# Optimization of process parameters for effective material surface roughness in abrasive flow machining process

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**Abstract - Abrasive flow machining is a nonconventional machining process and was developed in late1960's.The process provide a high quality surface of inner profiles that are difficult to access & is used to deburr,remove recast layer & radius surfaces with an economically acceptable rate of surface generation.Abasion occurs only where the media flow is restrict;other areas remain unaffected.The AFM process has found applications in a wide range of fields such as defence,surgical, aerospacce & tool manufacturing industries. one serious limitations of AFM processes is a low material removal rate because during machining not all the abrasive particles participate in removing material from the work piece. Limited efforts have hitherto been directed towards improving the efficiency of the process so as to achieve higher material removal rate and better surface quality of work piece .This paper discusses improved fixturing as a technique for productivity enhancement in terms of surface roughness .A rotating centrifugal force generating rod of fixed diameter 4.2 mm was used inside the cylindrical work piece ,which provides the centrifugal force to the abrasive particles normal to the axis of work piece .The effect of the key parameters on the performance of process has been studied .The results show that for a given improvement in Ra value the processing time can be reduced by as much as 70-80%.It is seen that the significant process parameters are materials(M)i.e Mild Steel ,Brass, GunMetal) abrasive mesh size(G),extrusion pressure(P) ,rpm of CFG rod(N). L9 orthogonal array based upon taguchi method has been applied for experimental design. Further ANOVA has been performed to measure the percentage contribution of different process parameters.**

**Keywords**

**AFM,CFG rod, RPM ,surface roughness , Taguchi, ANOVA**

## I. 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 and economically[3]. Modern metal working industry has several challenges such as to control costs, decrease lead time from design to production, improvement of product quality. The most labour-intensive uncontrollable area in the manufacture of precision parts involves final machining (or finishing) operations. Finishing operations usually cost approximately 15% of the total machining cost in a production cycle [8,15] AFM consists of two cylinders which were placed in opposite direction mounted vertically. Initially the abrasive medium was poured inside the lower cylinder in proper amount. The abrasive medium was the mixture of non Newtonian polymer, hydrocarbon oil and abrasive particles. There were many types of abrasive particles like silicon carbides, aluminum carbide, diamond and boron. In this study, the abrasive particles of aluminum oxides were used. This mixture was flow from lower cylinder to upper cylinder. In between these two cylinders, a fixture was attached. This fixture forms the restricted passage inside the work piece. This is a two way AFF process in which cylinder extrudes the abrasive medium back and forth inside the work piece. One cycle is completed, when abrasive medium obtained two strokes, one from lower cylinder and other from upper cylinder. The piston moves inside the hydraulic cylinder under hydraulic pressure.The abrasive particles in the abrasive media consist of cutting edge which assists in material removal from inside surface of workpiece. The tool rod inside the workpiece was also rotated at different speeds. When the rod rotates, it exerts centrifugal forces in all direction. It increases the interaction of workpiece surface and abrasive particles results in more material removal. This process has many applications in different fields like in aerospace,die making ,automotive,electronic and in surgical implants etc. In this research work, process parameters likeabrasive mesh size, abrasive concentration, extrusion pressure and rpm were varied at three different levels to depict their effect on surface finishing. Taguchi approach L9 has been adopted for their experimental design.According to experimental design, total twenty seven experiments were performed and output was noted. The effect of different process parameters such as abrasive mesh size(G), extrusion pressure(P), RPM(N) on different materials(M) has been studied at different levels.

