# Effect of Process Parameters on Abrasive Water Jet Penetration Capabilities on Inconel 718

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## Abstract

Nickel based super alloys are classified under hard to cut materials due to their mechanical, thermal and chemical properties. Inconel 718 being one among them is most commonly used in aerospace industry, space vehicles, nuclear power systems, steam turbine power plants which represents 25-45% of annual production, with its high strength and poor thermal conductivity is difficult to machine by traditional machining processes. So among non conventional machining abrasive water jet cutting with no thermal distortion, high machinability and very small cutting forces is mainly used to cut hard and difficult to cut materials. This study assess the effect of process parameters on abrasive water jet penetration capabilities on Inconel 718.The experiments were conducted on trapezoidal shaped specimen by varying the Water jet pressure, Jet traverse speed and Abrasive mass flow rate each at three level with full factorial experiments. The percentage contribution of individual and combined effects of the process parameters on penetration capability of water jet on Inconel 718 was analyzed using ANOVA. The contribution of Water jet pressure and Jet traverse speed and interaction between Water jet pressure and Jet traverse speed are most significant. The results obtained are used to build the statistical model which predicts the depth of penetration of AWJ in Inconel 718. The characteristics of the machined surface were analyzed using scanning electron microscope. This study helps to choose the correct parameters to cut the Inconel 718 with AWJ.

Keywords:Abrasive waterjet cutting, Inconel 718, full factorial experiments, ANOVA, Depth of penetration.

## 1. INTRODUCTION

Inconel 718 is one of the most commonly used nickel based super alloy which has around 25-45% of the annual production [1]. Inconel 718 is widely used in aerospace industry in engine parts typically in gas turbines, pumps, space crafts and rocket motors.Inconel 718 has high strength, corrosion resistance which can be used at -217°C to 704°C [2]. This super alloy is difficult to machine by traditional machining process due to the reasons like 1) work hardening occurs rapidly which leads to notch wear of the tool nose 2) Poor thermal conductivity develops high temperatures in the machining area upto 1200°C which leads to diffusion wear 3) Tough and continuous chips produced, due to high temperature properties its strength is maintained during machining [3, 4, 5], So nontraditional machining methods like AWJ (Abrasive Water Jet) machining and laser machining are used. AWJ machining is widely used to various engineering materials with typical advantages of no thermal distortion with very less cutting forces. It is used to cut wide range of materials mainly hard to cut materials like composites, ceramics, Ti-6Al-4V and Inconel 718 [6]. AWJ uses high pressurized water entrained with abrasives to remove the material from the work piece, the abrasives mixed with water act erosive medium [7, 8]. M. Ay et al., studied the effect of WP (Water pressure), TS (Traverse speed), AFR(Abrasive flow rate) and SOD (Standoff distance) on kerf on Inconel 718 using the Taguchi analysis. It was found out that the kerf is inversely proportional to the abrasive consumption & water pressure and is directly proportional to the traverse speed and standoff distanceAbrasive consumption and traverse speed were determined as the most effective parameters [9].

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Lenin K et al., studied the effect of Water pressure, Traverse Speed, Abrasive Flow Rate on surface roughness and kerf width on Inconel 718. The combinations of the cutting parameters was done using Taguchi's L9 array. Desirability analysis was employed to predict the optimal parameters as Water pressure = 3300 bar, feed rate = 180 mm/min and abrasive flow rate = 550 g/min. The ANOVA has shown water pressure as a significant parameter with 45.33% contribution [10]. B. Satyanarayan et al., found out optimal parameters for MRR (Material removal rate) and kerf width on Inconel 718 by varying WP, AFR and SOD and improved WP, AFR, & SOD together using Taguchi's grey relational analysis for multi response optimization. Also using ANOVA they found out water pressure has more significance on kerf and MRR than AFR and SOD [11]. Pravin R. Kubade et al., Studied the influence of WP, TS, AFR and SOD using L9 array on MRR and Surface Roughness on Inconel 718 using Taguchi method. Traverse speed has 90.27% contribution on MRR and abrasive flow rate of 42.51% on surface roughness and found out optimal parameter set for MRR and Surface Roughness [12]. Mustafa Ay et al., studied the effect of TS on AWJ machining of Inconel 718 on Surface Roughness, kerf taper ratio and kerf wideness. Six different TS were used for experimentation. They concluded that surface roughness and kerf taper ratio increased with traverse speed but kerf wideness decreased [13]. Arun S et al., optimized the process parameters water pressure, traverse speed, standoff distance and abrasive flow rate on Material Removal Rate (MRR) and surface roughness of Inconel 718 using L9 orthogonal array and ANOVA to find most significant factor. It was found that traverse speed is the most influencing factor on MRR and surface roughness [14].

