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Measuring Material Removal Rate of Marble by Using Abrasive Water Jet Machining

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Abstract : *This paper details measuring the material removal rate of marble by abrasive water jet machining. The effect of the three process parameters, i.e., water pressure, abrasive flow rate and standoff distance on material removal rate is investigated. In this investigation, we are using L16 orthogonal array and the analysis of variance that was helped to find the highly significant, significant and non significant parameters. Material removal rate increased when water pressure and abrasive flow rate increased.*
Keywords – *MRR, Abrasive water jet machining, Taguchi, ANOVA, Garnet abrasive.*

I. INTRODUCTION

Abrasive water jet machining (AWJM) is a process which is used to remove the material from the work piece due to erosion action of abrasive particles impacting at high velocity. To attain this high velocity, the particles are pass through a nozzle with compressed carrier gas, usually air. The technology and applications of water jet machining has been investigated since the early 1960s. Abrasive water jet machining is worked on the principles of abrasive jet machining and water jet machining. There are two types of water jet, i.e., pure water jet and abrasive water jet. AWJM is used in the machining of materials such as titanium, marble, steel, brass, aluminium, inconel, any kind of glass and composites. Different types of abrasive are used in abrasive water jet machining like garnet, olivine, aluminum oxide (Al203), silica-sand, glass bead, silicon carbide (sic), zirconium, etc. But investigation shows that 90% of the AWJM is done using garnet [1]. The geometry cut by the abrasive water jet is characterized by the top width, bottom width, initial damaged width etc. The cut geometry depends on the type of abrasives used in AWJM and cutting parameters like abrasive flow rate, standoff distance (SOD) of the nozzle from the target, work feed rate, pressure of water etc. Efforts of parameters have been made to improve the cutting performance of AWJM.

