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Effect and optimization of Process Parameters on surface roughness in Abrasive Flow Machining Process

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Abstract:-Abrasive flow machining is a non-conventional machining process which is used to machine complex shape and size of work piece that are difficult to machine with conventional method. In this process, abrasive medium flows inside the hollow cylindrical work piece surface. To enhance the efficiency of simple abrasive flow machining process, the setup was modified to make it hybrid process as centrifugal force assisted abrasive flow machining. In this experimental investigation, process parameters such as abrasive mesh size, abrasive concentration, number of cycle and rotational speed of rod were studied at some levels of to depict percentage change in surface roughness. L9 orthogonal away based upon taguchi method has been preferred for experimental design without considering any interaction.

Keywords- AFM, Surface Roughness, Taguchi method, ANOVA

1. Introduction-

Abrasive flow machining is non-traditional machining process which uses abrasive medium for finishing of internal parts of work piece. This process is used to finish metallic parts by using semi-solid paste which can reach inaccessible areas of complex geometrical components. The process is gaining wide spread attention for its ability to produce better and consistent results. This process is capable to produce surface finishing up to 10 times when initial surface roughness is in the range of 0.9-7 micron. AFM set up consist of two cylinders placed vertically in opposite direction. The abrasive medium flows from lower cylinder to upper cylinder and vice versa. Initially the abrasive medium was filled in lower cylinder which will flow back and forth under some hydraulic pressure through the passage formed by work piece and tool rod inside the fixture. The abrasive medium was mixture of non- Newtonian polymer, hydrocarbon gel and abrasive particle. The abrasive particle may be of silicon carbide, boron carbide, aluminum oxide and diamond. All constituent mixed in the suitable proportion. The abrasive particles in medium have random cutting edge with different orientations which was responsible for material removal from edges and hence better surface quality. To obtain high quality surface finish, abrasive particle should be capable of removing unwanted material from inner edge. For this, a setup has been made to increase the interaction between abrasive particle and inner surface of work piece. In this set up, centrifugal force has been generated to throw the abrasive particle in surrounding direction inside the work piece. Abrasive flow machining is suitable for work piece with complicated intersection that needs high cost and intensive labour. It has very economical method for finishing of internal parts of work piece. It finds application lot of areas like in medical instruments, automobile, pharmaceuticals, defense, aeronautics and space industry etc. In this study experiments were performed by varying abrasive mesh size, no. of cycle, abrasive concentration and rotational speed of rod at different levels.

2. Literature review

In the modern metal working industry, the final finishing processes of the complex and precision components are the most time and cost consuming ones. This consumes as much as 5–15 per cent of expenditure on the overall manufacturing process. More over the complex finishing processes require the manual handling which is very slow and manual deburring lead to health and safety problems. Modern difficult to machine materials, there manufacturing and complex designs of precision parts pose special machining and finishing challenges. AFM is one of the processes capable of addressing the above mention challenges. This process replaces the lot of manual finishing processes leading to more standardization of manufactured parts, hence there inter-changeability, mass production and reduced costs. Since 1960’s a lot of work has been done in the field of AFM and there hybridization with other manufacturing methods. According to Przyklenk K.,(1986); Rhoades L.J.,(1985); William R.E.et al.(1992) [1,2,3] keeping all other parameters constant, increase in extrusion pressure results in faster cutting. A part of total pressure is lost within the media due to its internal resistance to flow a part of total pressure is lost within and rest is imparted to abrasion particles contacting the work piece surface. A linear dependence between material removal and surface roughness versus number of cycle was indicating within 1 to 8 cycles (1-4). Some researchers also performed experiment to depict the effect of pressure and media viscosity on surface quality. They conclude that there was improvement in surface finish (5). To enhance the performance of AFM, magnetic field has been apply to the AFM process .the magnetic field increase the no. of active abrasive grits taking parts in abrasion. Due to which surface quality improves (6-7). Przylenk described that with small bore diameter of work piece, more grains comes in contact with the surface, hence improves surface finish (8). The abrasive media was rotated by using different shaped rods to increase work piece media interactions. The speed of rotation of CFG rod has a major effect on surface finishing (9-14). Taguchi method was used by researchers for engineering analysis. This method employs design of orthogonal array to compute the effect of process parameters on surface finish. 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 (15-17). In addition, to increase the performance of simple AFM, electrochemical process has been produce in the AFM process (18-20).It was noted that that there was a scope of extensive research work towards AFM process by considering the advantage of different machining process. This paper discusses the role of various process parameters which affects surface quality. Hence to study the effect on surface roughness, a setup has been designed and experiments were carried out.

