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Parametric Investigation of Gun Metal for Surface Roughness with Hybrid Abrasive Flow Machining Process

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Abstract

Abrasive Flow Machining (AFM) is an effective way to polish unsymmetrical, irregular/regular surfaces and interior structure of parts, which are difficult to reach by any conventional machining process. In this process abrasive laden visco elastic medium is extruded back and forth through the passages of the work-piece and tooling is fabricated to hold the workpiece firmely. Taguchi method, L_9 is used to see the effect of various parameters. This abrasive laden visco elastic medium is mixture of polymer, gel and abrasives. In this investigation the key parameters abrasive size, number of cycles, Pressure and diameter of rod were varied and rotational speed is constant to see their effects on material removal. The objective of the present paper is to study the effect of process variables on surface finish. The percentage contribution of Pressure was significant and the highest contribution for the present setup and its contribution was 37.60% . The percentage contribution of Number of cycle was 31.16% for the Ra. As the number of cycles increases from 3 to 7, the Ra goes on increasing.

Keywords: *AFM (Abrasive Flow Machining), Ra Surface finish, CFG centrifugal force generating, L_9 Taguchi*

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1. Introduction

Abrasive Flow Machining (AFM) is one of the latest nonconventional finishing processes, which possesses excellent capabilities for finish-machining of inaccessible regions of a component. It has been successfully employed for deburring, radiusing, and removing recast layers of precision components by extruding an abrasive laden polymer medium with very special rheological properties. High levels of surface finish and sufficiently close tolerances have been achieved for a wide range of components [1]. The polymer abrasive medium which is used in this process possesses easy flowability, better self deformability and fine abrading capability. A special fixture is generally required to create restrictive passage or to direct the medium to the desired locations in the workpiece.

The basic principle behind AFM process is to use a large number of random cutting edges with indefinite orientation and geometry for effective removal of material. The extremely thin chips produced in abrasive flow machining allow better surface finish upto 50nm, close tolerances in the range ± 0.5µm, and generation of more intricate surface [2]. In this process tooling plays very important role in finishing of material. In order to cater to the requirement of high-accuracy and high efficiency finishing of materials, AFM is gaining importance day by day. The AFM process has a limitation too, with regard to achieving required surface finish. With the aim to overcome the difficulty of longer cycle time, the present paper reports the findings of a hybrid process, which permits AFM to be carried out with additional centrifugal force applied onto the cutting media. Some of the advanced finishing processes use loose abrasives to finish complicated geometries by enhancing reach of abrasive particles to difficult-to-access regions of the work-piece surface [26]. The flexible nature of the abrasive laden media provides unique capabilities as areas inaccessible to traditional methods, and complex passages, can be finished to high quality by this process [27].

The Abrasive Flow Machining process is a process that involves extruding an abrasive-filled semisolid media through a workpiece passage. The elements required for AFM process are the machine, workpiece fixture (tooling) and media. The machine used in AFM process hydraulically clamps the work-holding fixtures between two vertically opposed media cylinder. These cylinders extrude the media back and forth through the workpiece(s).Two cylinder strokes, one from the lower cylinder and one from the upper cylinder, make up one process cycle. Both semiautomatic machines and high-production fully automated system are widely used. The extrusion pressure is controlled between 7-200bars, as well as the displacement per stroke and the number of reciprocating cycles is controlled. AFM process is an efficient method of the inner surface finishing process. In practical application, it has an obvious effect on surface finishing of the industrial valves, and the parts/components of die, etc.

2. Literature Survey

A number of studies [3,4,5], show that the material removal rapidly increases during the initial cycles and there after it stabilized at higher number of cycles. Siwert noted that abrasive particle to base material ratio (by weight) should vary from 4:1 to 1:4 with 1:1 as the most appropriate ratio. As the concentration of abrasive in the media increase, MR increases [7]. As the abrasive mesh size increases, the material removal value decreases [8]. 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 [9-10]. Different shapes of CFG rods also used to see their effect on ΔRa. The speed of rotation of CFG rod has a major effect on material removal [12-13].