II. LITERATURE REVIEW

A lot of research has been done on abrasive finishing of materials in the last few years and discussed in the following paragraphs. In 2009 Azmir & Ahsan [1] discussed a study of abrasive water jet machining process on glass/epoxy composite laminate. In this study E-glass fibres namely woven (plain weave) TGF-800 was used as the reinforcement materials. Six machining parameters were selected as control factors, i.e, abrasive types, WP, S.O.D, AFR,TR & cutting orientation. Aluminium oxide gave better surface finishing because hardness of aluminium & decrease kerf taper angle. High HP decrease SR & kerf taper angle. The influence of S.O.D result increase SR due to lower K.E & increase taper angle.In case of increase AFR & cutting orientation gave better SR & decrease kerf taper angle. SR & kerf taper angle is also increased when increase TR. In 2006 O.V krishnaiah chetty [2] described a use of single mesh size garnet abrasives in abrasive waterjet machining for cutting aluminium. The influence of three different single mesh size abrasives, pressure, traverse rate and abrasive flow rate; on depth of cut, top kerf width, bottom kerf width, kerf taper and surface roughness are investigate. single mesh size abrasives are found to yield decreased surface roughness than multi mesh size abrasives.If pressure increase then depth of cut, top kerf width, taper angle increases & surface roughness decreases. If TS increases then depth of cut, top kerf width increases & taper angle, surface roughness decreases. Kerf taper angle, top kerf width, SR decreases & depth of cut increases if ABR increases. In 2009 Kolahan et al.[3] carried out a set of experimental data has been used to assess the influence of abrasive water jet (AWJ) process parameters in cutting 6063-T6 aluminium alloy. The process variables are nozzle diameter, TS, WP and AFR. The Taguchi method and regression modeling are used in order to establish the relationships between input and output parameters. The objective was to determine a suitable set of process parameters that can produce a desired depth of cut, considering the ranges of the process parameters. In 2011 Selvan et al. [4] studied the influence of process parameters on depth of cut and surface roughness in abrasive water jet cutting of stainless steel. Experiments were conducted in varying water pressure, nozzle traverse speed, standoff distance and abrasive flow rate for cutting stainless steel plates using abrasive water jet cutting process. Increase of WP resulted in increase in depth of cut when mass flow rate, TS and S.O.D were kept constant, When WP is increased, the jet K.E increased that lead to more depth of cut. Higher AFR achieve higher cutting ability of the jet. But for higher AFR, abrasives collide among themselves and lose their K.E. It was evident that the surface was smoother near the jet entrance and gradually the SR increases towards the jet exit. In 1999 Wang & Wong [5] worked on the study of abrasive water jet cutting of metallic coated sheet steels. A study of (AWJ) cutting of metallic coated sheet steels is presented based on a statistically designed experiment. Top and bottom kerf widths appear to increase with the water pressure because higher water pressure should result in greater jet kinetic energy and open a wider slot on the work piece. Higher WP decreases kerf taper angle. Top & bottom kerf widths increase with an increase in the S.O.D although the rate of increase for the bottom kerf width is smaller. This may be result of jet divergence. Kerf taper is increasing with the S.O.D. The TS exhibits a negative effect on both top & bottom kerf widths, while kerf taper appears to increase with the TS. Higher AFR produces narrower kerf. From the experimental results, an increase in the TS causes a constant increase in the SR & SR decreases with an increase in the AFR. It can be found that the SR does not change linearly with WP. It decreases initially with an increase in WP. In 2008 Shanmugam et al. [6] defined minimization of kerf tapers in AWJM of alumina ceramics using a compensation technique.In this study, ceramic material was used with garnet abrasive. In this investigation, five process parameters were used i.e WP, S.O.D, TS, AFR & kerf compensation angle at six levels. Kerf taper compensation angle has changed the orientation of the kerf so that the taper angle increases on one kerf wall & decreases on the other. It is apparent that an increase in the TS results in an increase in kerf taper angle on both kerf walls. The effect of S.O.D on the kerf taper angle, from which it can be seen that by increasing on both cutting walls. If increase AFR decreases kerf taper angle. Kerf taper compensation angle is the most significant factor. In 2009 Rahman et al. [7] studied an elastic-plastic erosion model to develop an abrasive water jet model for cutting brittle materials. As a result, cutting model based on fracture mechanics was derived and introduced. The suggested model predicts the maximum depth of cut of the target materials as a function of the fracture toughness and hardness, as well as process parameters. The maximum depth of cut predicted by the suggested model was compared with published experimental results for three types of ceramics. The effect of process parameters on the maximum depth of cut for a given ceramic material is also studied and compared with experimental work. In 2009 Shanmugam & Masood [8] described an investigation on kerf characteristics in abrasive water jet cutting of layered composites. This paper presents an investigation on the kerf taper angle, an important cutting performance measure, generated by AWJ technique to machine two types of composites: epoxy pre-impregnated graphite woven fabric and glass epoxy. Based on the test conditions a combination of high water pressure, low transverse speed & low S.O.D is recommended to minimize kerf taper angle. The AFR have minimal effect on kerf taper angle. In 2014 Banerjee et al [9] studied the abrasive water jet cutting of borosilicate glass. In this work researcher used borosilicate glass material for cutting by AWJM. Different process parameters i.e water pressure, abrasive flow rate, traverse speed and standoff distance is use to measure the depth of cut. Model, thus developed on depth of cut gives an idea of influence of different parameters on cutting of amorphous borosilicate glass by AWJM.

III. EXPERIMENTAL WORK

3.1 Material

In the present study, makrana white marble was used as a materials. The marble is a brittle material and has the various applications as a building/construction material.

3.2 Equipment

The equipment used for machining the samples was Omax 5555 abrasive water jet machine equipped with a gravity feed type of abrasive hopper, an abrasive feeder system, a pneumatically controlled valve and a work piece table.

3.3 Experimental design

In the present study, three machining parameters were selected as control factors as shown in Table 1. The parameters and levels were selected on the bases of literature review on AWJM. The constant process parameters are shown in Table 2 .The garnet abrasive with size 80 mesh were selected. Based on Taguchi's method design of experiment with three factors a L16 orthogonal arrays table with 16 rows was selected for the experimentation.

