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Optimization of process parameter for surface finishing in abrasive flow finishing process

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Abstract-Abrasive flow finishing is a non-conventional finishing process that is used for finishing of work piece which are difficult to finish by conventional method i.e. by honing, lapping and other machining operations. It is used for polishing, deburring, removing recast layer of component and for cleaning of surfaces having complex shape and size of geometrical components. Abrasive flow finishing process polishes the surface by forcing the abrasive medium inside the work piece through the restricted area. One of the limitations of this process is that it is time consuming process and low material removal rate. To overcome these limitations, a structure has been developed. In this setup, centrifugal force has been generated by using a tool rod inside the hollow work piece to which rpm was provided. The abrasive mesh size, abrasive concentration, number of cycle, extrusion pressure, rotational speed of CFG rod, diameter of tool rod and shape of tool rod are the some important process parameter which affects the surface quality. In this research paper, the role of abrasive mesh size, extrusion pressure, abrasive concentration and rotational speed has been discussed on Gun metal as material of work piece. For experimentation design, taguchi approach L9 orthogonal array has been used and for analysis of result, ANOVA has been performed.

Keywords- AFF, Surface roughness, rotational speed Taguchi method, ANOVA

1. Introduction

Abrasive flow finishing is a nontraditional finishing process which uses abrasive media that flows inside the work piece and removes the material from edges. It 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 medium consists of large number of abrasive particles which have randomly cutting edge with different orientation and geometry for effective material removal. In order to meet the requirement of high accuracy and better quality surface, this process is gaining wide spread attention day by day. This process is capable to produce surface finishing up to ten times when initial surface roughness is in the range of 0.9-7 micron. It finds application lot of areas like in medical instruments like surgical implants, automotive, pharmaceuticals, die making defense, aeronautics and space industry etc. The output results in this process will be affected badly, if improperly control the process parameter. AFF generates uniform, repeatable and predictable results on an impressive range of finishing operations. In this research work, process parameters like abrasive 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.

2. Literature review

Recent advancements in the materials technology has led to the development of strong, hard and difficult-to-machine materials, which pose challenges to the existing manufacturing technologies in terms of increased processing time, cost and energy consumed. More over the recent advancements in the different technologies in general industry demand that the production of precision parts is much more precise and efficient. However, most of the precision finishing technologies cannot satisfy the simultaneous finishing requirements of efficiency and surface finish. In the present research work, a novel hybrid of AFF has been developed and tested with the aim to overcome the varied difficulties viz. low material removal, longer cycle time, cumbersome processes, high operating pressures, higher energy consumptions. The basic concept of present investigation is to achieve the synergetic finishing action by hybridizing Centrifugal force with Abrasive Flow Finishing (AFF). Walia et al. developed this new Hybrid AFM process. The centrifugal force is incorporated to explore the productivity enhancement of the process. The abrasive medium was rotated by using CFG rod to increase work piece media interactions. The speed of rotation of CFG rod has a major effect on surface finishing (1-6). It was observed that the combination of a high extrusion pressure and a higher speed of the centrifugal force generating (CFG) rod more favorable to obtain a higher degree of surface finish, while the combination of a larger grain size and a higher speed of the CFG rod cause higher material removal. From experimental results by Walia and Shan (2006),it can be seen that addition of centrifugal force with help of external guided arrangements in media increase improvement in surface finish and material removal rate. It has been reported that centrifugal force enhances the material removal rate (MRR) and improves the scatter of surface roughness (SSR) value in AFM leading to the development of Centrifugal Force assisted AFM (CFAAM). A rotating Centrifugal Force Generating (CFG) rod was used inside the cylindrical work piece, which provides the centrifugal force to the abrasive particles normal to the axis of work piece. It has been studied by Jain & Sankar (7) that in drill type AFM, abrasive intermixing depends not only on medium self-deformability as in AFM but also on the pressure from the drill bit, three types of flows (flow along the flute, reciprocating axial flow motion, and scooping flow) that occur in finishing zone and remixing of medium at exit from the finishing zone. Due to the combination of different flows, the work piece-abrasive contact length is no longer a straight line, rather it becomes curved; hence, the number of peaks that can be sheared increases, leading to higher material (finishing rate also improves compared to AFM process. The gap between the work piece surface and the drill bit was varied by changing drill bit diameter and geometry. Increase in drill bit diameter provides more surface finish. In order to enhance efficiency of the process, Mondal and Jain has been introduced a concept of rotating the media with rotated drill bit axis to obtain higher rate of finishing termed as drill bit-guided abrasive flow finishing (DBG-AFF) process (8-10). Electrochemical aided abrasive flow machining (ECAFM) is possible using polymeric electrolytes. Dabrowski et al. (2006) (11), Dabrowski et al. (2006) (12) 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. Modeling and analysis of hybrid electrochemical turning magnetic abrasive finishing of 6061 Al/Al2O3 composite has also been done by El- Taweel and Brar (13-14). Brar (15) developed a helical- AFM setup with the use of a stationary held drill-bit. The drill bit is held axially inside the cylindrical surface to be machined. As the media extrudes through the recess it follows the helical path and a combination of axial, radial, centrifugal forces leads to improved surface finish and more material removal. But there was a scope of extensive research work towards AFF process by considering the advantage of different machining process. This paper presents to study the role of different 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. Abrasive flow finishing Set up

