Investigation of Process Parameters on Improvement of MRR and Surface Roughness on Abrasive Water Jet Machine for Inconel 600

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Abstract— Abrasive water jet machining (AWJM) belongs to mechanical group of non-conventional processes in which mechanical energy of water and abrasive phases are used to achieve material removal or machining. The basic methodology is that the water is pumped at a sufficiently high pressure, 200-400 MPa (2000-4000 bar) using intensifier technology and material removal taking place by impact erosion of high pressure , 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 Surface roughness of Inconel 600 material. In this research paper, Taghuchi method is used to find optimum parameters for abrasive water jet machining (AWJM). The process parameters selected in this experiment are water pressure, abrasive flow rate, jet traverse speed and standoff distance. There is L9 orthogonal array used 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 optimum combination of AWJM process parameters satisfy the real need for machining of Inconel 600 in actual practice.

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

I. INTRODUCTION

Water jet machine uses cold supersonic abrasive erosion to cut almost any materials both metals and nonmetals. The highly pressurized water stream is forced through a tiny area which carries abrasive garnet to erode away the material. Abrasive water jet and pure water jet both start with pressurized water, water is pressurizes up to 60,000 p.s.i, or 4100 bar, then is transported to the cutting head w here the pressurized water passes through a tiny hole in jew el orifice. The pressure is exchanged for velocity which is w hat the water jet cuts with, water jet actually erode the material they are cutting. After w e pass the water jet stream through orifice, the garnet abrasive similar to that you find on to sand paper is feed through a delivery line which is located on the side of the cutting head, w here it is pulled in to the water jet stream via vacuum effect, and accelerated down the mixing tube. The abrasive garnet is mixed into water-stream and is accelerated like a bullet out of a rifle.

II. WORKING PRINCIPLE

Abrasive water jet cutting on the principle of high pressure water which is being forced through a small hole onto work piece to cut materials. In an Abrasive water jet cutting machine, Initially the water pump pressurizes the water and pumps it from a water tank or other water supply to the nozzle.

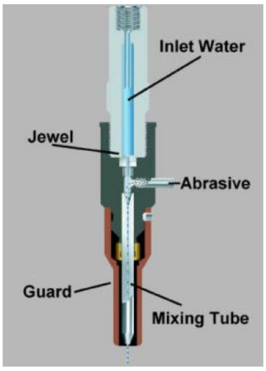

Fig. 1: A typical abrasive water jet

The heart of the abrasive water jet system is the abrasive nozzle. Water is pressurizes up to 400 MPa or more in the intensifier and expelled through a sapphire nozzle to form a coherent high velocity jet.

Abrasives are added into a specially shaped abrasive jet nozzle from separated feed ports. A part of water jet's momentum is transferred to the abrasives, whose velocities rapidly increases; as a result, a focused, high velocity stream of abrasive exits the nozzle and performs the cutting action of the work piece surface. After cutting, a water filled catcher tank collects the abrasive water mixture. The tank also acts to support the material and reduce noise.

High pressure abrasive water jet cutting is essentially an erosion process which involves two distinct mechanisms depending upon whether the eroded material is brittle or ductile in nature. The ductile erosion is defined as a cutting process in which the abrasive particles progressively cut the eroded material, eventually causing volume removal.

The brittle erosion is described as a cracking process in which material is removed by the propagation and intersection of cracks ahead of and around the abrasive particles. In fact, abrasive water jet cutting of any material takes place as a combination of ductile and brittle erosion wear mechanisms, but one or the other may dominate the cutting process.

III. ABRASIVE WATER JET CUTTING MACHINE ELEMENTS

Abrasive water jet cutting machines have four basic elements: pumping system, abrasive feed system, abrasive water jet nozzle and catcher.

- The pumping system produces a high-velocity water jet by pressurizing water up to as high as 400 Mpa using a high-power motor. The water flow rate can be as high as 3 gallons per minute.
- To mix the abrasives into this high-velocity water jet, the abrasive feed system supplies a controlled quantity of abrasives through a port.

- The abrasive water jet nozzle mixes abrasives and water (in mixing tube) and forms a high velocity water abrasive jet. Sapphire, tungsten carbide, or boron carbide can be used as the nozzle material. There are various kinds of water abrasive jet nozzles.
- Another element of the system is a catcher, for which two configurations are commonly known: a long narrow tube placed under the cutting point to capture the used jet with the help of obstructions placed alternately in the opposite direction and a deep water-filled settling tank placed directly underneath the work piece in which the abrasive water jet dies out.

