Parametric Optimization of Abrasive Water Jet Machining of Inconel-718 material

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Abstract - *Abrasive water jet machine (AWJM) is a non-conventional machining technique in which, material removal takes place from the work piece by impact erosion high pressure and high velocity water jet mixed with abrasive material to provide smooth surface finish. Experiments are conducted to study the influence of various process parameters of abrasive water jet machining on Material removal rate (MRR) and Surface roughness (Ra) of Inconel-718. Experiments are carried out using L9 Orthogonal array by varying Water Pressure (WP), traverse speed (TR), abrasive flow rate (AFR) and stand of distance (SOD) for Inconel-718 material. In the present paper an attempt has been made to optimize the AWJM process parameters of Inconel-718 using Taguchi method.*

Key Words: Abrasive Water Jet Machining (AWJM), Taguchi Method, ANOVA, SN Ratio, MRR, SR.

1. INTRODUCTION

Abrasive water jet machine (AWJM) is a non-traditional machining process widely used in industry and material processing [1-20]. Figure 1 shows Schematic of Abrasive Jet Machining. Abrasive water jet machining has various major advantages over other cutting technologies such as high flexibility, no thermal distortion, versatility in machining, smaller cutting forces and proved to be an effective technology for processing various engineering materials [2].

It is very difficult to machine an alloy using traditional machining methods because of its high strength and work hardening nature. Hence non-traditional methods like abrasive water jet machining and laser machining etc. are used [3, 4]. Inconel-718 is one among the family of nickel-chromium based super alloys which are having high strength, corrosion-resistant used at -217°C to 704°C extreme temperatures [5]. Inconel-718 having 8mm thickness is studied in the present investigation. Zain et al. integrated two different technique viz. Simulated Annealing (SA) and Genetic Algorithm (GA) to evaluate the optimum process parameters in the abrasive water jet machining that leads to minimum value of machining performance which is compared to the machining experimental data and regression modeling [6].

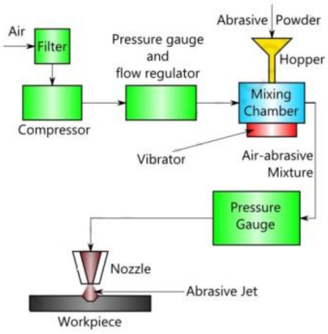

Figure-1: Schematic of Abrasive Jet Machining [2]

B. Satyanarayana et al. optimized the value of MRR and kerf width simultaneously of AWJM process on INCONEL 718 alloy using Taguchi grey relational analysis accurately. Minitab 17 was used for analysis purpose. Water pressure is the most influencing process parameter for MRR and Kerf width [7]. Z. Jurkovic et al. studied the influence and effect of various process parameter of ABWJ machining on surface roughness of machined parts. Two different materials such as stainless steel and aluminium alloy are considered for study and optimization was carried out by Taguchi method [8]. Farhad Kolahan et al. address the modeling and optimization of the process Parameters of AWJ machining technique to evaluate the effects of different parameters in cutting 6063-T6 aluminum alloy. Taguchi method and regression modeling are used to establish the relationships between input and output parameters. Model proposed by authors is then embedded into simulated annealing algorithm to obtain desired depth of cut [9]. Thakkar et al. worked on optimization of machining parameters on Material removal rate and Surface roughness of work piece of Mild Steel [10], Stainless Steel 403 [11], red mud reinforced banana/polyester hybrid composite [12], Inconel 718 [13,14], Inconel 800H [15], mild steel [16], ductile material such as AISI 4340, Aluminum 2219 [17] using Taguchi's method, Particle Swarm Optimization (PSO)

Technique [18], grey relational analysis [19].N. Yuvaraj et al. studied AJWM cutting process with multi response characteristics of AA5083-H32 by TOPSIS method [20].

Sonawane et al. has reviewed the various process parameter optimization of abrasive water jet cutting by using various optimization technique such Genetic Algorithm (GA), Teacher Learning Base Algorithm (TLBO), Partical Swam Optimization (PSO) [21]. This work deals with the study of process parameters need to be considered that influences optimal performance of AJWM for Inconel-718 using Taguchi method.

