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Experimental Investigation of Surface Roughness for Different Thickness of Aluminum in Abrasive Waterjet Machining

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Abstract. Abrasive waterjet machining is a novel method of machining complex shapes and profiles. Surface roughness is a widely used machining characteristic to define the quality of the machined components. This present study reports the effects of workpiece material thickness, abrasive mass flow rate and standoff distance on surface roughness while performing abrasive waterjet machining. A L9 Taguchi array is used for the design of experimentation signal to noise ratio and analysis of variance is carried out. The experimental results show that the most influential parameter affecting surface roughness is workpiece thickness.

Keywords. Abrasive waterjet machining, workpiece thickness, abrasive mass flow rate, standoff distance

1. Introduction

Machining processes have been the most widely used processes to convert raw material in to the final shape. The reasons for this are their versatility, uniqueness and ability to create complex geometries. However, the addition of new materials has always been a driving force for the invention/development of more advanced machining processes. Abrasive waterjet machining (AWJM) is one of the advanced machining processes and is categorized as a non-conventional machining process. In comparison to many other non-conventional machining processes AWJM is more efficient and accurate.

One of the most important aspects of AWJM is the absence of any heat affected zone. The principle of AWJM is that it uses highly pressurized (400 MPa) water which is mixed with abrasive particles while travelling towards the nozzle. Material is removed by the erosion process of the water and the abrasive particles [1]. The mechanism and material removal rate of AWJM depends mainly on process parameters and the type of abrasive used during machining. In a review it was noted that 80 mesh garnet is the optimum type and size in most cases [2]. Absence of any heat affected zone, burr free operation, low cutting forces and environment friendly process are some of the salient features of AJWM [1].

A wide range of materials for various applications, ranging from Inconel, glass, ceramics, titanium, composites and even heat sensitive alloys can be shaped using this process. The demand for materials having higher strength and heat resistant properties is on a rise in aerospace industry. Furthermore, these materials are difficult to machine owing to their properties (mainly physical & mechanical). These materials possess relatively lower thermal conductivity and higher strength. Therefore, higher cutting energies are required. Higher cutting forces and cutting temperatures eventually lead to shorter tool life [3].

The quality of machined parts can be gauged by surface roughness. Improvement in product quality is a main focus of most of the manufacturing industries. The literature throws some light on abrasive water jet machining performance for materials such as marbles, ceramics, aluminum etc [4]. Azmir et al investigated the effect of machining parameters in the cutting of epoxy glass fiber reinforced composites. They concluded that operating pressure, abrasive hardness, standoff distance and jet transverse rate were the most significant control factors that affect the surface roughness [5]. Tosun et al investigated the surface roughness of AWJ cut aluminum alloys by varying the traverse speed and water pressure and it was found that materials that possess higher mechanical properties have low surface roughness values [6]. Arola et al. performed experiments on high strength steels using AWJM. They concluded that with the increase in surface roughness, the depth of cut is also increased [7].

This research article deals with the surface roughness evaluation of abrasive water jet machined aluminum. Among the metals, aluminum has one of the widest ranges of applications including construction, aerospace and automobiles industries [8]. The experimentation was carried out by keeping standoff distance, abrasive mass flow rate and thickness of the workpiece as the input parameters while pump pressure, abrasive material, jet impact angle and nozzle diameter were kept constant. Surface roughness of the machined workpiece was the output parameter. Design of experiment (DOE) was carried out using Taguchi’s L9 orthogonal array. Signal to noise ratio (S/N) and analysis of variance (ANOVA) were performed to evaluate the effects on the response parameter.

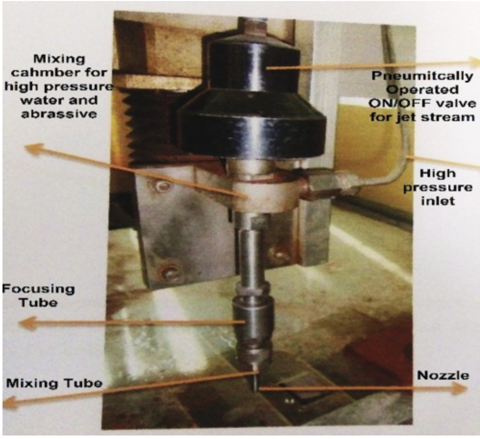
2. Experimental Design and Procedure

Aluminum was used as workpiece material having three different thicknesses (2mm, 4mm & 5mm). An abrasive waterjet machine (Model: WC3WB1212H IWM China) was used. The machine was equipped with an ultra-high pressure pump with a maximum working pressure of 270 MPa. The abrasive hopper was a gravity-fed type and the machine work table had dimensions of 1200 x 1200 mm. Spherical orifice was used to create the high pressure jet and tungsten carbide nozzle was used to form an abrasive waterjet as shown in figure 1a. The nozzle was periodical checked throughout the experimentation to assess any possible wear or clogging. Garnet was used as the abrasive having an 80 mesh size with a chemical composition of 36% FeO, 33%SiO_2, 20% Al_2O_3, 4% MgO, 3% TiO_2, 2% CaO and 2% MnO_2 as shown in figure 1b. The input parameters for this investigation were thickness of workpiece material, standoff distance and abrasive mass flow rate whereas the surface roughness Ra was taken as response parameter while keeping abrasive type and mesh, jet impact angle, orifice diameter, nozzle diameter and pump pressure as fixed parameters as shown in table 1.

