IMPLEMENTATION OF TAGUCHI APPROACH FOR PTIMIZATION OF ABRASIVE WATER JET MACHINING PROCESS PARAMETERS

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Abstract - In this paper, Taguchi method is applied to find optimum process parameter for Abrasive water jet machining (AWJM). Abrasive water jet machining is a non–traditional process of removal of material by impact erosion of high pressure, high velocity of water and entrained high velocity of grit abrasives on a work piece. Experimental investigation were conducted to assess the influence of abrasive water jet machining (AWJM) process parameters on MRR and surface Roughness (Ra) of aluminium. The approach was based on Taguchi's method and analysis of variance (ANOVA) to optimize the AWJM process parameter for effective machining and to predict the optimal choice for each AWJM parameter such as pressure, standoff distance, Abrasive flow rate and Traverse rate. For each combination of orthogonal array we have conducted three experiments and with the help of ANOVA it is found that these parameters have a significant influence on machining characteristics such as metal removal rate (MRR) and surface roughness (SR). The analysis of the Taguchi method reveals that, in general the standoff distance significantly affects the MRR while, Abrasive flow rate affects the surface Roughness. Experiments are carried out using (L_9) orthogonal array by varying pressure, standoff distance, Abrasive flow rate and Traverse rate respectively. Experimental results are provided to verify this approach.

***Keywords** - Abrasive Water Jet Machine (AWJM), Taguchi's method, ANOVA, MRR, SR*

I. INTRODUCTION

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, Stand-off distance of nozzle from the target. Abrasive flow rate, Traverse rate, works 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. Many researchers have been carried out on different parameters of AWJM Fecaier et al [1] and Ohlsson and Magnusson [2] investigated the force parameters involved during AWJ machining. Andreas and kavaeevic [3] investigated the properties and structures of high speed jets. Tikhomirow [4] worked on the possible feed rate depending on the standoff distance of the nozzle. Momer et al [5] investigated the influence of abrasive grain size distribution on abrasive water jet machining process. It's a non-conventional machining process.

Abrasive water jet machining is a relatively new machining technology in that it makes use of the impact of abrasive material to erode the work piece material. It is relies on the water to accelerated the abrasive material and deliver the abrasive to the work piece. In addition the water afterwards carries both the spent abrasive and the erode material solid tool to cut the material usually by a shearing process [6]. Previous investigation [7-10] indicated that even through some efforts have been made to increase the material rate (MRR), the taper ness of the drilled holes was not being reduce. Now an attempt has been made to increase MRR and to decrease the taper ness by varying standoff distance (S-O-D) with different chemical environment and chemical concentration. The AWJM is a non-contact, inertia less and faster cutting process that offers some advantage like narrow kerf width, negligible heat affected zone, reduced waste material and flexibility to machining process in different way[11].There are numerous associated parameters and factors of AWJM process that can influence the surface quality of the AWJ machined surfaced [11-13].

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 [14]. In the present study, the effect and optimization of machining parameters in terms of material removal rate (MRR) and surface roughness (Ra) will be investigated using Taguchi method and ANOVA.

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
$CF = T^2/n$
$S_T = \sum_{i=1 \text{ to } 27} X_i^2 - CF$
$S_Y = (X_{Y1}^2/N_{Y1} + X_{Y2}^2/N_{Y2} + X_{Y3}^2/N_{Y3}) - CF$
f_Y = (number 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. *Material*

In this investigation, the work piece 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 80 and hardness of 7.5 Mohs.

C. *Equipment*

The equipment used for machining the samples was Abrasive Water Jet Machine of model 2626 OMAX Jet Machining Centre equipped with OMAX-High-Pressure Pump with the design pressure of 345MPa (50,000 psi) and the nozzle diameter was 0.75mm. 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.

D. *Experimental Design:*

The experimental layout for the machining parameters using the L_9 orthogonal array was used in this study. This array consists of four control parameters and three levels, as shown in table1. In the taguchi method, most all of the observed values are calculated based on 'the higher the better' and 'the smaller the better'. 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 optimisation of the observed values was determined by comparing the standard analysis and analysis of variance (ANOVA) which was based on the Taguchi method.

Table 1 : Design Scheme of Experiments for Parameters and Levels

Control Parameters	**Level**			**Observed Values**
	1	2	3	
	Minimum	Intermediate	Maximum	
Pressure,P (MPa)	155	224	293	1. Material Removal Rate (mm^3/min) 2. Surface Roughness (Ra)
Stand of distance,S (mm)	2.5	3.5	4.5	
Abrasive flow rate,A(g/s)	4.5	6.5	8.5	
Traverse rate,T(mm/s)	1.5	2.5	3.5	

Table 2: Observed Values of MRR and SR

No. Of Trial	Control Parameter(Level)				Result /Observed Value					
	Pressure (MPa)	S-O-D (mm)	Abrasive flow rate (g/s)	Traverse rate (mm/s)	MRR (mm^3/min)			SR (μm)		
					1	2	3	1	2	3
1	155	2.5	4.5	1.5	30.16	30.78	30.67	4.08	4.29	4.19
2	155	3.5	6.5	2.5	32.83	32.92	32.85	5.16	5.49	5.33