IV. EXPERIMENTAL WORK

A. *Material*

AWJM is capable of machining geometrically complex and/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 etc.

Inconel, nickel-chromium-iron alloy 600 is a standard engineering material which is used for in this experiment. It has numerous characteristics and used for applications which require resistance to corrosion and heat. The alloy also has excellent mechanical properties and presents the desirable combination of high strength and good workability.

B. *Machining characteristics*

This study investigates the machining characteristics such as material removal rate (MRR). This is the most common key indicators used by many manufacturers.

Material Removal Rate (MRR)

$$MRR = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Time of machining}}$$

C. *Machine and Equipments*

The experiments are performed at Specific Jet Edge Pvt. Ltd which is leading abrasive water jet cutting machine company in Ahmedabad. The Abrasive Water Jet Machine model no is DWJ 2230. Machine Specifications are as per Table 1

Sr. No	Parameter	Specification
1	Table size	1500 mm X 3000 mm
2	X-Axis	1500 mm
3	Y-Axis	3000 mm
4	Z-Axis	210 mm
5	Ultra high pump	50 HP
6	Water Pressure	60,000 psi
7	Orifice diameter	0.30 mm
8	Number of nozzle	1
9	Dimensions of pump	1700 mm X 1500 mm X 1400 mm

Table. 1: Machine Specification

D. *Specimen Preparation*

Specimen is prepared from 10 mm thick plate of Inconel 600. Straight cut of 50 mm is taken out by cutting the work piece on Abrasive Water Jet Machine.

Fig. 2: Experimental setup preparation

E. *Sequential steps for conducting experiment*

As shown in flow chart step by step experiment activities. To perform experiments in systematic manner, MiniTab16 software is used for DOE and ANOVA analysis. Minitab16 software helps to identify significant parameter by calculating Signal to Noise ratio. Various features of the software not only help in experiments but also enhance the analysis capabilities by statistical approach. MINITAB provides both static and dynamic response experiments in a static response experiment; the quality characteristic of interest has a fixed level. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors. MINITAB calculates response tables and generates main effects and interaction plots.

F. *Selection of process parameter*

1) *Fixed parameter*

Fixed Parameters which are kept constant during experimentation are as shown in following table:

Oil Pressure	240 Kg/cm^2
Work piece material	Inconel 600
Work piece thickness	10 mm
Nozzle diameter	0.30 mm

Table. 2: Fixed parameter for experiment

G. *Control parameter and range selection*

Out of several available controllable input parameters on the Abrasive water jet machine, parameters shown in table 3 are selected with maximum feasible range.

Symbol	Control Factors	Unit	Level 1	Level 2	Level 3
P	Pressure	MPa	210	280	350
S	Stand of distance	mm	2	6	10
A	Abrasive Flow Rate	g/mn.	270	390	510

T	Jet Traverse Speed	mm/min.	90	150	210

Table. 3: Variable parameter and their selected level for experiment

V. DESIGN OF EXPERIMENT (DOE)

Design of experiments (DOE) is a powerful tool that can be used in a variety of experimental situations. DOE techniques enable designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. To achieve a thorough cut it was required that the combinations of the process variables give the jet enough energy to penetrate through the specimens.

Most researchers identified Abrasive water jet machining process parameters that greatly affect Response parameter. The Process Parameter like Standoff distance, impact angle, traverse rate, number of passes, abrasive material, abrasive particle size, abrasive shape, and abrasive mass flow rate, focusing tube diameter and focusing tube length water pressure orifice diameter etc. In this paper we have selected process parameter as Traverse rate (mm/min), Abrasive flow rate (gm/min) and Stand of distance (mm) to analyze its effect on MRR (gm/min) and Surface Roughness (**µ**m) in AWJM.

A. Experimental Procedure

In CNC Abrasive water jet machine, each parameter is set into the computer of the control panel and water pressure is set through the panel fitted in the ultra high pump.

The work piece is first weighted with the balancing machine and then kept on the rack of the working table.

After cutting the work piece the weight of the work piece is measured again and finding out the difference in weight, which is used to calculate the material removal rate.

