A Study of Optimized Parameter for Nickel Based Superalloys with Abrasive Waterjet Cutting

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Abstract **— The abrasive waterjet technology is a cutting process without heat. No smoke and toxic occurred during the cutting process. The cut surfaces of work pieces are clean and the quality is based on accordingly the configuration parameters. The research studies the cutting mechanism and optimized parameters for the cut surface quality. For reduce the loss of material and amount of abrasive garnet used in the process. The experiment will cut the Nickel based super alloys grade Inconel 718 thickness 6.35 mm. Design of experiment and determine the main parameters of cutting operation with Water pressure,**

Abrasive flow rate and Traverse speed. The analysis of the results obtained has been performed by Taguchi method. In order to identify the process parameters that is significant in affecting with the taper angle. The analysis of variance (ANOVA) has been carried out to estimate the relative contribution of each control factor. The cutting results showed that parameters are affected with taper angle as a function of kinetic energy loading.

Keywords **— Abrasive waterjet cutting, Inconel 718, Taper angle, Kinetic energy, Bernoulli equation**

I. INTRODUCTION

The alloys in Nickel based super alloys group which is very important in the aviation industry. This metal has a high strength due to the work hardening in the micro-structure. It is no great surprise that cutting and forming of material in this group is a very difficult. The use of heat and high energy in the process of cutting to cause problems from the heat (Heat Effected Zone) and residual stress, which affects the structure of the material. It appeared that the changes to the material properties. Furthermore, it is necessary to polish the surface after the cutting process.

This research was conducted to study the Abrasive waterjet cutting system. The intensity and the efficiency of the cutting process depend on process parameters. The cutting specimen (Inconel718) is designed to test and adjust the parameters in the cutting process. Many investigations have been conducted to understand the process variables on cutting performance measures. Kerf geometry and taper angle are characteristic of major interest in abrasive water jet cutting. In addition, statistical analysis and correlation result of the trend of graph to get a good cut quality.

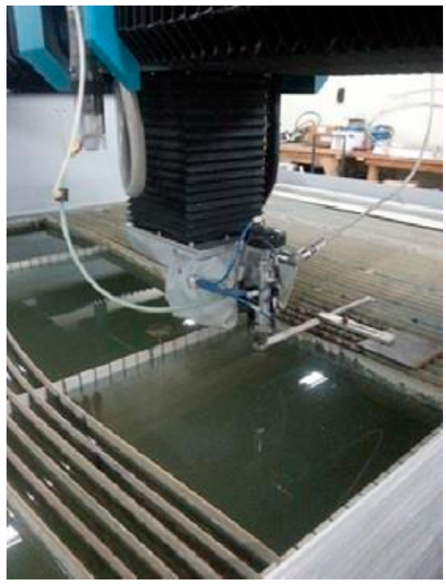

Fig. 1 shows a typical layout of an abrasive waterjet machine.

II. EXPERIMENT

A. Cutting experiment on Inconel 718

Cutting experiments were done on a two dimensional waterjet cutting machine type Flow Mach 4020b. During the cutting experiments the water pressure (psi), traverse speed (mm/min) and abrasive flow rate (lb/min) were changed in different levels.

TABLE I
VARIABLE PARAMETERS AND THEIR LEVELS

Parameters	Level 1	Level 2	Level 3
Water pressure (psi)	35000	45000	55000
Traverse speed (mm/min)	40	80	100
Abrasive flow rate (lb/min)	0.7	0.8	1

Other parameters were kept constant as follows:

Abrasive type: Garnet 80 (177µm)
Plate Inconel 718 thickness: 6.35 mm
Standoff distance: 2.5 mm
Diameter of abrasive nozzle: 1.016 mm

B. Design of experiments

A L9 orthogonal was selected for the experimentation which takes into account 3 factors at their 3 levels as shown in table 2. The total 9 runs were taken in this experimental investigation. These experiments were conducted three times at the same setting to get appropriate S/N rations [3].

