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Experimental Investigations on Magnetic Abrasive Finishing Process Parameters for Precision Applications

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Abstract: Magnetic abrasive finishing (MAF) is one of the most important engineering process with wide variety of applications. However, their parameteric selection is more difficult as compared to other processes because of the involvement of large process parameters. Hence, the aim of this paper is to study the performance of MAF process and to find out the optimum parameters while machining mild steel. The 2- level factorial design of experiment was done using design expert, where current, composition, speed and machining time were taken as input parameters. The output responses were the surface roughness values. The overall results revealed that the machining time is significant in effecting the surface finish of the component and with increase in machining time, percent improvement in surface finish is increased.
Keywords: MAF. Surface roughness, parameters, mild steel, precision etc.

I. INTRODUCTION

Good geometrical precision and part surface qualities are essential part of the high-tech industry. Finishing is regularly applied to parts to obtain precise surfaces (Yang et al. 2008). The quality of precision parts can be evaluated by the surface and edge quality. The geometry of edge is determined by deburring process for removing burr and rounding process, which is necessary for its function. The surface quality is determined by surface roughness and the stress state of the surface (Baron, 1975; Baron, 1986; Yamaguchi and Shinmura, 2000). Recent advances in various technological fields demand development and use of advanced engineering materials like different types of steels, non-ferrous metals, and ceramics. It is difficult to finish advanced engineering materials by finishing techniques such as lapping, honing, and super finishing cost-effectively. Also, processes need to meet the requirements of high surface finish, accuracy, and minimum surface defects. This has necessitated the development of alternate finishing technologies (Shinmura et al., 1990; Jain, 2004; Lambropoulos et al., 2010). These techniques include chemical mechanical polishing (CMP), electrical polishing (EP), and numerous others. However, both CMP and EP operations result in the formation of pollutants and surfaces with limited quality (Yang et al. 2008). Conventionl finishing processes such as grinding , lapping , honing , super finishing are good , but they have some problems such as high cost when finishing high strength material accurately , high energy consumption , ecologically they apply on the surface is high and sometimes may damage the surface which they finish (Deepak et al., 2004).

Magnetic Abrasive Finishing (MAF) is one of the non conventional machining processes which came to the surface in 1938 in a patent by Harry P.Coats, MAF is a fine finishing technique which can be employed to produce optical, mechanical, and electronic components with micrometer or sub micro meter form accuracy and surface roughness within nanometer range with hardly any surface defects(Sharma et al, Oct 2013) Magnetic abrasive finishing (MAF) is a technology in which a magnetic field forms a magnetic abrasive tool composed of abrasive particles and possessing ferromagnetic properties (Kanish T,C et al, 2012). Magnetic Abrasive Finishing (MAF) is one of the promising processes for obtaining high level of finish on metallic and non-metallic surfaces. In MAF process, the magnetic abrasives act as fine cutting tools and remove the material at micro level by providing low mechanical forces (Singh et al., Dec. 2014). The technology for super finishing needs ultra clean machining of advanced engineering materials such as silicon nitride, silicon carbide, and aluminum oxide which are used in high- technology industries and are difficult to finish by conventional grinding and polishing techniques with high accuracy, and minimal surface defects, such as micro cracks (Singh et al., 2003). Magnetic abrasive finishing (MAF) can be classified as nontraditional super finishing method for finishing surfaces with different shapes and working materials like flat plates, shafts, bearings parts, screws, tubes and many other mechanical parts that need a good surface finishing properties. MAF is effective in polishing, cleaning, deburring and burnishing metal parts (Hamad ,2010). Magnetically assisted Abrasive Finishing has been able to give good surface and edge finishing by help of Flexible Magnetic Abrasive Brush (FMAB) formed in the magnetic field. Under the action of magnetic field the magnetic abrasives gets compressed against the surface to be finished and when rotary motion is given to the work piece the abrasives wear out the work piece material in the form of very small chips(Singh et al, Nov. 2014). On this process, the tool part is played by a flexible magnetic brush (FMaB), formed by a magnetic abrasive powder (MAP), whose form is sustained through the action of a magnetic field. This way, the tool acquire the shape of the work piece, with the advantage of being self sharpening, thus dispensing complementary process such as dressing (Gomes et al, Nov. 2007).

