PARAMETRIC OPTIMIZATION OF ABRASIVE WATER JET MACHINING USING TAGUCHI METHODOLOGY

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ABSTRACT

In this research paper, Taguchi method is applied to find optimum process parameters for Abrasive Water Jet Machining (AWJM). Abrasive water jet machining is a non conventional machining process in which removal of material takes place by impact erosion of high pressure (1500-4000 bar), high velocity of water and entrained high velocity of grit abrasives on a work piece. The objective of experimental investigation is to conduct research of machining parameters impact on MRR and SR of work piece of Al 7075. The approach was based on Taguchi's method, analysis of variance and signal to noise ratio (SN Ratio) to optimize the Abrasive Water Jet Machining process parameters for effective machining and to predict the optimal choice for each AWJM parameter such as Traverse speed, Abrasive flow rate, Standoff distance and Abrasive grit size. There is L9 orthogonal array used by varying S, R, H, D respectively and for each combination we have conducted three experiments and with the help of Signal to Noise ratio we find out the optimum results for AWJM. It was confirmed that determined optimal combination of AWJM process parameters satisfy the real need for machining of Al 7075 in actual practice.

Keywords: Abrasive Water Jet Machine (AWJM), Taguchi' method, ANOVA, SN Ratio, MRR, SR.

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1. INTRODUCTION

As an advanced manufacturing technology, abrasive water jet machining processes (AWJM) is being increasingly used in various industries. Abrasive water jet machining makes use of the principles of both abrasive jet machining and water jet machining. In abrasive water jet machining a small stream of fine grained abrasive particles is mixed in suitable proportion, which in forced on a work piece surface through a nozzle material removal occurs due to erosion caused by the impact of abrasive particles on the work surface. AWJM is being used in different industries for a long time. AWJM is especially suitable for machining of brittle material like glass, ceramics and stones as well as for composite materials and ferrous and non-ferrous material. The characteristics of surface produced by this technique depend on many factors like jet pressure, standoff distance of nozzle from the target. Abrasive flow rate, Traverse rate, work materials. Non contact of the tool with work piece, no heat affected zone, low machining force on the work surface and ability to machine wide range of materials has increase the use of abrasive water jet machining over other machining processes. In addition, AWJ machining can be used in a variety of applications such as drilling, polishing, turning, and milling.

A review of the basic erosion models can be found in ^[1]. The erosion of materials caused by the impact of hard particles is one of several forms of material degradation generally classified as wear. Erosion was defined by Bitter [2] as "material damage caused by the attack of particles entrained in a fluid system impacting the surface at high speed", while Hutchings [3] defined erosion as "an abrasive wear process in which the repeated impact of small particles entrained in a moving fluid against a surface results in the removal of material from that surface". Solid particle erosion is a serious problem in gas turbines, rocket nozzles, cyclone separators, valves, pumps and boiler tubes. However, solid particle erosion can be utilized in manufacturing processes such as abrasive water jet cutting. Abrasive water jet (AWJ) machining is one of the recent non-traditional methods that have been used widely in industry for parting cuts on ductile materials such as aluminium, brass, steel, titanium, and nickel based alloys as well as brittle materials like glass, stone, and ceramics [4]. There are numerous associated parameters and factors of AWJM process that can influence the surface quality of the AWJ machined surfaced [5-7]. MRR increase by increasing abrasive mass flow rate. Increasing speed is also increase MRR. Full factorial design help for analysis as no separate combination needs for confirmation test [8]. Previous investigation [9-12] indicated that even through some efforts have been made to increase the material rate (MRR), the taperness of the drilled holes was not being reduce. Now an attempt has been made to increase MRR and to decrease the taperness by varying standoff distance (S-O-D) with different chemical environment and chemical concentration. Many researchers have been carried out on different parameters of AWJM Fecaier et al [13] and Ohlsson and Magnusson [14] investigated the force parameters involved during AWJ machining Andreas and kavaeevic [15] investigated the properties and structures of high speed jets Momer et al [16] investigated the influence of abrasive grain size distribution on abrasive water jet machining process. It's a non-conventional machining process. Tikhomirow [17] worked on the possible feed rate depending on the standoff distance of the nozzle.

2. METHODOLOGY

• Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) and F-test (standard analysis) are used to analysis the experimental data as given follows

Notation:

Following Notation are used for calculation of ANOVA method

- C.F. = Correction factor
 - T = Total of all result
 - n = Total no. of experiments

 S_T = Total sum of squares to total variation.