The experimental design of abrasive flow finishing machine is shown in figure 1. It carries two vertical cylinders mounted in opposite direction as shown in figure. The fixture is attached between these two cylinders. These all are tightened by bolts properly. The lower cylinder contains media which moves under hydraulic pressure. It moves from lower cylinder to upper cylinder and vice versa which constitutes a cycle. The primary function of the media cylinder is to contain a sufficient quantity of the media at desired extrusion pressure. Its secondary function is to guide the piston movement. The functional requirements include the capacity to contain required media volume, the strength to sustain hydrostatic pressure, and the wear resistance. The pressure gauge is shown in figure 2. It also contains lever from where movement of pistons was controlled. This machine mainly consist of three major elements i.e. Fixture, Abrasive media and work piece. The fixture was made up of nylon divided into three parts as shown in figure 3.There are many type of material for fixture like aluminium, nylon and Teflon etc. Due to light weight, wear resistance and strength, nylon material was preferred. A nylon fixture for holding the hollow cylindrical work-piece has been designed and developed. The work-piece is held in seat, at the interface to two parts and the fixtures are clamper together with the help of screws. The abrasive medium was prepared carefully with the help of abrasive particles of aluminium carbides, hydrocarbon Gel and polymer. The mixture was like semisolid which was changed after few experiments. After some experiments, capacity of medium reduces as it contains material of work surface and also its cutting edge diminishes. The work piece geometry is shown in figure 4. It is hollow cylindrical in shape and made up of gun metal. Initially the weight and surface roughness of work piece was measured. After each experiment, the work piece was cleaned properly by using acetone. Final surface roughness was measured and calculations work carried out.

There are many process parameters which are responsible for better surface finishing of work piece. In these parameters, some of the parameters were kept constant and four process parameters were varied at three different levels. The process parameter value is mentioned in table 1 and II. During the experimentation on the AFF machine, noise free working of machine, no leakage and cleanliness of the setup and environment was ensured. The personal safety was ensured using face shields and protective guards. Safety was also ensured by incorporating pressure relief valves, limit switches, to avoid high pressures, extreme movements of actuator rods and overheating of oil that was very inflammable. For the development of the AFF setup an existing frame of a 50 tons capacity hydraulic press has been used.

