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Material–Process Interaction in AWJM of AA6082-T6: A Materials Chemistry Approach to Material Removal and Surface Integrity

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Abrasive water jet machining is an effective non-conventional machining process that can precisely cut various materials by utilizing high-pressure water and abrasive particles. It also performs faster and can machine hard or heat-sensitive materials better than conventional cutting methods. The specific focus is on the AA6082-T6 aluminium alloy, which boasts high mechanical properties such as enhanced strength and corrosion resistance, making it desirable for various industrial applications. Optimizing machining parameters in AWJM is crucial to improving performance metrics like Material Removal Rate (MRR) and Surface Roughness (SR). The interaction between machining parameters, such as nozzle speed, water jet pressure, and abrasive feed rate, can often be complex, making it challenging to optimize machining outcomes. Consequently, a systematic approach is needed to determine the optimum conditions. In this investigation, the AWJM process was applied to the AA6082-T6 alloy, and the DOE method was used to optimize the key parameters. The results showed that the optimal conditions for maximum MRR and minimum SR were achieved at a water jet pressure of 340 MPa, a nozzle speed of 0.8 mm/sec, and an abrasive feed rate of 6.67 g/sec. Under these conditions, the measured MRR and SR values were 6.29 g/min and 5.04 Ra, respectively, reflecting the effective machining performance of the AA6082-T6 alloy under the AWJM process.

Keywords: AA6082-T6 aluminium alloy; abrasive water jet machining; design of experiments; surface roughness; material removal rate

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Abrasive water jet machining technology is an adaptable method for creating accurate cuts in a wide range of materials. The cutting procedure aims to achieve high levels of precision and efficiency. A very high-speed water jet may be used to abrasively grind sand and gravel. Consideration must be given to several performance-influencing factors while using abrasive water jet cutting. When developing a water-based abrasive application, it's crucial to keep aspects like water density and flow rate in mind [1]. A process model is a mathematical representation of the relationship between process parameters and their performance. There are essentially three types of models: experimental, analytical, and intelligence-based. Statistical regression and other conventional methods allow constructing models suitable for analytical and experimental applications [2-3]. Many researchers examined the influence of several process variables, such as nozzle velocity, depth, and abrasive flow rate, on the products' roughness. The surface roughness was assessed at the top, middle, and bottom of three different thickness cuts made under various circumstances. Based on experimental data, a feed-forward ANN was built to calculate surface roughness, and overall performance was evaluated, and the findings are compared to the experimental data [4]. The ANN learned the complex correlations between the primary AWJ input factors and cutting speed while maintaining the required cutting quality based on the application. For example, the suggested model may be utilized for parameter optimization and numerical simulations of the AWJ cut process [5]. AWJ experimental research applying Taguchi's method on austenitic stainless steel 304L indicated that increasing

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jet pressure (up to 300 MPa) and abrasive feed rate (up to 500 g/min) improves surface integrity and material removal substantially. For MRR, the optimal traverse speed was 150 mm/min and for surface roughness 90 mm/min. Material thickness was the most influential factor, which accounted for over 90% of the variation in roughness and up to 78% of the variation in MRR [6]. The non-thermal properties of AWJM are also utilized with jute fiber-reinforced polymer composites to avoid material damage. Using GRA and ANOVA, the interplay of process parameters, including standoff distance, traverse speed, and abrasive flow rate, was determined to produce the optimal settings for the minimum surface roughness and delamination. The confirmation tests confirmed such optimum settings to confirm high-quality machining [7]. Waterjet pressure was the critical parameter for the hard-to-machine austempered ductile iron, with the help of RSM with ANOVA analysis. Increasing waterjet pressure up to 360 MPa reduced surface roughness by 56.7% and kerf angle by 33%, but increased MRR by 35.46%. SEM further analyzed the surface morphology and erosion mechanisms [8].