 X_i = Value of results of each experiments (i = 1 to 27)

 S_{Y} = Sum of the squares of due to parameter Y (Y = P, S, A, T)

 N_{Y1} , N_{Y2} , N_{Y3} = Repeating number of each level (1, 2, 3) of parameter Y

 X_{Y1} , X_{Y2} , X_{Y3} = Values of result of each level (1, 2, 3) of parameter Y

 F_{Y} = Degree of freedom (D.O.F.) of parameter of Y

 f_T = Total degree of freedom (D.O.F.)

 f_e = Degree of freedom (D.O.F.) of error terms

 $V_{Y} = Variance of parameter Y$

 $S_e = Sum of square of error terms$

 $V_e = Variance of error terms$

 $F_{Y} = F$ -ratio of parameter of Y

 S_{Y} ' = Pure sum of square

C_Y= Percentage of contribution of parameter Y

 C_e = Percentage of contribution of error terms

$$\begin{split} CF &= T^2/n \\ S_T &= \sum_{i=1 \text{ to } 27} X_i^2 - CF \\ S_Y &= (X_{Y1}^2/N_{Y1} + X_{Y2}^2/N_{Y2} + X_{Y3}^2/N_{Y3}) - CF \\ f_Y &= (number \text{ of levels of parameter } Y) - 1 \\ f_T &= (\text{ total number of results}) - 1 \\ f_e &= f_T - \sum f_Y \\ V_Y &= S_Y/f_Y \\ S_e &= S_T - \sum S_Y \\ V_e &= S_e/f_e \\ F_Y &= V_Y/V_e \\ S_Y' &= S_Y - (V_e * f_z) \\ C_Y &= S_Y'/S_T * 100\% \\ C_e &= (1 - \sum P_Y) * 100\% \end{split}$$

• SIGNAL TO NOISE RATIO CALCULATION

Quality Characteristics:

S/N characteristics formulated for three different categories are as follows:

Larger is Best Characteristic:

Data sequence for MRR (Material Removal Rate), which are higher-the-better performance

characteristic are pre-processed as per Eq.1

 $S/N = -10 \log ((1/n) ((1/y^2))....1$

Nominal and Smaller are Best Characteristics

Data sequences for SR , which are lower-the-better performance characteristic, are preprocessed as per Eq.2 &3

 $S/N = -10 \log (y/s^2 y)$2

Where y^{h} is average of observed data y, sy^{2} is variance of y, and n is number of observations.

3. EXPERIMENTAL SET UP AND WORK PROCEDURE:

Material:

In this investigation, the work material Aluminium was used with the following main properties: Tensile Strength 90 MPa, Modulus of elasticity 69 GPa, and Density 2.71 g/cm³.

The abrasive used was garnet with mesh size of 60, 80, and 100 hardness of 7.5 mohs.

Chemical composition of Al7075 alloy is Al 91.02, Cu 1.65, Mg 2.0, Zn 5.0, and Mn 0.1.

Equipment

The equipment used for machining the samples was Abrasive Water Jet Machine, model no. 2626 OMAX Jet Machining Centre equipped with OMAX-High-Pressure Pump of 40 ksi (3376.43 bar). The OMAX variable speed, high-pressure pump is an electrically driven, variable speed, positive displacement, crank shaft drive triplex pump designed for use with the OMAX precision jet machining system and other applications requiring high pressure water required by the OMAX jet machining system to operate. The pump control panel provides a keypad display screen, and pumps start/stop controls. When the pump is attached to an OMAX jet machining centre, controls sheared between the Jet machining centre controller and the pump. The table size was 46''*31'' (1168*787 mm) and foot print was 116''L*72''W (2946mm*1829mm), weight (empty tank) was 3000 lbs-tables (1364 kg).X-Y cutting travel was 29''*26'' (737min*660min). Mixing tube diameter was 0.7620mm and jevel diameter was 0.3556mm and abrasive index was 0.94.

Experimental Design:

The experimental layout for the machining parameters using the L₉ orthogonal array was used in this study. This array consists of four control parameters and three level, as shown in table In the taguchi method, most all of the observed values are calculated based on 'the higher the better' and 'the smaller the better'. Pressure is kept constant at 240 MPa .Thus in this study, the observed values of MRR, and SR were set to maximum, and minimum respectively. Next experimental trial was performed with three simple replications at each set value. Next, the optimization of the observed values was determined by comparing the standard analysis and analysis of variance (ANOVA) and SN ratio which was based on the taguchi method.

