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Investigation of surface roughness Inconel 718 in waterjet turning

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KEYWORDS

AWJT
Inconel 718
Surface roughness

ABSTRACT

Abstract: Inconel 718, a nickel-based super alloy widely used in aerospace and gas turbine industries, offers exceptional temperature strength, corrosion resistance, and work hardening behaviour. However, machining this material presents challenges due to its high strength, low thermal conductivity and work-hardening characteristics. To address these difficulties, Abrasive Waterjet Turning (AWJT) emerges as a promising alternative to conventional machining methods. This paper focuses on the application of AWJT in turning Inconel 718, exploring its principles and effects. Various factors influencing machining performance, such as spindle speed, feed rate and depth of cut are thoroughly examined and optimized. The surface roughness of the machining surface had a minimum value of 2.09 μm at run 7 while run 8 had a maximum value of Ra of 2.61 μm. Based on the results, the machine quality falls under N7 on the surface roughness chart. The investigation delves into the impact of AWJT on surface roughness while also discussing methods for monitoring the AWJT process. Through this comprehensive analysis, the potential of AWJT for machining Inconel 718 is explored, offering valuable insights for enhancing performance and its broader application in the industrial sector.

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1.0 INTRODUCTION

Surface roughness plays a pivotal role in determining the quality and performance of machined components. In the realm of machining, abrasive waterjet turning (AWJT) stands as an innovative and unconventional method that holds great promise for various applications. Surface roughness is a fundamental parameter in manufacturing that significantly impacts the functionality and aesthetics of machined components. Achieving the desired surface finish is a critical consideration in various industries, such as aerospace, automotive, and medical, where precision components are commonplace. Consequently, research in machining processes and surface quality assessment continues to garner substantial attention. Abrasive waterjet turning (AWJT) is an unconventional machining technique that has gained recognition for its versatility, environmental friendliness, and capability to process a wide range of materials. The use of high-velocity abrasive particles entrained in a waterjet enables AWJT to remove material effectively, leading to intriguing possibilities in manufacturing and surface finishing. Unlike traditional turning processes, AWJT offers a contactless, non-thermal approach, making it particularly attractive for applications with stringent material integrity requirements. Through this effort, this paper aims to offer a comprehensive perspective on this critical facet of abrasive waterjet turning, ultimately advancing the comprehension and application of this innovative machining method in manufacturing industries.

Surface roughness in abrasive waterjet (AWJ) machining and traditional turning processes differs significantly due to the distinct mechanisms involved in each method. Surface roughness in these two methods is significantly different because each method employs distinct mechanisms or techniques for material removal and shaping. In traditional turning processes, a cutting tool with a defined geometry removes material from the workpiece. The tool's cutting edge makes physical contact with the workpiece's surface, and material is sheared away, resulting in a continuous chip formation. The surface quality obtained in traditional turning is generally dependent on factors such as the tool geometry, cutting speed, feed rate, and the properties of the workpiece material (Rajkumar et al., 2018).

In traditional turning, surface roughness achieved can vary and is influenced by the tool's sharpness, vibration levels, and the occurrence of built-up edge (BUE) on the tool (Khandelwal and Sharma 2019). Although advancements in tool materials and coatings have improved surface finishes, achieving an ultra-smooth surface can be challenging, especially when machining difficult-to-cut materials like Inconel 718. The presence of BUE and the formation of micro-irregularities can lead to increased surface roughness (Sreenivasan and Gupta 2017; Zhang and wang 2017).

Abrasive waterjet machining has become a widely adopted non-traditional technology in various industries today. One of its applications is abrasive waterjet turning, which offers the ability to machine cylindrical, conical, and other rotationally symmetric parts, particularly from challenging-to-machine materials. In waterjet turning, the workpiece rotates at a speed denoted as rotational speed, while the waterjet moves linearly in the axial direction at a speed represented as direction of workpiece direction (kassim et al., 2022). The waterjet can be positioned tangentially at a specified radius of the workpiece's symmetric axis. The resulting depth of cut (ap) is influenced by various factors in both configurations (Zhang et al., 2018). For a number of convincing reasons, abrasive waterjet turning (AWJT) is preferred over traditional turning techniques for hard materials. The main benefit of AWJT is that it can cut strong materials without producing heat, in contrast to traditional turning, which frequently results in excessive heat that might jeopardize the integrity of the material. Because there are no heat impacts during AWJT, there is no possibility of material hardening, warping, or unfavorable microstructure changes concerns that are frequently raised during conventional turning. Additionally, because AWJT uses abrasive particles that wear gradually, it results in reduced tool wear, lowering the requirement for frequent tool replacements and associated production expenses. AWJT is incredibly versatile and capable of handling a variety of hard materials with accuracy, as well as having the ability to create complicated shapes. Additionally, AWJT eliminates the need for lubricants or coolants, which minimizes costs and promotes environmental sustainability. It also reduces machining residues, easing cleanup procedures. In conclusion, AWJT is a favored option for machining hard materials due to its non-thermal, precise, and environmentally friendly qualities, providing high-quality results and increased operational efficiency.

