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Paper

Effect of Process Parameters on the Surface Roughness produced during Machining of Ceramics using AWSJ: An Experimental Investigation by Taguchi Signal to Noise Ratio

Deepak D [a] Anjaiah Devineni [a*]
[a] Department of Mechanical and Manufacturing Engineering
Manipal Institute of Technology, Manipal University, Manipal – 576104, Karnataka, India.
*Correspondence: anjaiah.d@manipal.edu, devineni.anjaiah@gmail.com

ABSTRACT

This paper reports the effect of process parameters on the surface roughness (R_a) produced on the machined surface of ceramic material using Abrasive water suspension jet (AWSJ). Machining experiments have been carried out by varying process parameters using Taguchi (L_{27}) Orthogonal Array and the response (R_a) data is analyzed using Signal to Nosie (S/N) ratio of smaller-the-better type. The main effects plot show that the surface roughness increases almost linearly with increase in SOD and nozzle feed rate and the roughness decreases with increase in abrasive particle hardness. The ANOVA results indicate that the process parameters that effect (contribution towards variation in response) the surface roughness significantly are: abrasive particle hardness - 42%, feeed rate - 32%, abrasive size - 18% and SOD - 5%. Optimum settings for process parameters that produce lower surface roughness on the machined surface are determined and the confirmation experiments are conducted at these settings and found that the surface roughness obtained is in good agreement (deviation of 8.4%) with predicted response.

Key words: AWSJ machining, Signal-to-Noise ratio, ceramics, ANOVA, optimization

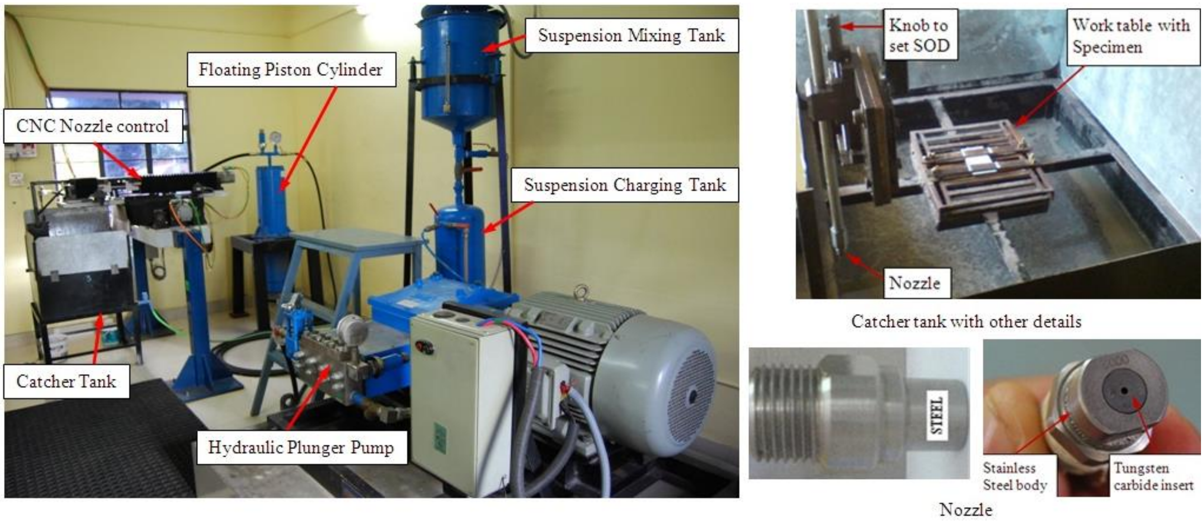
1. INTRODUCTION

Advances in research and development of new engineering materials are indispensable to meet the growing needs of industries. To process such materials, it is necessary to develop compatible machining techniques. Components with complex shapes that need to be produced from brittle and heat sensitive materials as well as composites can now be machined by an advanced manufacturing method called Abrasive Water Jet (AWJ) Machining (1 - 5). Abrasive Water Suspension Jet (AWSJ) is one of the variants of AWJ machining in which suspended abrasive particles in a liquid medium called slurry is pressurized and expelled through the nozzle. Through computer numerical control of jet movement, the work material having complex profiles with better surface quality and precision can be achieved. Benefit of AWSJ over AWJ is the generation of stable jet with higher power density, which leads to efficient energy transfer to abrasive particles (6-7). In AWSJ machining the abrasive suspension is accelerated through a fine orifice to produce a high velocity coherent jet which is capable of machining wide range of materials.