			Level			
Control Parameters	Unit	1	2	3	Observed Values	
		Min.	Interm- ediate	Max.		
Traverse Speed (S)	mm/min.	150	200	250	1. Material Removal Rate	
Abrasive flow rate (R)	g/s	3.5	5.5	7.5	(mm ³ /min)	
Standoff distance (H)	mm	1.5	2.5	3.5	2. Surface Roughness (Ra)	
Abrasive grit size (D)	μm	60	80	100		

TABLE 1: DESIGN SCHEME OF EXPERIMENT OF PARAMETERS AND

LEVELS

No. Of Trial	Control Parameter(Level)				Result /Observed Value					
	Traverse speed	Abrasive flow rate	Standoff distance	Abrasive grit size	(1	MRR mm ³ /mir	ı)	SR (µm)		
	(mm/min.) S	(g/s) R	(mm) H	(μm) D	1	2	3	1	2	3
1	150	3.5	1.5	60	34.17	34.7 9	34.69	3.12	3.01	3.98
2	150	5.5	2.5	80	36.02	36.5 6	36.47	3.89	3.63	4.66
3	150	7.5	3.5	100	37.75	37.9 1	38.08	4.98	5.38	5.43
4	200	3.5	2.5	100	35.46	35.7 8	35.67	5.37	6.10	5.98
5	200	5.5	3.5	60	38.74	38.9 7	37.87	3.58	4.43	4.10
6	200	7.5	1.5	80	34.76	34.9 4	30.86	4.78	5.31	5.07
7	250	3.5	3.5	80	36.74	36.8 9	36.79	5.36	4.98	5.71
8	250	5.5	1.5	100	37.98	38.1 7	38.54	4.79	5.15	6.13
9	250	7.5	2.5	60	39.95	40.1 6	40.23	5.47	5.12	4.69

TABLE 2: OBSEREVED VALUES OF MRR AND SR

TABLE 3: ANALYSIS OF VARIANCE AND F-TEST FOR MRR

Parameter	DOF	Sum Square	Variance	F-ratio	Pure Sum	Percent
(Y)	f _Y)	$(\mathbf{S}_{\mathbf{Y}})$	(V _Y)	(F _Y)	$(\mathbf{S}_{\mathbf{Y}})$	(C_{Y})
S	2	32.39379	16.19689	24.26393++	31.05873	26.81839
R	2	20.17976	10.08988	15.11526+	18.8447	16.2719
Н	2	27.73701	13.8685	20.77586+	26.40195	22.79739
D	2	23.48521	11.7426	17.59113+	22,15015	19.12607
Е	18	12.01553	0.66753			

TABLE4: ANALYSIS OF VARIANCE AND F-TEST FOR SR

Parameter	DOF	Sum Square	Variance	F-ratio	Pure Sum	Percent
(Y)	(f _Y)	(S _Y)	(V _Y)	(F _Y)	(S _Y)	(C _Y)
S	2	5.116089	2.558044	12.76186+	4.7152	24.61877
R	2	1.921622	0.960811	4.793404+	1.520733	7.939978
Н	2	0.758467	0.379233	1.891962+	0.357578	1.866967
D	2	7.748689	3.874344	19.32877++	7.3478	38.36397
Е	18	3.608	0.200444			

TABLE 5:SUMMARIZATION OF SIGNIFICANT PARAMETERS ON THE
MACHINABILITY OF AWJM

Parameter	MRR	SR
Traverse Speed (S)	++	+
Abrasive flow rate (R)	+	+
Standoff distance (H)	+	+
Abrasive grit size (D)	+	++

TABLE 6: S/N Ratio for MRR (Larger is Better)

1	2	3	S/N1	S/N2	S/N 3	Average
34.17	34.79	34.69	30.67289	30.82908	30.80408	30.76866
36.02	36.56	36.47	31.13087	31.26012	31.23871	31.20990
37.75	37.91	38.08	31.53833	31.57736	31.61393	31.57654
35.46	35.78	35.67	30.99477	31.07280	31.04606	31.03788
38.74	38.97	37.87	31.76319	31.81460	31.56590	31.71456
34.76	34.94	30.86	30.82159	30.86645	29.78791	30.49198
36.74	36.89	36.79	31.30278	31.33817	31.31459	31.31851
37.98	38.17	38.54	31.59109	31.63444	31.71823	31.64792
39.95	40.16	40.23	32.03033	32.07587	32.09100	32.06573