Table.1. Variable process parameter

S.NO.	Variable parameters	1.	2.	3.	4.
1.	Pressure(MPa)	151.68	206.84	262	317.16
2.	Abrasive flow rate(g/min)	300	400	500	600
3.	Standoff distance(mm)	0.7	0.8	0.9	1.0

Table.2. Constant process parameters

Orifice diameter(Diamond)	0.36mm
Nozzle diameter/mixing tube diameter	0.76mm
Nozzle length	100mm
Abrasive type	Garnet
Abrasive size	80 mesh
Carrier medium	Water

Table.3. Allocation of parameters
L16 orthogonal Array

Exp.no	Water pressure (MPa)	Abrasive flow Rate (g/min)	Standoff Distance (mm)
1.	151.68	300	0.7
2.	151.68	400	0.8
3.	151.68	500	0.9
4.	151.68	600	1.0
5.	206.84	300	0.8
6.	206.84	400	0.7
7.	206.84	500	1
8.	206.84	600	0.9
9.	262.00	300	0.9
10.	262.00	400	1
11.	262.00	500	0.7
12.	262.00	600	0.8
13.	317.16	300	1
14.	317.16	400	0.9
15.	317.16	500	0.8
16.	317.16	600	0.7

A circular workpiece has been cut from square piece. Each combination of parameters can achieve certain material removal rate indicating to the operator by splashing of jet. In this study, the thickness of machined marble work piece is 16mm. The material removal rate was measured by the difference of initial weight of work piece and the final weight of work piece after machining to time taken through the cutting. L16 orthogonal array(OA) has been used to minimize experiments. The whole details of L16 orthogonal array and allocation of parameters shown in Table 3. ANOVA technique was used to find results. ANOVA is a computational technique that helps to estimate the relative contributions of each control factor, is found to be a very helpful DOE tool. ANOVA provides insight into the main effects, as well as interaction effects of factors.

IV. RESULTS AND DISCUSSIONS

4.1 Analysis of variance

The effect of process parameters were investigated by using ANOVA. Table 4 shows the ANOVA analysis for material removal rate.

Table.4. Analysis of variance for Mean for MRR (g/sec)

SOURCE	**DF**	**SEQ SS**	**MS**	**F**	**P**	**%**
WP(MPa)	3	0.166702	0.055567	57.34	0.000	66.693
AFR(g/min)	3	0.076484	0.025495	26.31	0.001	30.599
SOD (mm)	3	0.000953	0.000318	0.33	0.806	0.3801
ERROR	6	0.005815	0.000969			66.693
TOTAL	15	0.249954	0.055567			30.599
DF - degrees of freedom, SS - sum of squares, MS - mean squares(Variance), F-ratio of variance of a source to variance of error.						

This analysis were carried out for a 95% confidence level. It was found that sod is not significant parameter because the probality of sod is more than 0.05. Control factor (water pressure) is the most significant factor and the abrasive flow rate have almost equally significant effect on MRR.

4.2 Effect of control factors on MRR(g/sec)

ANOVA as carried out to analysis the effect of process parameter on the MRR and to differentiate the most significant parameters in the generation of MRR. The effect of process parameters on the MRR are shown in Figure 1.

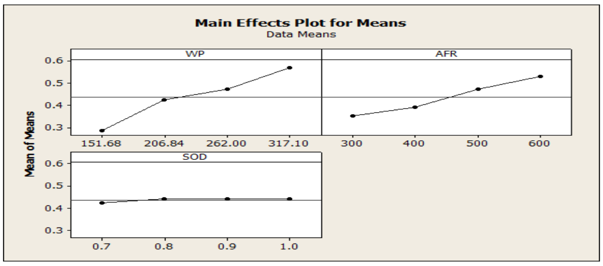

Fig.1. Effect of control factors on MRR.

From figure1, it is observed that when increase water pressure from level 1 to level 4, MRR also increases. When water pressure is 151.68MPa, MRR is minimum and at level 4 water pressure is 317.16MPa, MRR is maximum. When increase in abrasive flow rate from level 1 to 4, results MRR increases. In this case, higher abrasive flow rate is desirable to produce a higher the MRR. The influence of SOD is not significant as that of other process parameters.

V. CONCLUSION

Out of all the selected parameters only two parameters water pressure, abrasive flow rate were significantly affecting the material removal rate in abrasive water jet machining. With concerning to the average response, water pressure as most significant parameter for MRR. The percentage contribution of water pressure for MRR is 66.693%. It was found that the standoff distance failed the test of significant at 95% confidence level therefore it was pooled out. It has been concluded from the results that input parameters setting of water pressure at 317.16 Mpa i.e level 4, AFR at 600 g/min i.e level 4 have given the optimum result for MRR.

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