EXPERIMENTAL INVESTIGATION OF PROCESS PARAMETERS ON SURFACE ROUGHNESS IN HYBRID ABRASIVE FLOW MACHINING PROCESS (AFM)

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Abstract- Abrasive flow machining (AFM) is a non-traditional machining process which is used to deburr, polish and radius surfaces & edge by flowing an abrasive medium inside the workpiece surface to be machined. To make the process efficient, hybrid machining process has been employed by providing a centrifugal force generating rod with rotational mechanism in AFM setup. These centrifugal forces assist the media to rotate continuously as it moves axially inside the cylindrical workpiece. In this experimental study parameters such as abrasive grit size, abrasive concentration, rotational speed of rod and diameter of rod were varied to observe their effects on surface finish. The results reports that all the process parameters have remarkable effect on response parameter. L9 orthogonal array based on taguchi method has been employed for experimental design without considering any interaction.

Keywords- CFAAFM,CFG, Centrifugal force, Surface finish, taguchi method

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1. INTRODUCTION

Conventional process such as honing, lapping, boring, and grinding and other process have been used for finishing. But their use is limited to the geometry of the workpiece and up to a certain value. But Abrasive flow machining (AFM) is mostly used in finishing of complex inaccessible geometry and critical components. It removes very small quantity of material by flowing a semi-solid abrasive media inside the surface to be machined.AFM set up consist of two vertically opposite cylinders with the help of media was extruded back& forth through the passage formed by the workpiece and tooling. The abrasive media was made up of polymer, gel and abrasive grains. Different types of abrasive grains were used like silicon carbide, aluminum oxide, boron carbide and diamond etc. This abrasive media consist of large number of random cutting edge with Indefinite orientation & geometry for effective material removal. The extremely thin chip produced during operation produce better surface finish. To enhance the rate of finishing, it was necessary to increase interaction between workpiece & abrasive. To do this, a set up has been developed in which tooling rod was kept inside the cylindrical workpiece (11). This rod restricts the passage of acting abrasive particle moving axially inside the workpiece. A special fixture was used to direct the abrasive medium to the workpiece. The element required for this process was machine, workpiece, fixture (tooling) & media. To reduce the longer cycle time, this present paper discusses the role of hybrid process which allows AFM to be club with additional centrifugal force applied on to media(7). This process is gaining importance day by day. This process has found application in many areas like aerospace, automobile, medical instruments, finishing of industrial valves, die making and semiconductor equipments etc. The key parameters were different abrasive grit size, abrasive concentration, rotational speed of CFG rod and diameter of tooling rod. The Dominant process parameter was found to be RPM of rod followed by abrasive concentration, abrasive grit size and diameter of CFG rod.

1.1 LITERATURE SURVEY

The concentration of abrasive in the media, grit size & the viscosity were major parameters which has a significant effect on surface finish. At higher concentration of abrasive, the improvement in ΔRa was rapid. As the abrasive grit size increases, the ΔRa value increases (1-2). Some researchers performed experiment to study the effect of pressure & viscosity on surface finish. They conclude that there was a considerable improvement in surface finish (3). To increase the performance of AFM, magnetic field has been applied to the AFM process .the magnetic field increase the no. of active abrasive grits taking parts in abrasion. Due to which surface quality improves (4-5). Przylenk described that with small bore diameter of work piece, more grains comes in contact with the surface, hence improves surface finish (6). Some researchers also noted that surface finishing improves more for a specified no. of cycle. Different shapes of CFG rods also used to see their effect on ΔRa. The abrasive media was rotated by using different shaped rods to increase workpiece media interactions. The speed of rotation of CFG rod has a major effect on surface finishing (7-8). Jain et.al used neural networks &multivariable regression analysis for modeling of AFM process (9). Rhoades reported that the depth of penetration is mainly dependent on abrasive grain size, relative hardness and extrusion pressure (10). Taguchi methods used by many researchers for engineering analysis. This method employs design of orthogonal array to compute the effect of process parameters on surface finish (11-13). Sharma modified the basic AFM setup by designing new fixturing for holding a drill bit stationary inside the hollow cylindrical work piece. The improved AFM setup has been named as the Helical-AFM Setup (12). In order to enhance productivity of the process, Mondal and Jain has been introduced a concept of rotating the media along rotated drill bit axis to achieve higher rate of finishing and material removal. This process was termed as drill bit-guided abrasive flow finishing (DBG-AFF) process (13).Though many researches were carried out on the machining process towards the aim of achieving better surface quality. but it needs more attention towards hybrid machining process by considering the advantages of different machining process. To produce better surface finish, it requires more research work contribution to modify this process. To enhance the quality of surface, the present study discusses the role of key parameter towards the modification & provides experimental study of hybrid AFM in terms of % ΔRa. The experiments have been conducted to test the effectiveness and for the optimization of the different diameters CFG rods and of different AFM process parameters towards the development of process. Keeping these objectives in mind, attempt has been made to work in this area.