Taguchi methods used by many researchers for engineering analysis. This method employs design of orthogonal array to compute the effect of process parameters on material removal [11]. Jain and Jain [15], reported that at higher pressure the improvement in material removal just tends to stabilize probably due to localized rolling of abrasion particles. Williams and Rajurkar and Williams et. al. have investigated that viscosity of the media is one of the significant parameters of the AFM process. Keeping all other parameter constant, an increase in viscosity improves material removal rate [4,6]. Sarah et al. [14] presented a neural network model as an off-line controller for AFM of automotive engine manifold to predict when the AFM process should be stopped to achieve the required airflow rate through manifold body.

The objective of this paper is to study the effect of different process parameters on surface finish of gun metal workpiece, a setup has been designed & experiments were carried out to test the significant effect. The amount of abrasion or stock removal that occurs is directly related to the slug length of flow, which in turn is governed by media flow volume [21]. Researcher have also developed models for the formation of CIP chain structures around Sic abrasive for the MRAFF process; surface finish of upto 0.4 micron R_a has been achieved by this process [20]. Walia et al, [16] suggested that Abrasive flow machining process (AFM) is a process to polish metallic components using a semi-liquid paste which can reach inaccessible undercut areas of a complicated component. Abrasion occurs wherever the medium enters and passes through the most restrictive passages. Reddy et al, [19] studied the effect of key parameters on the performance of the process through response surface methodology (RSM). The media act as a self-modulation abrasive medium with good fluidity and viscosity so the cutting tools are flexible [17]. Kozak et al, [18] quoted that a hybrid approach where two or more material removal processes act simultaneously offers more scope, if not to enable a single cut from solid, then as a means to increase productivity in completion of an intermediate (semi finishing) or finishing task.

AFM process and its evaluated process parameters such as pressure, speed of the flow, volume of the media, types of abrasive, affects the polishing of work piece [22]. Dabrowski et al, [24] experimented with the electrochemically assisted abrasive flow machining (ECAFM) using polypropylene glycol (PPG) with NaI salt share and the ethylene glycol PEG with KSCN salt share. Modelling using non-linear multi-variable regression analysis and artificial neural networks was carried out to conduct parametric analysis and to understand, in depth, the Drill Bit-Guided Abrasive Flow Finishing (DBG-AFF) process [23]. Jones & Hull developed a test rig and for the process during a research on development of an automated polishing method to be applied on surfaces used in the forming and shaping of materials such as powder metallurgy products, casting and forging alloys, plastics and glass [25].

3. Experimental Set-Up

Schematic diagram of abrasive flow machining process is shown in figure 1.

Figure 1 Hybrid AFM Set-up

The abrasive media consist of three parts: silicon based polymer, hydrocarbon gel, and abrasive particles and non Newtonian liquid polymer. All these constituents were mixed in equal proportion to form the medium. The abrasive used in this study was aluminium oxide (Al_2O_3). The fixture used in this research was made up of three parts as shown in figure 2.

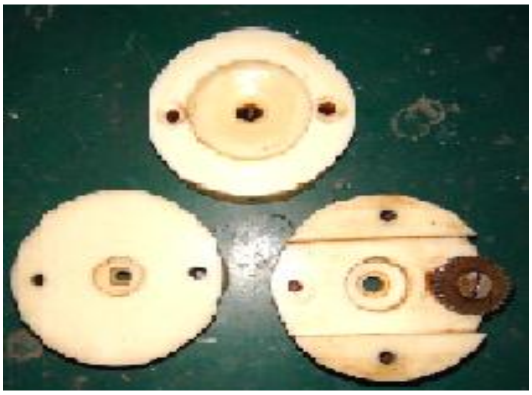

Figure 2 AFM Fixture Parts

Figure 3 Workpiece

Figure 4 CFG rod

Figure 5 SJ-400 surface roughness tester

The cylindrical workpiece and the CFG rod (Shaft) 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 cylindrical work piece as shown in figure 3 was fitted between this CFG rod (Shaft). The CFG rod shown in figure 4. This Ø 12 ×16-mm long cylindrical workpiece initially drilled followed by boring to 8.00±0.05mm as shown in fig 3. Before any measurement the workpiece was cleaned by acetone properly. Initially the Ra of workpiece was measured & after experiment final Ra was measured. Figure 5 shows the surface roughness tester SJ-400.