3. **AFM Set up**

The schematic diagram of abrasive flow machining set up was shown in figure 1. The fixture was made up of nylon. It has divided into three parts as shown in figure 2. The tool rod attached with gear was fixed between two idle gears, which form a gear train. The tool rod was of triangular shape. 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 abrasive medium was poured inside the lower cylinder. The piston forces the media to moves out towards upper cylinder under extrusion pressure. The schematic view is shown in figure 3. The holes are produced inside the cylinder for keep it of light weight. A direct current motor has been used to provide continuous output without any fluctuation. The rotational speed of tool rod can be varied with the help of speed regulator as show in figure 4. The gear train was rotated by a mechanism provided by direct current motor, bevel gear and shaft. The cylindrical work piece and tool rod was put up in other part of fixture. These parts of fixture were tightened with the help of bolts. The work piece was prepared by drilling and boring operation. Initial surface roughness was in the range of 2.5-3.1 micron. The work piece was 16mm long, 13mm outer diameter and 9mm inner diameter. The work piece was cleaned properly before and after each experiment by using acetone. The experiment design was prepared by using taguchi method. L9 orthogonal array based upon taguchi technique was preferred for experimental design and total 27 experiments were performed.

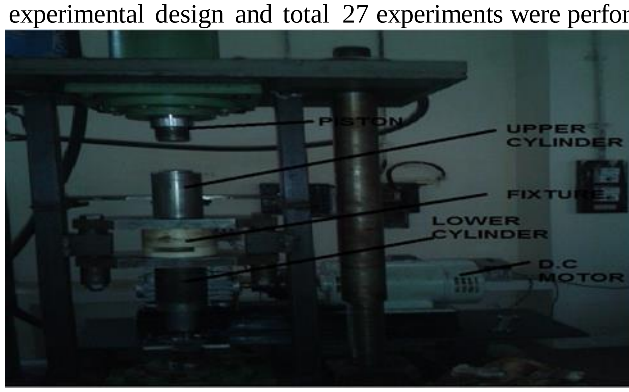

Fig. 1 AFM Machine

Fig. 2 Cylinder

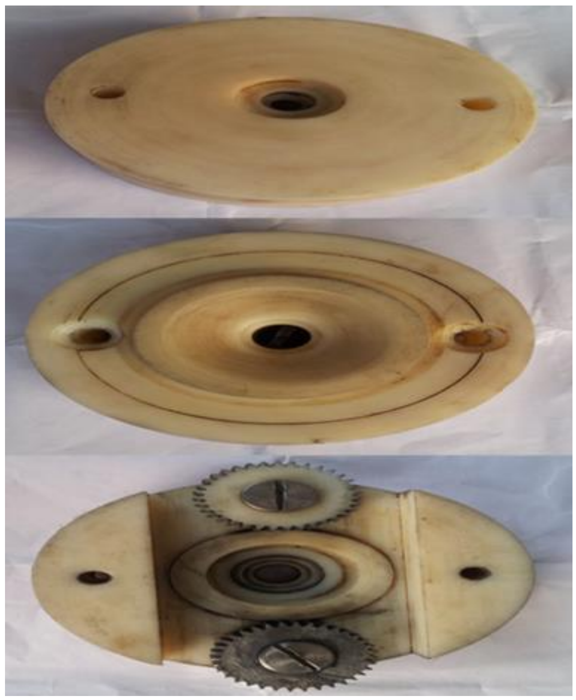

Fig.3 Fixture Parts

Fig. 4 Speed Regulator

4. Parameters and their Range

The selected parameters & their range are shown in table 1& 2.

