Optimization of Abrasive Flow Machining Parameters on Launch Vehicle Component Using Taguchi Method

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Abstract— Abrasive flow machining is a non-conventional machining process which is used to polish, deburr, and radius hard to reach surfaces like intricate geometries and edges by flowing an abrasive laden viscoelastic polymer over them. Conventional methods have limitations for machining such components with complex geometries. In this process , abrasive medium flow inside the crossed holes of a launch vehicle's fluid component made of Z30C13 stainless steel . In this study, the effect of process parameters such as abrasive size, abrasive concentration and number of cycles were studied on surface roughness. Taguchi's L9 orthogonal array is preferred with three levels of parameters for experimental design without considering any interaction. The percentage contribution of each factor is found by ANOVA.

Keywords— Abrasive Flow Machining, Abrasive Size, Abrasive Concentration, Number of Cycles ,Surface Roughness, Z30C13 Stainless Steel, Taguchi Method, ANOVA.

INTRODUCTION

Abrasive flow machining is a process for producing high quality surfaces that are difficult to access, especially inner profiles and is used to deburr, remove recast layer and radius surfaces. The launch vehicle fluid control components have cross holes, internal passageways, concave & convex edge blending and micro slots. Deburring and polishing of these features is difficult because of inaccessibility of tools. Manual deburring increases the risk of damaging finished surfaces. Many of the recent anomalies in control components have been attributed to loose metal particles getting entrapped on the seating surfaces. More often these particles are found to be generated from cross holes or internal passageways which are hidden from the normal vision. These particles are at many times not visible to the naked eye and can be seen only under magnification. Specialized viewing equipment's are not normally available at the shop floor to locate such type of particles. As a result machining of such components to the required finish become difficult at the shop floor. AFM is an ideal solution for precision deburring, polishing and edge radiusing of internal and external surfaces of machined components. AFM involves the use of an abrasive laden polymer which is forced to flow through the restricted flow passage with the help of the hydraulic cylinders. Abrasive action is highest in most restricted passage leading to the removal of burrs and edge polishing. The objective of the present work is to find out the set of optimum conditions for the selected control factors in order to reduce surface roughness using Taguchi's robust design methodology in abrasive flow machining of Z30C13 stainless steel.

2. LITERATURE SURVEY

Literature survey is carried out extensively to explore the various process parameters of abrasive flow machining and their effect on various output responses[1-10]. A thorough study of taguchi's optimization and ANOVA have been conducted to optimize the process parameters of this study [11-12]. The concept of prediction of results using regression model and ANN were also studies [13].Very few works have been carried out in the optimization of process parameters in abrasive flow machining of Z30C13 stainless steel with different controlled parameters such as abrasive size, abrasive concentration and number of cycles etc.

3. EXPERIMENTAL SETUP AND DESIGN

A two way abrasive flow machine setup has been developed for the study. The details of the machine is shown below. The work material selected is Z30C13 stainless steel.

3.1 Specification of Abrasive Flow Machine

The machine consist of a timer circuit to control the speed and direction of flow, two pneumatic cylinders which uses the power of compressed gas to reciprocate back and forth. One back and forth movement of the piston is called a cycle. The number of cycles can be adjusted by setting the timer circuit, to get desired number of cycles. The machining tests are conducted under the different conditions of abrasive size, abrasive concentration and number of cycles.

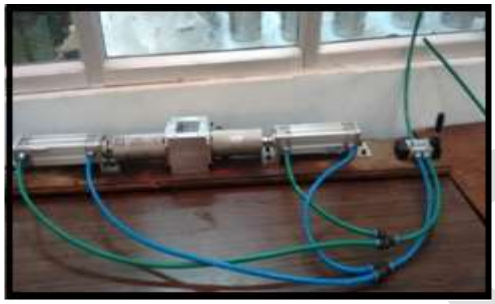

Figure No.1: Abrasive flow machine

3.2 Workpiece

The workpiece used is a launch vehicle fluid component which is made of Z30C13 stainless steel. Z30C13 is a martensitic stainless steel with 12% Chromium which is sufficient to give good corrosive resistance properties. Stress relieved and hardened conditions provide full corrosion resistance. It can resists corrosion by fresh water, atmosphere, carbonic acid, steam, gasoline, crude oil, perspiration, sterilizing solutions, etc .Typical applications are cutlery, valve parts, surgical instruments, spindles, nozzles, shafts, gears. It presents high strength after quenching and can be magnetized.