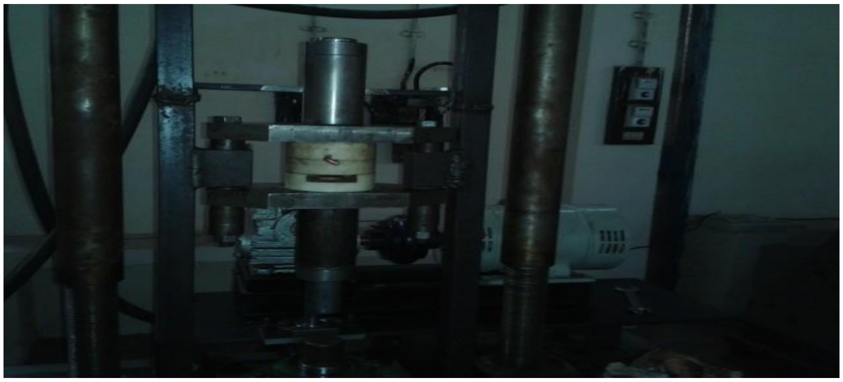

Fig. 1 AFF Machine

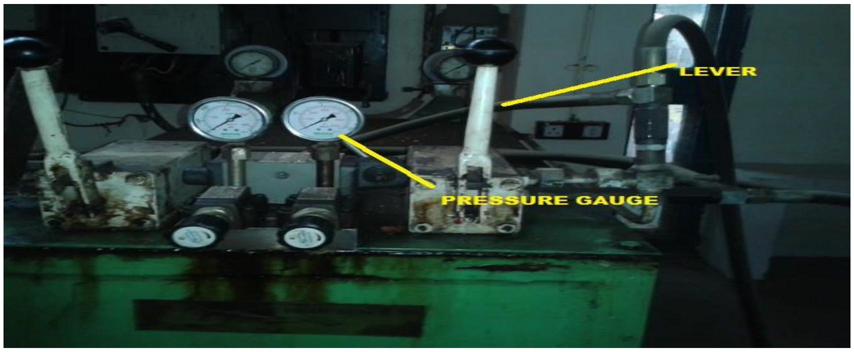

Fig. 2 Pressure gauge and operating levers

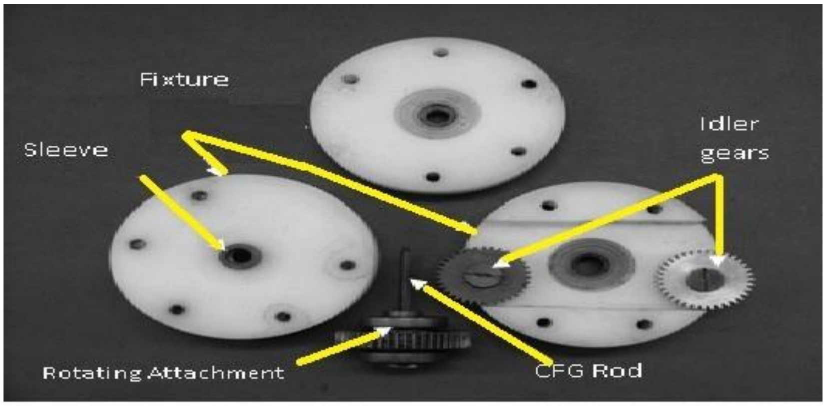

Fig.3.Fixture Parts And Tool Rod

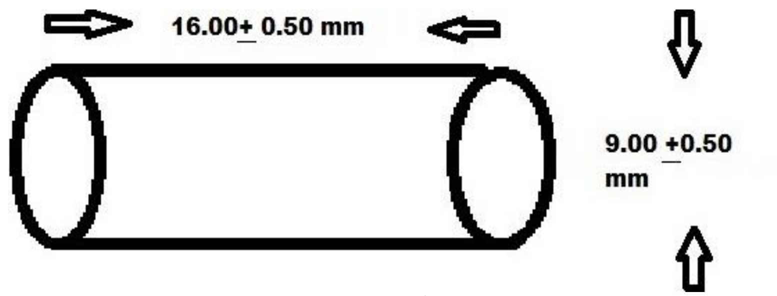

Fig. 4 Geometry of work piece

TABLE1. Experimental specification and process parameters value

Sr. No	Process Parameters	Range	Unit
1	Number of cycle	8	Number
2	Shape of CFG rod	Triangular	-----
3	Diameter of CFG rod	4.2	mm
4	Initial surface roughness	2.8-3.40	µm
5	Media flow volume	290	cm^3
6	Fixture material	Nylon	
7	Polymer-Gel ratio	1:1	Percentage by weight
8	Work piece Material	Gun Metal	
9	Temperature	32 ± 2	°C
11	Reduction Ratio	0.94	-----
12	Hydraulic Press	50	Ton

Table2. Process Parameters Value at Different Level

Symbol	Parameter	Unit	Level1	Level2	Level3
G	Abrasive Size	No. (micron)	100	200	300
P	Extrusion Pressure	N/mm^2	2	4	6
C	Abrasive Concentation	------	0.95:1	1:1	1.05:1
R	Rotational speed of CFG rod	RPM	0	25	50