Now-a-days the various former researchers work on MAF process. Khairy 2001 explored the surface roughness trends especially with respect to the effect of particle size and the machining time for bonded MAPs. The working parameters were used in this research: grain size, rotational speed, finishing time, and magnetic flux density. Jain et al., 2001 designed MAF set up for finishing cylindrical work pieces .In this study, the work piece was kept between two magnets and cutting force was controlled by working gap and magnetic field. Mori et al., 2003 clarified the mechanism of magnetic abrasive polishing using planar type process for non-magnetic material stainless steel SUS 304. Jain et al.2014,: examined in MAF, two types of forces generated by flexible magnetic abrasive brush (FMAB) are responsible for finishing: (i) normal magnetic force responsible for packing the magnetic abrasive particles and providing micro indentations into the work piece, and (ii) tangential cutting force responsible for micro chipping due to rotation of the FMAB. Kadhum et al.2015,: studied that within the examined range, the increase in the volume of powder (the largest impact) improves the finishing quality of surface for non-ferromagnetic material because the machining pressure between the magnetic brush and work piece increases considerably with the increase in the volume of powder. Gill and Singh, 2015: all the three individual parameters current, speed of work piece, machining time in MAF have significant effect on the surface roughness. I it can be seen that as the current increases (from 3.62 amp to 8.38 amp) resulting increase in the %age improvement in surface roughness (ΔRa).

From the study of literature it was observed that majority of research work had done on cylindrical parts of aluminium alloys. However, there is still need to work on plane surface of aluminium alloys by the using of MAF. In current study, It is proposed to learn the consequence of abrasive particles using test rig created on milling machine of university lab on Al alloys. (1) To prepare experimental set up to work under given process parameter. (2) To study effect of emery abrasive on the % improvement in surface finish (3) 2- Level full factorial approach was used to validate the number of experiments (4) To find most critical process parameter by using full factorial orthogonal array and Minitab software.

II. MATERIALS AND METHODS

The setup having all required dimensions were taken on the milling machine. It was ensured that the parameters like , magnetic flux density, speed and machining time can be varied and composition of abrasive particles. The design was prepared with the help of Auto cad software.

A. *Electromagnetic Design*

We designed and manufactured an electromagnetic for surface finishing of flat work piece by using a milling machine. The electromagnetic attached with milling machine with the help of spindle.

Fig. 1 Pictorial View of Electromagnetic Design

B. Mild Steel Rod

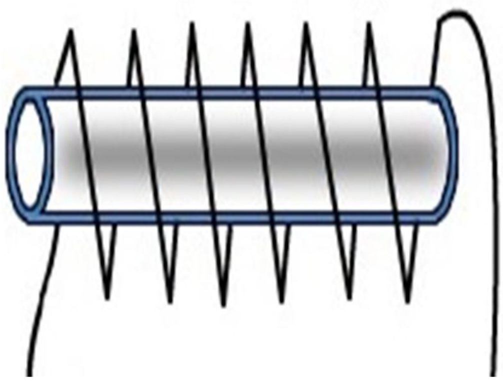
The mild steel rod was prepared of dimensions length 400 mm and 50 mm diameter. The mild steel rod was prepared on the lathe machine. The upper part of the rod was tapered of length 100 mm. And the lower part of rod is round.

C. Electromagnets

A aluminium wire mounted on the circular side of the prepared mild steel rod to make electromagnets. The selected aluminium wire was of 16^{th} number. The number of turns of the aluminium wire was 2750 on the core. The reason for taking 2750 turns is to obtain desirable magnetic force. For the insulation of the coil two fibre rectangular plates were mounted at the ends of coils on core. Two bushes were used to hold the two fibre plates on mild steel rod. In between the two fibre plates the aluminium wire was wrapped. The two slip rings and carbons were used .The carbons slides on the slip ring. The slip ring connected with coil wire which wrapped on the rod. The current in the coil pass through the carbon and slip ring. Basic purpose of magnetization unit is to generate the required magnetic field to assist the finishing process. Main parts of magnetization unit are:

1) D.C. Power
2) Electromagnet

Dimmer was used to vary the current and voltage. Figure shows dimmer which consist of step-down transformer and rectifiers to change the AC supply to DC output. It also consist of digital ac voltage meter and analogue ammeter. The connections were made between the dimmer and setup. The power was given from plug board to dimmer and then from dimmer to set up. At the end the setup was completely prepared and mounted on the milling machine as shown in following figure.



