To conduct the surface finish experiments, the work piece was mounted on the table of MAF machine with a base plate. The work piece was made parallel to the electromagnet using a dial indicator (least count-0.01mm) to maintain proper gap between them. The work piece was made parallel in both X and Y direction. The position of work piece in XY plane was kept in such a way that the center of the electromagnet coincide with the center of the work piece.

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5. Working gap between electromagnet and work piece was maintained by a feeler gauge and this gap was filled with the MAPs. The amount of MAPs depends on the working gap. Percent by weight method was used to calculate the amount of MAPs in the working gap. The amount of abrasive powder and iron powder can be calculated separately as mentioned below- If the working gap is G, De is the diameter of electromagnet, then the volume V of working gap will be

$$V= \frac{\pi}{4} D_e^2 . G \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$V_{al\text{-}oxide}$ = % of Al-oxide × V……….(2)

V_{iron} = % of iron × V ………………(3)

In equation (2, 3) there is no consideration for air voids. It treats the MAPs as a solid mass. To compensate for the air voids 70% of the total calculated mass was taken for experimentation. Above this value of mass fraction there was a difficulty in achieving the working gap due to particles in the FMAB getting closely packed.

M actual = 0.7 × Mass of iron or al-oxide particles ….(4)

where

Density (SiC) = 3.21 g/cm^3

Density (Al_2O_3) = 3.95 g/cm^3

Density (Fe) =7.8 g/cm^3

On the basis of literature review 3% oil of actual mass was taken to give binding strength to the MAPs. Viscosity (μ) of oil is 12.23 N-s/m_2 at 300 K.

6. First initial weight of MAPs measured with the weighing machine of least count 0.01 mg and 3% of engine oil was added as binder. Experiments were performed carefully so that MAPs can be collected easily after the experiment.

7. On supplying current to the electromagnet, it gets energized and the MAPs fill between the electromagnet and work piece. The MAPs get aligned along the magnetic lines of forces making FMAB. By giving rotation to the magnet, this FMAB performs the actual finishing operation.

8. After completing the finishing operation, work piece and magnetic brush were clean manually using clean cloth. Initial weight of cloth was measured before the experiment and after the cleaning final weight of cloth gives material removal of particular experiment.

9. Area of finishing surface was same in every experiment that is 30.0096 cm^2 approximately.

10. Experiments were conducted for time duration of 20 min, 30 min, 40 min with both abrasive powders Al_2O_3, SiC to calculate their productivity in magnetic abrasive finishing (MAF). There are three mesh sizes of each abrasive that is 100, 200, 400. Three Experiments were conducted by each abrasive powder for each time duration of finishing of die steel (EN31).

IV. EXPERIMENTAL PARAMETERS

The parameters chosen for this study are-

1. Mesh size of the abrasive particles
2. Finishing time
3. Initial surface roughness

The ranges of the values of the variable parameters selected from literature for MAF process are shown in Table 1 & Table 2 show the constant parameters for the present study.

Table 1 Variable parameters and their ranges used in MAF

Parameter	Ranges of Values
Mesh size of the abrasive particle	100, 200, 400
Finishing time	20 min, 30 min, 40 min
Initial surface roughness	1.40-1.50 μm

Table 2 Fixed parameters and their values in experiments

Parameter	Value
Working Gap	1 mm
Size of iron particles	400 μm
Abrasives used in MAP	SiC, Al_2O_3
Percent of oil in MAP	3 %
Current Supplied	0.92 Amp
Work-piece	Flat ferromagnetic die steel(EN31)
Percent composition of iron in MAPs	60
RMP	90
Feed Rate	22.7mm/min

V. RESULTS AND CONCLUSIONS

A Characteristic Material Removal (MR)

Material removal was taken as a response parameter in MAF process. It was estimated by calculating the difference between initial weight of the specimen and final weight of the specimen after processing at a specified set of conditions by MAF. A precision electronic balance (least count 0.01 mg) was used to measure the weight of the specimens.

MR = Initial weight – Final weight …. (5)

A series of experiments have been carried out with a variation of different abrasives and time and are presented in the results. Different three dimensional graphs have been plotted to analyze the effect of various parameters on the response characteristics of material removal (mg/cm^2) in magnetic abrasive finishing (MAF) process.

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Table 3: Experimental results of SiC - 100 for material removal (mg/cm^2)

Time (min)	Material (mg/cm^2)		Removal	Avg. MR
1	0.183	0.1796	0.2006	0.187
20	1.886	1.806	1.859	1.849
30	2.575	2.512	2.602	2.562
40	3.218	3.188	3.168	3.192

Table 4: Experimental results of SiC - 200 for material removal (mg/cm^2)

Time (min)	Material Removal (mg/cm^2)			Avg. MR
1	0.156	0.16	0.156	0.157
20	1.396	1.409	1.489	1.431
30	1.836	1.906	1.786	1.842
40	2.335	2.325	2.409	2.356

Table 5 Experimental results of SiC - 400 for material removal (mg/cm^2)

Time (min)	Material Removal (mg/cm^2)			Avg. MR
1	0.141	0.13	0.133	0.135
20	1.042	1.029	1.116	1.062
30	1.366	1.342	1.306	1.338
40	1.662	1.572	1.592	1.609

Table 6: Experimental results of Al_2O_3 - 100 for material removal (mg/cm^2)

Time (min)	Material Removal (mg/cm^2)			Avg. MR
1	0.153	0.172	0.175	0.167
20	1.589	1.476	1.656	1.573
30	2.142	2.229	2.122	2.164
40	2.675	2.735	2.659	2.69

Table 7: Experimental results of Al_2O_3 - 200 for material removal (mg/cm^2)