Previous studies have laid a substantial foundation for understanding the intricacies of surface roughness in AWJT. Researchers have explored a wide array of factors affecting surface quality, including process parameters, tool geometries, and workpiece materials. The work of Bera and Das (2019) provided a valuable review, summarizing the key findings related to AWJT. They explored, in the waterjet turning process, material removal occurs due to a mixture of abrasive dust, water, and air in the jet. The cutting force involved is minimal, allowing for the cutting of long and relatively small-diameter parts. This process is particularly suitable for machining brittle and difficult-to-cut materials such as glass, ceramics, composites, as well as various superalloys and titanium alloys (ASTM International 2018). Moreover, Mohamad et al. (2023) investigated the "barrelling effect" during AWJT of Inconel 718, an issue affecting surface roughness. To cut tough materials, waterjet turning cutting uses a high-pressure stream of water combined with abrasive particles. The abrasive particles operate as micro-cutting tools when the waterjet with abrasives comes into contact with the surface of the workpiece, quickly and precisely eroding and removing material. This abrasive action reduces heat generation and maintains material integrity while enabling precise shaping and cutting of many materials, from metals to ceramics.

The performance evaluation of different machining technologies typically involves optimization methods. In this section, the authors discuss the use of optimization methods to improve the performance of abrasive waterjet machining. They specifically discuss the use of response surface methodology (RSM), which is a statistical technique that can be used to optimize complex processes (Gupta and Kumar 2017). The process's quality is often characterized by the surface finish of the machined components. In this research work, the waterjet turning process is under investigation, focusing on the extent of material removal and various parameters related to the surface roughness of the machined parts (Zhang and Zhang 2019). Experimental research has been conducted to determine the main characteristics of tangential waterjet turning. Authors discuss the importance of surface finish in machining and the potential of tangential abrasive waterjet turning to produce high-quality surfaces.

Surface roughness in abrasive waterjet turning is a dynamic and evolving field of research. The findings of previous researchers have provided valuable insights into the influence of process parameters, machining strategies, and material effects on surface finish. However, challenges related to tool wear, surface integrity, and process control persist and demand continued attention.

This paper aims to contribute to the ongoing discourse surrounding surface roughness in AWJT by examining the existing knowledge base, addressing previous findings, and highlighting the current challenges. By doing so, we endeavor to provide a comprehensive perspective on this vital aspect of abrasive waterjet turning, ultimately advancing the understanding and application of this innovative machining method in manufacturing industries. However, it is essential to note that achieving the desired surface finish in AWJ machining may require optimization of process parameters, such as the abrasive particle size, jet pressure, traverse speed, and standoff distance. Additionally, post-processing steps, such as abrasive flow finishing or polishing, may be employed to further enhance the surface quality when ultra-smooth finishes are required.

Overall, while both traditional turning and abrasive waterjet machining have their merits, AWJ offers advantages in terms of surface finish, especially for complex materials like Inconel 718. The unique erosion-based mechanism of AWJ can result in smoother surfaces and reduced surface defects, making it an attractive option for precision machining applications.

2.0 SURFACE FINISH N-GRADE

The International Organization for Standardization (ISO) has developed a range of standards applicable to various industries and applications. However, abrasive waterjet turning (AWJT) does not have a specific "N grade" ISO number, unlike traditional machining processes. ISO numbers are commonly used to classify materials based on their machinability, but this classification is not directly applicable to AWJT. This is because AWJT is a non-traditional machining process that utilizes the erosive power of high-velocity water mixed with abrasive particles to cut materials, diverging from the conventional method of using a cutting tool.

Despite the absence of a specific ISO N grade standard for AWJT, many researchers do not prioritize its use. Instead, ISO grades are typically employed in manufacturing designs where a specific surface finish, as per ISO standards, is specified. Each roughness grade number is associated with a Ra number, measured in microns, providing a standardized indication of surface roughness. In figure 1, the details concerning various AWJ operations with ISO grade numbers have been presented, offering insights into the surface finish achieved through different abrasive waterjet turning processes.

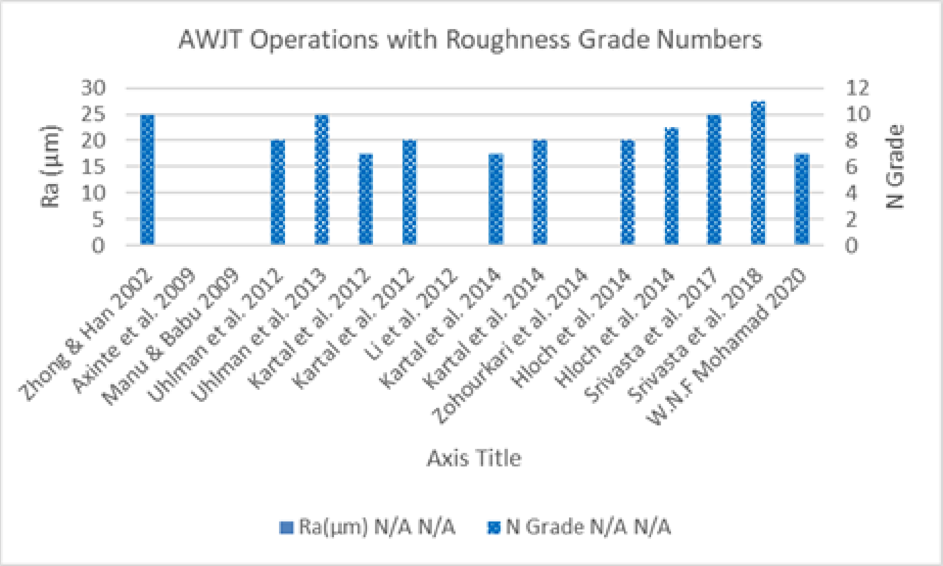


Figure 1: Various AWJT Operations surface finish equivalent with N grade (source Mohamad et al., 2020).