2. EXPERIMENTAL SETUP

Figure 2 shows the setup of AWJ machining test rig. The AWJ machine consists of an intensifier pump that generates high pressure water, abrasive feeding system and a cutting head which generates AWJ by abrasive injection. The movement of the cutting head on the work-

Figure- 2: Experimental setup at Universal Gasket, Gokulshirgaon Kolhapur, Maharashtra- India

piece is controlled by computer numerical control system. The eroded material during machining is collected at catcher tank in which the remaining energy of the spent jet gets dissipated.

Table- 1: Factors and Levels

Factors	Level 1	Level 2	Level 3
Water Pressure (WP)	40000	47000	54000
Traverse Speed (TS)	32	52	72
Abrasive Flow Rate (AFR)	180	280	380
Stand off Distance (SOD)	2	4	6

Figure -4: Samples used for AWJM (Inconel-718)

3. MATERIALS AND METHODS

The Abrasive Water Jet Machining equipment used consists of a high pressure pump Streamline SL-V 50 Plus made by KMT that is fitted on a CNC cutting portal with an abrasive feeding system that varies the feed rate in the range of 100–10000 grams/min. Abrasive material used was Garnet sand.

Table-3: Composition of Inconel-718

C	Ni	Mn	P	S	Cr	Mo	Si	Cu	Fe	Al	Ta
0.0 198	~ 5 4	0.0 986	0.0 164	<0. 150	3. 5 2	0.0 166	0.0 263	0.0 263	18. 67	0.4 51	~0. 660

The orifice used had an inner diameter of 0.35 mm and the focusing tube (nozzle) inner diameter was 0.76 mm. Abrasive material 80mesh was chosen (the values of abrasive particles granulation varies between 150 - 300µm).

Table- 4: Mechanical Properties of Inconel-718 [1]

Density	8220 kg/m^3
Modulus of Elasticity (at 27 °C	208 Mpa× 10 (3)
Coefficient of thermal expansion (at 21°C)	12.810 (-6)/ °C
Tensile strength	1407 Mpa

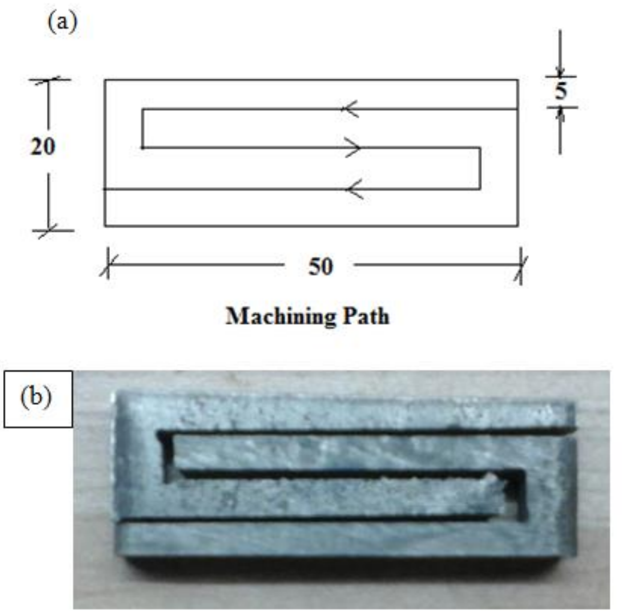

Figure-2: (a) Machining Path (b) Machined work piece

Table-5: Experimentation for MRR and SR

Sr. No.	Water Pressure (psi)	Traverse Speed (mm/min)	Abrasive flow rate gms/mm)	Stand off distance(mm)	MRR (gms/min)	SR (µm)
1	40000	32	180	2	2.355	2.324
2	40000	52	280	4	4.062	2.521
3	40000	72	380	6	5.969	2.221
4	47000	32	280	6	3.075	2.209
5	47000	52	380	2	3.905	2.201
6	47000	72	180	4	4.706	3.862
7	54000	32	380	4	2.937	2.163
8	54000	52	180	6	3.930	2.619
9	54000	72	280	2	5.239	2.433

