Experimental Investigations on Pocket Milling of Brass using Abrasive Water Jet Machining

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Abstract— **Abrasive Water Jet Machining (AWJM) is one of the most popular unconventional machining processes used to machine difficult-to-machine materials. Apart from regular cutting, it is also used for turning, threading, slotting, milling etc. This paper details the experimental investigations on Abrasive Water Jet Pocket Milling (AWJPM) on Brass (CuZn40) using garnet abrasive. The influence of waterjet pressure, step-over, traverse rate and abrasive mass flow rate were studied on the output responses such as depth of cut and surface roughness (R_a). The experiments were designed using L_9 Orthogonal Array and ANOVA analysis helped in determination of significant process. ANOVA analysis on depth of cut indicated that waterjet pressure, step-over and traverse rate are the most significant process parameters for brass alloy. However, ANOVA analysis for surface roughness (R_a) was inconclusive and the significant process parameters could not be determined.**

Keywords— Abrasive Water Jet Machining (AWJM), Abrasive Water Jet Pocket Milling (AWJPM), Garnet abrasives, Orthogonal array, ANOVA, Response graph.

I. INTRODUCTION

Abrasive Water Jet Machining (AWJM) has received considerable attention from industries owing to its beneficial characteristics in machining various materials, particularly difficult-to-machine and thermally sensitive materials [2]. AWJM uses the mechanical energy of the high velocity jet of water and abrasive to achieve material removal by impact erosion. Besides cutting, many operations such as turning, threading, slotting and milling can be performed using AWJM. There has been certain degree of research in the fields of slotting, turning using AWJM, but the studies related to milling using AWJM is very scarce [3]. If the depth of cut is controlled during the milling process, then it is known as pocket milling. In abrasive water jet pocket milling (AWJPM), the waterjet is not allowed to pass all the way through the workpiece. The advantages of AWJPM are less burr formation, minimum thermal distortion, negligible tool wear, absence of tool breakage and tool deflection [2-9].

The process parameters in AWJPM are broadly classified into six categories namely (1) Hydraulic parameters: waterjet pressure, orifice diameter and water flow rate (2) Mixing chamber and acceleration parameters: focus nozzle diameter and focus nozzle length. (3) Cutting parameters: traverse rate, number of passes, stand-off distance and impact angle (4) Abrasive parameters: abrasive flow rate, abrasive particles diameter, abrasive size distribution, abrasive particle shape and abrasive particle hardness (5) Work material: composition, hardness and harder materials (6) Milling parameters: Step-over size, number of passes and nozzle path movement (Figure1). The influence of these parameters on the output responses have to be studied for brass alloy.

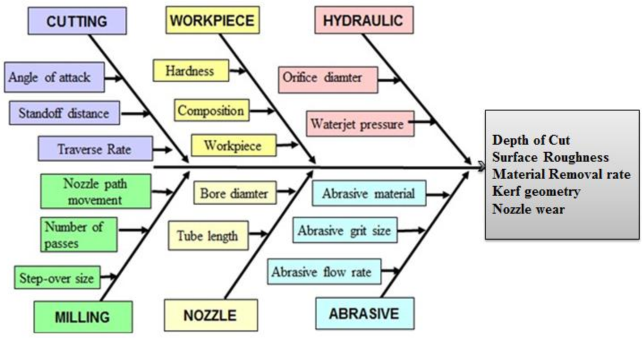

Fig. 1. Fishbone diagram for AWJPM

II. LITERATURE REVIEW

Literature review related to AWJPM is briefly presented here. Wang et al (2003) carried out an experimental investigation on an alumina ceramic considering multi-pass cutting. The cutting parameters considered are traverse rate, number of passes, traverse direction, etc. They have found that traverse rate and traverse direction are found to be significant. They have also found that with the appropriate combinations of input process parameters in the multi-pass cutting has distinct advantages over single-pass cutting.

Shipway et al (2005) studied the surface characteristics of AWJPM on titanium alloy (Ti6A14V). They observed that the material removal rate is about 55 % lower at higher traverse speeds (0.01 m/s) with smaller grit size (80 mesh) than that of with the larger grit size (200 mesh). They have also observed that increase in traverse rate results in the reduction in surface waviness, while using both grit sizes of abrasives (garnets). The reduction is being most significant while using larger grit size of the abrasives. They have also observed that the material removal rate was high at the lowest traverse rate (0.003 m/s) and decreased rapidly with increase in the traverse rate. From their studies, it is observed that increase in the waterjet pressure for different traverse rate results in an increase in the surface waviness and also the waterjet pressure has significant influence on the surface waviness at the lower traverse rate than that of the higher traverse rate.

Fowler et al (2009) have carried out AWJPM in titanium alloy (Ti6Al4V) to study the effects of different abrasives (white and brown aluminium oxide, garnet, glass beads and steel shots). They have observed that the ratio between the hardness of the workpiece and the abrasive particle is more significant than that of abrasive particle shape. They have also observed that increase in the material removal rate and surface roughness with the increase in the abrasive particle hardness. They have observed that among the different input process parameter, traverse rate is found to be more significant for material removal rate for different abrasives.