(a)

(b)

(c)

(d)

Fig. 2 Pictorial view (a) Electromagnet (b) Pictorial view of Bush (c) Slip Ring (d) Carbons

D. Machine Details

The taper part of the rod was inserted into the hole of a milling machine spindle. And the work piece was used with the dimensions of length 60 mm, 50 mm width and 3 mm thickness. The work piece was mounted on the machine table.

Fig. 3 Pictorial view of Milling Machine Set up

E. Measurement Of Responses

The weight of abrasives and ferromagnetic particles was done on the weighing machine. The range is 0.1gm to 220 gm. The model used was CX 220. The final surface roughness value was measured with surface roughness tester. Digital Gauss-meter was used for checking the amount of magnetic flux produced at specific current/voltage. So that the required amount of flux can be produced. The units of gauss meter used were tesla.

F. Selection Of Process Parameters

Several process parameters were used during Magnetic abrasive finishing. These are classified as:

1) *Fixed Parameters:* The fixed parameters remain unchanged during the Magnetic abrasive finishing process. These are:
a) *Work piece material:* The material of work piece was taken as Aluminium 6082 flat pieces throughout the experimentation.
b) *Abrasive material:* There are two types of abrasive materials used and there are:
i) *Emery Abrasive:* Emery was used for material removal which results in finishing operation.
ii) *Iron:* Because emery is a non-magnetic material so Emery could not be used for material removal in magnetic flux. To perform finishing operation with Emery abrasives, Iron powder was mixed with these Emery abrasives. Iron powder act as a bonding agent which bond the emery abrasives.
c) *Working gap:* The working gap between magnetic pole and work piece was fixed.

2) *Variable Parameters*
a) *M.F.D:* The magnetic flux density was varied during experimentation. The M.F.D. was varied between 2 Amp to 5 Amp.
b) *Composition of abrasive:* In the abrasive the parameter of Iron and emery was varied and it taken from (20+80) to (30+70).
c) *Machining time:* Machining time also varied for each experiment was taken as 9 and 15 minutes. To measure time, a stopwatch was used.
d) *Speed in (R.P.M.):* The speed is varied for each experiment from 140 rpm to 230 rpm.

G. Design Of Experiment

To check the working characteristics of designed setup, experimental work has been planned. In the present work four key process variables have been set on the developed setup. The range of each parameter was decided by conducting preliminary trials. Once the range of parameters is selected an experiment has been designed following principles of design of experiment approach.

This approach used to reduce the no. of experiments. The tabular representation of two level four factor design is represented in the Table 1. The negative sign (-) represents the lower level and the positive sign (+) represents the higher level of a particular parameter. Interaction means the combined effect of two or more factors on the process performance. The following factors or process variables have been included in the experimental design. The symbol (1) represents that all the four factors are at low level, (a) represents factor A at high level and all the other factors at low level. Similarly (ab) represents that factors A and B are at their high levels and others (i.e. C & D) are at low levels and the sequence is thus accordingly. The field response (last column) represents magnitude of the performance characteristics obtained from a run under specific treatment combination. The experiments have been conducted as per treatment. In this study used parameters are as listed in Table 2 below.

Table 1. Experimental Design

RUN	FACTORS				RESPONSE
	A	B	C	D	
1 (1)	-	-	-	-	
2 (a)	+	-	-	-	
3 (b)	-	+	-	-	
4 (ab)	+	+	-	-	
5 (c)	-	-	+	-	
6 (ac)	+	-	+	-	
7 (bc)	-	+	+	-	
8 (abc)	+	+	+	-	
9 (d)	-	-	-	+	
10 (ad)	+	-	-	+	
11 (bd)	-	+	-	+	
12 (abd)	+	+	-	+	
13 (cd)	-	-	+	+	
14 (acd)	+	-	+	+	
15 (bcd)	-	+	+	+	
16 2^4 (abcd)	+	+	+	+	

Table 2. Selected Parameters

Sr. No.	Parameters	Minimum Value	Maximum Value
1.	M.F.D	2 Amp	5 Amp
2.	Composition (Emery +Iron powder)	(20+80)	(30+70)
3.	Machining time (min.)	9	15
4.	Speed in (R.P.M)	140	230

III. RESULTS AND DISCUSSIONS

The response chosen in the present study is percentage change in surface finish (ΔRa). The initial surface roughness of work pieces is equal for all the work pieces. This variation was taken into account by considering the ratio of change in surface roughness to the initial roughness as response and it is given by Eq. 1.

$$\Delta Ra = \frac{\textit{Initial roughness} - \textit{Final roughness}}{\textit{Initial roughness}} \times 100 \qquad (1)$$

According to 2 level full factorial approach we have done the four trial experiments on the work pieces. The effective parameters are speed in rpm, composition of abrasive, current, machining time were taken. In the trial experiments we take 4-4 values of each

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parameters. After the experimentation the surface roughness were measured. We choose the two values (minimum surface roughness value and maximum surface roughness value) from the trial experiments for final experiment.