## II. LITERATURE REVIEW

Modern material technology has been trying to create strong hard and difficult machine material to overcome the processing time,cost and energy consumption but not the simultaneous finishing requirements of surface finishing and efficiency.A nova l hybrid of AFF(Abrasive flow finishing)with synergetic finishing action by Centrifugal force has been developed by Walia et al to overcome such finishing problems.The Centrifugal force is incorporated to explore the productivity enhancement of the process.Walia(1,2,4,7) claimed that abrasive media was rotated by triangular CFG rod of fixed diameter 4.2 mm to increase work piece media interaction.The combination of high extrusion pressure and high speed of CFG rod is more favourable to surface finishing.Przyklenk [16] claimed its effect both on material removal and surface roughness as significant. At higher pressure, the improvement in material removal just tends to stabilise. A number of studies [9, 12–14,16,17] have shown that abrasion is pronounced in some initial cycles, after which both material removal rate and improvement in surface roughness get stabilized.It also has been observed that the greater the reduction ratio, the more is the material removal from the workpiece for a specified number of cycles. There exists.while the combination of a larger grain size and higher speed of CFG rod cause higher material removal. Walia and Shah (2006) [1,4] observed that addition of Centrifugal force by external guided arrangement in media increase improvement in surface finish and material removal rate(MRR).Centrifugal force enhance MRR and improves the scatter of surface roughness (SRR) value in AFM leading to production of Centrifugal force assisted abrasive flow machine (CFAAAFM).Jain and Shankar (11) found that in drill type AFM found that in drill type AFM, abrasive intermixing also depends on pressure from the drill bit, three types of flow(along flute, axial flow, scooping flow) with medium- deformability.Due to combination of different flows, the work piece –abrasive contact length becomes curved not a straight line, number of peaks increased, resulting high finishing rate. To increase efficiency, Mondal and Jain used the concept of drill- bit-guided abrasive flow finishing (DBG-AFF) process(3,10,16). Dabrowski et al (2006), (5-6) experimented with the electrochemically assisted abrasive flow machine(ECAFM) using polypropylene glycol (PPG) with NaI salt share and the ethylene glycol PEG with KSCN salt share.

Magnetically assisted abrasive flow machining, which is the combination of AFM and magnetic abrasive finishing (MAF), has been given better results than obtained from individualAFM or MAF [11].

## III. EXPERIMENTAL SET-UP

The major elements to perform the experiment consist of machine, fixture and abrasive media. The schematic diagram of machine is shown in figure 1.The material used for manufacturing of fixture was Teflon. It was shown in figure attached with gear train. A direct current motor has been used to provide rotation to this gear train with the help of a bevel gear and a rotating shaft. The rotational speed varied with the help of a speed regulators. The workpiece was placed carefully between upper and lower fixture. The fixture is placed in between the lower and upper cylinder. The workpiece was cleaned with a before and after each experiment. The workpiece was made up of mild steel, brass and gun metal. The workpiece was prepared by drilling and boring operation in as shown in figure III. The abrasive medium was the mixture of polymer, gel and abrasive particles of different size. All these constituents were mixed together in ratio1:1:1.Different types of abrasives like diamond powder, silica, aluminium oxide and particles of boron can be used. In this study, abrasive particles of aluminum oxides were used.