Table 1. Details of parameters used during experimentation

Variable Input Parameters	Unit	Level 1	Level 2	Level 3	Dependent Parameters
Thickness of workpiece	mm	2	4	5	Surface roughness (R_a)µm
Abrasive mass flow rate (AFR)	g/min	125	150	175	
Standoff distance (SOD)	mm	3.0	3.5	4.0	
Fixed Input Parameter					
Pump pressure	MPa	135			
Jet impact angle	degree	90			
Orifice diameter	mm	0.25			
Nozzle diameter	mm	0.8			

Taguchi L9 array was used for DOE. Surtronic 25 (Taylor Hobson Ltd. UK) surface roughness meter was used to measure surface roughness. Machine parameters were set to the designed level as suggested by the L9 array. All experiments were performed using single pass cutting. A rectangular piece of 10mm×20mm was machined by abrasive waterjet as shown in figure 1c. The surface roughness was measured at the center of the cut for each experiment and repeated three times to detect any dispersion in the data. The Signal to Noise (S/N) ratio was determined using MINITAB 16 to rank the parameters according to their effect on the response parameter and subsequently analysis of variance (ANOVA) was performed to quantify the significance of parameters with respect to response parameters along with their percentage contribution.



(a) Abrasive waterjet cutting head

(b)Garnet abrasive particles

(c) Workpiece after cutting

Figure 1. (a) Detail of abrasive waterjet cutting head, (b) Abrasive and (c) machined workpiece

3. Results and Discussion

Table 2 shows the results for the response parameters.

Table 2. Surface roughness results.

Exp No	Thickness of workpiece (mm)	SOD (mm)	AFR (g/min)	Surface roughness (μm)
1	2	3.0	125	6.80
2	2	3.5	150	6.10
3	2	4.0	175	5.38
4	4	3.0	150	2.76
5	4	3.5	175	1.86
6	4	4.0	125	3.34
7	5	3.0	175	2.34
8	5	3.5	125	3.82
9	5	4.0	150	2.94

Table 3 shows the S/N ratio values (the smaller the better) for surface roughness. It was observed that thickness of workpiece was ranked the most influential parameter among the three input parameters with the highest delta value.

Table 3. Results of S/N Ratio

Level	Thickness of workpiece	SOD	AFR
1	-15.657	-10.951	-12.922
2	-8.228	-10.913	-11.297
3	-9.464	-11.486	-9.130
Delta	7.430	0.573	3.792
Rank	1	3	2

Main effects plot for surface roughness is shown in figure 2. It can be seen from the figure that thickness of workpiece has a nonlinear relationship with surface roughness. Increasing the thickness of workpiece initially decreased the surface roughness and a further increase in workpiece thickness resulted in higher value of surface roughness. An increase in thickness of workpiece material increases the surface roughness and this result is in agreement with the results reported for aluminum [9].

The same pattern is observed from the results of 4mm and 5mm thickness, however an unusual pattern for surface roughness has been observed at 2mm thickness.

It can also be observed from the figure that AFR has an inverse relationship with surface roughness, as higher values of AFR result in smaller values of surface roughness. This is because higher values of AFR produce a larger number of impacts and cutting edges per unit area which is required for the cutting of the material. More cutting edges result in enhancement of water jet cutting action by taking off more material thereby reducing the surface roughness. The main effects plot for SOD also revealed that there is no significant effect of standoff distance on surface roughness.

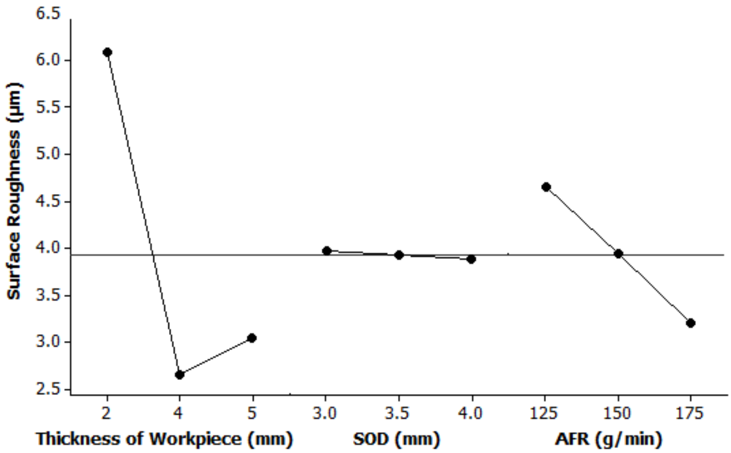


Figure 2. Main effects plot

The significance of input parameters is quantified through ANOVA as given in table 4. It was observed that thickness of material and abrasive mass flow rate proved to be the significant parameters at the 95% confidence interval, whereas standoff distance was found to be insignificant. The percentage contribution (PCR) shows that thickness of the material is most influential parameter which affect the surface roughness.

Table 4. ANOVA results at 95% confidence interval

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PCR
Thickness	2	21.3416	21.3416	10.6708	988.04	0.001	86.66%
SOD	2	0.0096	0.0096	0.0048	0.44	0.692	
AFR	2	3.1976	3.1976	1.5988	148.04	0.007	12.92%
Error	2	0.0216	0.0216	0.0108			
Total	8	24.5704					

S = 0.103923 R-Sq = 99.91% R-Sq(adj) = 99.65%

4. Conclusions

The following conclusions are drawn from the present research.

- Thickness of the workpiece material has the most significant effect on surface roughness at the 95% confidence interval.

- Abrasive mass flow rate has an inverse relation with surface roughness i.e. increasing the abrasive mass flow rate decreases the surface roughness.
- The standoff distance has been found to be statistically insignificant for surface roughness.

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