A. Effect Of Magnetic Flux Density On Surface Finish In 1st Trial Experiment

From the results as shown in fig 4, it can be noticed that initially there is a little improvement of surface finish with increase in magnetic flux density and after that it almost increased linearly. In which take the 4 values of magnetic flux density in trial experiments. From that choose the two values minimum and maximum of %age of Ra for final experimentation.

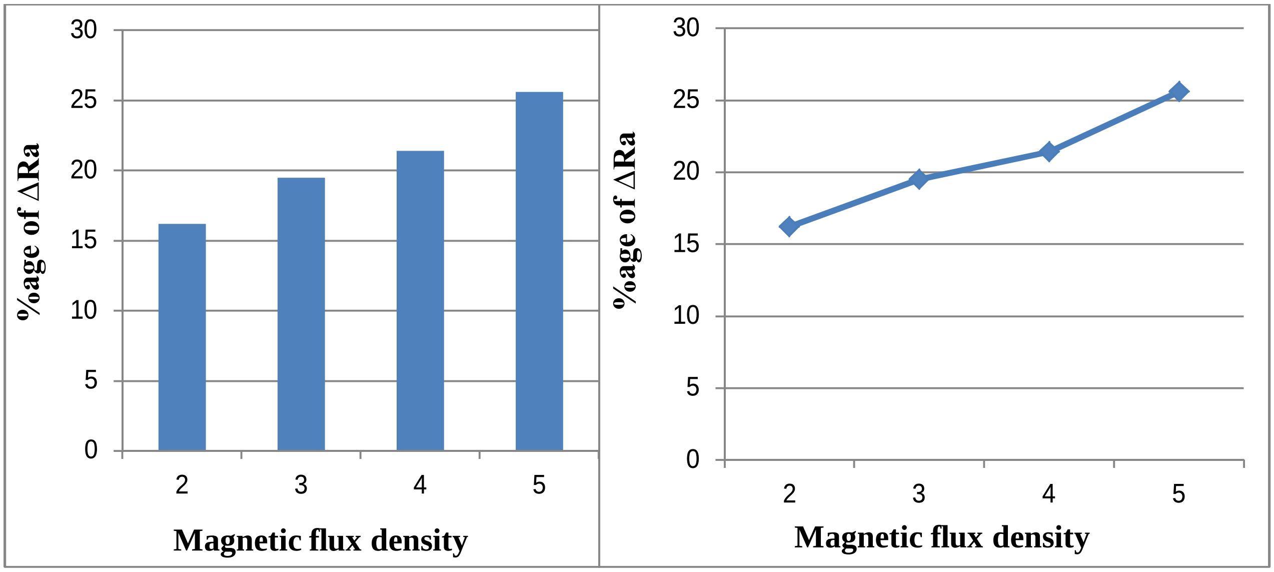

Fig. 4. Effect of Magnetic flux density on surface finish

B. Effect Of Speed On Surface Finish In 2nd Trial Experiment

As shown in figure 5, the optimum value of ΔRa in surface finish, exists near working gap. As the speed increases the improvement of surface finishing increases. But after working gap 6mm the surface finishing decreases. From the trial experiment for final experimentation choose the two values according to 2 Level full factorial approach.