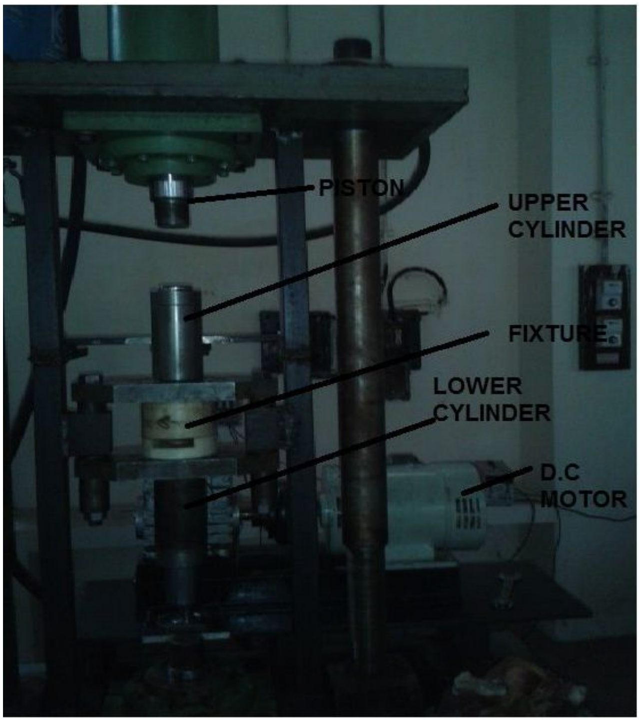



Figure 1 CFAAFM Set up

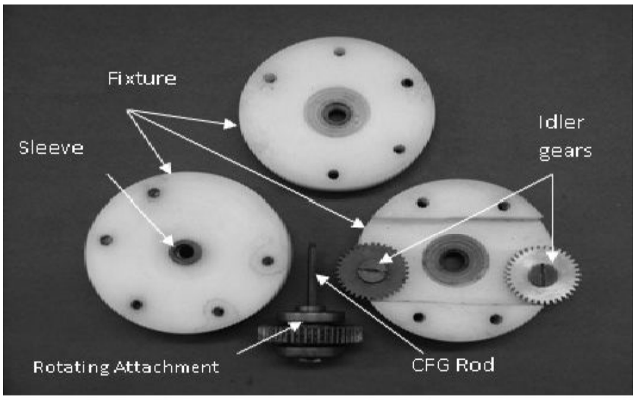



Figure I1 Fixture

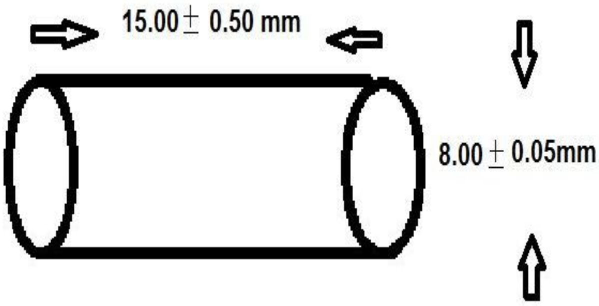



Figure III Workpiece Geometry

*3.1 Experimentation Work*

The percentage of improvement in surface finish is calculated as follows, Percentage improvement in surface finish(ΔR).

$$\Delta R = \frac{SR(\text{before AFM}) - SR(\text{after AFM}) \times 100}{SR(\text{before AFM})}$$

The roughness value was recorded with the help of Mitutoyo SJ-201 Surface Roughness Tester. The experimental design is based upon taguchi method by using $L_9$ ($3^4$) orthogonal array without considering any interactions. Each parameter was varied with different level .As ΔRa is higher the better type characteristics, so signal to noise ratio i.e. S/N ratio was depicted by using formula:

$$(S/N)_{HB} = -10 \text{ LOG } (MSD_{HB})$$

Where

$$MSD_{HB} = \frac{1}{R_i} \sum_{i=1}^{R} (1/y_i^2)$$

$R_i$ = Number of repetitions, $y_i$= response value
For experimental analysis, analysis of variance (ANOVA) has been performed. F- Test was performed to indicate the significant AFM parameters which affect material removal.

*Process Parameters and their Range*
There are some parameters which kept constant for experimentation work as mentioned in table 1.

TABLE1. Constant Parameters Value

| **Sr No.** | **Process Parameters** | **Range** | **Unit** |
|---|---|---|---|
| 1 | No. of cycle | 5 | No. |
| 2 | Extrusion pressure | 2,4,6 | $N/mm^2$ |
| 3 | Shape of CFG rod | Triangular | ----- |
| 4 | Diameter of CFG rod | 4.2 | Mm |
| 5 | Initial surface Ra | 3.15-3.55 | µm |
| 6 | Media flow volume | 290 | $cm^3$ |
| 7 | Fixture material | Teflon | ------- |
| 8 | Polymer-Gel ratio | 1:1 | percentage by weight |
| 9 | Abrasive to media ratio | 1:1 | percentage by weight |
| 10 | Temperature | 30 ± 2 | °C |
| 11 | Reduction Ratio | 0.94 | ----- |

The selected process parameters to be studied in this process were varied at three levels. These values are shown in table 2

. TABLE2. Process Parameters at different levels

| | Parameter | Unit | Level1 | Level 2 | Level3 |
|---|---|---|---|---|---|
| M | Material | …… | mild steel | gun metal | brass |
| G | Abrasive Size | No.(micron) | 100 | 150 | 200 |
| P | Pressure | $N/mm^2$ | 2 | 4 | 6 |
| N | Rotational speed of CFG rod | Rpm | 0 | 15 | 30 |

*3.2 Experimental Design*

The experimental design is based upon $L_9$ orthogonal array based upon taguchi method. Experiments were conducted according to the test conditions specified by the L9 OA. Each experiment was repeated three times in each of the trial conditions. Thus, twenty seven work-pieces were selected and in each of the trial conditions and for every replication,Surface roughness was measured. The data is recorded in Table 3.$R_{a1}$, $Ra_2$ and $Ra_3$ represents repetitions of each experiment.