4. Experimentation work

The Percentage change in surface roughness value calculated as:

$$\%\Delta R_a = \frac{\text{Initial Surface Roughness} - \text{Surface Roughness after finishing}}{\text{Initial Surface Roughness}} \times 100$$

Table 3.Orthogonal Array L_9 With S/N Ratio Of Various Response Characteristics

S N	G	P	C	R	R_1	R_2	R_3	S/N
1	100	2	0.95	0	9.45	9.67	9.87	19.70
2	100	4	1	25	24.89	24.88	24.75	27.90
3	100	6	1.05	50	15.98	15.91	16.02	24.07
4	200	2	1.05	25	14.28	14.67	14.58	23.23
5	200	4	0.95	50	17.33	17.75	17.58	24.89
6	200	6	1	0	25.12	25.33	25.24	28.04
7	300	2	1	50	42.67	42.74	42.82	32.62
8	300	4	1.05	0	41.81	41.23	41.34	32.35
9	300	6	0.95	25	38.32	38.76	38.93	31.75

R1, R2, R3, denotes Δ Ra value for repetitions of every experiment.
The initial and final surface roughness was recorded with Mitutoyo SJ-201 Surface Roughness Tester. For experimental analysis, L9 (3*4) orthogonal array based on taguchi methodology was adopted. Each parameter was varied at three different levels. As ΔR_a higher the better type quality characteristics. So S/N ratio calculated for this type as:

Where

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

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

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

R = Number of repetitions, y = response value. HB= higher the better
The percentage improvement in surface roughness for signal to noise ratio (S/N ratio) and raw data at three levels i.e. L1, L2, and L3 for each parameter was shown in table 4 & 5. Analysis of variance (ANOVA) and F-Test was performed. These test values indicate the significant AFF parameters affecting the quality of the work surface.

5. Experimentation Result

Table 4: Main Effect -Signal To Noise (S/N Data)

L1	23.89	23.89	26.70	25.44
L2	25.39	25.39	27.63	29.52
L3	32.24	32.24	27.19	26.55
L2-L1	1.50	1.50	0.93	4.08
L3-L2	6.85	6.85	-0.44	-2.97
Difference	5.36	-3.63	-1.37	-7.05

Table 5: Main Effect (Raw Data)

Level	Abrasive size	Pressure	Abrasive Conc.	RPM
L_1	16.82	22.31	25.45	21.96
L_2	19.10	27.95	26.01	30.94
L_3	40.96	26.62	25.42	23.98
L_2-L_1	2.27	5.65	0.56	8.98
L_3-L_2	21.86	-1.33	-0.58	-6.96
Difference	19.59	-6.97	-1.14	-15.93

L1, L2 and L3 denoted the value of S/N data and raw data at different levels of parameters. L2-L1 and L3-L2 denotes the effects, when the process parameter value varies from L1 to L2 and L2 to L3 respectively.

6. Discussion of Results

a) Effect of Abrasive mesh size on surface roughness

After performing experiments, from results it was depicted that there was a significant effect on surface quality as size of abrasive varies. As abrasive mesh size increases from 100 to 200 and 200 to 300, size of abrasive particles decreases. It means finer grain size of abrasive particles results in more improvement in quality or more percentage change in surface roughness as abrasive mesh size increases. More fine grain removes finer material from inner edge of work piece but large number of cut on spots of work piece. Due to this surface roughness value decreases, as abrasive mesh size increases.

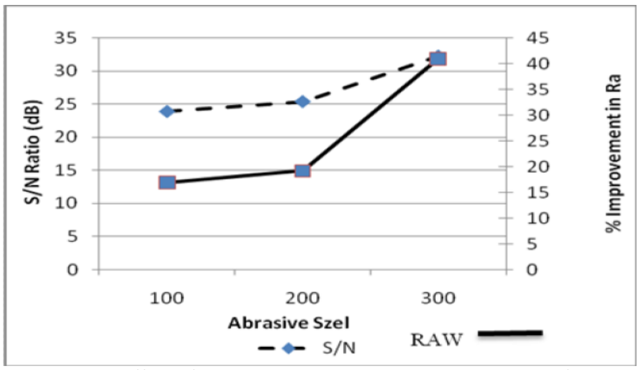

Fig.5. Graph: I (a) Effect of abrasive size on percentage change in surface roughness

b) Effect of Extrusion Pressure on surface roughness

From the graph 1(b), it was depicted that as extrusion pressure increases, there was a improvement in surface quality up to a certain limit. But after this limit, quality deteriorates. The reason was that as pressure increases, the interaction between work piece and abrasive particles increases which results in more improvement in surface finish. But after this an pressure increases, abrasive particles moves axially without making any interaction with work piece surface, so percentage change in roughness was more at 2nd level instead at highest level.