2. METHODOLOGY

2.1 AWSJ Machining - Experimental set up

The experimental set up used in the preset work is showin in figure 1 which is developed indigenously based on principle of indirect pumping. Suspension mixture is prepared by mixing water, polymer and abrasives in a slurry preparation tank and then it is transfered to floating piston cylinder. The slurry is pressurised by means of high pressure water supplied by reciprocating plunger pump to the floating piston cylinder and expelled through the tungsten carbide nozzle to from a high velocity abrasive suspension jet. The nozzle is controlled by two-axis CNC machine in X and Y directions. The length of the nozzle is 23 mm with inlet diameter of 8 mm and exit diameter of 1.0 mm.



Catcher tank with other details

Nozzle

Figure 1: AWSJ machining set up

2.2 Machining Experiments

Table 1 shows six process parameters and their levels chosen for the present work. The machining experiments are conducted by varying these parameters to investigate their effect on surface roughness which include main effects and the suspected interaction effects between selected parameters (Pressure*SOD, Pressure*Feed rate and Pressure*Abrasive concentration). Therefore the minimum number of experiments required to find the above mentioned effects is 25 which is based on the total degrees of freedom. Hence the nearest Taguchi L_{27} orthogonal array expermental design is selected. During experimention, the jet impact angle is maintained at 90° and single pass cutting is made. The Zycoprint polymer is used in preparation of suspension mixture in the proportion of 48 ml in 5 liters of water. The thickness of clay based ceramic workpiece is 8 mm.

Table 1. Process parameters for machining of ceramic workpiece

Code	Variable parameters	Level 1	Level 2	Level 3
A	Pressure (MPa)	15	20	25
B	Standoff distance (mm)	2	3	4
C	Feed (mm/min)	125	175	225
D	Abrasive concentration	5	10	15
E	Abrasive size (microns)	190	125	80
F	Abrasive type	Garnet	Al Oxide	Silicon Carbide

2.3 Analysis of response data

Specimens are machined as per the experimental design for a length of 20 mm to evaluate the effect of process parameters on the surface roughness (R_a) and each experiment was replicated twice. The R_a values are measured along the cut surface using Taylor Hobson Surtronic 3+ instrument for a sampling length of 10 mm and their values are shown in Table 2. The objective is to select the process parameters which produce minimum R_a values.

The response data is analyzed using Signal to Nosie (S/N) ratio of smaller-the-better type as given by the equation (1). In this equation, y_i is the response data (R_a) at i^{th} trial and n is number of replications,The term signal represents the desirable value and noise represents the possible error.

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

Table 2. Experimental design and responses

Expt. No.	Variable parameters						Surface roughness (Ra)		S/N Ratio
	A	B	C	D	E	F	Trial 1	Trial 2	
1	15	2	125	5	190	1	10.63	11.17	-20.75
2	15	2	175	10	125	2	10.49	11.31	-20.76
3	15	2	225	15	80	3	11.23	11.57	-21.14
4	15	3	125	10	80	3	10.06	10.74	-20.35
5	15	3	175	15	190	1	11.42	12.38	-21.52
6	15	3	225	5	125	2	11.81	12.99	-21.88
7	15	4	125	15	125	2	10.24	10.76	-20.43
8	15	4	175	5	80	3	11.23	12.17	-21.37
9	15	4	225	10	190	1	12.87	13.33	-22.35
10	20	2	125	5	190	2	9.06	9.74	-19.47
11	20	2	175	10	125	3	10.19	10.61	-20.34

12	20	2	225	15	80	1	13.16	13.84	-22.61
13	20	3	125	10	80	1	11.65	12.75	-21.74
14	20	3	175	15	190	2	9.89	10.51	-20.18
15	20	3	225	5	125	3	11.58	12.22	-21.51
16	20	4	125	15	125	3	9.72	10.48	-20.09
17	20	4	175	5	80	1	13.36	14.04	-22.74
18	20	4	225	10	190	2	11.14	11.86	-21.22
19	25	2	125	5	190	3	8.69	9.11	-18.99
20	25	2	175	10	125	1	11.91	12.29	-21.66
21	25	2	225	15	80	2	11.36	12.44	-21.52
22	25	3	125	10	80	2	10.26	10.94	-20.51
23	25	3	175	15	190	3	9.31	9.69	-19.56
24	25	3	225	5	125	1	13.27	13.93	-22.67
25	25	4	125	15	125	1	11.51	12.10	-21.44
26	25	4	175	5	80	2	11.77	12.43	-21.66
27	25	4	225	10	190	3	10.67	11.33	-20.83