3.0 EXPERIMENTAL PROCEDURE

In this study, a round bar workpiece measuring 16 × 50 mm made of Inconel 718 is mounted on the spindle of a conventional lathe, with an Abrasive Waterjet (AWJ) acting on the work surface similar to a cutting tool. Before conducting the experiments, a dial indicator is used to measure the runout, which represents the misalignment between the workpiece's axis of rotational symmetry and the axis of nozzle movement. The aim is to achieve precise measurements of linear movement. The dial indicator used has an accuracy of 0.001 mm (1 µm), and zeroing is done using an electronic edge finder. The experimental setup for AWJT is shown in Figure 2, where the offset mode turning is achieved by shifting the jet velocity vector away from the centerline of the workpiece. A cylindrical workpiece is held in the collect head of a rotary motorized jig. The AWJ experiments are conducted using a flow 3-axis CNC abrasive waterjet machine (MACH 100 1313b series) equipped with a single intensifier pump capable of delivering pressures up to 380 MPa. The machine offers a cutting envelope of 1.3 m × 1.3 m, with an accuracy of ± 0.00254 mm per 1 m at traverse speeds of up to 100 mm/min. The nozzle used is a flow 40-30, and its motion is controlled by a robotic arm.

For all the turning tests, mesh size #80 garnet abrasives mixed with water in the mixing chamber are utilized. The use of garnet abrasive in waterjet cutting is preferred because of its inherent benefits. Garnet is extremely effective at cutting a variety of materials, including metals and ceramics, and has a Mohs hardness grade of 7.5-8. Due to its density, it keeps moving quickly in the high-speed waterjet stream, facilitating effective cutting. The quality and consistency of the garnet's grains, which provide reliable and predictable cutting performance, are also highly valued. Additionally, the fact that it is a natural, non-toxic mineral and is affordable adds to its appeal. Despite garnet's popularity, the choice of abrasive material might change depending on the needs of a certain application and the characteristics of the material.

The selection of process parameters and levels is based on a previous study and a set of pilot experiments (Mohamad et al. 2020). The selection of factors and their respective levels in the design of experiments (DOE) represents a critical aspect of this study. To elucidate this process, researchers begin by defining the research objective and identifying potential factors that may affect the response variable, categorizing them into independent and control factors. Factor levels are thoughtfully determined, often utilizing two or three-level options. Efficiently identifying the most influential factors is facilitated through screening techniques. To understand the effect of process variables, their interactions, and their contribution to performance measures, a reliable statistical methodology, the two-level factorial design, is used. In this study, the L 16 two-level factorial methodology type design is employed to analyze the AWJT process.

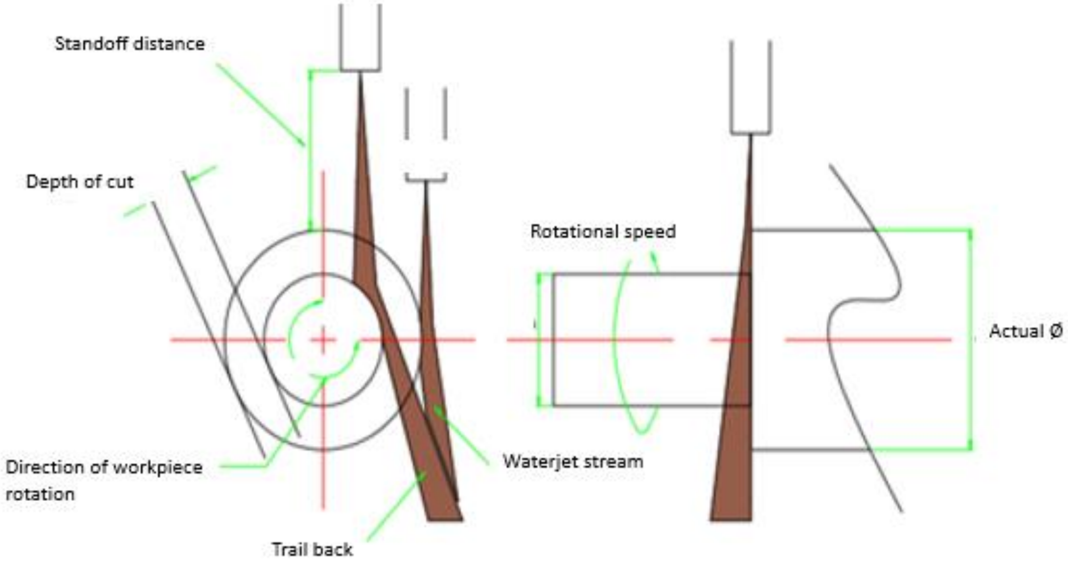


Figure 2: Mechanism of rotary AWJT offset-mode (tangential method) where the jet placed in a given radius.