Table- 6: Signal-to-noise ratio for MRR and SR

Sr. No.	Water Pressure (psi)	Traverse Speed (mm/min)	Abrasive flow rate gms/mm)	Stand off distance(mm)	MRR (gms/min)	SR (µm)
1	40000	32	180	2	7.439	-7.324
2	40000	52	280	4	12.174	-8.031
3	40000	72	380	6	15.518	-6.930
4	47000	32	280	6	9.756	-6.883
5	47000	52	380	2	11.832	-6.852
6	47000	72	180	4	13.453	-11.736
7	54000	32	380	4	9.358	-6.701
8	54000	52	180	6	11.887	-8.360
9	54000	72	280	2	14.384	-7.722

Table- 7: Response table for Signal-to-noise ratio for MRR

Levels	Water Pressure	Traverse Speed	Abrasive flow rate	Stand off distance
1	11.71	8.85	10.92	11.21
2	11.62	11.96	12.10	11.66
3	11.87	14.45	12.23	12.38
Delta	0.19	5.60	1.31	1.17
Rank	4	1	2	3

Table- 8: Analysis of Variance (ANOVA) for MRR

Sources	DOF	Sum of Squares	Mean Square	% Contribution
Water Pressure	2	0.0626	0.0313	0.119
Traverse Speed	2	47.232	23.616	90.276
Abrasive Flow Rate	2	3.125	1.562	5.972
Stand off Distance	2	1.902	0.951	3.635
Total	8	52.319	26.160	100

Table- 9: Statistical values for Regression Analysis for MRR

Predictor	Coefficient	SE Coefficient	T	P
constant	-1925	0.6851	-0.28	0.793
C1	-0.00000667	0.401236	-0.54	0.618
C2	0.062892	0.004327	14.53	0.000
C3	0.0027935	0.0007857	3.56	0.024
C4	0.12292	0.04327	2.84	0.047

S=0.2120 R-Sq=98.3% R-Sq(adj)=96.6%

Source	DF	SS	MS	F	P
regression	4	10.4366	2.6092	58.06	0.001
Resudual error	4	0.1797	0.0449		
total	8	10.6164			

Table- 10: Response table for Signal-to-noise ratio for SR

Levels	Water Pressure	Trasverse Speed	Abrasive flow Rate	Stand off Distance
1	-7.428	-6.967	-9.140	-7.299
2	-8.490	-7.748	-7.545	-8.822
3	-7.595	-8.796	-6.827	-7.391
Delta	1.062	1.827	2.313	1.532
Rank	4	2	1	3

Table- 11: ANOVA for SR

Sources	DOF	Sum of Squares	Mean Square	% Contribution
Water Pressure	2	1.956	0.978	9.889
Traverse Speed	2	5.043	2.521	25.498
Abrasive flow Rate	2	8.409	4.204	42.516
Stand off Distance	2	4.370	2.185	22.095
Total	8	19.778	9.888	100

Table- 12: Statistical values for Regression Analysis for SR

Predictor	Coefficient	SE Coefficient	T	P
Constant	2.125	1.523	1.39	0.236
C1	0.00000998	0.00002749	0.36	0.735
C2	0.015167	0.009622	1.58	0.190
C3	-0.003428	0.001747	-1.96	0.121
C4	0.00758	0.09622	0.08	0.941
S=0.4714 R-Sq=61.8% R-Sq (adj)=23.6 %				

Source	DF	SS	MS	F	P
Regression	4	1.4381	0.3595	1.62	0.326
Reidual Error	4	0.8888	0.2222		
Total	8	2.3269			

Table- 13: Prediction error percentage and prediction variance

Ex. No.	Verification Expt. For	Water Pressure	Traverse Speed	Abrasive flow Rate	Stand off Dist.	Predicted Value	Experimental value	% Error
1	MRR	54000	72	380	6	5.757	6.312	9
2	SR	40000	32	380	2	1.718	1.962	12

Regression Equation for MRR:

MRR = - 0.192 - 0.000007(C1) + 0.0629 (C2) + 0.00279 (C3) + 0.123 (C4)