From the literarture review, it is observed that few works are carried in AWJPM on brass. This paper analyses the effect of waterjet pressure, step-over, traverse rate and abrasive mass flow rate on the depth of cut and surface roughness (R_a) on brass during AWJPM. The experiment is designed using L_9 orthogonal array. The responses are then measured and ANOVA analysis is performed to determine the significant parameters.

III. EXPERIMENTAL SETUP AND PROCEDURE

Precision WaterJet Machining Center (Model: 2626) manufactured by M/s OMAX Corporation, USA is used for this work. The equipment details are given in Table 1.

Fig. 2. Photograph of the AWJM setup at Anna University

AWJPM is carried out in Brass (CuZn40) of thickness 6 mm. Brass was chosen as the workpiece as it is used for many industrial purposes. The vicker's hardness test was performed on the workpiece at 0.5 Kg load for 10 seconds. The average value of hardness was found to be 128.4 HV. Garnet abrasive of grit size of mesh #85 is used for the experimention. The four input parameters that were varied at three levels (low, medium and high) are given in Table 2. Raster path is chosen while cutting the workpiece materials. The raster path is a path in which the abrasive waterjet moves in straight cut. However, during at the ends of each pass, the jet makes a 90^0 turn, after which it moves linearly as per the pre-specified step over distance. Thereafter, it takes another 90^0 turn and then proceeds for the next straight cut. This step is repeated to cover the entire area specified by the user. A typical raster path is shown in Figure 3.

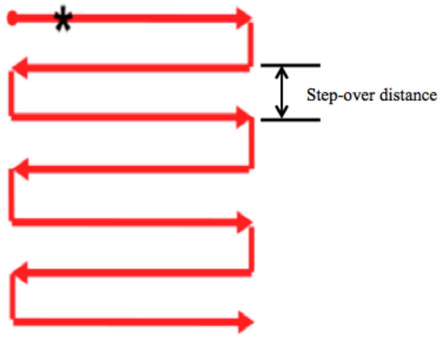

Fig. 3. Flow pattern of raster path

The experimental results are given in Table 3. The depth of cut is measured using TESA IP67 Digital Vernier Calliper with least count of 0.01mm, while the surface roughness (R_a) is measured using a Mahr Marsurf make surface roughness tester with a traverse rate of 5.6 m, cut-off length of 0.8 mm and Phase corrected Gaussian filter.

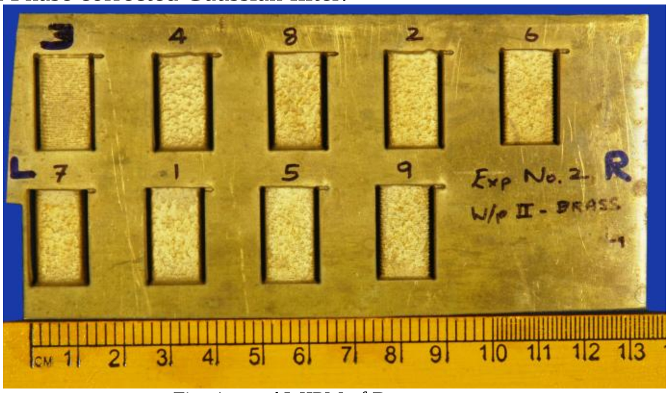

Fig. 4. AWJPM of Brass

IV.RESULTS AND DISCUSSIONS

The depth of cut and surface roughness (R_a) values obtained in brass is given in Table 4. ANOVA TM software is used for statistical analysis. The input parameters which contribute significantly have been determined and the response graphs are plotted.

ANOVA table (Table 4) indicates that the waterjet pressure, step-over and traverse rate are significant process parameters (at 95% confidence level). Abrasive flow rate is found to be insignificant. Response graphs in Figure 5 indicate that the depth of cut decreases as step-over decreases, this is due to the increase in number of waterjet passes overlapping per unit area of workpiece. Depth of cut decreases with increase in traverse rate, this is due to the fast movement of the waterjet over the workpiece. These results coincide with the literature review [7]. However, the depth of cut increases with increase in the waterjet pressure. As the waterjet pressure increases, the kinetic energy of abrasive particles also increases thus resulting in higher material removal rate and hence higher depth of cut is achieved.

While ANOVA analysis successfully yielded the significant parameters for the resultant depth of cut, the same is not found for surface roughness (R_a). From Table 5, the significance of individual parameters could not be determined using the L_9 Orthogonal Array Design Of Experiments approach. This indicates that higher order of experimentation is necessary to determine the significant parameters.

However, from the response graphs (Figure 6), it is observed that lower R_a values are obtained with low waterjet pressure,

low step-over, low traverse rate and high abrasive flow rate. This may be due to the high overlapping of waterjet passes and increased exposure time of waterjet on the workpiece that results in lesser R_a values.