TABLE 7: S/N Ratio for SR (Smaller is Better)

1	2	3	S/N 1	S/N 2	S/N 3	Average
3.12	3.01	3.98	-9.88309	-9.57132	-11.99766	-10.48402
3.89	3.63	4.66	-11.79899	-11.19813	-13.36771	-12.12161
4.98	5.38	5.43	-13.94458	-14.61564	-14.69599	-14.41573
5.37	6.10	5.98	-14.59948	-15.70659	-15.53402	-15.28003
3.58	4.43	4.10	-11.07766	-12.92807	-12.25567	-12.08713
4.78	5.31	5.07	-13.58855	-14.50189	-14.10015	-14.06353
5.36	4.98	5.71	-14.58329	-13.94458	-15.13272	-14.55346
4.79	5.15	6.13	-13.60671	-14.23614	-15.74920	-14.53068
5.47	5.12	4.69	-14.75974	-14.18539	13.42345	-14.12619

Taguchi Analysis: S/N Ratio for MRR versus S, R, H, D

Response Table for Signal to Noise Ratios Larger is better

Level	S	R	Η	D
1	31.18	31.04	30.97	31.52
2	31.09	31.52	31.44	31.01
3	31.68	31.38	31.54	31.42
Delta	0.59	0.48	0.56	0.50
Rank	1	4	2	3



Figure 1:S/N Ratio of MRR for different levels

Taguchi Analysis: S/N Ratio for SR versus S, R, H, D

Response Table for Signal to Noise Ratios Smaller is better

Level	S	R	Η	D
1	-12.38	-13.47	-13.07	-12.27
2	-13.83	-12.96	-13.87	-13.60
3	-14.43	-14.21	-13.70	-14.77
Delta	2.05	1.25	0.80	2.50
Rank	2	3	4	1





4. RESULTS AND DISCUSSION:

The following discussion focuses on the different of process parameters to the observed values (MRR and SR) based on the Taguchi methodology.

Material Removal Rate (MRR)

Main effects of MRR of each factor for various level conditions are shown in figure1. According to figure 1 the MRR increases with four major parameter S, R, H, and D. MRR is maximum in the case of **Traverse Speed(S)** at level 3 (250), in the case of **Abrasive flow Rate (R)** at level 2 (5.5), in the case of **Standoff distance (H)** MRR will be maximum at level 3 (3.5), and in the case of **Abrasive griet Size (D)** at the level 1 (60). So the optimal parameter setting for the MRR found **S3R2H3D1**

Surface Roughness (SR)

Figure 2 evaluates the main effects of each factor for various level conditions. According to the figure 2 the surface Roughness decreases with four major parameter S, R, H, and D. SR will be minimum in the case of **Traverse Speed** (S) at level 1 (150), in the case of **Abrasivw flow Rate(R)** at level 2 (5.5), in the case of **Standoff distance** (H) at level 1(1.5) and in the

case of **Abrasive grit Size** (**D**) condition surface Roughness will be minimum at level 1 (60). So the optimal parameter setting for minimum surface roughness is **S1R2H1D1**.

CONFIRMATION TEST

The confirmation experiments were conducted using the optimum combination of the machining parameters obtain from Taguchi analysis. These confirmation experiments were used to predict and verify the improvement in the quality characteristics for machining of Aluminium. For MRR predicted process combination is **S3R2H3D1 and for S1R2H1D1** and found MRR 36.12 mm³/min and SR 2.34 μ m.

CONCLUSIONS

This paper presents analysis of various parameters and on the basis of experimental results, analysis of variance (ANOVA), F-test and SN Ratio the following conclusions can be drawn for effective machining of aluminium (Al7075) by AWJM process as follows:

• Traverse Speed (S) is the most significant factor on MRR during AWJM. Meanwhile Abrasive Flow Rate, Standoff distance, and Abrasive Grit Size are sub significant in influencing. The recommended parametric combination for optimum material removal rate is **S3R2H3D1**

• In case of surface Roughness Abrasive Grit Size is most significant control factor and hence the optimum recommended parametric combination for optimum surface Roughness is

S1R2H1D1.

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