Regression Equation for SR:

SR = 2.12 + 0.000010 (C1) + 0.0152 (C2) - 0.00343 (C3) + 0.0076 (C4)

3. RESULTS AND DISCUSSION

Surface roughness is one of the most important consideration which helps to decide, how rough a workpiece material is machined [22]. It is observed that smooth surface finish is obtained near jet entrance and gradually becomes rough near jet exit because as the abrasive particles moves down they lose their kinetic energy and deteriorates cutting ability [23]. For experimentation purpose four basic parameters i.e. water pressure, abrasive mass flow rate, nozzle traverse speed and nozzle standoff distance are considered, which controls the process outputs parameters such as material removal

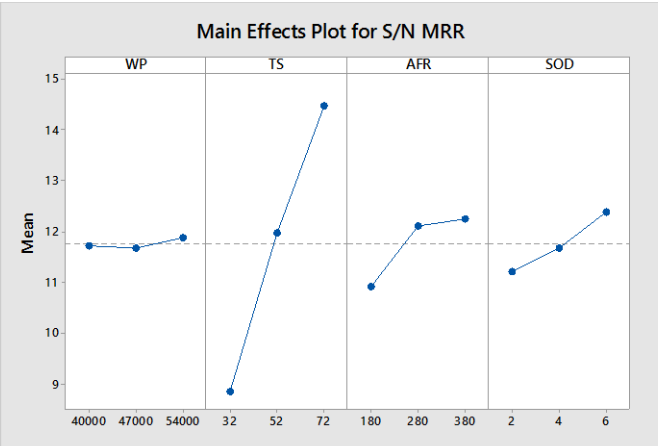

Figure-5: Main Effects plot for S/N Ratios of MRR

rate and surface roughness. The effect of each parameter on material removal rate and surface roughness is studied while keeping all other parameters constant [24-33].Figure 5 shows the main effect plot of MRR at different parameters like Water Pressure, Traverse speed, Abrasive flow rate and Standoff distance in Abrasive water jet machining of Inconel-718 material.