The study is conducted on the test apparatus shown in Figure 3 by using a high-pressure intensifier (by pump 50 APC). The maximum working pressure is 400 MPa at a flow rate of 5 dm3/min. However, for safety factor the researcher is prohibited to set the pressure up to 350 MPa. The cutting head used is mounted on 3 axis Flow Mach 2b CNC machine (Figure 3). The console is designed for convenience, the roll-around control allows the researcher to move around freely. Flow Mach 2b CNC machine and specification as can be seen in Table 1. The working area is 1300 mm x 1300 mm x 1000 mm. The machine is equipped with an abrasive feeder from the Flow corporation company. The machine has mach 2 (2469.6 km/hrs) speed of sound, laterally at the twice speed as the aircraft travels forwards.

Figure 3: Flow Mach 2b water jet machine.

Table 1: AWJT specifications.

Specification	Description
Model	Flow-Mach 2b
Traverse Range	Up to 10 m/min
Linear Straightness Accuracy	± 0.07 mm/m
Repeatability	± 0.060 mm
Water Pressure	400 MPa

4.0 RESULTS AND DISCUSSION

Table 2 presents the outcomes of the Abrasive Waterjet Turning (AWJT) experiments conducted on Inconel 718, comprising 17 comprehensive trials. The utilization of Design of Experiments (DOE) in this research offers the advantage of establishing a thorough analysis. By employing statistical analysis, we can identify the effects of main parameters, interactions of parameters, and the significance of each parameter. Additionally, mathematical models can be generated based on the analysis, providing potential for multi-objective optimization.

The recorded surface roughness results from the set of predefined parameters ranged from 2.09 μm to 2.61 μm. Remarkably, this surface roughness is comparable to that achieved in conventional turning processes with a Ra ≤ 3 μm (Su et al., 2007; Yazid et al., 2011; Sulaiman et al., 2013). Notably, the results align with those obtained from the turning process with an N grade of 7. The nozzle's ability to maintain continuous piercing throughout the extended duration of the experiments demonstrates that the combination of AWJT parameters employed is competitive for machining Inconel 718.

To ensure unbiased results, the order of experiments was determined by a randomly chosen run number. The surface roughness, material removal rate, and roundness of the response were found to have statistically significant impacts on the overall data. In contrast, the accuracy of the dimensions was determined to be not significant, and consequently, the measurement validity will not be discussed in this section.

Table 2: Outcomes of the Abrasive Waterjet Turning (AWJT) experiments conducted on Inconel 718, comprising 17 comprehensive trials.

Standard Run	**A: Feed Rate, V (mm/min)**	**Spindle Speed, N (rev/min)**	**Depth of cut, ap (mm)**	**Surface Roughness,Ra JIS 1997 (μm)**	**Standard deviation**
1	1	60	0.3	2.51	0.21
2	3	60	0.3	2.47	0.19
3	1	90	0.3	2.09	0.16
4	3	90	0.3	2.42	0.27
5	1	75	0.1	2.27	0.23
6	3	75	0.1	2.31	0.17
7	1	75	0.5	2.13	0.14
8	3	75	0.5	2.61	0.22
9	2	60	0.1	2.36	0.20

10	2	90	0.1	2.16	0.14
11	2	60	0.5	2.44	0.22
12	2	90	0.5	2.34	0.21
13	2	75	0.3	2.37	0.27
14	2	75	0.3	2.20	0.15
15	2	75	0.3	2.22	0.14
16	2	75	0.3	2.44	0.21
17	2	75	0.3	2.46	0.18

4.1 ANOVA For Surface Roughness

The model F-value of 7.18 demonstrates significance, indicating a mere 0.32% probability that the model's creation occurred by chance. All P-values for the model terms A, B, AB, and AC are less than 0.05, rendering them statistically significant. The model terms are ranked according to the F-value, revealing that feed rate (A) exerts the most significant influence on surface roughness, followed by spindle speed (B), the interaction between feed rate and depth of cut (AC), and the interaction between feed rate and spindle speed (AB). The lack of fit F-value of 0.18 is non-significant, implying that the model adequately predicts the data. The Predicted R2 is in reasonable agreement with the Adjusted R2 of 0.7655, and the Adeq precision ratio of 0.6589 verifies that the signal is sufficient. As a result, this model proves valuable for navigating the design space.