3. RESULTS AND DISCUSSION

3.1 Effect of operating parameters on surface roughness

Experiments are conducted by varying the process parameters (Table 1) using Taguchi L_{27} OA design. R_a values and the corresponding S/N ratio obtained for each run are shown in Table 2. The mean S/N ratio obtained at each level of different process parameters is shown in Figure 2. It is observed that, the surface roughness (S/N ratio) decreases with increase in operating pressure and abrasive concentration. The higher pressure generate higher jet kinetic energy which can effectively erode the ceramic material in the jet exposed region and hence reducing the striations and thus surface roughness. Also, richer the abrasive concentration in AWSJ, the mode of machining involves cutting as-well-as grinding, thus reducing the surface roughness. It is also observed that the surface roughness increases (i.e., decrease in SN ratio) with increase in SOD and feed rate. This is due to the fact that higher SOD leads to jet expansion resulting in production of scratches on cut surfaces. At higher feed rate, the time for effective machining is reduced, where only primary cutting takes place. Further, it is observed that decrease in abrasive particle size results in increase in surface roughness almost linearly. Generally, larger particles carry more energy, hence a stable jet. When these particles impinge on the target surface, the probability of fragmentation in to smaller particles is high, the fragmented particles participate in secondary cutting action that results in smoothing of the cut surface. Whereas, the smaller abrasive particles carry lesser kinetic energy, hence results in decrease in the stability of jet. Upon impinging on the target surface, some particles lose their energy which produces scratches on kerf walls resulting rough surface.

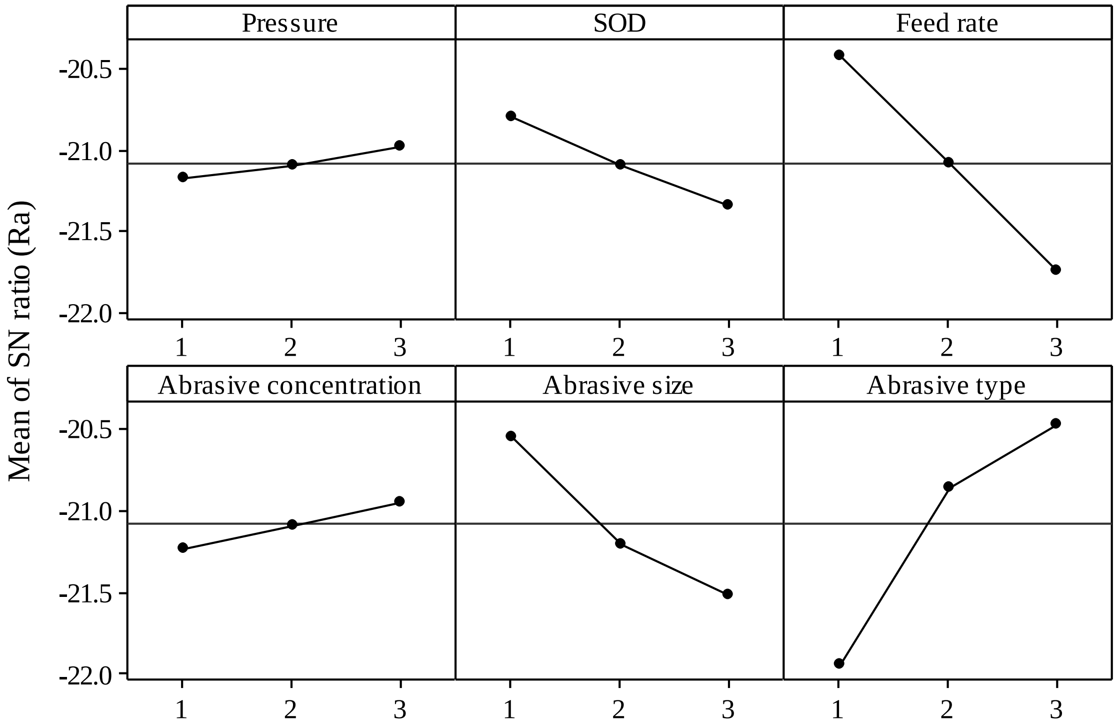


Figure 2 Main effect plot of surface roughness in terms of S/N ratio

Also it is seen from the figure 2 that, the type of the abrasive used exhibits a significant effect. Compared to garnet and aluminum oxide, the silicon carbide abrasives produced lower surface roughness on the machined surface of ceramic material. Higher the hardness of abrasive, higher is the penetrating capability into material which results in better machining. Also, silicon carbide abrasive particle being harder fracture into smaller paricles upon impact on the target surface and thus form fresh fine cutting edges. Further action of these smaller abrasive particles on machining surface produce the grinding effect leading to reduction of surface roughness.