Figure No.2: CAD model of the workpiece

3.3 Abrasive Media

The abrasive media used in Abrasive Flow Machining provides the actual material removal that is polishing, deburring and edge radiusing The abrasive media mainly consist of two parts: silicon based polymer and abrasive particles. The abrasive particle used in this study were Silicon Carbide (SiC). This particles are mixed with the polymer base to get the abrasive media.

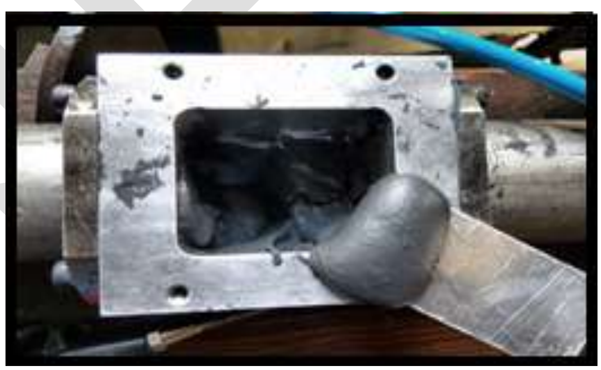

Figure No. 3: Abrasive media

The abrasive media were developed from Vikram Sarabhai Space Center's Polymer lab of ISRO.

3.4 Design of Experiments

In this work, the optimum conditions for surface roughness in abrasive flow machining of Z30C13 stainless steel is obtained by using Taguchi robust design methodology. $L_9(3^3)$ orthogonal array is used to conduct the experiment.

3.4.1 Selection of control factors and levels

Three process parameters with three levels are chosen as the control factors such that the levels are sufficiently far apart so that they cover wide range. The process parameter and their ranges are finalized reference from books and literature.. The three control factors selected are abrasive size (A), abrasive concentration (B) and number of cycles (C). Launch vehicle component made of Z30 C13 stainless steel were used in experimentation. The machining is performed for nine individual components. The control levels and their alternative levels are listed in Table No.1.

Table No. 1 Control Factors and Levels

Factors /Level	**Abrasive size (A) (µm)**	**Abrasive concentration (B) (% by weight)**	**Number of cycles (C) (cycles/min)**
1	8	30	100
2	63	40	200
3	150	50	300

3.4.2 Selection of orthogonal array

In this study, AFM parameters such as particle size, abrasive concentration and number of cycles are selected and the numbers of levels selected for each parameter are three. The Taguchi's orthogonal array method is a very effective method to deal with responses influenced by multi-variables. Compared to the conventional approach to experimentation, this method reduces the number of experiments that are required to model the response functions. The selection of Orthogonal array (OA) is based upon the number of factors and levels that are considered for doing the experiment. The degree of freedom (DOF) for each of the factor is 2 (DOF for a factor = number of levels - 1) and therefore the total DOF obtained is 8 (i.e., 4x2=8).The selected OA's degree of freedom must be greater than the total DOF of all the factors. The DOF for an OA is given by number of experiments minus 1. Hence L9 is selected for the study which has 8 degrees of freedom which is the smallest array that can be selected with the 3 level 3 factor experiment. The selected OA is presented on the following Table. 2. The Factor assignment for L_9 (3^3).has been tabulated in Table No.3.

Table No.2: Standard L_9 (3_4) O.A .

Experiment Number	**Column**		
	A	**B**	**C**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table No. 3: Experimental Design

Experiment Number	**Column**		
	Abrasive size(A) (µm)	**Abrasive concentration (B) (% by weight)**	**Number of cycles (C) (cycles/min)**
1	8	30	100
2	8	40	200
3	8	50	300
4	63	30	200
5	63	40	300
6	63	50	100
7	150	30	300
8	150	40	100
9	150	50	200

3.4.3. Plan of experiments

The scope and objective of the present work have already been mentioned in the forgoing cases. Accordingly, the present study has been done through the following plan of experiment:

1. A two way abrasive flow machine and fixture, for positioning the workpiece while machining is developed.
2. Workpiece is made as per the required dimension by a CNC milling machine for the experiment.
3. Abrasive media is developed from Vikram Sarabhai Space Center, Trivandrum.
4. Machining parameters abrasive size, abrasive concentration and number of cycles are selected through knowledge from extensive literature survey and also in view of machine standard specifications.
5. The machining is done by filling the abrasive media inside the cylinders and by fixing the workpiece in the fixture.
6. The nine different combination of levels of the parameters are set one by one and machined .