Table 1 Specifications of this roughness tester SJ-400

Item	Description
Measured Profile	P, R, W, DIN4776, MOTIF.R, MOTIF.W
Parameter	Ra, Ry, Rz, Rq, Rp, Rv, Sm, S, Pc, mr, R3z, δc, HSC, mrd, Δa, Lo, Ppi, Sk, Ku, Δq, Rx, Rpk, Rvk, Rk, Mrl, Mr2, A1, A2, Vo, AR, W, AW, Wx, Wte, Rz1max, Rmax*1
Filter	2RC, PC75, GAUSS
Cut off Length	0.08, 0.25, 0.8, 2.5, 8mm (0.002, 0.01, 0.03, 0.1, 0.3in)
Number of Sampling Length	1, 3, 5 and L (Arbitrary Lenght)
Resolution	0.000125 µm / 0.00492 µin (16 bits)
Statistical Data Item	Mean, Maximum, Minimum, Standard Deviation (One Parameter per Profile), GO/NG Judgement (UL/LL, Three Parameters per Profile)
Internal Memory Capacity	Upto Measurement Condition Files
External I/O	RS-232C, SPC, Memory Card (option)
Power Supply	AC Adapter, Built-in Battery Pack (Nickel-Hydrogen)

4. Experimentation

4.1 Process parameters

The selected process parameters value at different level and constant process parameters are shown in table 2.

Table 2: Process parameters value at different level

Symbol	Process Parameters	Unit	Level 1	Level 2	Level 3
A	Mesh Size	--	100	150	200
S	Square CFG Rod Cross-Section Area	mm^2	4.5	8	12.5
N	No of cycles	Number	3	5	7
P	Pressure	N/mm^2	3	5	7
Polymer-to-Gel Ratio: 1:1, Work-piece material: Gun Metal, Rotational speed: 40 rpm, Abrasive type: Al_2O_3, Shape of CFG rod: Square, Media Flow Volume: 290 cm^3, Reduction Ratio: 0.95, Media Viscosity: 810 Pa.s.					

4.2 Initial and final Ra of workpiece

Ra value of Gun Metal workpiece shown below

Table 3: Initial and final Ra value of workpiece

Exp. No.	**Repetition R1**		**Repetition R2**		**Repetition R3**	
	Initial Ra	Final Ra	Initial Ra	Final Ra	Initial Ra	Final Ra
1	1.63	1.54	1.50	1.41	1.78	1.68
2	1.84	1.58	1.97	1.69	1.72	1.48
3	1.88	1.68	1.63	1.46	1.96	1.76
4	1.42	1.29	1.54	1.40	1.46	1.33
5	1.88	1.68	1.93	1.70	1.67	1.48
6	1.48	1.33	1.55	1.38	1.49	1.33
7	1.78	1.34	1.63	1.21	1.87	1.43
8	1.66	1.49	1.74	1.57	1.57	1.42
9	1.52	1.32	1.69	1.47	1.61	1.40

4.3 Experimental design

Taguchi recommends orthogonal arrays (OA) for laying out of experiments. These OA's are generalized Graeco-Latin squares. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns. The use of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple. The array forces all experimenters to design almost identical experiments [28].

Larger the better:

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

where

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

The experimental results of various response characteristics percentage improvement in surface roughness are shown in table 4. R1, R2 and R3 represents the three response values for three repetitions of each trial.