TABLE II
L9 ORTHOGONAL ARRAY OF PARAMETERS

Experiment No.	Parameters		
	Water pressure (psi)	Traverse speed (mm/min)	Abrasive flow rate (lb/min)
1	35000	40	0.7
2	35000	80	0.8
3	35000	100	1
4	45000	40	0.8
5	45000	80	1
6	45000	100	0.7
7	55000	40	1
8	55000	80	0.7
9	55000	100	0.8

All Inconel 718 plates were cut with full penetration in a length of 20 mm for each experiment parameter, as shown in Fig. 2.

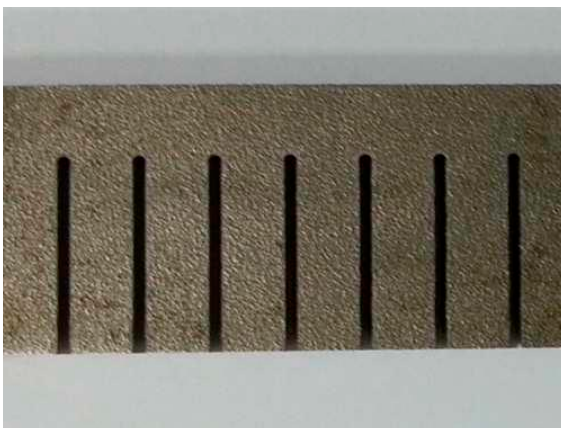

Fig. 2 The cutting surface of Inconel 718 specimen

After the cutting experiments top kerf width (Wt) and bottom kerf width (Wb) were measured for determination the taper angle.

III. RESULTS AND DISCUSSION

A. Accuracy and taper of the cutting gap

The groove taper characteristic at side view from film X-ray radiograph along the path of cut direction as shown in Fig. 3

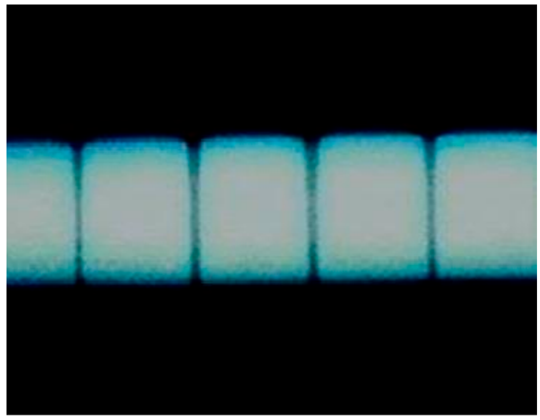

Fig. 3 Characteristic of the taper of the cutting gap from film X-ray radiograph

The main problem having effect on the accuracy of abrasive waterjet cutting is the cutting gap. The cut surfaces are almost never parallel [5]. In this case the kerf is wider at the upper side than the lower side, where the jet goes out from the workpiece. The complex geometry is usually considered like a taper, as shown in Fig. 4.

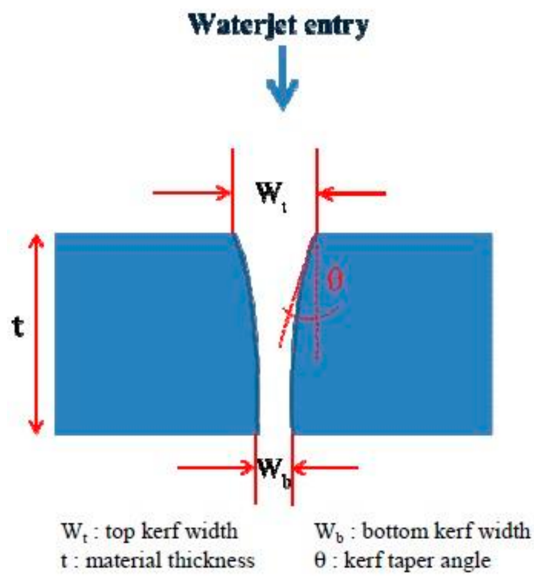

Fig. 4 The characteristic of taper angle

Kerf taper is normally expressed by kerf taper angle as [4]:

$$\theta = \arctan \frac{Wt - Wb}{2t} \quad (1)$$

From the equation can be calculated the taper angle and analysis of the results is done by software "MINITAB 17" specifically used for the design of experiment application. To analyse the effect of process parameters from taper angle, ANOVA is carried out to distinguish the most significant parameters in the generation of taper angle. For a good analysis, three tests should be verified. Figure 5 gives the residual plots for mean. This normal probability plot shows the normal distribution of residuals. It shows that the residual fall on straight line which implies that errors arenormally distributed.