Table 1. Different Constant Process Parameters

Sr. No.	Process Parameters	Range	Unit
1	Extrusion pressure	7	N/mm^2
2	Shape of CFG rod	Triangular	-----
3	Diameter of CFG rod	4.2	Mm
4	Initial surface Ra	2.5-3.10	
5	Media flow volume	290	cm^3
6	Fixture material	Nylon	-------
7	Polymer-Gel ratio	1:1	Percentage
8	Work piece Material	Gun Metal	
9	Temperature	32 ± 2	°C
10	Reduction Ratio	0.94	-----

Table 2. Process Parameters Value At Different

Symbol	Parameter	Unit	Level1	Level2	Level3
G	Abrasive Size	No.(micron)	50	100	150
N	Number of Cycle	Number	4	8	12
C	Abrasive Concentration	------	0.85:1	1:1	1.15:1
R	Rotational speed of CFG rod	rpm	0	20	40

5. Experimentation work

The percentage change in surface roughness value calculated as:

$$\Delta Ra = \frac{Initial\ Roughness - final\ roughness}{Initial\ roughness}$$

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 calculated for this type as:

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

Where

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

R = Number of repetitions, y = response value.

The percentage improvement in surface roughness for S/N ratio and raw data at three levels L1, L2, L3 for each parameter was shown in table III & IV. Analysis of variance (ANOVA) and F-Test performed. The test values indicate the significant AFM parameters affecting the finishing quality of the surface.

1. Results

Table 3. Orthogonal Array L9 with S/N Ratio of Various Response Characteristics

S.No	G	N	C	R	R_1	R_2	R_3	S/N
1	50	4	0.85	0	9.45	9.67	9.87	19.70
2	50	8	1	20	24.89	24.88	24.75	27.90
3	50	12	1.15	40	15.98	15.91	16.02	24.07
4	100	4	1.15	20	14.28	14.67	14.58	23.23
5	100	8	0.85	40	18.33	18.75	18.58	25.37
6	100	12	1	0	25.12	25.33	25.24	28.09
7	150	4	1	40	27.67	27.74	27.82	28.86
8	150	8	1.15	0	27.22	27.03	27.1	28.66
9	150	12	0.85	20	23.32	23.76	23.93	27.48

R1, R2, R3 denotes ΔRa value for repetitions of every experiment.

Table 4: Main Effect (S/N Data)

Level	Abrasive size	No. of Cycle	Abrasive Conc.	rpm
L_1	23.89	23.93	25.47	24.18
L_2	25.55	27.31	26.21	28.27
L_3	28.34	26.53	26.10	25.32
L_2-L1	1.66	3.38	0.74	4.09
L_3-L_2	2.79	-0.78	-0.11	-2.95
Difference	1.13	-4.16	-0.85	-7.03

Table 5: Main Effect (Raw Data)

Level	Abrasive size	Number of Cycle	Abrasive Concentration	RPM
L_1	16.82	17.31	20.67	17.30
L_2	19.43	23.50	21.01	25.94
L_3	26.18	21.62	20.76	19.20
L_2-L_1	2.61	6.20	0.34	8.64
L_3-L_2	6.75	-1.88	-0.25	-6.74
Difference	4.14	-8.08	-0.59	15.38

L_1, L_2 and L_3 denote the value of S/N data and raw data at different levels of parameters. L_2-L_1 and L_3-L_2 denotes the effects, when the process parameter value varies from L_1 to L_2 and L_2 to L_3 respectively.

6. Graph Discussion

a.) Effect of Abrasive mesh size on surface roughness

Fig 4(a) shows that percentage change in surface roughness was more at third level (G_3).The reason is that as the abrasive mesh size increases, size of abrasive particles decreases results in finer material. Due to this finer abrasive grain comes in contact with work piece, which produces better quality surface. So as abrasive mesh size increases quality of surface improves.