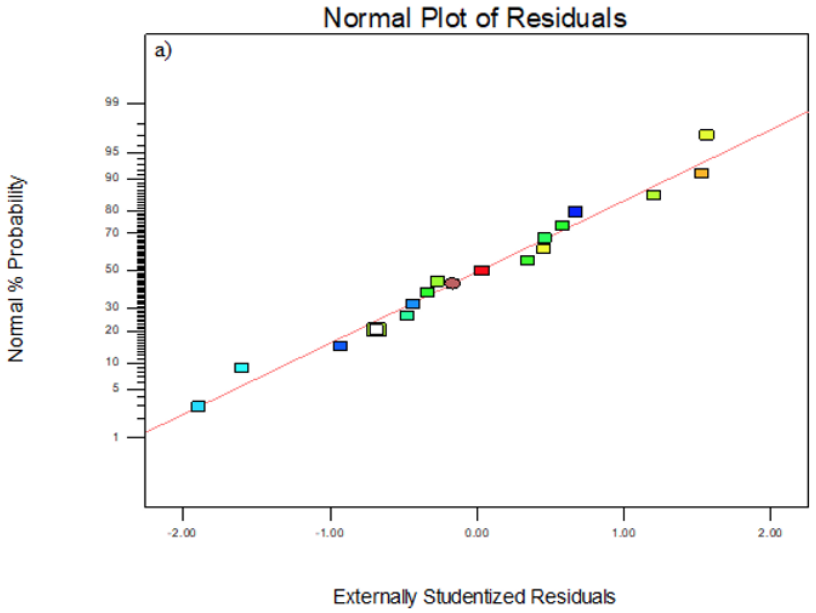
In simpler terms, the model holds significance and can effectively predict the surface roughness of a workpiece. The feed rate emerges as the most influential factor impacting surface roughness, followed by spindle speed, the interaction between feed rate and depth of cut, and the interaction between feed rate and spindle speed. Overall, the model is reliable in predicting the data, and the signal strength is satisfactory.

Table 3: ANOVA for Surface roughness

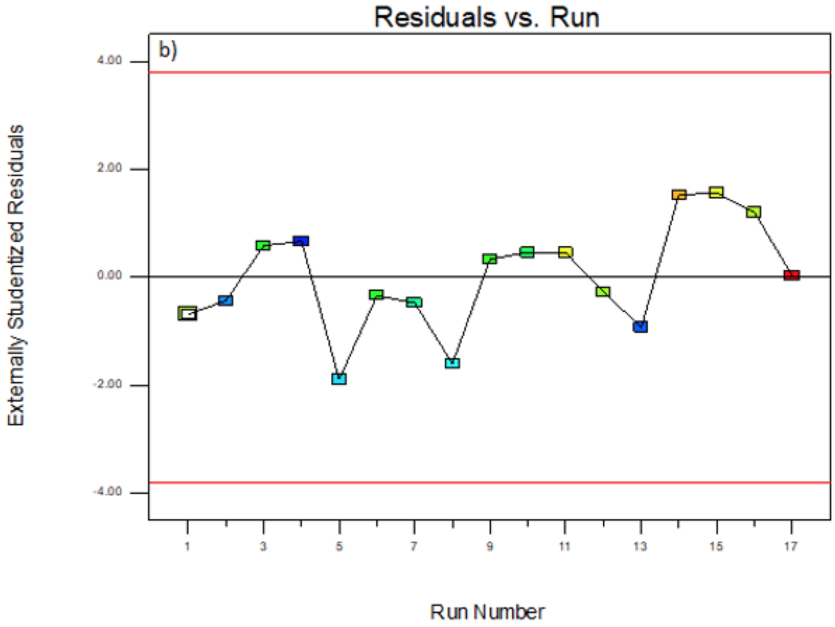
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Value**	**p-value Prob > F**	
Model	0.26	5	0.052	7.18	0.0032	significant
A-feed rate	0.08	1	0.08	11.04	0.0068	
B-spindle speed	0.073	1	0.073	10.12	0.0087	
C-ap	0.023	1	0.023	3.14	0.1041	
AB	0.036	1	0.036	5	0.0471	
AC	0.048	1	0.048	6.61	0.026	
Residual	0.079	11	7.23E-03			
Lack of Fit	0.019	7	2.77E-03	0.18	0.9738	not significant
Pure Error	0.06	4	0.015			
Cor Total	0.34	16				
Std. Dev.	0.085		R-Squared	0.7655		
Mean	2.34		Adj R-Squared	0.6589		