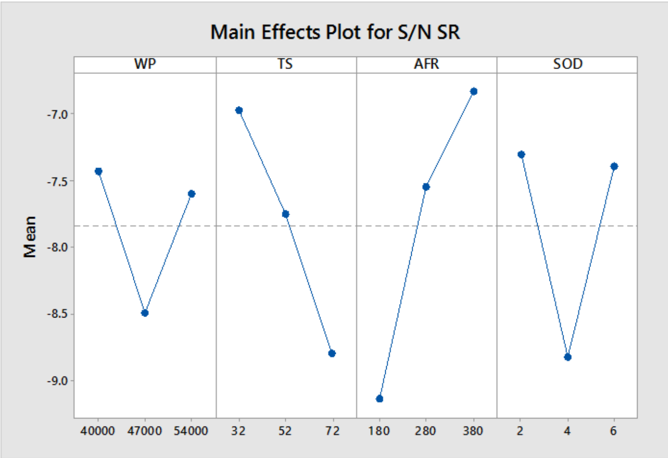

Figure-6: Main Effects plot for S/N Ratios of SR

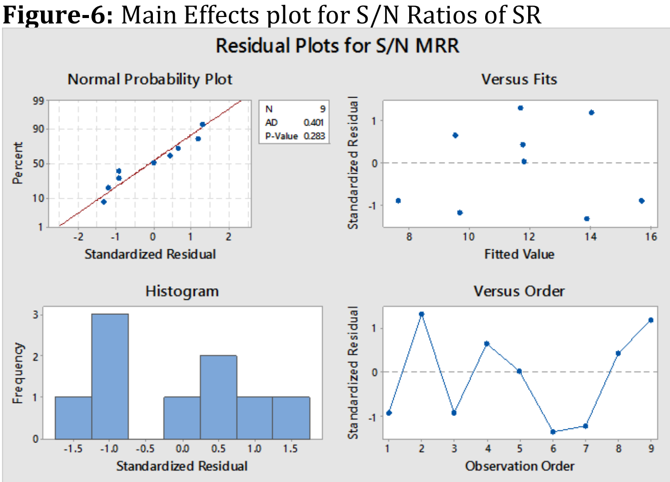

Figure-7: Residual plots for MRR

Main effects of MRR of each factor for various level conditions are shown in above figure. According to above figure5 the MRR is mostly influenced by Traverse Speed (TS) at level 3 (72). There is negligible effect of Abrasive Flow Rate (AFR), Standoff Distance (SOD) and Water Pressure (WP) was observed. So the optimal parameter setting for the MRR found WP (54000), TS (72), AFR (380), SOD (6). Fig. 6 shows the main effect plot of Water Pressure, Traverse speed, Abrasive flow rate and Standoff distance, above plot evaluates the main effects of each factor for various level conditions. According to figure6 the SR is mostly influenced by Abrasive Flow Rate (AFR) at level 3 (380), whereas negligible effect of Traverse Speed (TS), Standoff Distance (SOD) and Water Pressure (WP) was observed. So the optimal parameter setting for the MRR found is WP (54000), TS (72), AFR (380), SOD (6). Fig. 7 and 8 shows residual plot for MRR and Ra in Abrasive water jet machining process of Inconel-718 material. Residual plot is used to determine whether the predicted model meets the assumptions made in the analysis. Normal probability plot shows the data is normally distributed and variables which influences the response. Histogram indicates the data is skewed and not outliers exist. Residuals versus order of the data indicate that there are systematic effects in the data due to time or data collection order [34].

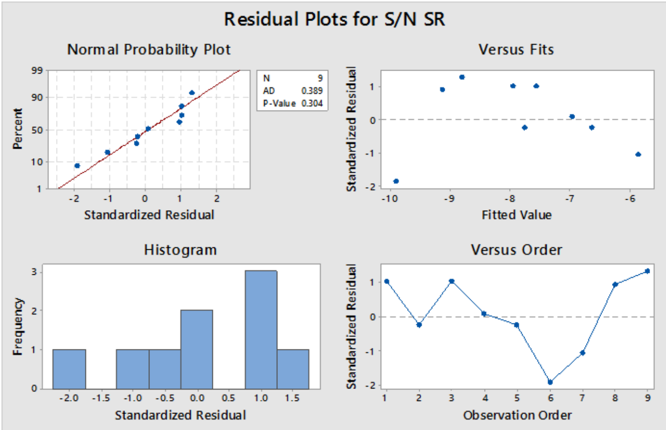

Figure-8: Residual plots for SR

3. CONCLUSIONS

This paper presents optimization of the process parameters on abrasive water jet machining for Inconel-718 material by taking Material removable rate (MRR) and surface roughness (SR) as responses. The following conclusions can be drawn for effective machining of Inconel-718 by AWJM process as follows:

Traverse Speed (S) plays a vital role on influencing material removable rate (MRR) by 90.27% as observed in ANOVA test. Then the major contribution on MRR is abrasive Flow Rate which is about 5.97%. We also observed that Standoff distance is sub significant in influencing MRR. In case of surface Roughness Abrasive Flow Rate major significance of about 42.51%.Traverse speed and Standoff distance having sub significance influence on SR by 25.49% and 22.09 % respectively.

The confirmation experiments were conducted using the optimum combination of the machining parameters obtained from Taguchi analysis. The recommended parametric combination for optimum material removal rate is Water Pressure-54000 psi, Traverse Speed-72 mm/min, Abrasive Flow Rate-380 grams/min and Standoff Distance 6 mm and the optimum response value of MRR is 6.312 grams/min.

The confirmation experiments were conducted on Surface roughness with Water Pressure-40,000 psi, Traverse Speed-32 mm/min, Abrasive Flow Rate-380 grams/min and Standoff Distance 2 mm as obtained from Taguchi analysis. The optimal response values for Surface roughness are 1.962 μm.

Table- 14: Optimal set for MRR and SR

Physical requirement	Optimal conditions			
	Water Pressure	Traverse Speed	Abrasive flow rate	Stand of distance
Maximum MRR	54000	72	380	6
Minimum SR	40000	32	380	2

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