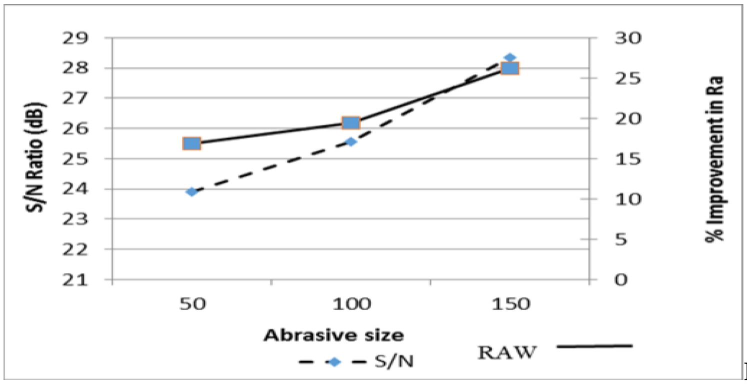

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Fig: 5 (a) Effect of abrasive size on percentage change in surface roughness

b.) Effect of Number of cycle on surface roughness

It was further noticed from the Figure 4 (b) that as the number of cycles increase, the ΔRa and S/N Ratio increases. As the number of cycle increases, more and more material removed from edges leading to improvement in the surface finish. Also the effect of number of cycles was significant on the basis of Raw Data and S/N Ratio Data (refer ANOVA Table).

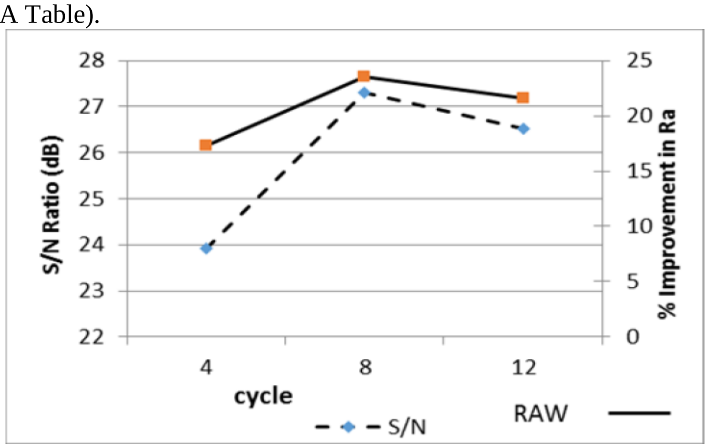

Fig: 5 (b) Effect of Number of Cycle on Percentage Change in Surface Roughness

c.) Effect of Abrasive Concentration on surface roughness

From Fig 4(c), it was conclude that as the concentration of abrasive increases, surface finishing improves. At higher concentration, more abrasive particle comes in contact with work piece resulting in more abrasion, which improves finishing of internal parts. But after a certain level of concentration, abrasive particle produces scratches on the work piece which affect surface quality.

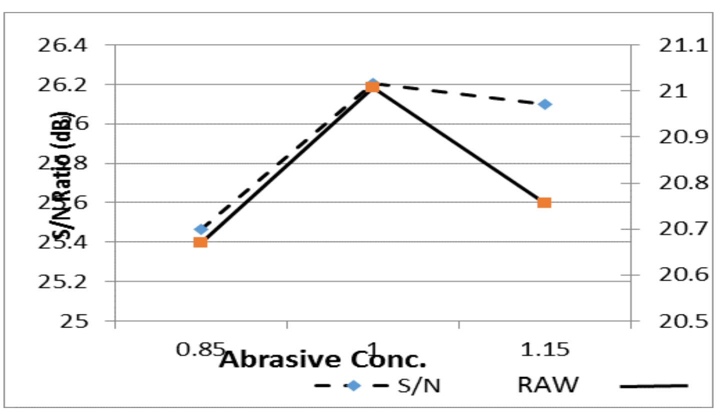

Fig: 5 (c) Effect of Abrasive Concentration on Percentage Change in Surface Roughness