2. HYBRID AFM

The fixture used in this research was made up of three parts as shown in fig 1.The cylindrical workpiece and the CFG rod puts up in between these parts. The media was extruded from one cylinder to other cylinder through restricted passage provided by fixture and CFG rod. The process was made hybrid by providing a mechanism for produce centrifugal force. This mechanism consists of a D.C geared motor which provides rotational speed to CFG rod inside the workpiece. When this CFG rotates, centrifugal force acts on the media which increases the workpiece–media interaction and hence improves surface finish. The Abrasive media consist of silicon based polymer, hydrocarbon gel & abrasives. The abrasive used in this research was aluminum oxide of different grit size. the cylindrical workpiece was made up of brass. Initially it was drilled followed by boring having initial range of Ra was 1.7-2.2μm.The workpiece was Ø 12 ×16-mm long cylindrical parts & central hole bored to 8.00±0.05 mm as shown in fig 3. Finally the workpiece was machined by CFAAFM at different rotational speed of CFG rod. The workpiece was cleaned by acetone & after that final Ra value was measured.

Figure 1 CFAAFM fixture parts and rotating attachment

Figure 2 Photographs of variable speed attachment

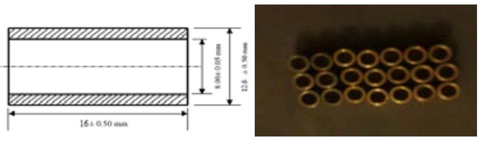

Figure 3 Work-Piece Geometry

3. EXPERIMENTATION-WORK

The percentage change in Ra value is calculated as:

$$\Delta R_a = \frac{(\text{Initial Roughness} - \text{Roughness after machining}) \times 100}{\text{Initial Roughness}}$$

The surface roughness was measured by Mitutoyo SJ-201 Surface Roughness Tester. For experimental analysis, L9 (3*4) orthogonal array based on taguchi methodology was adopted.Each parameter was studied at three levels. As ΔRa is higher the better type quality characteristics. So S/N ratio was calculated for this type as:

$$\left(S/N\right)_{HB} = -10 \log\left(MSD_{HB}\right)$$

$$\text{Where} \quad MSD_{HB} = \frac{1}{R}\sum_{j=1}^{R}\left(1/y_j^2\right)$$

R = Number of repetitions, y = response value
Analysis of variance (ANOVA) , F-Test was performed. These test values indicate the significant AFM parameters affecting the finishing quality of the surface. The selected parameters & their range is specified in table 1.
The % improvement in ΔRa for s/n ratio & average value of raw data at three levels L1, L2, L3 for each parameter shown in table 3 & 4.

Sr.no .	Process Parameters	Range	Unit
1	Abrasive grit size(G)	60,100,200 (250 ,150,75)	No.(Micron)
2	Abrasive Conc.(C)	1,1.15,1.30	% by weight
3	Shape of CFG rod	Triangular	-------
4	DIA of rod (D)	3.2,4.2,5.2	mm
5	RPM (R)	0,40,80	RPM
6	Extrusion pressure	4	N/mm2
7	No. of cycle	6	No.
8	Media flow volume	290	cm3
9	Workpiece material	Brass	-----
10	Polymer-Gel ratio	1:1	% by weight
11	Temp. of media	32 ± 2	°C
12	Reduction Ratio	0.95	-----

TABLE 1: PROCESS PARAMETERS AND THEIR RANGE

4. RESULTS

The scheme of experiments based on Taguchi's L9 Array (OA)for the setting of various parameters is as given in the Table2.