TABLE3. Experimental result of response characteristic surface roughnessl

| S.N.o. | Material | Grit size | Pressure | Rpm | $R_{a1}$ | $R_{a2}$ | $R_{a3}$ | S/N |
|---|---|---|---|---|---|---|---|---|
| 1 | M | 100 | 2 | 0 | 7.52 | 7.51 | 7.55 | 17.53 |
| 2 | M | 150 | 4 | 15 | 21.76 | 21.71 | 21.64 | 26.73 |
| 3 | M | 200 | 6 | 30 | 17.25 | 17.24 | 17.33 | 24.75 |
| 4 | G | 100 | 4 | 30 | 15.28 | 15.33 | 15.35 | 23.71 |
| 5 | G | 150 | 6 | 0 | 13.77 | 13.95 | 13.34 | 22.72 |
| 6 | G | 200 | 2 | 15 | 28.12 | 28.08 | 28.01 | 28.96 |
| 7 | B | 100 | 6 | 15 | 29.98 | 29.77 | 29.92 | 29.51 |
| 8 | B | 150 | 2 | 30 | 27.22 | 27.03 | 27.1 | 28.66 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | B | 200 | 4 | 0 | 26.22 | 26.33 | 26.46 | 28.41 |

The Surface roughness for S/N ratio & average value of raw data at three level $L_1$, $L_2$, $L_3$ for each parameter shown in table 4. Where $L_1$,$L_2$ and $L_3$ denotes the value of S/N & raw data at levels 1,2 & 3 of parameters.$L_2$-$L_1$ is the main effect when the corresponding parameter changes from level 1 to level 2. $L_3$-$L_2$ is the main effect when the corresponding parameter changes from level 2 to level 3.

TABLE4. Average Values and S/N value with effect:Surface roughnessl (db)

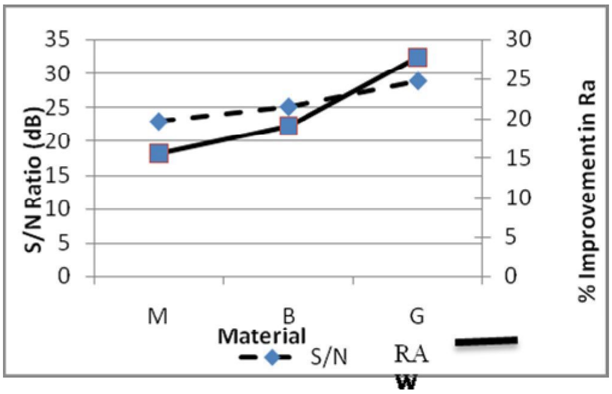
| LEVEL | M | | G | | P | | N | |
|---|---|---|---|---|---|---|---|---|
| | S/N data | Raw Data | S/N data | Raw data | S/N data | Raw data | S/N data | Raw data |
| L1 | 23.00 | 15.50 | 23.58 | 17.58 | 25.05 | 20.90 | 22.89 | 15.85 |
| L2 | 25.13 | 19.03 | 26.04 | 20.84 | 26.28 | 21.12 | 28.40 | 26.55 |
| L3 | 28.86 | 27.78 | 27.37 | 23.89 | 25.66 | 20.28 | 25.71 | 19.90 |
| L2-L1 | 2.13 | 3.52 | 2.46 | 3.26 | 1.23 | 0.22 | 5.51 | 10.70 |
| L3-L2 | 3.73 | 8.76 | 1.34 | 3.06 | -0.62 | -0.84 | -2.70 | -6.65 |
| DIFF. | 1.60 | 5.23 | -1.12 | -0.20 | -1.85 | -1.05 | -8.21 | -17.36 |