3	155	4.5	8.5	3.5	33.52	33.91	34.29	6.19	6.38	7.12
4	224	2.5	6.5	3.5	31.83	31.97	31.88	4.37	4.48	4.41
5	224	3.5	8.5	1.5	34.32	34.79	33.81	6.38	6.49	6.15
6	224	4.5	4.5	2.5	30.82	30.93	30.87	4.12	4.34	4.28
7	293	2.5	8.5	2.5	32.37	32.82	32.56	4.89	4.91	4.81
8	293	3.5	4.5	3.5	33.15	33.79	33.91	3.81	3.85	3.89
9	293	4.5	6.5	1.5	35.36	36.12	37.23	5.82	5.89	5.93

Table 3 : Analysis of Varience and F Test for MRR

Parameter (Y)	DOF (f_Y)	Sum Square (S_Y)	Variance (V_Y)	F-ratio (F_Y)	Pure Sum (S_Y')	Percent (C_Y)
P	2	18.3678	9.1839	51.3353^{+}	18.0100	22.6860
S	2	23.1536	11.5768	64.7110^{++}	22.7958	28.7144
A	2	22.9911	11.4956	64.2571^{+}	22.6333	28.5097
T	2	11.6537	5.8269	32.5707^{+}	11.2959	14.2287
E	18	3.2218	0.1789			

Table 4 : Analysis of Varience and F Test for SR

Parameter (Y)	DOF (f_Y)	Sum Square (S_Y)	Variance (V_Y)	F-ratio (F_Y)	Pure Sum (S_Y')	Percent (C_Y)
P	2	1.1636	0.5818	15.6861^{+}	1.0894	4.4306
S	2	5.2875	2.6437	71.2779^{+}	5.2133	21.2027
A	2	15.3082	7.6541	206.3655^{++}	15.2340	61.9571
T	2	2.1610	1.0805	29.1318^{+}	2.0868	8.4871
E	18	0.6677	0.03709			

Table 5 : Summarization of Sifnificant Parameters on Response of AWJM

Parameters	MRR	SR
Pressure,P (MPa)	+	+
Stand of distance,S (mm)	++	+
Abrasive flow rate,A(g/s)	+	++
Traverse rate,T(mm/s)	+	+