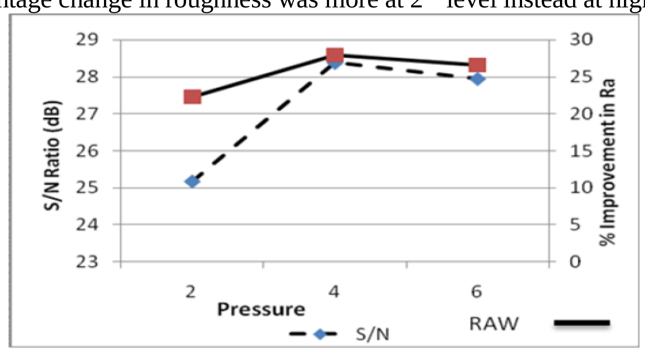

Fig.6. Graph: I (b) Effect of Extrusion Pressure on percentage change in surface roughness

c) Effect of Abrasive Concentration on surface roughness

From graph 1(c), it was noted that abrasive particles concentration in abrasive media plays a very important role towards improvement in surface finishing. As abrasive particle concentration in abrasive medium increases, viscosity of media increases and more abrasive particles comes in contact with work piece. Due to this they remove more material and hence better surface finish. But as viscosity of medium increases after a certain limit, surface quality deteriorates. Now abrasive particles start digging into finished surface and produces scratches on the inner side.

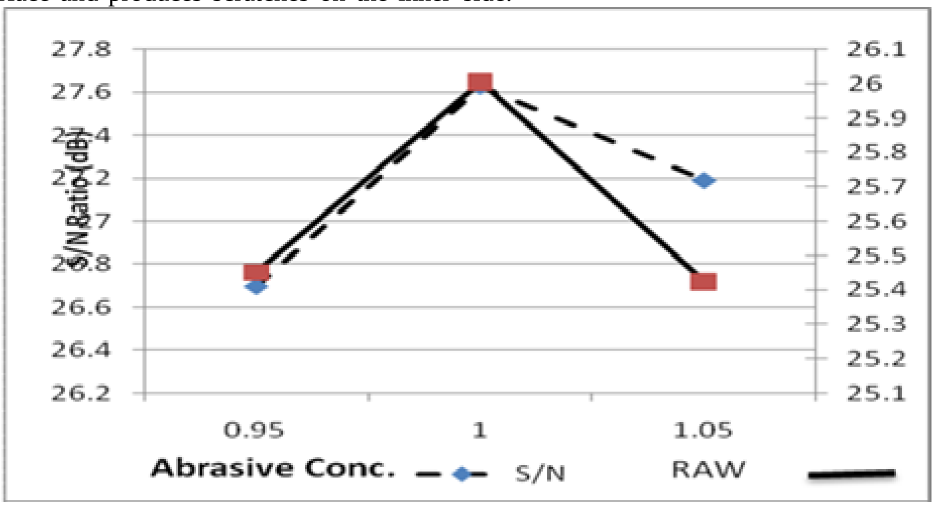

Fig.7. Graph: I(c) Effect of Abrasive Concentration percentage change in surface roughness

d) Effect of rotational speed on surface roughness

After experimentation work, it was depicted that the process parameter rotational speed of CFG rod has a key role in improving the surface quality of work piece in a short time than in simple abrasive flow finishing process. It was shown in graph 4(d) that percentage change in surface roughness improves, when the rotational speed was increased up to 25 and surface quality deteriorates, when its value increases beyond 25 rpm. Whenever no rpm has been provided, percentage change in surface roughness is very small. But when rpm was given, it produced centrifugal force in surrounding direction. This centrifugal force acts on abrasive medium which increases the interaction between abrasive particles and work piece surface. So now abrasive particles makes contact with work surface under combination of axial and centrifugal force. But when rpm value was increased after a certain limit i.e. at 50 rpm, the abrasive particles produces scratches on the work surface. It was also noted that centrifugal force reduces the machining time by 60-70%.