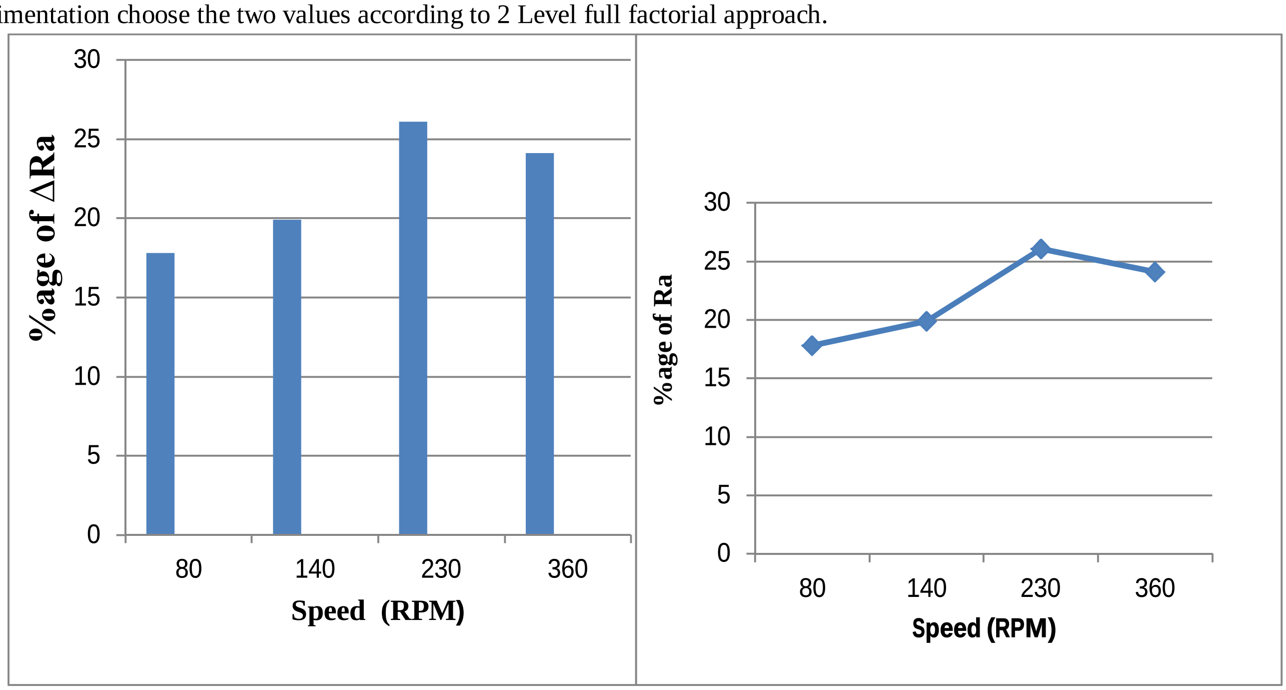

Fig. 5. Effect of Speed on surface finish

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C. Effect Of Composition On Surface Finish In 3rd Trial Experiment

Figure 6 illustrated that (20+80) composition of Fe + iron abrasive has optimum value of surface finish. The value of surface finish is less at (30+70) and increases up to (20+80) and then again decreases till (10+90) composition of Fe + emery. From the trial experiment for final experimentation choose the two values of composition of abrasives according to 2 Level full factorial approach.