Table 4: L_9 orthogonal array with experimental results of various response characteristics %improvement in Ra

Sr no.	A	S	N	P	R1	R2	R3	S/N ratio
1	1	1	1	1	5.81	5.71	5.21	14.90
2	1	2	2	2	14.01	13.95	13.66	22.84
3	1	3	3	3	10.11	10.23	10.13	20.13
4	2	1	2	3	8.63	8.90	8.63	18.81
5	2	2	3	1	11.14	11.55	11.25	21.07
6	2	3	1	2	9.87	10.47	10.30	20.17
7	3	1	3	2	24.71	25.41	23.33	27.76
8	3	2	1	3	9.84	9.60	9.47	19.68
9	3	3	2	1	12.84	12.66	12.71	22.10

4.4 Discussion of results

4.4.1 Effect of Abrasive Size

Figure 6 shows that use of finer grain size of the abrasive particles results in greater improvement of surface roughness. The reason for this seems obvious as with the constant mass ratio of abrasive-to-media used, the more number of finer grains would make finer but more number of cuts on the high spots of the work surface; consequently generating smoother surface.

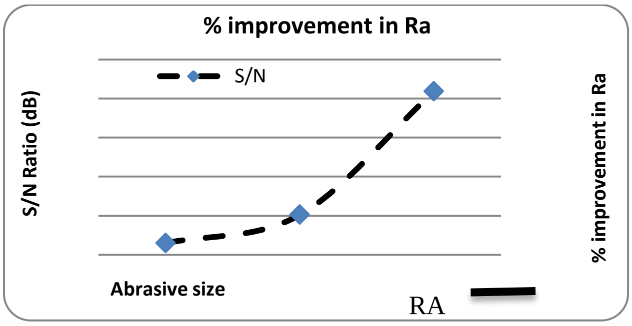

Figure 6 Effect of Abrasive Size on (%age imp. in R_a and S/N Ratio)

4.4.2 Effect of Shaft Size

Figure 7 shows that with the increase in Shaft size from first level, the surface finish decreases up to second level and then onwards also it decreases up to third level. Because there is sufficient gap between workpiece and shaft therefore %Ra is better at first level.

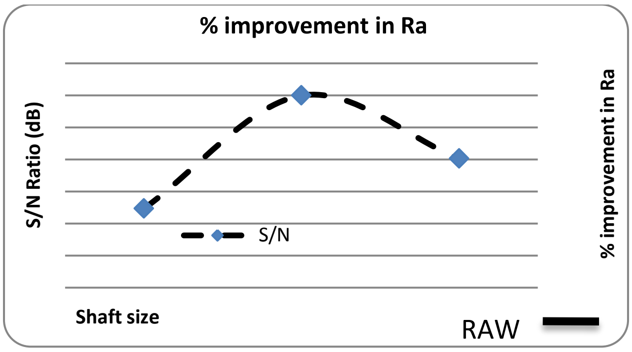

Figure 7 Effect of Shaft Size on (%age imp. in R_a and S/N Ratio)

4.4.3 Effect of No. of cycles

It is noticed from the figure 8 that during the initial few cycles, the rate of abrasion is greater causing higher ΔR_a after which it slows down. This is due to the reason that initially, the total peaks available upon the surface of the work piece are more. The more the number of peaks, the more will be the rough surface. However, as the surface is subjected to repeated cycles, the number of peaks and their height goes on decreasing hence more improvement in surface roughness occurs initially and it declines after a few cycles.

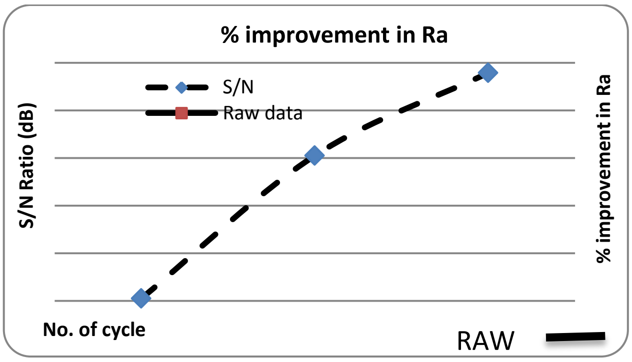

Figure 8 Effect of No. Of cycles on (%age imp. in R_a and S/N Ratio)

4.4.4 Effect of Pressure

Figure 9 shows the increase in extrusion pressure improves the work surface finish. Within the range of extrusion or axial pressure applied the higher the pressure the greater is the improvement in surface finish, which tends to stabilize beyond a certain level. Higher axial pressure enables the abrasive particles to roll on the surface with more force resulting in faster removal of metal peaks on the work surface and hence rapid achievement of the required surface finish.

