# Optimization of Parameter for Abrasive Water Jet Machining Using Taguchi Method

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**Abstract- In this research paper, 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'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), ' method, ANOVA, SN Ratio, MRR, SR.***

## I. 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 increases 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.

## II. Methodology

### A. 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

$CF = T^2/n$, $S_T = \sum_{i=1 \text{ to } 27} Xi^2 - CF$

$S_Y = ( X_{Y1}^2/N_{Y1} + X_{Y2}^2/N_{Y2} + X_{Y3}^2/N_{Y3}) - CF$

$f_Y$ = ( number of levels of parameter Y) – 1

$f_T$ = ( total number of results)-1

$f_e = f_T - \sum f_Y$ , $V_Y = S_Y/f_Y$

$S_e = S_T - \sum S_Y$ , $V_e = S_e/f_e$

$F_Y = V_Y/V_e$ , $S_Y' = S_Y - (V_e*f_z)$

$C_Y = S_Y'/S_T * 100\%$, $C_e = ( 1- \sum P_Y)*100\%$

*B.* 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 pre- processed as per Eq.2 & 3

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

S/N= -10 log ((1/n) (∑(y$^2$)) ................................................ 3

Where y$^\wedge$ is average of observed data y, sy$^2$ is variance of y, and n is number of observations.

## III. Experimental Set Up And Work Procedure

### *A. 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/cm$^3$. The abrasive used was garnet with mesh size of 60, 80, 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.

### *B. 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.

### *C. 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 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 method.

TABLE 1: DESIGN SCHEME OF EXPERIMENT OF PARAMETERS AND LEVELS

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

TABLE 2: TAGUCHI ANALYSIS: S/N RATIO FOR MRR VERSUS S, R, H, AND D RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS LARGER IS BETTER

| Level | S | R | R | 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 |

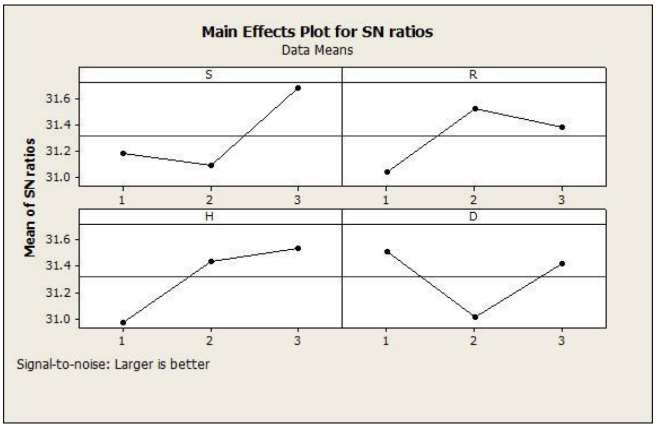


Figure 1: S/N Ratio of MRR for different levels

TABLE 3: 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 | R | 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 |

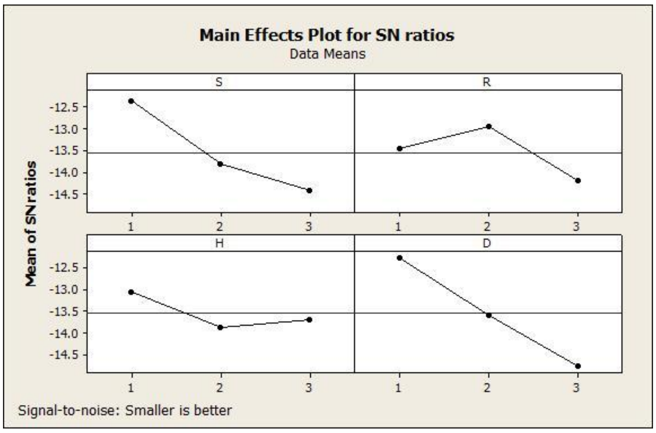


Figure 2: S/N Ratio of SR for different levels

## IV. 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.

### A. *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

### B. *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 Abrasive 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.

## V. 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 $mm^3$/min and SR 2.34µm.

## VI. 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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