Time (min)	Material Removal (mg/cm^2)			Avg. MR
1	0.146	0.157	0.139	0.147
20	1.192	1.122	1.192	1.169
30	1.469	1.562	1.616	1.544
40	1.749	1.896	1.909	1.852

Table 8: Experimental results of Al_2O_3 - 400 for material removal (mg/cm^2)

Time (min)	Material Removal (mg/cm^2)			Avg. MR
1	0.148	0.132	0.123	0.134
20	0.863	0.756	0.953	0.857
30	1.129	1.003	1.096	1.07
40	1.336	1.276	1.449	1.353

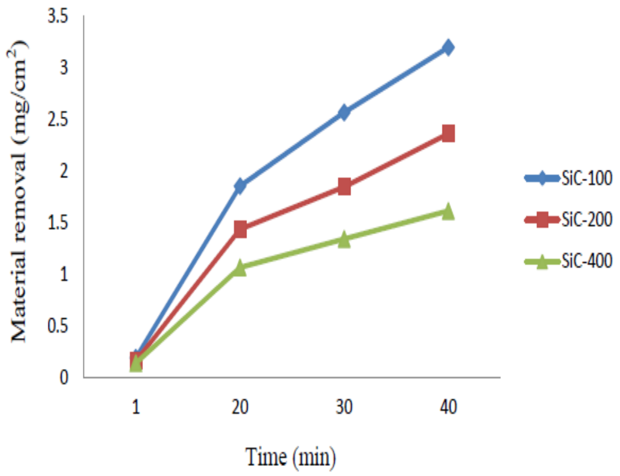

Figure 1 Material removal curves for different mesh sizes of SiC abrasive

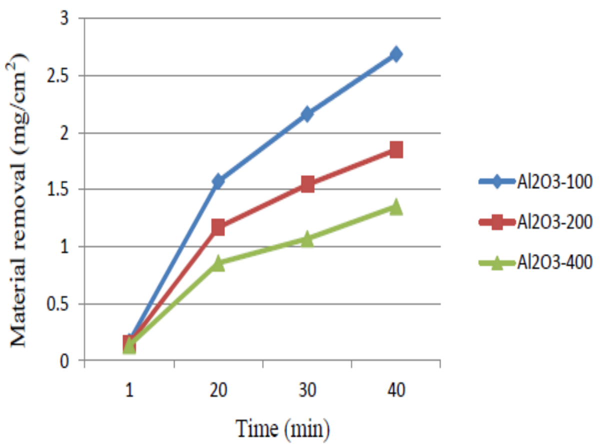

Figure 2 Material removal curves for different mesh sizes of Al_2O_3 abrasive

Figure 1 and 2 present curves showing the combined set of investigated results obtained during finishing of die steel (EN31) on magnetic abrasive finishing (MAF) setup. It is clear from these figures that the initially material removal increases with high rate which decreases with increasing time because of blunting of abrasive powder. It is also observed that material removal rate of SiC-100 is more than the SiC-200, SiC-400. In magnetic abrasive finishing material removal of Al_2O_3-400 is less than the SiC-100, Al_2O_3-100, SiC-200, Al_2O_3 -200 but is nearly equal to SiC-400.

B Regression Analysis

In this section, a regression equation is developed considering Magnetic Abrasive Finishing parameters e.g. Machining Time (X, min) and , Mesh size (Y) . A

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mathematical model is developed for response characteristic of material removal (MR, mg/cm^2) during finishing of die steel (EN31) . The additively test results shows that the predicted values utilizing developed mathematical models make a good agreement with the experimental results.

Linear model Polynomial for material removal (MR, mg/cm^2) is given by the equation no.

MR = f(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 ------------------ (6)

where Coefficients (with 95% confidence bounds) are as under:

p00 = 1.138 (0.06312, 2.213)
p10 = 0.07205 (0.002835, 0.1413)
p01 = -0.007024 (-0.0104, -0.003646)
p20 = -5.944e-05 (-0.00119, 0.001071)
p11 = -0.0001111 (-0.0001634, -5.879e-05)
p02 = 1.323e-05 (7.474e-06, 1.899e-05)

Goodness of fit:
SSE: 1.82 78 R-square: 0.911
Adjusted R-square: 0.9017

RMSE: 0.1947 which indicates a good fit of the model.

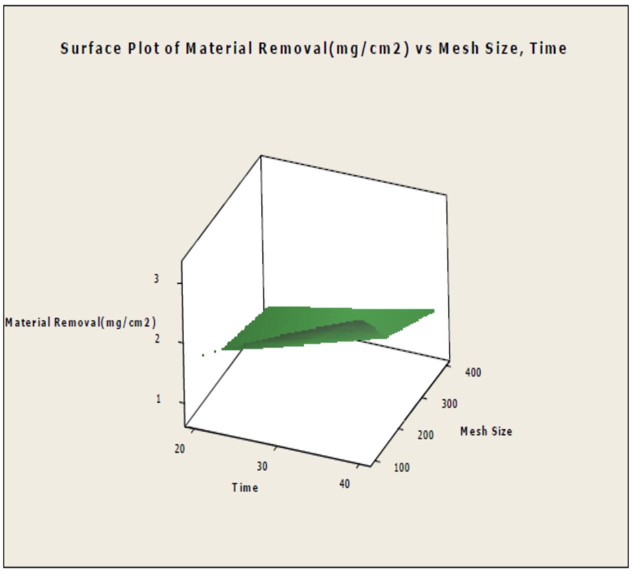

Figure 3 Contour plot for effect of Mesh size of abrasive powders and finishing time (min) on material removal

From figure 3, it is observed that material removal (MR) increases with decrease in mesh number. It is also observed that material removal increases with increase in finishing time.. Abrasive size is more significant parameter than the duration of finishing. Material removal increases with increase of both i.e. size of abrasive powders and finishing time.

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