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Optimization of AWJM Parameters during the Machining Of En-19 Alloy Steel by Taguchi Methodology

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ABSTRACT

Abrasive water jet machine (AWJM) is a non-traditional machining process. This is process of removal of materials by impact erosion of high pressure water jet. High velocity of water and high velocity of abrasive particles on a work piece are impinged to cut the material. Experimental investigations were conducted to assess the influence of abrasive water jet machining (AWJM) process parameters on response-Material removal rate (MRR) of EN19 alloy steel. The approach was based on Taguchi’s method and analysis of variance (ANOVA) to optimize the AWJM process parameters for effective machining. Experiments are carried out using L16 Orthogonal array by varying traverse speed, abrasive mass flow rate (AMFR), stand of distance (SOD), and water pressure (WP) for EN19 material. In present study experimental conditions show that the optimum values of the input factors has direct influence on process response, which can provide a theoretical basis for selection of machining parameters to improve its machining efficiency.

Keywords: AWJM, MRR, ANOVA, S/N-RATIO, Statistical Analyses

1. Introduction

Abrasive water jet machining is one of the most recently developed modernized cutting processes. It uses a fine jet of high pressurized water mixed with abrasive particle to cut the material by means of erosion. Abrasive water jet machining is used to machining a wide series of metals and non-metals mainly hard materials which are “difficult to cut”. Most specific features of abrasive water jet machining have no thermal distortion, capability to contour, small cutting force and ability of machining from one to another of various tasks. AWJ machining technology introduced for commercial use in the 1980's. Lot of research and modern techniques has been made to explore it's applications but still many aspects of this technology remains to be fully understood. Abrasive water jet machine (AWJM) is a non-traditional machining process. Abrasive water jet machining has various distinct advantages over the other cutting technologies, such as no thermal distortion, high machining versatility, high flexibility and small cutting forces, and has been proven to be an effective technology for processing various engineering materials. The mechanism and rate of material removal during AWJ depends both on the type of abrasive and on a range of cutting parameters. Abrasive water jet machine can cut hard and brittle materials like Steels, Non-ferrous alloys Ti alloys, Ni- alloys, Polymers, Metal Matrix Composite, Ceramic Matrix Composite, Concrete, Stone-Granite, Wood, Reinforced plastics, Metal Polymer Laminates.

2. Experimental Procedure

Abrasive water jet machine provides cold cutting operations of work pieces with more or less complex geometries on all type of ferrous and non-ferrous materials up to particularly thickness. AWJM have many advantages like cutting different materials with the same tool, no contact between the tool and the specimen, no heat affected zones, no toxic fumes and excellent cutting precisions. A typical abrasive water jet machining system is mainly consisting of the following components like Water treatment unit, high pressure intensifier abrasive feed system abrasive get nozzle and other connecting accessories such as control valve. As shown in the figure-1.