Sr no.	G	C	R	D	R1	R2	R3	S/N
1	60	1	0	3.2	6.82	6.91	6.74	16.67
2	60	1.15	40	4.2	31.94	31.22	31.33	29.96
3	60	1.30	80	5.2	15.94	14.86	15.29	23.71
4	100	1	40	5.2	27.57	27.86	28.39	28.92
5	100	1.15	0	3.2	11.75	11.62	11.89	21.40
6	100	1.30	80	4.2	14.89	14.98	14.45	23.38
7	200	1	80	4.2	16.57	16.22	16.1	24.24
8	200	1.15	0	5.2	12.84	12.34	12.86	22.05
9	200	1.30	40	3.2	43.81	43.98	43.01	32.78

TABLE 2: ORTHOGONAL ARRAY L9 WITH RESPONSE

R1, R2, R3 represents %improvement in surface Roughness value for three repetitions of each trial.

LEVEL	G	C	R	D
L1	23.	23.28	20.71	23.62
L2	24.57	24.47	30.56	25.86
L3	26.36	26.63	23.12	24.9
L2-L1	1.12	1.19	9.85	2.24
L3-L2	0.79	2.16	-7.44	-0.96
DIFF	0.67	0.96	-17.29	-3.20

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TABLE 3. MAIN EFFECT (S/N DATA)

Where L1,L2 and L3 denotes the value of S/n data at levels 1,2 & 3 of parameters.L2-L1 is the main effect when the corresponding parameter changes from level 1 to level 2. L3-L2 is the main effect when the corresponding parameter changes from level 2 to level 3.

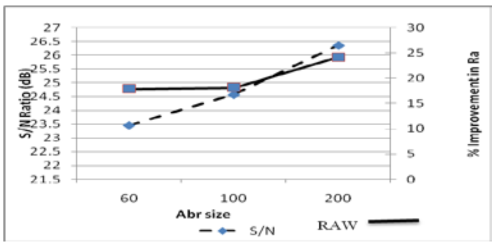
LEVEL	GRIT	CON	RPM	DIA
L1	17.89	17.02	11.43	20.73
L2	18.16	18.64	34.35	20.86
L3	24.19	24.58	14.47	18.66
L2-	0.26	1.64	22.92	.13
L3-	6.04	5.94	-19.87	-2.19
DIF	5.78	4.31	-42.79	-2.32

TABLE 4. MAIN EFFECT (RAW DATA)

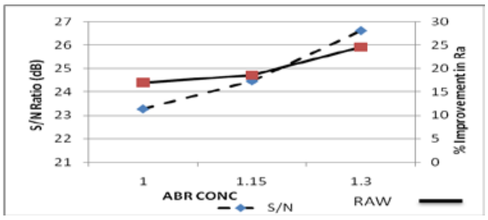
L1,L2 and L3 denotes the average value of raw data at levels 1,2 & 3 of parameters.L2-L1 is the avg. main effect when the corresponding parameter changes from level 1 to level 2. L3-L2 is the avg. main effect when the corresponding parameter changes from level 2 to level 3.

5. DISCUSSION

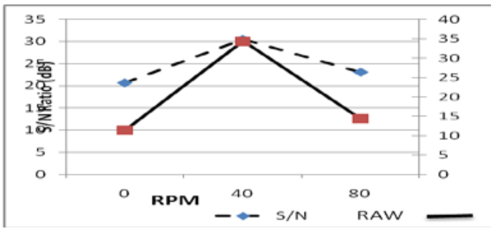
From the fig 4(a) it was deducted that as the mesh size increases, quality of surface improves. Because as mesh size increases, size of particle decreases which equals finer materials and more no. of finer grains produce better surface finish. From fig4(b), it was inferred that as the conc.of brasive increases, ΔRa improves. Because at higher conc. more abrasive grains interact with workpiece resulting in more abrasion which improves surface finishing quality. It can be observed from fig 4(c) that as the rotational speed increases, ΔRa increases up to 40 RPM & then decreases. Because when no RPM was given,the motion of abrasive only due to extrusion pressure which acts in axial direction. But when RPM was given, % change in ΔRa is more. Because now motion of abrasive is due to extrusion pressure & centrifugal force which acts in normal direction to workpiece. So the length of the path of motion of abrasive per unit time increases. Due to which more no. of surface peaks comes in contact with abrasive & hence improves surface finish. But at higher RPM, normal force on abrasive at which they strikes with surface peaks increases. So it produces deeper scracth & surface finish deteriorates. In fig 4(d) it is shown that as the dia of CFG increases, the ΔRa improves up to a limit & then start decreasing.the reason for this is that as dia increases, the gap b/w the workpiece & CFG rod decreases. So the area through which abrasive passes decreases & results in more interation with workpiece & hence quality of surface finish improves. But if we further increases the dia. of CFG rod which creates more restricted passage for abrasive, then it produces deep scratch on workpiece leading to lower ΔRa.