Gustavo A Escobar-Palafox et al., conducted experiments on Inconel 718 using DOE considering WP, TS, AFR and Abrasive size on taper ratio, Surface roughness of different

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zones in the machined surface and subsurface condition. The result showed WP has non linear behavior in quality of surface and sub surfaces, AFR is a major factor which controls the quality of the cut surfaces [15].Dr S .Srinivas and N. Ramesh Babu assessed the penetration capability of Abrasive water jets on Al-SiC particulate metal matrix composites by doing experiments on trapezoidal shaped specimens by varying WP, AFR and TS each at three levels. Using ANOVA they found out the contribution of each parameter and combined effects of parameters and concluded that contribution of Water pressure and Traverse speed are more than abrasive flow rate [16]. Dr S. Srinivas and N. Ramesh Babu studied machinability of Al-SiC carbide particulate metal matrix composites by processing them with 60, 80, and 120 mesh size garnet and SiC abrasives. It was found out that 80 mesh size abrasives are best for getting higher depth. Further choice of abrasive material size depends on size of SiC particulate matrix material and size of the focusing nozzle [17].

It is clear that there has been lot of research working being carried out on Aerospace application materials like Inconel 718, the previous work have been done mainly on Material removal rate, kerf, and surface roughness and it is not clear about depth of penetration. So this study investigates maximum depth of penetration capabilities of abrasive water jet on Inconel 718. The thicker wedge shaped specimen is used to conduct the experiments, by varying Water jet pressure, Jet Traverse speed and Abrasive mass flow rate.

## 2. EXPERIMENTAL PROCEDURE

In this study, Inconel 718 super alloy is used which was commercially provided in 250×150×50 (mm) dimension. It was brought down to trapezoidal shape as shown in figure 1 for the experiments using the Wire EDM facility at BMSCE Bengaluru. The chemical composition of the alloy was validated using the EDAX using VEGA V3 machine at BMSCE Bengaluru and is tabulated in table 1 it meets the required composition.

The experiments are carried out on OMAX make Abrasive Water Jet machine at BMSCE Bengaluru. Figure 2 shows the mounting arrangement of the trapezoidal work piece in the machine. The preliminary experiments are conducted to finalize the values of the parameters such as Water pressure, Traverse speed and Abrasive flow rate.

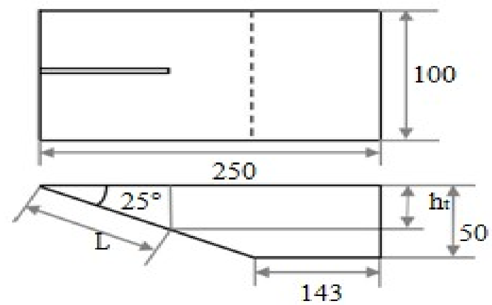


**Fig. 1. Specimen dimensions**

**Table 1: Chemical Composition of Specimen**

| Element | Weight % | Atomic % |
|---|---|---|
| AlK | 0.97 | 1.94 |
| SiK | 4.02 | 7.71 |
| NbK | 1.34 | 0.78 |
| MoK | 0.50 | 0.28 |
| TiK | 1.77 | 1.99 |
| CrK | 20.40 | 21.16 |
| MnK | 0.73 | 0.72 |
| FeK | 18.44 | 17.80 |
| CoK | 0.48 | 0.44 |
| NiK | 51.36 | 47.18 |

First the minimum water pressure with minimum abrasive flow rate condition was used and traverse speed and standoff distance were varied and the high water pressure with maximum abrasive flow rate traverse speed was varied to fix the traverse speed as with the available size of the work piece with maximum cutting condition at 20 mm/min the work piece was cut to its full depth and at 50mm/min it came around 40mm which was the limit of the size of the material. Then the preliminary experiments were conducted by varying the WP, AFR, SOD and TS using #60, #80, #100 mesh garnets by which the #60 mesh size and SOD 0f 2 mm was finalized. The range of the process parameters are in table 2.

**Table- 2: Process parameters and their levels**

| Factors | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| Water Pressure (Mpa) | 100 | 200 | 300 |
| Traverse Speed (mm/min) | 75 | 125 | 175 |
| Abrasive flow rate (Kg/min) | 0.3017 | 0.4054 | 0.5994 |
| Abrasive size | 60# | | |
| Orifice Diameter | 0.25 | | |
| Focusing nozzle Diameter | 1.07 Tungsten Carbide | | |
| Abrasive material | Garnet | | |
| Jet impact angle | 90° | | |

To study the influence of dynamic parameters and the interaction between these parameters on the penetration capability of the abrasive water jet the full factorial experimentswere conducted i.e three factors each at three levels total of 27 experiments. All the experiments were carried out by keeping the nozzle at 2mm at an impact angle of 90°. The abrasive water jet was made to traverse onto the length of the work piece to get the maximum depth of penetration.