4.2 Model Validation of Surface Roughness

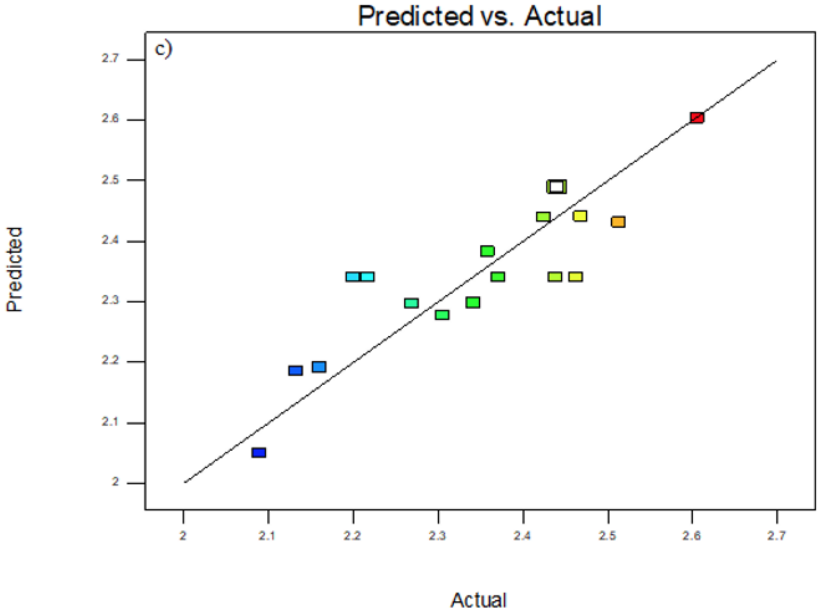
The validation model of surface roughness from the result and conclusion made by ANOVA needs to be verified using residual analysis for full acceptance. Normal plot probability (Figure 4.1a) is used to indicate that there is probability of an error in normal conditions. The distribution of errors is normal because all points are close to straight lines and the distribution of points has also been thinning at both ends of the line. According to (Montgomery, 2000), the state of the entry point that points down at the left end of the line, and pointing upwards at the right end of the line indicates that the distribution of errors at both ends is smaller than the expected size. Cook's distance (Figure 4.1b) is used to measure the effect of each experiment's value on the model and probability of an isolated error from all error values. Most of the points are close to the value of 0 and less than 0.6 which states that there are no isolated errors for all life values. The largest value to be displayed is 1 value above this limit will be truncated. Figure 4.1c depicts the anticipated and actual plots, which can be used to determine whether the model is adequate. The estimated value that is greater than the real value is above the line, while the anticipated value that is less than the actual value is below the line. The fact that all of the points approach the straight line implies that the difference between the two is minimal. Figure 4.1d shows a Box-Cox plot for the regression analysis. The plot shows the current power, represented by the dotted line at 1 on the x-axis. This means that the response data has not been transformed. The response data can be transformed by a range of powers from -3 (inverse cubed) to +3 (cubed). The plot shows the original data without any transformation. The data can be transformed by a range of powers, from the inverse cube to the cube.



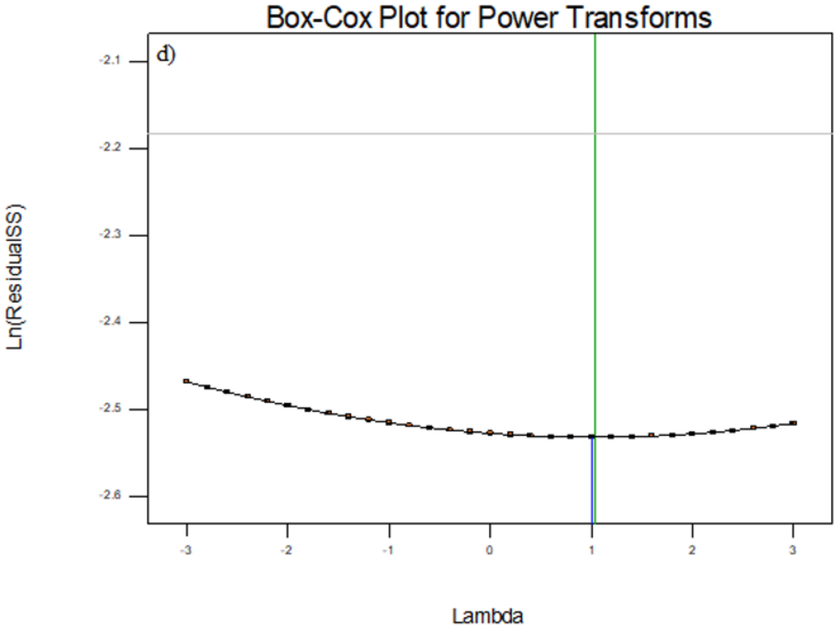
(a)


Residuals vs. Run
b)
Externally Studentized Residuals
4.00
2.00
0.00
-2.00
-4.00
1
3
5
7
9
11
13
15
17
Run Number

(b)


Predicted vs. Actual
c)
Predicted
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
Actual

(c)



(d)

Figure 4: Diagnostic plot for surface roughness (a) Normal probability (b) Residual vs Run (c) predicted vs actual response (d) Box-cox plot.

4.3 Correlation Parameters on Surface Roughness

The interaction effect of spindle speed (B) and feed rate (A) is shown in the response surface graph in Figure 5. This graph shows that reducing the feed rate will increase the surface roughness. This means that a higher quality of surface can be obtained at a low feed rate as long as the spindle speed is not affected much. Figure 6 shows the measured values of Inconel 718 alloy's average arithmetic surface roughness as a function of different feed rates in AWJT conditions. The average surface roughness values ranged from 2.09µm to 2.61 µm. This is a significant decrease from the typical surface roughness values for turning parts. It is clear from the recorded findings that increasing the feed rate causes an increase in surface roughness. This is a predictable outcome, but what stands out is how the cutting conditions affect surface roughness.