## IV. RESULTS AND DISCUSSION

### *a) Effect of type of material on ΔRa*

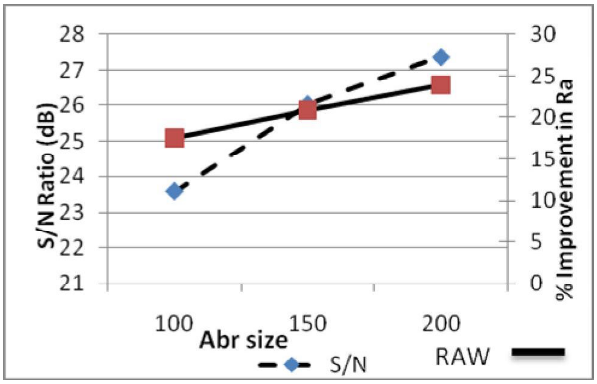
Graph 4(a) shows that maximum $\Delta R_a$ and S/N Ratio is at the third level (G) at Gun metal as a work piece. The lowest ΔRa and S/N ratio has been observed at first level (M) in case of mild steel as a effect on the response parameters of work piece material with. For ΔRa and S/N ratio brass lies between mild steel and gun Metal as shown in graph .The overall effect of type of material on the %age improvement in ΔRa is insignificant based on S/N Ratio data (ANOVA Table), and it is also insignificant based on raw data (Table).

Graph: IV (a) Effect of type of material on ΔRa




*b) Effect of Abrasive particle size on ΔRa*

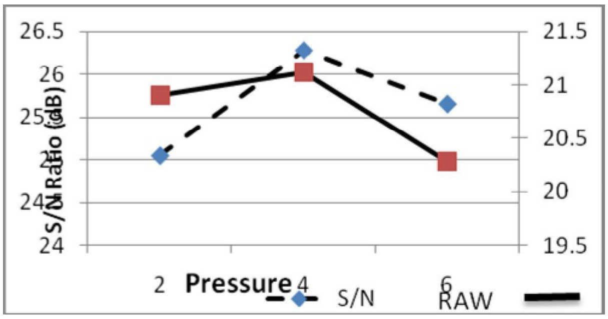
Another observation , It can be seen from the Graph 4 (b) that as the mesh size increases, quality of surface improves. Because as mesh size increases, size of particle decreases which equals finer materials and more no. of finer grains produce better surface finish.




Graph ΔRa.: IV (b) Effect of abrasive Size on ΔRa

*c) Effect of Extrusion Pressure on ΔRa*

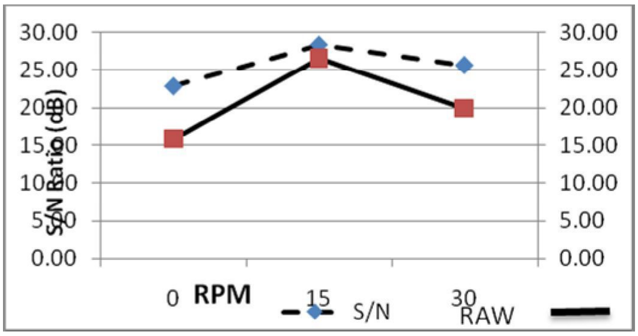
Graph 4(c) shows that percentage improvement in Ra increases as the pressure increases up to 4 MPa then it decreases with further increase in pressure up to 6 MPa. The increase up to 4 MPa can be attributed to the fact that as the pressure increases the force involved in cutting action increases and resulting in more no of peaks are sheared off which result in smother surface. At this pressure we got very smooth surface further increase in pressure enable the abrasive particles to strike the Surface with greater force and resulting in deeper scratches, and poor surface finish.



Graph: IV (c) Effect of Extrusion Pressure on ΔRa

*d) Effect of RPM on ΔRa*

It can be observed from fig 6.2(d) 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 work piece. 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 scratch & surface finish deteriorates.