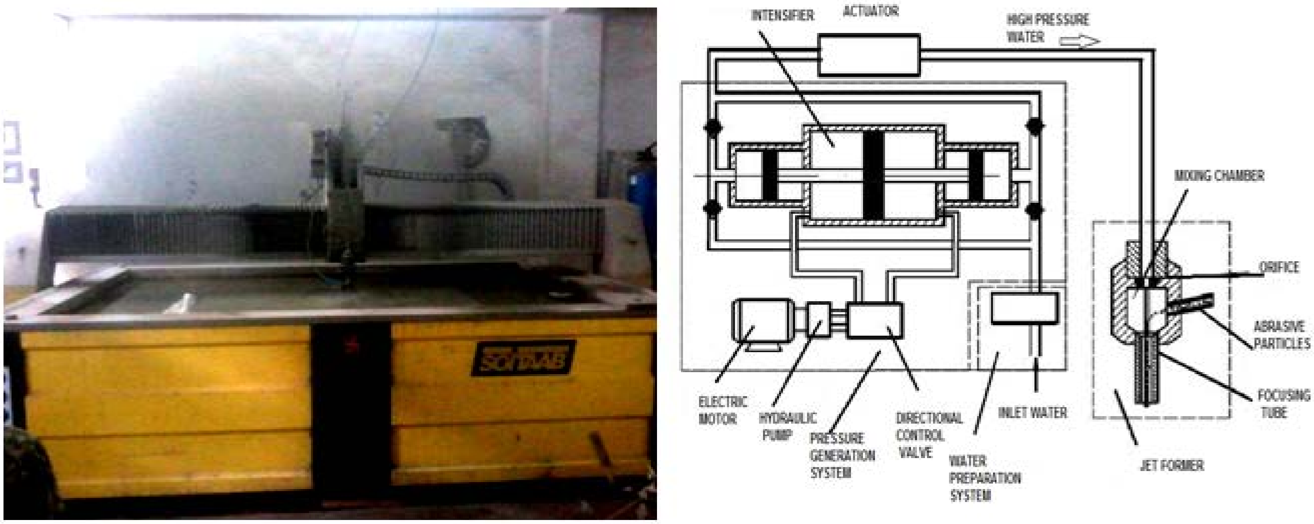

Figure 1: Abrasive water jet machine & components

This all components make the system manipulated by a cutting head positioning device or robot handling system which is responsible to execute a nozzle motion along the predetermined path. A water catcher is placed at the bottom work material to collect the abrasive particles and water.

2.1 Material Specification

AWJM is capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels. EN19 material has been selected because it is widely used for industrial application in metal forming; peening, casting of transmission rod and camshafts. In this research work EN19 selected as a specimen material.

Element	Percentage
Carbon	0.36
Silicon	0.40
Manganese	0.70
Sulphur	0.040 MAX
Phosphorous	0.035 MAX
Chromium	1.20
Molybdenum	0.35

Table 1: Chemical Composition of EN-19 Metal

2.2 Experimental Conditions

The experimental abrasive ingredients were silicon carbide, which were mixed with water. The work-piece material used in the experimental studies was EN-19. During the AWJM experiments, a rectangular slab is used which is fitted on work bench of machine. Total 16 holes are produced according to process to analyze the different values of given process parameters. These process parameters are then analyzed by the Minitab software which is used to analyze statistical data.

2.3 Design of Experiment Based On Taguchi Method

In this investigation carried out by varying four control factors traverse speed, pressure, abrasive mass flow rate and Standoff distance on SOITAAB DWJ machine. A Orifice diameter 0.25 mm, Nozzle diameter 0.2 mm, abrasive size garnet 80 mesh, Water flow rate 3.1 ltr/min and Impact angle 90` used as a constant for every experimental work. Control factors along with their levels are listed in Table 2. Hence Taguchi based design of experiment method was implemented. In Taguchi method L16 Orthogonal array provides a set of well-balanced experiments, and Taguchi's signal-to-noise. (S/N) ratios, which are logarithmic functions of the desired output, serve as objective functions for optimization.

Factors	**Unit**	**Type**	**Levels**	
			1	**2**
Abrasive mass flow rate	gm/min	Numeric	250	350
Pressure	Psi	Numeric	35000	45000
Traverse speed	m/min	Numeric	50	60
Standoff distance	Mm	Numeric	2	6

Table 2: Factors and Levels of Independent Variables

2.4 Specimen Detail

L16 Orthogonal array obtain based on the control factors. Total 16 no. of experiments (Holes dia. 15mm each) has been carried out on rectangular bar which have dimension 155mm*80mm size and 15mm thick of EN-19 material.

Figure 2: Specimen before Machining

Work-piece after machining for each experiment shown in figure-2 Mass of material removal is calculated based on mass difference by using MRR formula.