+ + Most Significant + Sub significant Parameter

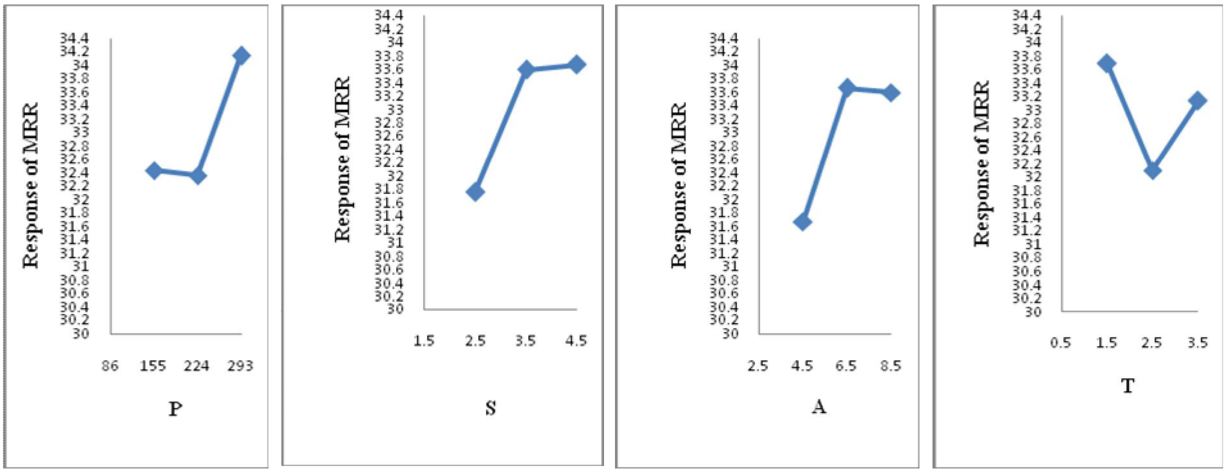

Fig. 1 : Main influence of each parameter on MRR

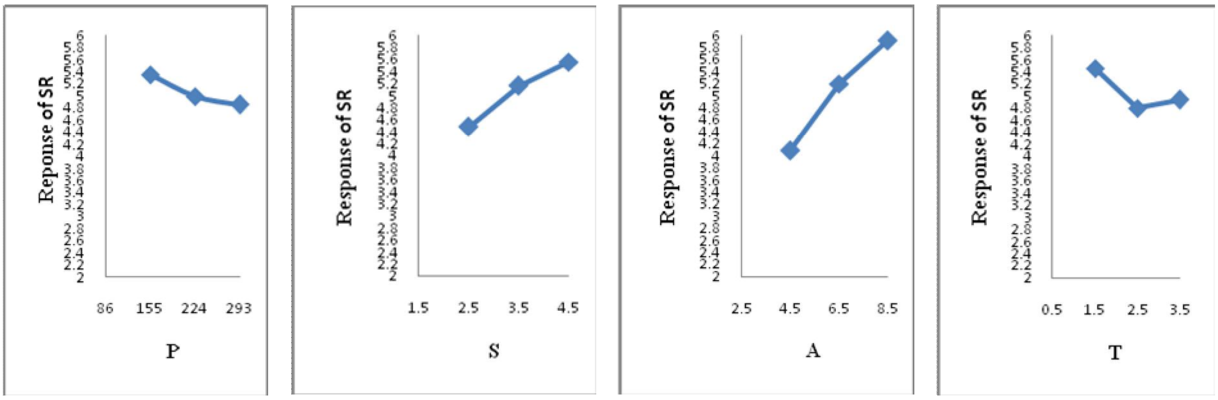

Fig. 2 : Main influence of each parameter on SR

III. 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

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 P, S, T, A. MRR is maximum in the case of **pressure** at level 3 (293), in the case of **SOD** at level 3 (4.5), in the case of **Abrasive flow rate** MRR will be maximum at level 2 (6.5), and in the case of **Traverse rate** at the level 1 (1.5).So the optimal parameter setting for the MRR found P3S3A2T1.

B. Surface Roughness

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 P, S, A, T. SR will be minimum in the case of **pressure** at level 3(293), in the case of **SOD** at level 1 (2.5), and in the case of **Abrasive flow rate** at level 1(4.5) and in the case of **Traverse rate** condition surface Roughness will be minimum at level 2 (2.5). So the optimal parameter setting for minimum surface roughness is P3S1A1T2.

TABLE. 6 : Predicted Optimum Condition for MRR

Parameters	Level Description	Level
P	293	3
S	4.5	3
A	6.5	2
T	1.5	1

TABLE.7: Predicted Optimum Condition for SR

Parameters	Level Description	Level
P	293	3
S	2.5	2
A	4.5	1
T	2.5	2

IV. 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 **P3S3A2T1 and for SR P3S1A1T2 and found MRR 34.12** mm^3/min and SR **3.34**µm.

V. CONCLUSIONS

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

1. Pressure is the most significant factor on MRR during AWJM. Meanwhile standoff distance, Abrasive flow rate and Traverse rate are sub significant in influencing. The recommended parametric combination for optimum material removal rate is **P3S3A2T1.**
2. In case of surface Roughness Abrasive flow rate is most significant control factor and hence the optimum recommended parametric combination for optimum surface Roughness is **P3S1A1T2.**

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REFERENCES

[1] Fekaier,A.J.C. Guinot, A. Schmitt and G. Houssaye,1994. Optimization of the abrasive jet cutting surface quality by the workpiede reaction forces analysis, 12th Intl. Conf. Jet Cutting Tehnol., pp:127-134.

[2] Ohlsson, L. And C. Magnusson, 1994. Mechanisms of striation formation in abrasive water jet cutting, 12th Intl. Conf. Jet Cutting Technol., pp:151-164.

[3] Andreas, W.M. and R. Kovacevic, 1998. Properties and structure of High Speed water Jets. Principle of Abrasive Water Jet Machining.

[4] Tikhomirov, R.A., V.F. Babanin, E.N. Petukhov, I.D. Starikove and V.A. Kovalev,1992. High Pressure Jet Cutting, ASME Press, New York.

[5] Momer, A.W., R. Kovacevich and R. Schuneman, 1996. The influence of abrasive grain size distribution on abrasive water jet machining process. Proceedings of the 25th Nor American Manufacturing Research Conference, Society of Manufacturing Engineers, Deavborn.

[6] Module 9, lesson 37, non-conventional machining, version 2 ME, IIT Kharagpur.

[7] M. Hashish, Pressure effect i AWJ machining, J. Eng. Mater. Technol. 3 (1989) 221-228.

[8] A.R.C. Westwood, Control and application ofenvironment sensitive fracture processes, J. Mater Sci. 9 (1974) 1871- 1995.

[9] Hashish, M., 1991, “advances in composite Machining with Abrasive-Waterjets”. Process. Manuf. Comp. Mat. 49 (27): 93-111

[10] Y.Enomoto, Sliding fracture of soda-lime glass in liquid environment, J. Mater. Sci. 6 (1981) 3365-3370.

[11] M. Hashish, A Model of Abrasive Water Jet Machining, J. Eng. Mater. Techol. Trans. ASME (1989) 154-162.

[12] Ramulu, M. And Arola, D., 1994, “The Influence of Abrasive Waterjet Cutting Conditions on the Surface Quality of Graphite/Epoxy Laminates”, Int. J. Mach. Tools Manuf. 34 (3): 295-313.

[13] Konig, W. And Rummenholler, S., 1993 “Technological and Industrial Safety Aspects in Milling FRPs”, ASME Mach. Adv. Comp. 45 (66): 1-14.

[14] Vaubhav.j.limbachiya[1*],Prof Dhaval.M.Patel[2] Vol. 3 No. 7 July 2011, “An Investigation of Different Material on Abrasive Water jet Machine”. ISSN: 0975-5462

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