AWJM has been effectively utilized for machining anisotropic and non-homogeneous metal matrix composites, specifically aluminum matrix composites. These composites experience high temperatures and wear on cutting tools with traditional machining methods. In one study, AA6026/SiC composites prepared using stir casting with 4% and 8% silicon carbide reinforcement were machined through the AWJM process under varying parameters. The study's outcome reveals improved material removal rates and kerf angles with higher SiC loading, although surface roughness deteriorates due to the presence of SiC. Grain size analysis showed smaller grains in composite specimens with SiC inclusions and Al-Si eutectic phase formation for the 8% composite sample during solidification. The L27 orthogonal array significantly optimized the process parameters and improved the results of AWJM [9]. Another study focused on drilling hybrid composites reinforced with Ni-P-coated glass fiber and Al_2O_3 nanowires using AWJM. Grey Relational Analysis was utilized for input parameters like water pressure, traverse speed, and abrasive mass to minimize delamination at both inlet and exit holes. In this optimal setting, minimal delamination was observed, and a superior surface quality was achieved compared to conventional machining [10]. A further research study evaluating material removal rate, surface roughness, and circularity under optimal AWJM conditions revealed deviations within the acceptable error allowance of 5%, with MRR at 3.303%, SR at 4.28%, and circularity at 4.597%, thus proving the accuracy of the output results [11]. The effects of water flow rate, abrasive, and nozzle design on the machinability of brittle and ductile materials and composites have been investigated using various statistical and computational modeling approaches in addition to well-designed experiments [12]. An existing statistical model can assess the surface structure of water jet cutting factors. Investigators could extrapolate experimental data regarding the performance results of composite materials through regression analysis [13]. A Design of Experiments (DoE) approach was employed to measure surface roughness and kerf angle. The metal removal rate was determined after classifying these features into several categories. Research on abrasive water jet turning has shown that the nozzle transverse speed and depth of cut are the two most crucial and statistically significant characteristics [14]. Conversely, turnover velocity is considered a less important metric. Results demonstrated faster material removal, enhanced output, and the lowest surface kerf profile when stand-off distance, water pressure, and nozzle speed were increased. Surfaces are flat and smooth when machining materials according to standard procedures [15]. In complex engineering applications, precision is essential. The optimization methods are described and used to develop and compare machining parameters to get the best results. Key to these different methods is improving machining performance to minimize negative impacts and maximize the influence on key desirable variables [16-17]. Parametric optimization is a systematic and efficient procedure used to adjust and align the parameters of machine tools to achieve the best potential results. Surface quality can be evaluated on heat-treated and non-heat-treated specimens by analyzing machining parameters and conducting simulations. The optimal outcome facilitates the identification of the best surface roughness solution [18].

Even though AWJM is commonly utilized for cutting complex or tough machining materials, little research has been performed to optimize process parameters for high-strength aluminum alloys. While some studies have been conducted, limited research exists on the combined effects of cutting parameters for AA6082-T6. This study aims to optimize the AWJM parameters, including water jet pressure, nozzle speed, and abrasive feed rate to machine AA6082-T6 using a design of experiments (DOE) approach. The goal of the study is to optimize the process parameters to identify those that maximize Material Removal Rate (MRR) and minimize Surface Roughness (SR) to improve the efficiencies and surface roughness of AWJM samples.

EXPERIMENTAL

A6082-T6 Aluminium Alloy

The aircraft industry is one of the most prominent global users of lightweight aluminium alloys, which are also widely used in various other fields. Aeroplanes that utilize lightweight aluminium alloys serve as an example of this. This metal truly excels in making high-strength structural components. Its combination of high ductility, excellent durability, and fatigue resistance makes it an outstanding option for structural parts. The strength-to-weight ratio of the AA6082-T6 alloy is notably high, and it has proven to be particularly useful in high-temperature applications, as well as in the aviation industry. The AA6082-T6 alloy is recognized for its exceptional strength, making it one of the strongest alloys compared to other aluminium alloys. Table 1 displays its physical and mechanical qualities. Figure 1 depicts the AA6082 base material's microstructure in its natural state. At a magnification of 100 times, there are small grains present, and there is also the production of Al-Si as eutectic particles, along with tiny $Cu\text{-}Al_2$ and Mg_2Si particles in the primary phase of aluminum that have precipitated as extremely fine particles.

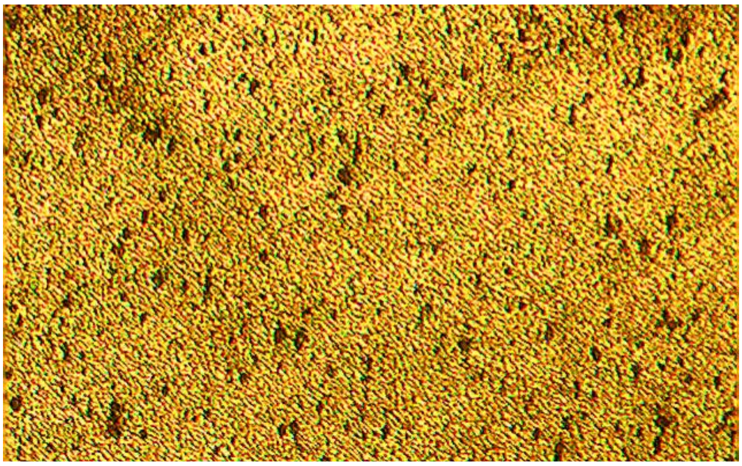

Figure 1. Microstructural Observations in AA6082-T6 alloy base Material.

Table 1. Physical properties of AA6082-T6 alloy.