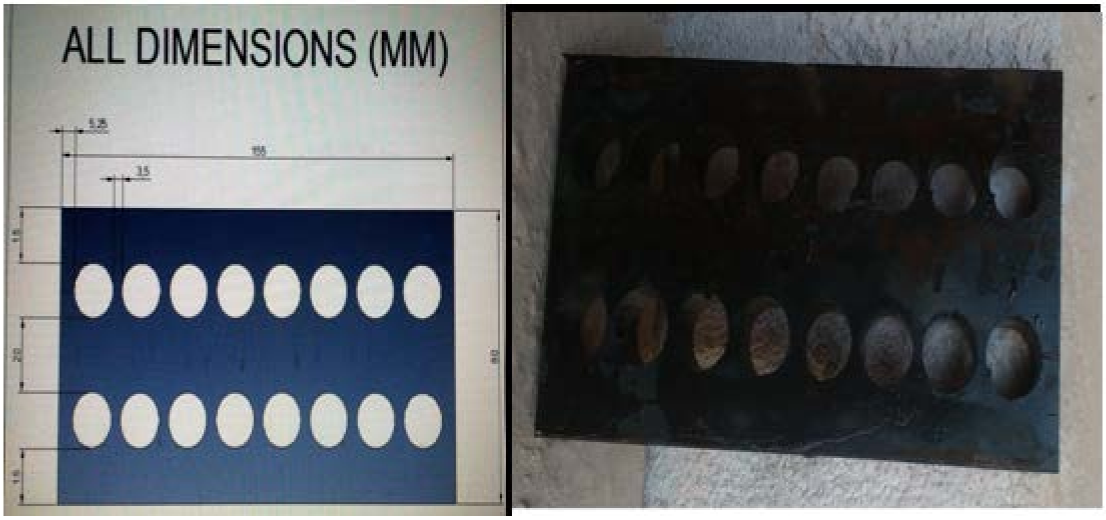

Figure 3: Specimen after Machining

2.5 Material Removal Rate:-

MRR is expressed as:

Material Removal Rate (mm3/min). = $\frac{\text{Reduction in weight of work piece in gm}}{\text{Density of work piece * machining time}}$

$$MRR = \frac{Wi - Wf}{\rho * t}$$

Where Wi= initial weight of specimen

Wf= final weight of specimen

ρ = Density of material

t = Machining time

3. Results and Analysis

3.1 Calculation of Signal to Noise ratio: SN ratio can be calculated based on response requirement. Material removal rate preferred always higher is better. According to Taguchi technique MRR calculated based on Higher is better (Eqn-1). The analysis carried out on MINITAB 16 software. Table-3 Show the Taguchi`s L16 Orthogonal Array and result of MRR. Table-4, Shows the result with calculated Signal to Noise ratio.

This equation is represent by

$$(MSD_{HB}) = -10 \log \left[\frac{\sum \frac{1}{y^2}}{n}\right] \text{.............. (1)}$$

EXP NO	ABRASIVE MASS FLOW RATE	WATER PRESSURE	TRAVERSE SPEED	STAND OFF DISTANCE	MATERIAL REMOVAL RATE
1	250	35000	50	2	2.310

2	250	35000	50	6	1.497
3	250	35000	60	2	2.638
4	250	35000	60	6	1.702
5	250	45000	50	2	3.766
6	250	45000	50	6	2.794
7	250	45000	60	2	4.431
8	250	45000	60	6	3.791
9	350	35000	50	2	1.781
10	350	35000	50	6	1.362
11	350	35000	60	2	2.210
12	350	35000	60	6	1.968
13	350	45000	50	2	2.502
14	350	45000	50	6	2.316
15	350	45000	60	2	3.408
16	350	45000	60	6	3.773

Table 3: Experimental Results for MRR

3.2 Analysis Of Variance (ANOVA)

Analysis of Variance (ANOVA) is a powerful analyzing tool to identify which are the most significant factors and contribution among all control factors for each of machining response. It calculates variations about mean ANOVA results for the each response. Based on F-value (Significance factor value) important parameters can be identified. Table 5 and Table 6 are ANOVA Table obtained by Minitab 16 software. ANOVA Table contains Degree of freedom (DF), Sum of Squares (SS), Mean squares (MS), Significant Factor ratio (F-Ratio), Probability (P).

3.3 Result Discussion for Material Removal Rate (MRR)

Analysis of Variance tables 5 shows the effect of parameter on MRR. The significant parameters can be easily identified .Traverse speed is a most significance factor for MRR and it has p-value<0.05. Abrasive flow rate and Stand of distance has less effect on MRR.