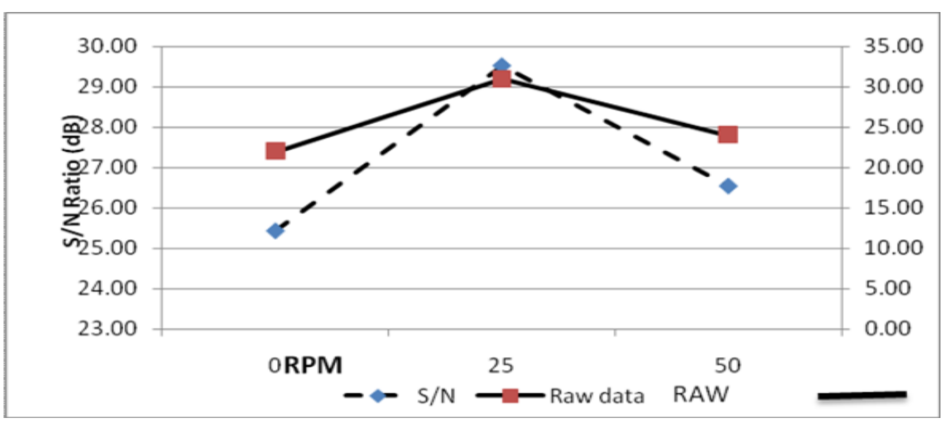

Fig.8. Graph: I(d) Effect of rotational speed on percentage change in surface roughness

7. Analysis of Variance (ANOVA)

Analysis of variance has been used for raw data to study the significance and percentage contribution of different parameters. It was depicted that percentage contribution of Abrasive mesh size (85.12), rotational speed of tooling rod (10.63), 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 Extrusion Pressure (N_2), 2nd level of rpm (R_2) & 2nd level of abrasive concentration

Table 6 (A) Pooled ANOVAs' (Raw Data)

Source	SS	DOF	V	F ratio	P
G	3196.33	2	1598.17	41048.83	85.12
P	156.83	2	78.42	2014.15	4.18
C	1.953	2	0.98	25.08	0.05
R	399.13	2	199.57	5125.79	10.65
Error	0.70	18	0.0039		0.02
Total	3754.95	26			100.0

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 (72.10%), rotational speed of rod (16.16%) and Extrusion Pressure (10.96%).It was noted that percentage change in surface roughness for S/N (Signal to noise ratio) data was highest for 2nd level of abrasive (G_2), 2nd level of Extrusion Pressure (P_2), 2nd level of rpm (R_2) & 2nd level of abrasive concentration (C_2).

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

Source	SS	DOF	V	F-ratio	SS'	P
G	118.93	2	59.46	91.38	117.62	72.10
P	18.07	2	9.04	13.89	16.17	10.96
C	1.30	Pooled				
R	26.65	2	13.33	20.48	25.35	16.16
Error	1.301	2	0.65		21.98	0.79
Total	164.95	8			164.95	100.0

*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. The developed centrifugal force Aided Abrasive Flow finishing (CFAFF) is very effective in enhancing the response parameters of Percentage Improvement in R_a (%ΔR_a) during the finishing of internal cylindrical surfaces of Gun Metal work-pieces. For the selected machine and similar operating parameters and conditions; improvement in the surface finish has been observed over the basic AFF process.
2. All the four main process parameters Abrasive mesh size, Abrasive concentration, Extrusion Pressure, and Rotational speed of CFG rod have significant effect on the response parameters of percentage improvement in the surface finish.
3. The result shows that the percentage contribution of Abrasive mesh size is 72.10% for the Percentage improvement in ΔR_a. Abrasive mesh Engineering Research, Volume 4, Issue 6, June- 2013. Size has the highest contribution towards the response characteristics percentage improvement in ΔR_a.

4. The percentage contribution of Extrusion Pressure 10.96% respectively for the percentage improvement in ΔR_a..
5. The Rotational speed of CFG rod is also Significant for the present setup and its contribution is 16.16% for percentage improvement in ΔR_a. At second level of rotational speed of 25 rpm the surface finish is the best.
6. It is noted that the optimal process parameters are $G_3P_2C_2R_2$ for better results.

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