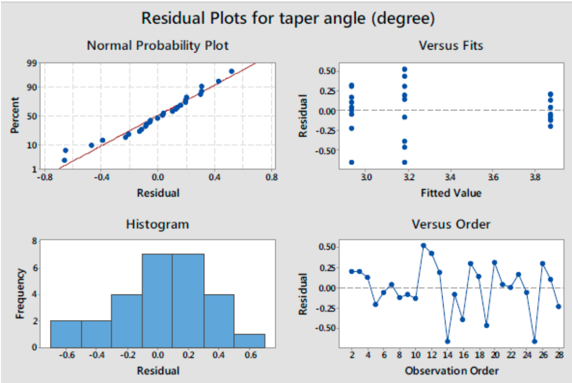

Fig. 5 Residuals plot analysis for taper angle

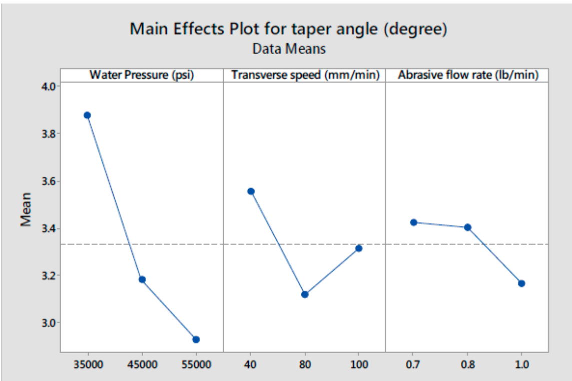

Fig. 6 Effect of process parameters on taper angle

It's is observed from figure 6 that traverse speed exhibits a negative effect on taper angle. The taper angle increases in a function of traverse speed at higher speed. As a matter of fact, a faster passing of abrasive waterjet allows fewer particles to strike on the target material and hence generate a narrower slot.

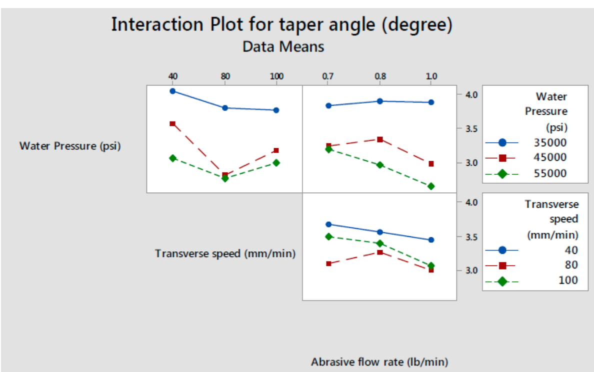

Fig. 7 Interaction plot for taper angle

The interaction plot of parameters for taper angle is shown in Fig. 7.

1) Water pressure correlate with traverse speed at 55000 psi and 80 mm/min promising results in the minimum taper angle.

2) Water pressure correlate with abrasive flow rate is found at 55000 psi water pressure and abrasive powder 1 lb/min is likely to result in minimal taper angle.

3) Traverse speed correlate with abrasive flow rate found that traverse speed 80 mm / min and abrasive flowrate 1 lb/min promising results in the minimum taper angle.

B. Energy of the cutting jet

The load energy at the upper side of the workpiece can be determined like this [2]:

$$E_m = \frac{m_a - V^2}{2} \tag{2}$$

where

m_a : mass of the abrasive, kg

v : speed of the particles in the jet, m/s

From the Bernoulli equation for the water particles speed [1]:

$$v = \sqrt{\frac{2p}{\rho}} \tag{3}$$

where

p : applied pressure, Pa

r : density of the water (1000kg/m3)

Mass of the abrasive material can be calculated by:

$$m_a = \dot{m} \, . \, t_a \tag{4}$$

where

m_a : abrasive mass flow rate, kg/s

t_a : loading time, s

Considering the loading time:

$$t_a = \frac{d}{f} \tag{5}$$

where

d : diameter of abrasive nozzle, m

f : feed rate of the head, m/s

From the equations (2)-(5) get:

$$E_m = \frac{\dot{m}.d.p}{\rho.f} \tag{6}$$

The waterjet energy can be defined for applied cutting test parameters. From the equation can be calculated the loading of kinetic energy and analysis of the results as shown in Fig. 8.