7. Surface roughness (Ra) is measured from the internal passage of the workpiece using Taylor Hobson Talysurf

4. RESULTS AND DISCUSSION

In the experiment, the desired characteristic for surface roughness is lower the better. It means that lowest surface is desirable for better performance. The equation to find the S/N ratio for this characteristic is given below.

$$S/N = -10\log[\frac{1}{n}\sum_{i=1}^{n}(y_i^2)] \quad (1)$$

Where, n is the number of measurements in a trial and yi is the measured value in a trial.
The results of surface roughness values of 9 experiments and the signal to noise ratios of each set of experiment for L9 array is tabulated in Table No. 4.

Table No. 4: Experimental data for surface roughness (Ra)

Particle size (µm)	**Abrasive concentration (% by weight)**	**No. of cycles (cycles/min)**	**Ra(µm)**	**S\N Ra**
8	30	100	0.61	4.293403
8	40	200	0.57	4.882503
8	50	300	0.49	6.196078
63	30	200	0.65	3.741733
63	40	300	0.58	4.73144
63	50	100	0.57	4.882503
150	30	300	0.68	3.349822
150	40	100	0.7	3.098039
150	50	200	0.67	3.478504

Based on the analysis of S/N ratio, the optimal machining performance for the surface roughness is obtained at particle size 8 µm (level 1), abrasive concentration 50 % by weight (level 3) and number of cycles 300 cycles/min (level 3). In the analysis, particle size is shown as the most influencing parameter followed by abrasive concentration and number of cycles.
The ANOVA calculation is performed for the results obtained i.e. Surface roughness values from Table No.4. The calculations are done with the Minitab Statistical Software version 17.

Table No.5: Analysis of Variance for Surface Roughness

Source	**Degrees of Freedom**	**Sum of squares**	**Mean of Squares**	**F ratio P**	**P**	**% of contribution**
Particle size	2	0.024867	0.012433	93.25	0.011	68.41
Concentration	2	0.007400	0.003700	27.75	0.035	20.35
No. of cycles	2	0.004067	0.002033	15.25	0.062	11.10
Error	2	0.000267	0.000133			0.14
Total	8	0.036600				

Based on the ANOVA results in Table No.5, the percentage contribution of various factors to surface roughness is identified. Here, particle size is the most influencing factor followed by abrasive concentration. The percentage contribution of Particle size and Abrasive concentration towards surface roughness is 68.41% and 20.35% respectively. Also the probability level of Number of cycles is more than α (0.05) which indicates that Number of cycles has least contribution towards surface roughness. The main effects plot shows the influence of each level of factors and the SN ratio with maximum value is taken as the optimum values of surface roughness. The plot shows that surface roughness increases as particle size increases and decreases with increase in concentration and number of cycles