The arithmetic surface roughness decreases with decreasing feed rate. This is a predictable outcome, but what stands out is how cutting situation affects arithmetic surface roughness. To minimize the impact of depth of cut on surface roughness during waterjet turning of Inconel 718, it's essential to optimize the cutting parameters, such as jet pressure, abrasive particle size, and feed rate, as well as maintain the waterjet system to ensure consistent performance. The reason why increasing the rotational speed (RPM) does not significantly affect the surface finish during waterjet turning of Inconel 718 is due to the nature of the waterjet cutting process. In waterjet cutting, a high-pressure stream of water is used to erode the material being cut. The addition of abrasive particles to the water stream can further enhance the cutting ability of the waterjet. During waterjet turning, the cutting tool is rotated around the workpiece, allowing for the creation of complex shapes and contours.

The surface finish of a waterjet cut is affected by several factors, including the feed rate, cutting depth, abrasive particle size and concentration, and rotational speed of the cutting tool. The rotational speed of the cutting tool has a lesser effect on the surface finish than the other factors because waterjet cutting is not affected by heat. Instead, the waterjet cutting process relies on the erosive effect of the water and abrasive particles to remove material from the workpiece. Therefore, increasing the rotational speed of the cutting tool during waterjet turning of Inconel 718 may not significantly affect the surface finish. However, it is important to note that other factors, such as the feed rate and cutting depth, can still have a significant impact on the surface finish.

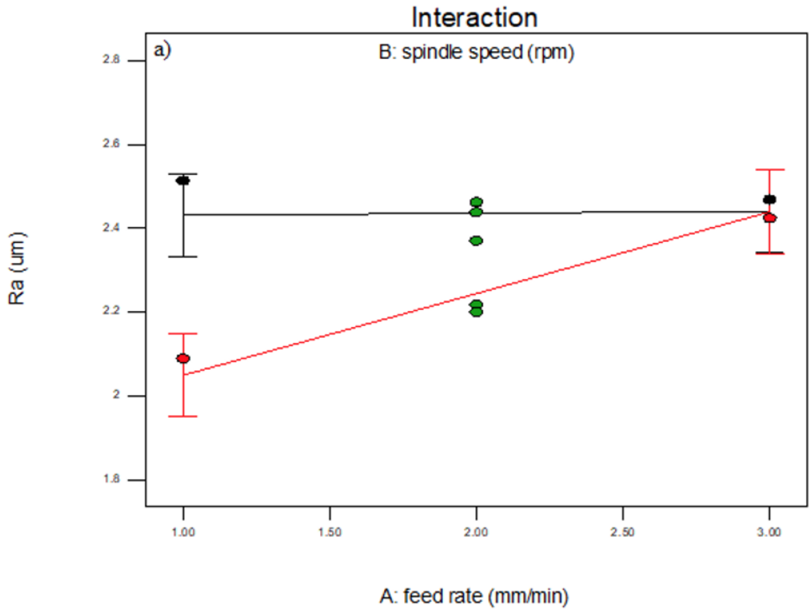


Figure 5: Response surface showing the interactive effect of spindle speed and feed rate on surface roughness.

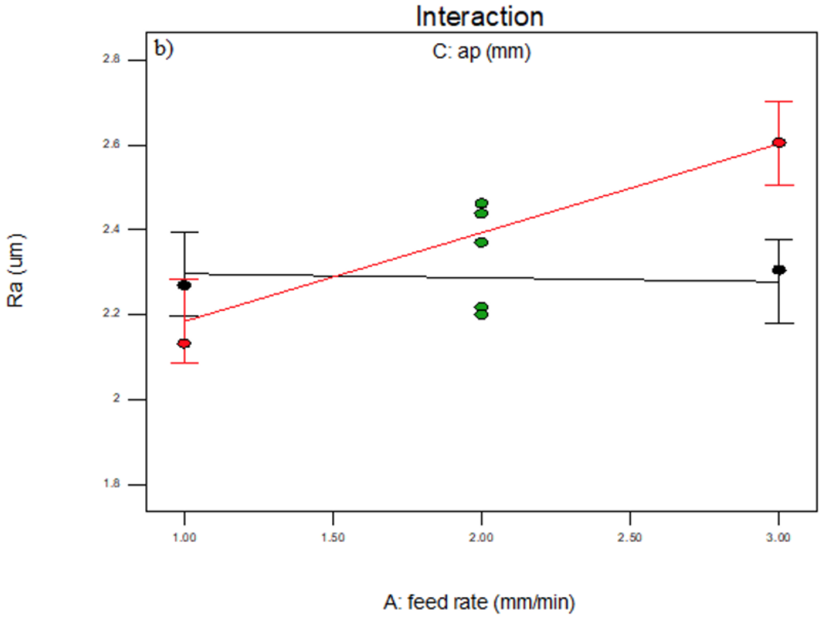


Figure 6: Response surface showing the interactive effect of depth of cut and feed rate on surface roughness.