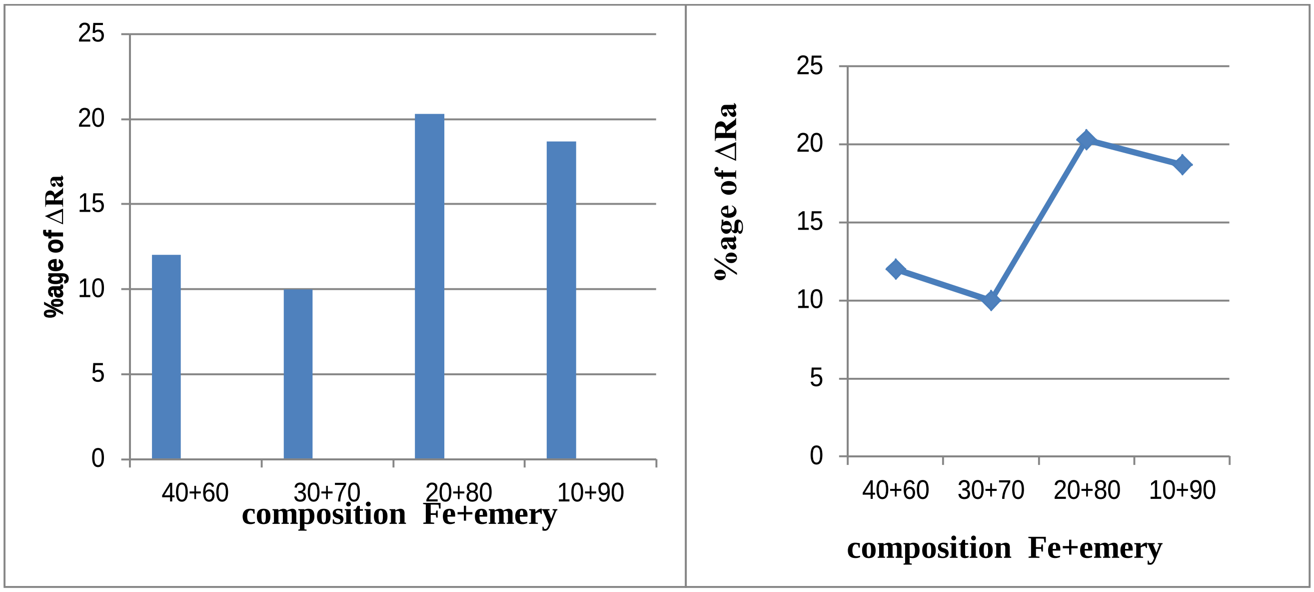

Fig. 6. Effect of Composition of abrasive on surface finish

D. Effect Of Machining Time On Surface Finish In 4th Trial Experiment

The figure 7 showed that the least machining time 9 minutes gives the minimum % improvement surface finish (ΔRa). It increases with increase in machining time. In which take the 4 values of machining time in trial experiments. From that choose the two values minimum and maximum of %age of Ra for final experimentation.

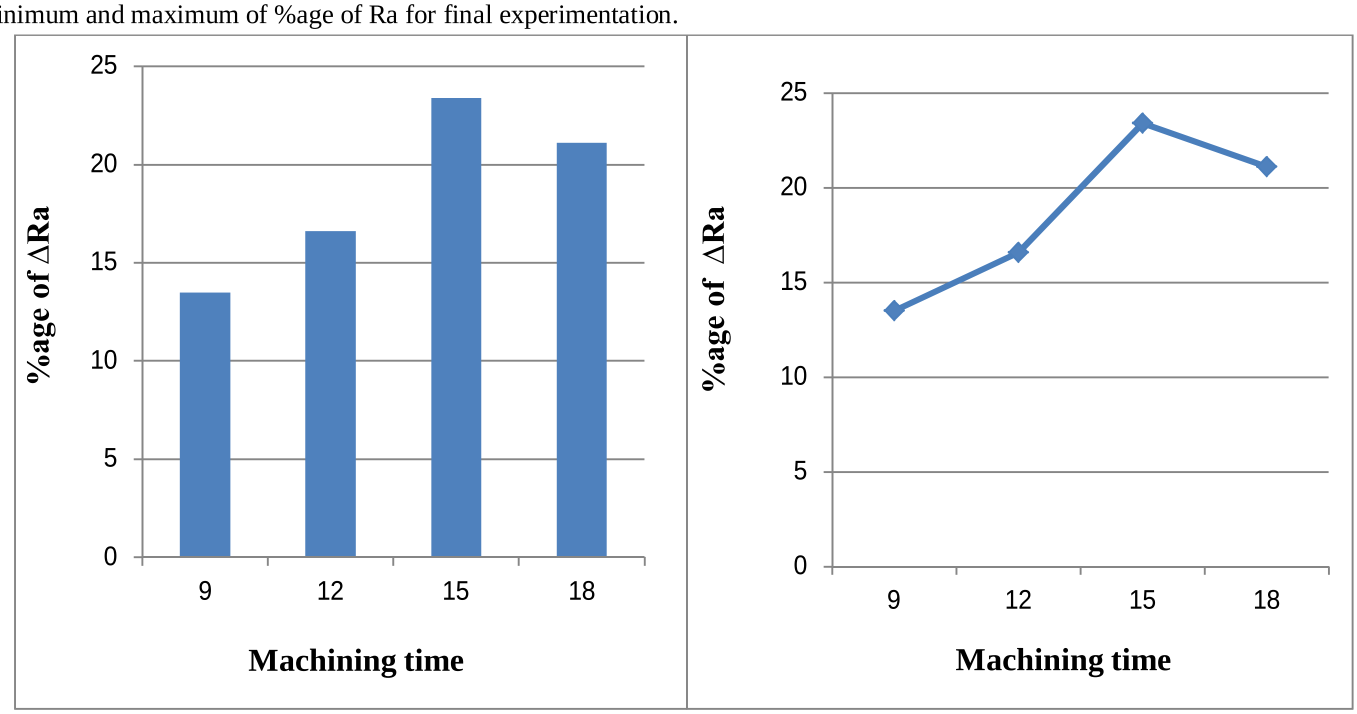

Fig. 7. Effect of Machining time on surface finish

After the trial experiments taken the two values from each parameter according to 2 level full factorial approach. Table 3 shows ΔRa at different values of each parameter.