V. CONCLUSIONS

This work aims to determine the significant input parameters in AWJPM of brass for achieving higher depth of cut and lower surface roughness (R_a). ANOVA analysis is carried out to identify the significant process parameters and their corresponding response graphs were plotted. The watejet pressure, step-over and the traverse rate play the most significant role in achieving higher depth of cut. The depth of cut reacts inversely with step-over and traverse rate. However, it varies directly with waterjet pressure. This indicates that at high step over and high traverse rate, leads to lower depth of cut. The abrasive flow rate is found to be a non-significant parameter. In the case R_a it is observed that a higher order of experimentation is necessary to understand the effects of input parameters. This leaves a lot of scope for future study.

TABLE I. Awjm Details

Machine Used	OMAX 2626 Precision Jet Machining Center
Power	22 kW, 50 Hz
Min Pump Pressure	138 MPa
Max Pump Pressure	413 MPa
CNC Work Table size	1168 mm x 787 mm
Work Envelope	X-Y cutting travel of 737 mm x 660 mm
Focusing Nozzle diameter	0.76 mm
Orifice diameter	0.35 mm

TABLE II. Variable Process Parameters At Different Levels

S. No.	Variable Parameters	Levels		
		Low	Medium	High
1	Waterjet Pressure (MPa)	138	155	172
2	Step Over (mm)	0.2	0.3	0.4
3	Traverse Rate (mm/min)	1500	2000	2500
4	Abrasive Mass Flow Rate (kg/min)	0.22	0.32	0.42

TABLE III. Experimental Results

S. No	Input Process Parameters				Output Process Parameters	
	Pressure (MPa)	Step Over (mm)	Traverse Rate (mm/min)	Abrasive Flow Rate (kg/min)	Surface Roughness (µm)	Depth of Cut (mm)
1	138	0.2	1500	0.22	5.77	2.77
2	138	0.3	2000	0.32	7.48	1.02
3	138	0.4	2500	0.42	5.7	0.34
4	155	0.2	2000	0.42	7.19	2.18
5	155	0.3	2500	0.22	9.56	1.05
6	155	0.4	1500	0.32	6.9	1.5
7	172	0.2	2500	0.32	5.69	2.46
8	172	0.3	1500	0.42	4.99	2.57
9	172	0.4	2000	0.22	10.33	1.26

TABLE IV. Anova Table Of Depth Of Cut

Source	Pool	DF	S	V	F	S'	ρ
P*	-	2	0.83	0.41	349.15	0.83	14.59
SO*	-	2	3.17	1.58	1336.15	3.17	55.96
TR*	-	2	1.66	0.83	699.40	1.66	29.27
AFR	Y	2	0.00	0.00	-	-	-
(e)	-	2	0.00	0.00	-	0.01	0.17
Total	-	8	5.66	0.71	-	-	-

P – Waterjet Pressure
SO – Step Over
TR – Traverse Rate
AFR – Abrasive Flow Rate
(e) – Error
Y – Pooled Value
DF – Degrees of Freedom
S – Sum Of Squares
V - Variance
F – F ratio
S' – Pure Sum of Squares
ρ – Percentage Contribution
***** - Significant Parameter

TABLE V. Anova Table Of R_a

Source	Pool	DF	S	V	F	S'	ρ
P	Y	2	3.73	1.86	-	-	-
SO	Y	2	3.40	1.70	-	-	-
TR	-	2	9.02	4.51	2.53	5.46	20.30
AFR	-	2	10.75	5.37	3.02	7.18	26.70
(e)	-	4	7.13	1.78	-	14.25	53.00
Total	-	8	26.89	3.36	-	-	-

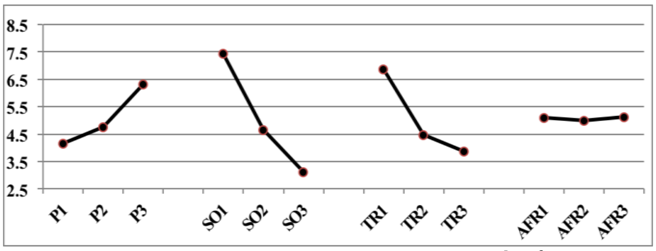

Fig. 5. Mean Responses– Parameters Vs Depth Of Cut

P – Waterjet Pressure
SO – Step Over
TR – Traverse Rate
AFR – Abrasive Flow Rate

1 – Low Level
2 - Medium Level
3 – High Level

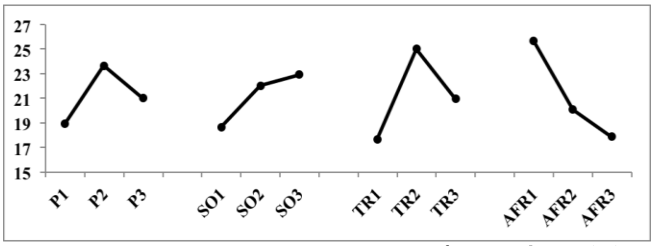

Fig. 6. Mean Responses–Parameters Vs Surface Roughness (R_a)

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