Source	Degree of freedom	Seq. Sum Of Squares	Adj. Mean square	F-value	p-value Prob>F
AMFR	1	0.8141	0.81406	43.50	0.001
WP	1	7.9990	7.99900	427.48	0.000
TS	1	1.9551	1.95510	104.48	0.000
STD	1	0.9230	0.92304	49.33	0.001
AMFR*WP	1	0.2394	0.23937	12.79	0.016
AMFR*TS	1	0.0905	0.09045	4.83	0.079
AMFR*STD	1	0.5180	0.51804	27.68	0.003
WP*TS	1	0.3773	0.37730	20.16	0.006
WP*STD	1	0.0597	0.05966	3.19	0.134
TS*STD	1	0.0549	0.05487	2.93	0.147
Residual Error	5	0.0936	0.01871		
Total	15	13.1244			

Table 4: Resulting ANOVA table for Material Removal Rate

Source	Degree Of Freedom	Seq. Sum Of Squares	Adj. Mean square	F-value	p-value Prob > F
AMFR	1	0.8141	0.81406	21.81	0.002
WP	1	7.9990	7.99900	214.35	0.000
TS	1	1.9551	1.95510	52.39	0.000
STD	1	0.9230	0.92304	24.73	0.001
AMFR*WP	1	0.2394	0.23937	6.41	0.035

AMFR*STD	1	0.5180	0.51804	13.88	0.006
WP*TS	1	0.3773	0.37730	10.11	0.013
Residual Error	8	0.0936	0.01871		
Total	15	13.1244	Total		
R-Squared	0.997			Adj. R-squared	0.992

Table 5: Reduce ANOVA Table for Mean for Material Removal Rate

The table-5 shows the reduce ANOVA table for mean for metal removal rate after elimination of insignificant model terms. After eliminate the non-significant terms, it is clear that the value of "Prob>F" for main effect of abrasive mass flow rate (AMFR), water pressure (WP), Traverse speed (TS) and standoff distance (SOD) with two level interaction of AMFR and WP; AMFR and SOD; WP and TS are less than 0.05. So these terms are still significant modal terms which play an important role in processing of metal. The R-squared value is equal to 0.997 or close to 1 which is most desirable. The adjustable R-squared value is equal to 0.992. The result shows that the adjusted R^2 value is very near to the ordinary R- squared value.

3.4 Maximization of Material Removal Rate

In order to achieve the maximum material removal rate, input factors should be controlled according to the effect.

Factors	Level		Delta (Max.-Min.)	Rank
	1	2		
AMFR	2.866	2.415	0.451	4
WP	1.934	3.348	1.414	1
TS	2.291	2.990	0.699	2
SOD	2.881	2.480	0.480	3

Table 6: Response Table for Material Removal Rate

(AMFR- Abrasive mass flow rate, WP- Water pressure, TS- Traverse speed, SOD- Standoff distance),Table-6 shows the delta values (difference of maximum and minimum values of cutting parameters) for material removal rate. It is found that in cutting process of material is mainly affected by water pressure. The most effective controllable parameter is relatively high from these values. After this, other parameters like traverse speed, standoff distance and abrasive mass flow rate followed with ranking wise.