Table 3. Surface finish of experimentations

RUN	FACTORS				RESPONSE
	CURRENT (AMP)	COMPOSITION Fe + iron	SPEED (IN RPM)	MACHINING TIME (MIN.)	%AGE OF SURFACE FINISHING
1 (1)	2	30+70	140	9	15
2 (a)	5	30+70	140	9	11.25
3 (b)	2	20+80	140	9	22.5
4 (ab)	5	20+80	140	9	11.25
5 (c)	2	30+70	140	15	51.25
6 (ac)	5	30+70	140	15	52.5
7 (bc)	2	20+80	140	15	50
8 (abc)	5	20+80	140	15	22.5
9 (d)	2	30+70	230	9	8.75
10 (ad)	5	30+70	230	9	5
11 (bd)	2	20+80	230	9	33.75
12 (abd)	5	20+80	230	9	32.5
13 (cd)	2	30+70	230	15	22.5
14 (acd)	5	30+70	230	15	21.25
15 (bcd)	2	20+80	230	15	20
16 2^4 (abcd)	5	20+80	230	15	16.25

In which the fixed parameters are gap 5mm abrasives. And the above table was used to illustrate the bar and line chart of results. The initial roughness of work piece was 0.80 and that was reduced after the experiments. The whole graph Fig. 8 illustrates the actual result of whole experiments. It elucidate the how the ΔRa is fluctuated in different experiments and different parameters.5,6 and 6 no. experiment showed best result of ΔRa. Highest level of surface finish witnessed in six no. experiment. In which magnetic flux density 5 amp, the composition of iron and emery was 30+70, speed of spindle 140 rpm and machining time 15 minutes. We know that highly FMAB formed at high current which helped to obtain the strong brush for higher surface finish then the 5 amp current was best for making strong FMaB.

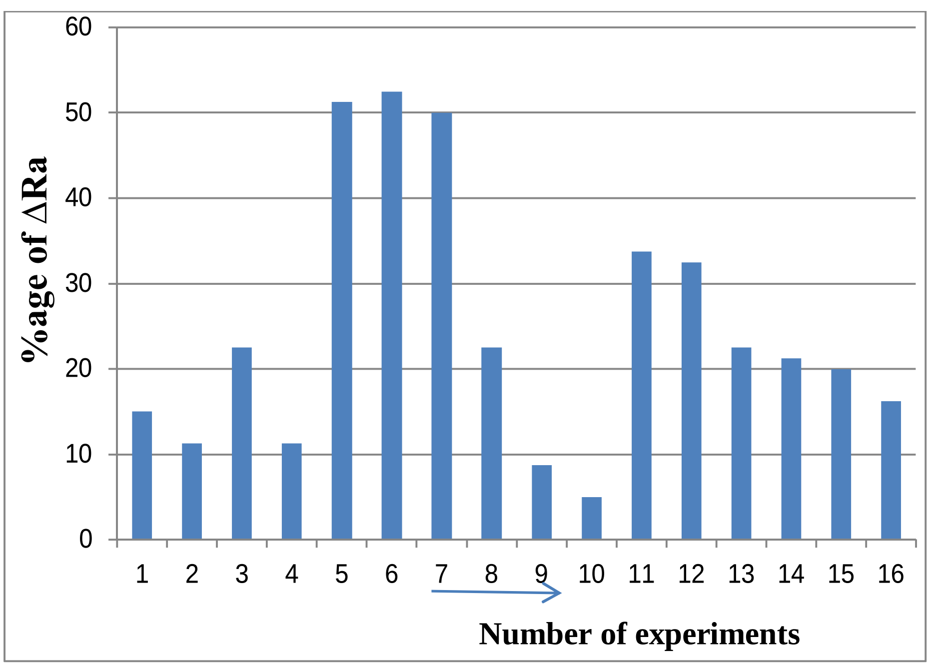

Fig. 8. Effect of surface finish on flat work pieces

Table 4. Response table for means

Levels	Current (Amp.)	%age of composition	Speed(rpm)	Machining time(min.)
1.	27.96	26.09	29.25	32.03
2.	21.56	23.43	20	17.50
Delta (Δ)	6.40	2.66	9.25	14.53
Rank	3	4	2	1