The maximum depth of penetration was identified when there was splashing of the jet which indicates that the jet could not penetrate into the material. To find out the depth of penetration the formula ht =L sin 25° was used where L is the slant height of the cut made.

**Fig 2. Experiments on Inconel 718 block.**

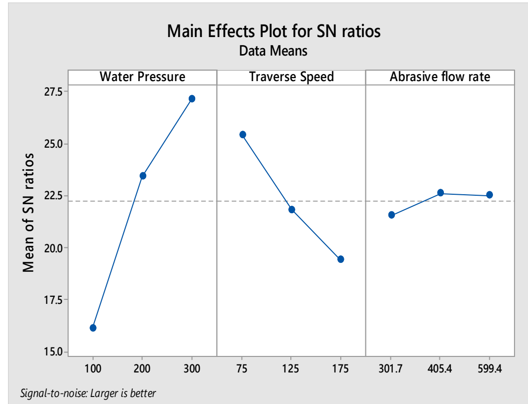


**Fig 3. Depth of penetration versus Water pressure, Traverse speed and abrasive mass flow rate.**

## 3. RESULTS AND DISCUSSION

All the 27 experiments output values were tabulated and the maximum depth of penetration was observed at WP=300Mpa, TS= 75mm/min and AFR= 599.4 gm/min and the minimum depth of penetration at WP=100Mpa, TS= 175mm/min and AFR= 301.7 gm/min. Figure 3 shows the main effect plot of variation of mean of depth of penetration with respect to WP, TS and AFR. The S/N ratio for the Depth of penetration is considered as "larger is the better". It is clearly indicated that the WP and TS have the considerable effect on the output response. The optimum values were obtained WP at level 3, TS at level 1 and AFR at level 3 for depth of penetration. With increase in the water pressure and AFR the depth of penetration increased and with increase in the traverse speed it decreased. ANOVA is used to find the percentage contribution of the each parameter and the interactions. ANOVA is an evaluating tool which gives an over view of most influencing variables and its percentage contribution among all control factors for machining response considered individually

The parameter having the F value more than standard F ratio from the statistical table is more significant and the one with less value is insignificant, in the same manner the parameter with P value less than significance level has significant contribution on the response and the and the parameter with P value more than significance level has no effect on the response. The ANOVA analysis is done for the depth of penetration using the general linear model at significance level of 0.05 and confidence level of 95% given in the table 4. The regression equation is developed and the result from the experiments and the equation is compared and the error is calculated. The total percentage contribution of water pressure, mass flow rate of abrasives and traverse speed of jet and the interactions amounts toaround 98.10% on depth of penetration of abrasive water jet in the target material Inconel 718. Among the interactions the interaction between water pressure and traverse speed is the only significant factor for the output parameter with 3 % contribution. The percentage error column around 1.9% indicates the contribution of other parameters such as dimensions of orifice and focusing nozzle, variation in size of abrasives used in the water jet on the depth of penetration, and the interactions of these parameters are not considered in the ANOVA analysis.

**Table- 4: ANOVA Result of the for depth of penetration**

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | % C |
|---|---|---|---|---|---|---|---|
| Water Pressure | 2 | 1282.00 | 1282.00 | 641.001 | 473.65 | 0.000 | 68.17 |
| Traverse Speed | 2 | 467.06 | 467.06 | 233.528 | 172.56 | 0.000 | 24.74 |
| Abrasive flow rate | 2 | 27.58 | 27.58 | 13.788 | 10.19 | 0.006 | 1.32 |
| Water Pressure*Traverse Speed | 4 | 63.43 | 63.43 | 15.857 | 11.72 | 0.002 | 3.09 |
| Water Pressure*Abrasive flow rate | 4 | 17.00 | 17.00 | 4.251 | 3.14 | 0.079 | 0.61 |
| Traverse Speed*Abrasive flow rate | 4 | 8.62 | 8.62 | 2.154 | 1.59 | 0.267 | 0.17 |
| Error | 8 | 10.83 | 10.83 | 1.353 | | | 1.90 |
| Total | 26 | 1876.51 | | | | | 98.10 |

## 4. CONCLUSION

This study clearly indicates that water pressure and traverse speed are important parameters to get the maximum depth of penetration than abrasive flow rate. Table 4 the ANOVA result clearly indicates Water Pressure with 68.17% the most significant factor and TraverseSpeed with 24.74% the next significant factor. Among the interaction Water pressure and traverse speed interaction contributes more to the response.This study will guide the researchers and the industries to choose the process parameters to get the required depth of penetration in Inconel 718.From other studies it was observed that for Material removal rate Traverse speed is the most significant factor and Abrasive flow rate for surface roughness so the combinations of these multiple output response optimizations has to be done for the Inconel 718 alloy.

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