No. of trial	**Control Parameter (Level)**				**Result / Observed value**							
	Water Pressure	Stand of distance	Abrasive Flow rate	Jet traverse speed	MRR (g/min.)				Surface Roughness (µm)			
					1	2	3	Avg.	1	2	3	Avg.
1	210	2	270	90	40.41	40.4	40.94	40.92	5.47	5.77	5.59	5.61
2	210	6	390	150	43.99	44.28	43.85	44.04	6.91	7.38	7.12	7.14
3	210	10	510	210	44.92	45.61	45.78	45.43	8.29	8.58	9.51	8.79
4	280	2	390	210	42.65	43.00	42.56	42.74	5.86	6.03	5.89	5.92
5	280	6	510	90	45.99	46.79	45.14	45.97	8.55	8.73	8.21	8.50
6	280	10	270	150	41.30	41.60	41.21	41.37	5.52	5.84	5.71	5.69
7	350	2	510	150	43.38	44.14	43.47	43.66	6.55	6.60	6.42	6.53
8	350	6	270	210	44.42	45.45	45.27	45.05	5.11	5.18	5.19	5.16
9	350	10	390	90	47.38	48.58	49.70	48.56	7.80	7.92	7.92	7.88

Table. 4: L-9 Orthogonal array with Observation table

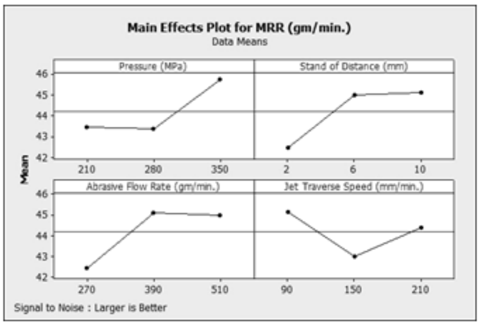

Fig. 3: Main Effects plots for MRR (g./min.)

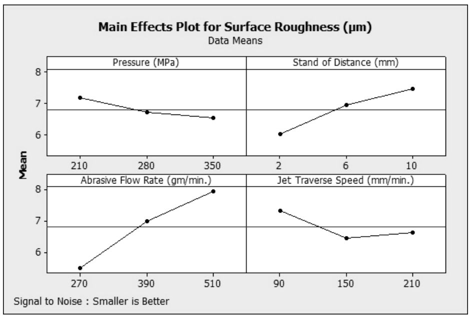

Fig. 4 Main Effects plots for Surface Roughness (µm)

VI. RESULTS AND DISCUSSION

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

A. Material Removal Rate (MRR)

Main effects of MRR of each factor for various level conditions are shown in figure 6.1 According to figure 3, the MRR increases with four major parameters Pressure (P), Stand of Distance (S), Jet Traverse Speed (T) and Abrasive Flow Rate (A). MRR is maximum in the case of pressure at level 3 (350), in the case of Stand of Distance at level 3 (10), in the case of Abrasive flow rate MRR will be maximum at level 2 (390), and in the case of Traverse rate at the level 1 (90).So the optimal parameter setting for the MRR found P3S3A2T1.

B. Surface Roughness

Figure 4 evaluates the main effects of each factor for various level conditions. According to the figure 4 the surface Roughness decreases with four major parameters Pressure (P), Surface Roughness (S), Abrasive Flow Rate (A), Jet Traverse Speed (T). Surface Roughness will be minimum in the case of pressure at level 3 (350), in the case of Stand of distance at level 1 (2), and in the case of Abrasive flow rate at level 1 (270) and in the case of Traverse rate condition surface Roughness will be minimum at level 2 (150). So the optimal parameter setting for minimum surface roughness is P3S1A1T2.

Parameter	Level Description	Level
Pressure	350	3
Stand of Distance	10	3
Abrasive flow rate	390	2
Jet traverse speed	90	1

Table. 5: Predicted Optimum Condition for MRR

Parameter	Level Description	Level
Pressure	350	3
Stand of Distance	2	1
Abrasive flow rate	270	1
Jet traverse speed	150	2

Table. 6: Predicted Optimum Condition for Surface roughness

VII. CONFERMATION 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 Inconel 600. For MRR predicted process combination is P3S3A2T1 and for SR P3S1A1T2 and found MRR 48.56 gm/min and SR 4.48µm.

VIII. CONCLUSION

This thesis 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 Inconel 600 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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