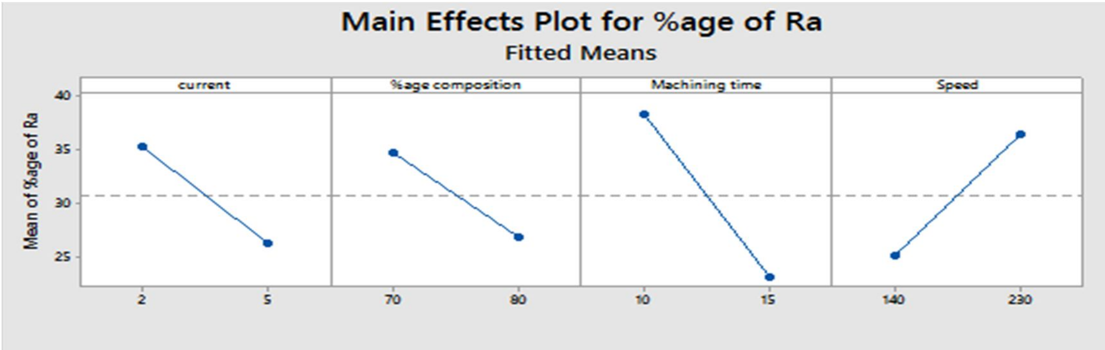

Fig. 9. Main effect plot for %age of Ra

1) *Current:* The effect of current on surface finish for fitted mean in Table 4 and Fig. 9. It can be seen that the values of fitted mean decrease as a value of current increase and is optimum at is 2 amperes current.
2) *% Composition:* The effect of % composition on the surface finish for fitted mean. It can observe from the chart the surface finish decrease, when % composition increased from 70 to 80.
3) *Machining Time:* The effect of machining time on the surface finish for fitted mean. Higher surface noted at 10 minutes but it decreased when time varies from 10 to 15 minutes.
4) *Circumferential Speed:* In the present study it was observed from the results that with increase the RPM surface finish improved. When it varies from 140 rpm to 230 rpm. The optimum level is 230 rpm.

E. Comparative Result

Effect of speed on change in surface finish:-In the present study it was observed from the results that with increase the RPM surface finish improved. When it varies from 140 to 230. The optimum level is 230 rpm. Similar results are seen in (Sharma and Singh 2003) and (Bhutani et al., 2004). Effect of machining time on change in surface finish:-In the present study it was observed from the results that surface finish improved to a small extent with increase in machining time and then tends to increase linearly. The fact is that when we increased the machining time, the number of abrasive particle cycles in the cylindrical specimen's increases. These effects were helpful for better flat finishing process. Effect of % composition of emery on change in surface finish:-In the present study it was observed from the results that with increase in % composition of emery particles surface finish is improved .The fact is that at higher percent composition of emery particles, abrasive particle composition in the cylindrical specimen's increases. Thus, the abrasive particles of the flexible magnetic abrasive brush remove the peaks of the irregularities on the surface of the work piece and it improves the surface finish. Similar results were concluded by Mulik and Pandey, 2011 that increasing percentage weight of SiC abrasives results in the increase of ΔRa. Effect of current on change in surface finish :- In the present study it was observed from the results that with increase in magnetic flux density surface finish increased. But when we reduced the current then the surface finish is reduced. Similar results were concluded by Yahya M. Hamad, 2010.

IV. CONCLUSIONS

From the presented experimental results and analysis, following conclusions can be drawn:
In the present work, MAF setup has been designed and fabricated. The performance of the MAF setup for different parameters was also studied. Experimental MAF process on Al 6082 with the use of loosely bounded MAPs has been carried out. It is concluded from the results and discussion that machining time, magnetic flux density, % composition of abrasive particles and speed of milling machine are the parameters which significantly influence the change in surface finish value (ΔRa).

A. Machining Time is significant in effecting the surface finish of the component, with increase in machining time, percent improvement in surface finish is increased
B. Initially the Surface finish increases with a decrease the speed of milling machine but thereafter improvement in surface finish decreases with further increase in speed of milling machine.
C. With the increase in percent composition of emery particles, improvement in the surface finish.
D. The magnetic flux density also effecting in the surface finish of work piece, with increase the magnetic flux density (current) the surface finish is also increased. When we reduce the current the then surface finish is also reduced.

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