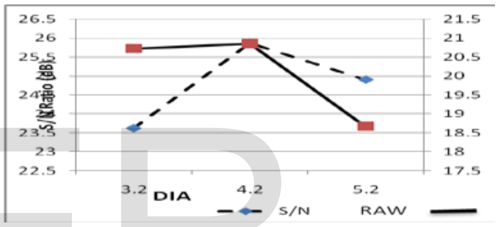
(a) Effect of abrasive size on S/N data & RAW data



(b) Effect of abrasive conc.on S/N data & RAW data



(c) Effect of rotational speed on S/N data & RAW data



(d) Effect of dia of CFG rod on S/N data & RAW data.

6. ANALYSIS

To study the significance of the parameters, ANOVA was performed. From the table 5, it was observed that all the parameters significantly affects the mean in the % improvement in ΔRa. it was noted that % contribution of RPM is highest (83.74) followed by abrasive conc. (8.49), abrasive size (6.86) & diameter of CFG rod(0.81) . Also it was noted that % improvement in ΔRa for raw data was highest at third level of abrasive size (G_3), third level of abrasive concentration (C_3), second level of RPM (R_2) & second level of dia of CFG rod (D_2).

Table 5 POOLED ANNOVA (RAW DATA)

Source	SS	df	V	F ratio	SS'	P%
G	76.18	2	38.09	598.78*	75.03	6.86
C	94.25	2	47.13	740.86*	93.11	8.49
R	929.61	2	464.81	73.07*	928.47	83.74
D	9.01	2	4.50	70.81*	7.86	0.81
Error	1.14	18	0.06		5.72	0.10
Total	1110.2	26			1110.2	100

SS- Sum of square, df-degree of freedom, V-variance, SS'- pure sum of square. *Significant at 95% confidence level, Fcritical = 3.4928.

6.1 CALCULATION OF OPTIMUM RESPONSE

CHARACTERISTICS

The mean at the optimal %change in ΔRa is calculated as: ΔRa=A`3+C`3+R`2+D`2-2T`

T`= overall mean of % improvement in ΔRa for raw data=20.08%

A`= Mean value of % improvement at 3rd level of Abrasive size=24.19%

C`= Mean value of % improvement at 3rd level of Abrasiveconc=24.58%

R`= Mean value of % improvement at 2nd level of RPM = 34.35 %

D`= Mean value of % improvement at 2nd level of dia of CFG rod =20.86%

After calculation, we get ΔRa =63.82%

The confidence interval of confirmation experiments (CICE) and of population (CIPOP) is calculated by using the following equations

$$CI_{CE} = \sqrt{F_\alpha(1,f_e)V_e\left[\frac{1}{n_{eff}}+\frac{1}{R}\right]} \qquad CI_{POP} = \sqrt{\frac{F_\alpha(1,f_e)V_e}{n_{eff}}}$$

Fα(1,fe) = The F-ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom fe = 4.414 (Tabulated-F value)

N= Total number of result = 27 (treatment = 9, repetition = 3)

Ve = Error variance = 0.06 (Table 5)

R = Sample size for confirmation experiments =3

fe=error DOF = 18 (Table 5)

$$n_{eff} = \frac{N}{1+[\text{DOF associated in the estimate of mean response}]}$$

=3

So, $CI_{CE} = \pm 0.4201$

And $CI_{POP} = \pm 0.088$

The 95% confirmation interval of predicted optimal range (for confirmation run of three experiments) is:

63.4<% improvement in Ra >64.24

The 95% confirmation interval of the predicted mean is:

63.73<% improvement in Ra>63.91

6.2 Confirmation Experiments

In order to confirm the results obtained, three confirmation experiments have been conducted for response characteristic of %age improvement in surface roughness. For the maximum MR, the optimal levels of the process parameters are $G_3C_3R_2D_2$.

7.1 Conclusion

The following conclusion was noticed from the results:

1. It is possible to increase the efficiency of simply AFM process by making it hybrid. The speed of rotation of CFG rod has highest contribution (83.74%) for improvement in surface finish.
2. The % contribution of abrasive concentration is 8.49. As the abrasive concentration increases, surface finishing improves. Concentration can be more improves to see more effects.
3. Abrasive size has (6.86%) contribution for improvement in quality of surface. As size of abrasive increase, abrasive particle size decreases & % change in ΔRa improves. For better surface finish, smaller particle size should be used.
4. Diameter of CFG rod is also significant and shows (0.81%) contribution towards surface quality.

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