Graph: IV (d) Effect of Rotational speed on ΔRa

## V. Selection of Optimum Levels

In order to study the significance of the process parameters towards the percentage improvement in Ra, analysis of variance (ANOVA) was performed. The pooled versions of ANOVA of the raw data and the S/N data for **ΔRa** are given in tables 5 & 6. From these tables, it is clear parameters M, G, P and N significantly affect the mean in the % improvement in **Brass** values. It was noted that % contribution of first parameter i.e. type of material was highest (50.38) followed by RPM (36.80), Extrusion pressure (0.24) & abrasive mesh size (12.56). Also it was noted that **ΔRa** for raw data was highest at third level of abrasive size ($G_3$), third level of type of material ($M_3$), second level of RPM ($N_2$) & second level of Pressure ($P_2$). **ΔRa** is the "higher the better" type of quality characteristic. Therefore, higher values of **ΔRa** are considered to be optimal.

| Source | SS | DOF | V | F ratio | P% |
|---|---|---|---|---|---|
| Type of material | 719.64 | 2 | 359.82 | 22410.92* | 42.96 |
| Abrasive size | 179.48 | 2 | 89.74 | 5589.48* | 18.07 |
| Pressure | 3.40 | 2 | 1.70 | 105.78* | 2.15 |

| | | | | | |
|---|---|---|---|---|---|
| RPM | 525.76 | 2 | 262.88 | 16373.02* | 13.77 |
| Error | 0.29 | 18 | 0.02 | | 0.40 |
| Total | 1428.57 | 26 | | | 100 |
| SS- Sum of square, dof-degree of freedom, V-variance, SS'- pure sum of square. *Significant at 95%, $F_{critical}$ = 19 confidence interval, $F_{critical}$ = 19*Significant at 95% confidence SS-Sum of square, dof-degree of freedom, V-variance, SS'- pure sum of square. *Significant at 95% | | | | | |

Table 5 Pooled Anova (RAW data) ΔRa

Table 6 Pooled Anova (S/N data) ΔRa

| Source | SS | DOF | V | F ratio | P% |
|---|---|---|---|---|---|
| Type of Material | 52.77 | 2 | 26.39 | 23.31* | 42.96 |
| pressure | 2.264 | POOLED | ---------- | ---------- | ---------- |
| Abrasive size | 22.20 | 2 | 11.10 | 9.81 | 18.07 |
| RPM | 45.61 | 2 | 22.80 | 20.15* | 37.13 |
| Error | 2.26 | 2 | 1.13 | | 1.84 |
| Total | 122.84 | 8 | | | 100 |
| SS- Sum of square, dof-degree of freedom, V-variance, SS'- pure sum of square. *Significant at 95%, $F_{critical}$ = 19 confidence interval, $F_{critical}$ = 19*Significant at 95% confidence level, $F_{critical}$ = 19 | | | | | |

## VI. CONCLUSION

Rotating CFG rod used inside the hollow cylindrical work piece Provides the centrifugal force to media is being processed byCFAAFM and an increase in percentage improvement in surface roughness and efficiency was achieved: Centrifugal Force Assisted Abrasive Flow Machining (CFAAFM), a hybrid machining process suggested in the research work can be considered as one of the important processes in the field of micro- finishing/ machining of precision components. The following important conclusions can be drawn from this research work:

1. It is possible to enhance the productivity of AFM by improved fixturing. With the introduction of CFG rod and providing rotation to it, as much as 75–85% reduction

2 All the four main process parameters
Abrasive mesh size(G),material(M),Extrusion Pressure(P), and Rotational speed of CFG rod(N) have significant effect on the response parameters of percentage improvement in the surface finish.

3 The developed setup is working efficiently and it has reduced the experimentation duration with

lesser fatigue to the operator of the two-way CFAAFM machine.

4 The percentage contribution of Extrusion Pressure(P) 0.24% & Abrasive size (G) 12.56 respectively for the percentage improvement in ∆Ra.

5 The Rotational speed of triangular CFG rod is also significant for the present setup and its contribution 36.80% for improvement in ∆Ra .

6 . It is noted that the optimal process parameters are$M_3G_3P_2N_2$ for better results

7. Experiments using orthogonal array technique on different materials i.e gunmetal, brass, mild steel test pieces confirm that after specific number of cycles better surface finish was produced in CFAAFM as compared to conventional AFM.

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