d.) Effect of rpm on surface roughness

It can be observed from the Figure 4(d) that increase in Rotational speed of CFG rod first improves the surface finish and after the second speed level surface finish starts deteriorating. According to RAW and S/N ratio data, the maximum surface finish was achieved at 20 rpm. Both the analysis predicts the deterioration of surface finish after the middle level of 20 rpm. This can be attributed to the fact that at more Rotational speed of CFG rod, abrasives dig deeper into the material i.e. more abrasives strike on the work piece surface and produce deep scratches. But before middle level of rotational speed of CFG rod the media moves in a block and individual abrasives are not as much digging into the work-piece so an improvement in the surface finish is observed.

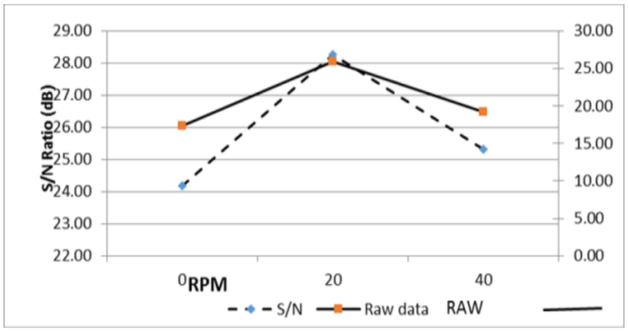

Fig: 5 (d) Effect of Rotational Speed on Percentage Change in Surface Roughness

7. **Anova analysis**

Analysis of variance method used for raw data to study the significance and percentage contribution of different parameters. It was noted that percentage contribution of Abrasive mesh size (43.08), rotational speed of tooling rod (38.14), Number of cycle (18.68) and abrasive concentration (0.06) .It was noted that percentage change in surface roughness for raw data was highest for 3rd type of abrasive size i.e. 150, 2nd level of number of cycle (N2), 2nd level of rpm (R2) & 2nd level of abrasive concentration (C2).

Table 6 (A) Pooled Anovas (Raw Data)

Source	SS	DO F	V	F ratio	P
G	419.28	2	209.64	7127.08	43.08
N	181.77	2	90.88	3089.77	18.68
C	0.551	2	0.2755		0.06
R	37.17	2	185.58	6309.23	38.14
Error	0.53	18	0.029		0.05
Total	973.304	26			100

SS - Sum of square, DOF-degree of freedom, V-variance, SS'- pure sum of square. *Significant at 95% confidence level, $F_{critical}$ = 3.49

In S/N data analysis the percentage contribution of abrasive mesh size (39.51%), rotational speed of rod (34.76%) and number of cycle (24.49%).It was noted that percentage change in surface roughness for S/N data was highest for 3rd type of abrasive (G3), 2nd level of number of cycle (N2), 2nd level of rpm (R2) & 2nd level of abrasive concentration (C2).

Table 6 (B) Pooled Anovas (S/N Data)

Source	SS	DOF	V	F-ratio	SS'	P
G	30.32	2	15.16	31.71	29.36	39.51
N	18.79	2	9.39	19.65	17.83	24.49
C	0.956	Pooled				
R	26.67	2	13.34	27.90	25.72	34.76
Erro	0.956	2	0.48	28.99	21.66	1.25
T	76.74	8		122.844	76.73	100.00

*Significant at 95% confidence level, $F_{critical}$ =19.00

8. Conclusion

After the experimental work and analysis of results, the following points were noticed:

1. Centrifugal force improves the efficiency and performance of simple AFM process and also reduces the machining time.
2. The centrifugal force improves the surface quality of work piece. More Improvement in surface quality can be obtained by varying levels of process parameters.
3. It is possible to increase the efficiency of simply AFM process by using hybrid AFM. The abrasive mesh size has highest contribution followed by rotational speed of CFG rod, number of cycles and abrasive concentrations in both RAW and S/N data towards improvement in surface finish.

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