4.4 Observation

In contrast, abrasive waterjet machining utilizes a high-velocity jet of water mixed with abrasive particles to erode and remove material from the workpiece's surface. In AWJ machining, there is no direct physical contact between the tool and the workpiece. The abrasive particles entrained in the waterjet impact the workpiece, causing erosion and material removal. The absence of direct contact between the tool and the workpiece in AWJ machining offers several advantages. First, there is minimal tool wear, which means there is no deterioration of the cutting tool that could affect the surface finish. Second, the AWJ process is capable of producing smoother surfaces compared to traditional turning. The erosion mechanism of AWJ results in a more uniform removal of material, reducing the likelihood of micro-irregularities and surface defects.Generally, abrasive waterjet machining tends to provide a smoother surface roughness compared to traditional turning, especially for challenging materials like Inconel 718. AWJ can achieve surface finishes with lower roughness values and reduced waviness, resulting in improved surface quality. Moreover, the AWJ process does not introduce thermal effects, minimizing the risk of thermal distortion or recast layers on the machined surface.

From the observation, the standard deviation from the sample from 0.14 to 0.27. it can be seen that the maximum dispersion when the parameter setting Fr=3 mm/min, N=90 rev/min and ap=0.3 mm whereas, the minimum variation during Fr=2 mm/min, N=90 rev/min and ap= 0.1mm. Table 4.4 shows both sample maximum and minimum Ra variation from run 4 and 10 respectively. Ra dispersion value very small between (0.14-0.27 %) compare to milling (Kasim, 2022) 3.7%. It was noticed that the roughness ranging between 2.09 - 2.61 µm which falls under N7 grade, hence, it was comparable with conventional turning Ra ≤ 3 µm ((Sulaiman et al., 2013) (Yazid et al., 2016).

Table 3: The different of standard deviation of Ra (a) Maximum with 2.37 µm (b) minimum with 2.16 µm.

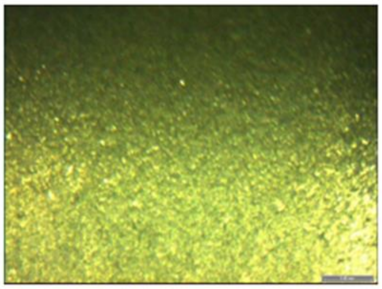
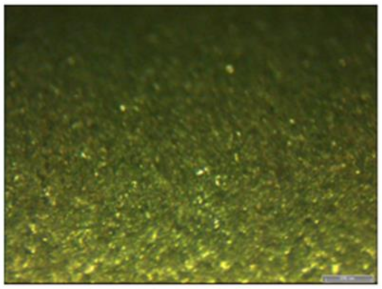
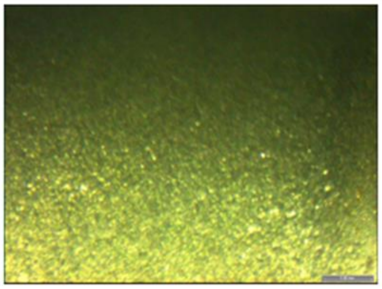
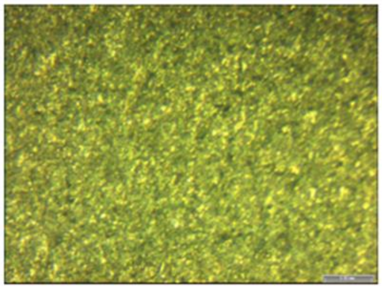
(a) Ra 2.16 µm with 0.14 deviation (Specimen 2: a_p=0.1, Fr=2 mm/min, N=90 rev/min)		
(b) Ra 2.37 µm with 0.27 deviation (Specimen 9: a_p=0.3, Fr=3 mm/min, N=90 rev/min)		
Surface Roughness	1.0 x magnification	2.0 x magnification

Table 3 displays AWJ cutting process set-up. After going through the orifice, high pressure water had a maximum speed of 100 m/s accompanied by a focusing nozzle. This in turn resulted in a transition of momentum in the mixing chamber and the nozzle from a high velocity jet to abrasive particles. In machining AWJT, Standoff distance promotes a marked shift in a kerf taper consistency. The increase in the distance from the standoff leads to increase in kerf angle and decrease in kerf width. The ideal standoff between the nozzle and the workpiece should also be minimal to achieve a more uniform shape and a good surface finish (Mohamad et al., 2020).

CONCLUSIONS

The paper investigates the application of Abrasive Waterjet Turning (AWJT) in turning Inconel 718, exploring its principles and effects. The investigation delves into the impact of AWJT on surface roughness while also discussing methods for monitoring the AWJT process. The study concludes that AWJT is a promising alternative to conventional machining methods for Inconel 718 due to its ability to produce smoother surfaces and minimal tool wear. The average roughness of the surface is smaller in the case of the tangential process and it does not show a clear change as a function of the feed speed. The statistical analysis of surface roughness reveals a robust correlation, supported by the adjusted R^2 and R^2 values of 0.7655 and 0.6589, respectively. These metrics affirm the model's capacity to precisely predict surface roughness using the process parameters. Furthermore, the confirmation experiment validates the predicted values, demonstrating excellent agreement with the actual experimental results, with the highest relative error remaining at a mere 3.0% across all machining trials. In summary, abrasive water jet turning can be used to machine materials well, but ensuring the required size is not accurate for finishing.

With tangential abrasive water jet turning, better surface quality can be achieved. The investigation also provides insights into optimizing various factors influencing machining performance, such as spindle speed, feed rate, and depth of cut. Overall, the study offers valuable insights for enhancing performance and the broader application of AWJT in the industrial sector.

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