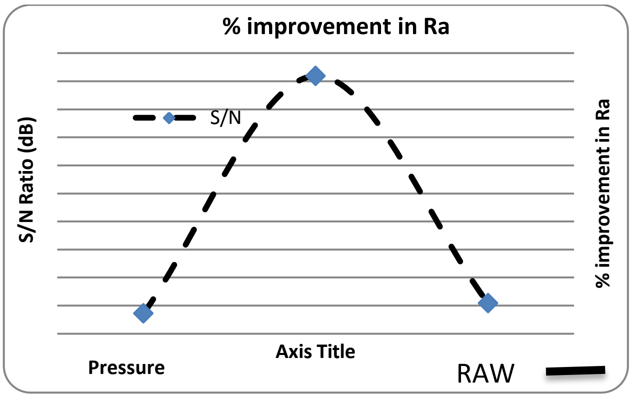

Figure 9 Effect of Pressure on (%age imp. in R_a and S/N Ratio)

5. Analysis

The percentage contribution of Abrasive size is (28.30%) for percentage improvement in R_a followed by shaft size (2.51%) number of cycles (31.16%), and Pressure (37.60%). The percentage improvement in R_a is the "higher the better" type of quality characteristic. Therefore, higher values of $^{\Delta}R_a$ are considered to be optimal. It is clear from the figure the figure 4, figure 5, figure 6 and figure 7 that the percentage improvement in R_a for raw data is highest at the third level of Abrasive size (A_3),First level of shaft size (S_1), third level of number of cycles (N_3), second level of pressure (P_2).

Table 5: Pooled ANOVA (Raw Data, %age imp in R_a)

SOURCE	SS	DOF	V	F-RATIO	P%
Pressure (P)	254.21	2	127.11	775.56	37.60
No of cycles (N)	210.70	2	105.35	642.81	31.16
Abrasive size (A)	191.3	2	95.65	583.63	28.30
Shaft size (S)	16.97	2	8.49	51.77	2.51
Errror	2.95	18	0.16	--	0.00
Total (T)	676.17	26	--	--	100

*Significant at 95% confidence level, $F_{critical}$ = 3.55
SS-Sum of Squares, DOF- Degree of Freedom, V-Variance

Table 6: Pooled ANOVA (S/N Ratio, %age imp in R_a)

SOURCE	SS	DOF	V	F-RATIO	P %
Pressure	34.39	2	17.20	45.79	36.13
Number of Cycles	34.42	2	17.21	45.83	36.16
Abrasive size	25.62	2	12.81	34.11	26.91
Shaft size	0.75	**POOLED**			
Error	0.75	2	0.38	--	0.79
Total (T)	95.19	8	--	--	100

*Significant at 95% confidence level, $F_{critical}$ = 3.55
SS-Sum of Squares, DOF- Degree of Freedom, V-Variance

Conclusion

The important conclusions for this research work are enlisted below:

- The three main process parameters Abrasive size, , No. of cycle and Pressure have significant effect on the response parameters of percentage improvement in the surface finish?
- The Pressure also or the Ra.
- The percentage contribution of Pressure was significant and the highest contribution for the present setup and its contribution was 37.60%. The percentage contribution of Number of cycle was 31.16% for the Ra. As the number of cycles increases from 3 to 7, the Ra goes on increasing.
- The result shows that the percentage contribution of Abrasive size is 28.30% for %age improvement in Ra and Shaft size shows percentage contribution in %age improvement in Ra is 2.51%, which is very negligible so it was pulled.

Future Scope

This process can be club with another finishing processes to get the advantages of each one.

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