3.2 Analysis of variance on S/N ratio

The S/N ratio obtained for the responses (Table 2) are analyzed using ANOVA and the results are shown in Table 3. The process parameters are subjected to F Test to find their effect on the response parameter (R_a) at 95% confidence level. It is observed that the SOD, Feed rate, abrasive concentration, size and its type have significant effect on the response (R_a). It is also observed that the suspected interaction effects between the selected factors (Pressure*SOD, Pressure*Feed rate and Pressure*Abrasive concentration) are found to be insignificant ($F_{observed} < F_{critical}$) hence ignored.

Table 3. The ANOVA for surface roughness

Source	DF	SS	MS	F
Pressure	2	0.1623	0.08116	3.89
SOD	2	1.3332	0.66660	31.93
Feed rate	2	7.9594	3.97969	190.62
Abrasive concentration	2	0.3654	0.18269	8.75
Abrasive size	2	4.4483	2.22416	106.53

Abrasive type	2	10.5723	5.28615	253.19
Pressure*SOD	4	0.0580	0.01451	0.69
Pressure*Feed rate	4	0.0181	0.00453	0.22
Pressure*Abrasive concentration	4	0.0045	0.00112	0.05
Residual Error	2	0.0418	0.02088	
Total	26	24.9633		

3.3 Optimization of process parameters

The mean values of S/N ratio obtained for the responses due to variation in process parameters settings is shown in Table 4. The table also shows the maximum variation of response as Delta value. Based on the Delta values the parameters are ranked according to their effects. Further, considering the mean response, settings for process parameters which generates high S/N ratio are chosen as operating pressure – level 3, SOD - level 1, feed rate – level 1, abrasive concentration – level 3, abrasive size – level 1 and abrasive type – level 3 (silicon carbide). Therefore, the optimum settings for the process parameters which produce minimum surface roughness are $A_3B_1C_1D_3E_1F_1$. At the optimum settings, the surface roughness (y) is predicted by equation (1), (2), (3) and (4). The predicted surface roughness at settings $A_3B_1C_1D_3E_1F_1$ is 7.82 µm with maximum deviation ± 0.154 µm. Confirmation experiments are conducted at optimum settings to verify the accuracy of the predicted response. The surface roughness thus obtained is found to be in agreement with the predicted results with maximum deviation of 8.40 %.

Table 4. Response Table for mean values of S/N ratio

Level	Pressure	SOD	Feed rate	Abrasive conc.	Abrasive size	Abrasive type
1	-21.17	-20.80	-20.42	-21.23	-20.54	-21.94
2	-21.10	-21.10	-21.09	-21.08	-21.20	-20.85
3	-20.98	-21.35	-21.75	-20.94	-21.51	-20.46
Delta	0.19	0.54	1.33	0.28	0.97	1.48
Rank	6	4	2	5	3	1

$$n_{eff} = \frac{\text{Number of trials}}{1+\text{Total DF}} = 2.16 \quad (2)$$

$$\text{T}=\frac{\sum \text{Response}}{\text{Number of trials}} = 12.476\ \mu\text{m} \quad (3)$$

$$\text{y}=\text{Response at}\,[A_3 + B_1 + C_1 + D_3 + E_1 + F_1] - 5\text{T} = 7.82\ \mu\text{m} \quad (4)$$

$$\text{Confidence interval (d)} = \pm\sqrt{\left[F(\alpha, \text{Error DF})\frac{\text{MS Error}}{n_{eff}}\right]} = 0.154\mu\text{m} \quad (5)$$

4. CONCLUSIONS

Following conclusions have been drawn from the present work.

- The experiments conducted on ceramic work-piece by varying the process parameters reveal that the effect of SOD, feed rate, abrasive size and type on the surface roughness produced using AWSJ machining is statically significant.
- It is observed that the surface roughness increases almost linearly with increase in SOD and feed rate. A typical observation is that the surface roughness increases with decrease in the abrasive size in the range of 190 – 80 µm. It is also observed that the harder abrasive particles reduce surface roughness.
- The contribution of significant process parameters towards the variation in the response (R_a) is Abrasive type - 42 %, Feed rate - 32 %, Abrasive size -18 % and SOD - 5 %.
- The effect of operating pressure and abrasive concentration on the response is insignificant whose contribution is marginal (1 %).
- The optimum settings of process parameters that produce lower surface roughness on the machined surface is A3B1C1D3E1F1. The surface roughness obtained from the confirmation experiments conducted at optimum settings is in good agreement (deviation of 8.4%) with predicted response.

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