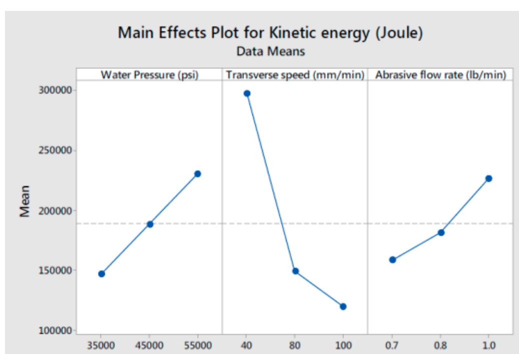

Fig. 8 Effect of process parameters on kinetic energy

The kinetic energy decreases with increase the transverse speed as shown in figure 8. This is due to the fact that as the work moves faster, less number of particles are available that pass through a unit area. Therefore, less number of impacts and cutting edges are available per unit area, which results a top kerf width wider than bottom kerf width.

The interaction plot for taper angle is shown in Fig. 9. There are clear correlation between the parameters and the kinetic energy. This phenomenon could be explained that increase pressure and abrasive flow rate result increased the kinetic energy of the jet impingement.

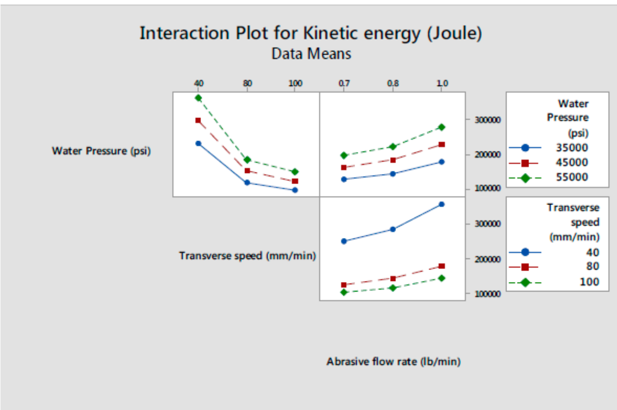

Fig. 9 Interaction plot for kinetic energy

The taper angle increases in a function of kinetic energy as shown in Fig. 10. The particles of the jet at higher kinetic energy have enough energy for material removal at the top side more than bottom side. There are resulting in a wider kerf width at the top side of the cut.

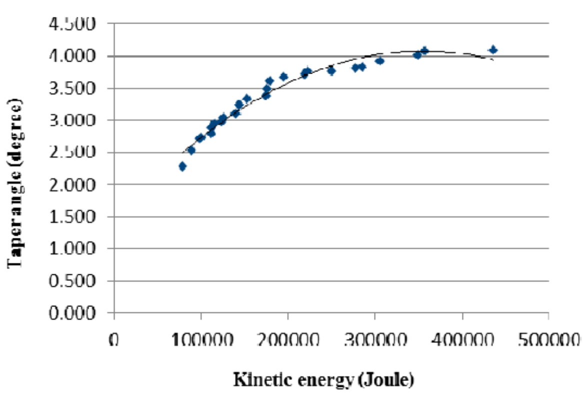

Fig. 10 Taper angle as a function of kinetic energy of the jet

IV.CONCLUSIONS

Accuracy of the abrasive waterjet cutting is mainly defined by the form of cutting gap.

- The cutting gap is always taper and the taper angle is decreasing from up-to-down.
- The widths of the cutting gap depend on the parameters as a function of kinetic energy loading.
- An increase in the water pressure and abrasive flow rate are associated with a decrease in the taper angle because of the abrasive jet is able cut through much wide at the bottom as well.

From the results it can be established that the extent of tempering of the kerf basically depends on the quantity of the energy input.

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