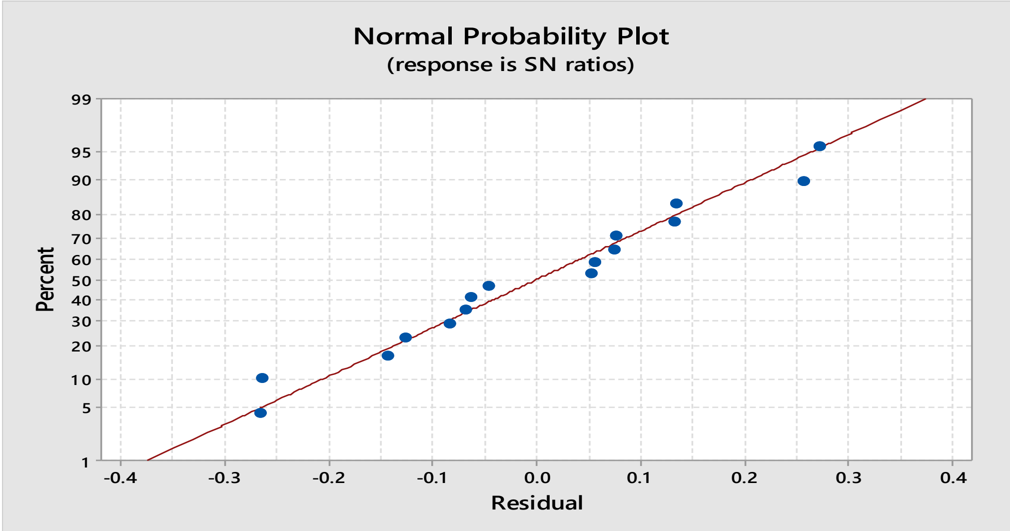

Figure 4: Normal probability plot of residuals for S/N ratios for Material Removal Rate

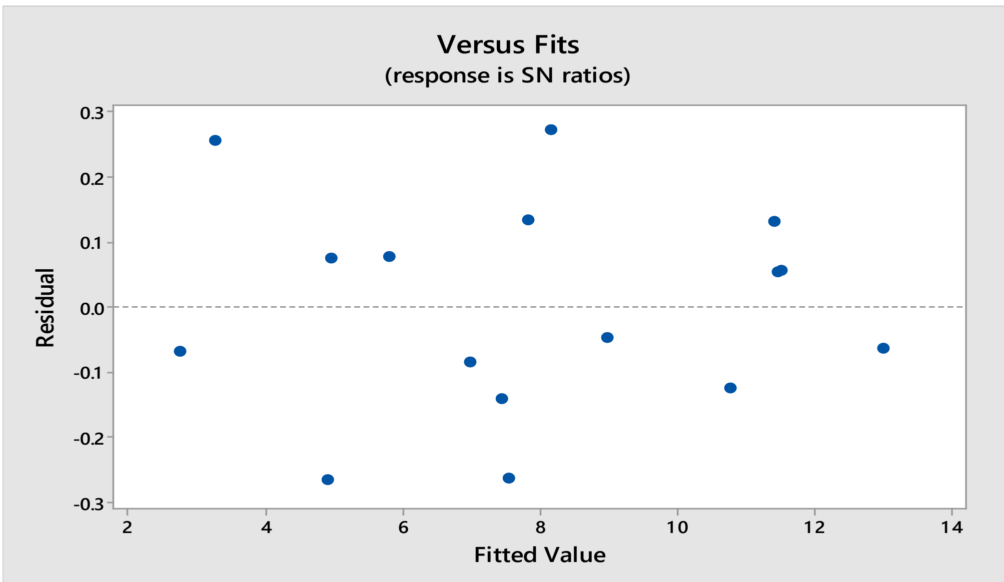

Figure 5: plot of residuals v/s predicted S/N ratio for Material Removal Rate

4. Conclusion

In this research work, the cutting processes were conducted on a SOITAAB abrasive water jet machine on EN-19 high quality alloy steel. Different combinations of input factors are used to perform the cutting process to obtain a high MRR value. For these combinations of data L-16 orthogonal array was used. These combinations results were further analyzed and investigated by ANOVA using Minitab software.

The following conclusions drawn from the research work are as follows:

- Water Pressure is the main significant factor for material removal rate.
- The increase in Water Pressure gives maximum material removal rate.
- The increases in Traverse Speed give maximum removal rate.

- The input parameters are listed according to their significant level as Water Pressure; Traverse Speed; Standoff Distance and Abrasive Mass Flow Rate.
- The material removal rate increases by increasing Traverse Speed particularly at limit value, after this value it produces low material removal rate.
- The decrease in Abrasive Mass Flow Rate increases the Material Removal Rate.
- The decrease in standoff distance can increase the Material Removal Rate.
- The optimal level of cutting parameters setting for maximum Material Removal is 250gm/min Abrasive Mass Flow Rate;45000 psi Water Pressure; 60 mm/min Traverse Speed and 2mm Standoff Distance.

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