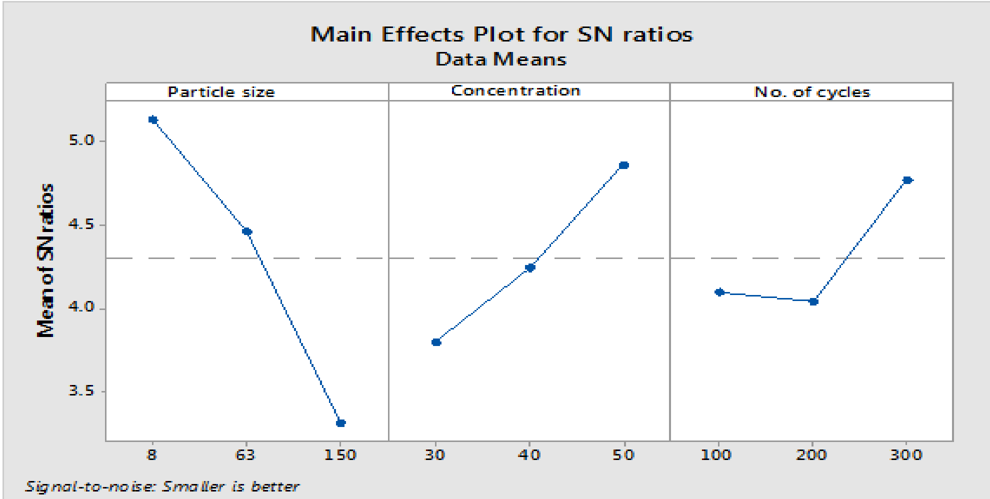

Figure No. 4: Signal to Noise Plot for Surface Roughness

4.1 Regression equation for surface roughness

The regression equation is found from the available results for predicting the surface roughness with a different combination of the process parameters.

Surface Roughness, Ra (µm) = 0.7305 + 0.000898 Particle size (µm) - 0.003500 Concentration (% by weight) - 0.000217 No. of cycles

4.2Confirmation Test

The confirmation test is the final step in verifying the results obtained from Taguchi's design approach. The optimal conditions are set for the significant factors and experiments are run under specified machining conditions. The results from the confirmation experiment are compared with the predicted results based on the parameters and levels tested. The predicted result is also compared with the results predicted by ANN. The optimal combination is present in the selected orthogonal array so no need of further experimenting. The validity of the regression equation is checked by taking random combination from the 27 combination, other than the 9 and predicting the roughness value of each combination by regression and ANN and experimenting with the same combination. The results are compared to validate the regression equation.

Table No.6: Experimental v/s Predicted results

LEVEL	Experimental Ra	Predicted Ra	
		by regression	by ANN
A1B3C3 (OPTIMAL)	0.49	0.497	0.49
A1B3C1	0.56	0.54	0.544
A2B3C3	0.54	0.55	0.542
A3B3C2	0.649	0.64	0.67
A1B1C3	0.58	0.58	0.59

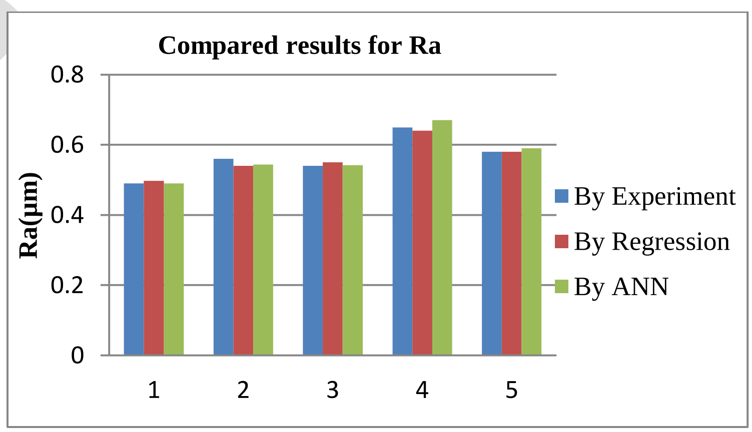

Figure No 5: Compared result for Ra

5. CONCLUSION

In this study the effect of abrasive flow machining parameters on surface roughness of Z30C13 stainless steel was studied using Taguchi's L9 orthogonal array method. From the results, it is found that, abrasive size and concentration play a significant role in AFM operation related to surface roughness. Number of cycles has no significant effect on surface roughness. Also it is found that, for lower surface roughness the optimum levels for abrasive size, concentration and number of cycle are 8μm (level 1),50 % by weight (level 3) and 300 cycles/min (level 3) respectively. Analysis of variance (ANOVA) is used to find the significance of the machining parameters and their contributions on surface roughness individually. Particle size is found to be the most influencing parameter on surface roughness with 68.41 % contribution followed by the concentration with 20. 35 % contribution. The obtained result is used to model a regression equation. The validity of the model is found by predicting and experimenting the unknown parameter combination and comparing the result. In this study the predicted and experimented results are almost similar which shows the regression model is fit for prediction

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