Sl. No.	Physical Property	Value
1	Density	2.70 g/cm³
2	Tensile Strength	295 MPa (min)
3	Modulus of Elasticity	70 GPa
4	Hardness	89 HB
5	Thermal Conductivity	180 W/m.K
6	Thermal Expansion	24 x10^{-6} /K
7	Electrical Resistivity	0.038 x10^{-6} Ω .m

Figure 2. Experimental Abrasive Water Jet Machine.

AWJ Machining Details

The experimental tests were conducted utilising an abrasive water jet cutting machine (Figure 2) on a 500 mm x 50 mm x 50 mm AA6082-T6 alloy block. The X-Y actions on the AWJ are measured in mm at 300 mm along the X axis and in mm at 1500 mm along the Y axis. The device had a hopper for the abrasive material that was supplied by gravity. Under AWJM, some of the input elements that collected for the response of material removal rate, surface roughness are the abrasive feed rate, the nozzle speed rate, and the waterjet pressure. The full factorial approach is used to estimate three degrees of machinability for a given material based on four parameters: the water jet pressure, the nozzle speed rate, and the abrasive feed rate. Table 2 contains information on the components and degrees of machinability associated with each parameter. During the AWJM procedures, a total of sixteen different types of experimental cutting are carried out using a predetermined set of parameters by the Box-Behnken method. Then, the rate of material removal and the roughness of the surface are each measured and evaluated.

Figure 3 shows the machining samples created from AA6082-T6 materials using an AWJ machine. As stated in Table 2, the samples were machined utilizing a variety of machining settings. Table 3 contains the experimental findings of AWJM's AA6082-T6, its influential factors, and the values that resulted from those parameters.

RESULTS AND DISCUSSION

Normal Probability

Experimental design is often utilized in process development to provide the most comprehensive solution possible. The typical method does not use statistical data from a limited number of trials; instead, it relies on a complex and multifaceted process currently in progress to predict insights and outcomes. The most common experimental designs employed in manufacturing investigations are two- and three-level full factorial designs.

Researchers might use factorial designs to investigate the combined influence of process elements on a response. A full factorial design (FFD) can be used to analyze both the primary properties and relationships in research. The FFD utilizes every possible permutation of the factor levels in each trial or replication of the study [19]. The increasing number of test points results from the growing emphasis on a component or the number of variables in a constructive design. A factorial design enables researchers to examine the main and secondary effects of an experiment's variables. This method can study how multiple independent factors interact with the dependent variables or process outputs.

Table 2. AWJ machining factors and levels.

Sl.No	AWJ Machining Factors	L1	L2	L3
1	Abrasive Feed Rate (g/sec)	3.33	5	6.67
2	Water Jet Pressure (MPa)	280	310	340
3	Nozzle speed rate (mm/sec)	0.5	0.67	0.8

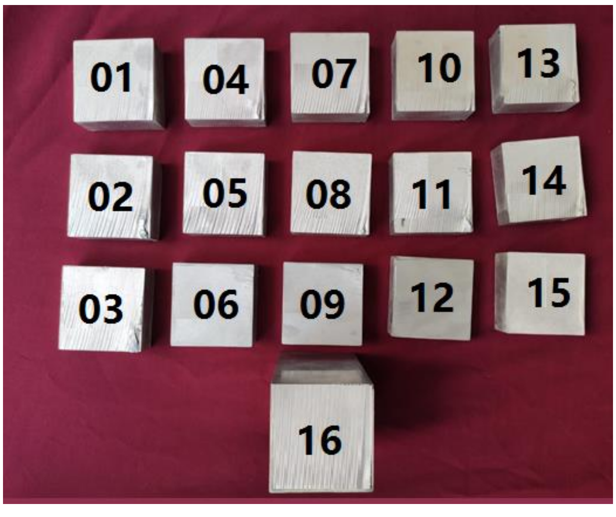

Figure 3. Machined AA6082-T6 samples in Abrasive Water Jet Machining.

Table 3. AWJM Experimental results of AA6082-T6 alloy.

Expt. No	Abrasive Feed Rate (g/sec)	Water Jet Pressure (MPa)	Nozzle Speed (mm/sec)	MRR (g/min)	Surface Roughness (Ra)
1	6.67	280	0.5	5.727	6.468
2	6.67	340	0.8	4.779	6.369
3	6.67	280	0.8	6.345	5.480
4	6.67	280	0.8	6.197	4.220
5	3.33	280	0.5	6.216	6.043
6	3.33	280	0.8	4.792	5.698
7	3.33	340	0.5	4.268	6.263
8	3.33	280	0.5	4.896	6.623
9	6.67	340	0.5	5.415	6.884
10	6.67	340	0.8	6.183	5.951
11	3.33	340	0.8	4.272	6.372
12	3.33	280	0.8	4.928	6.873
13	6.67	340	0.5	5.138	7.642
14	6.67	280	0.5	5.096	6.051
15	3.33	340	0.8	4.981	6.933
16	3.33	340	0.5	6.242	6.264

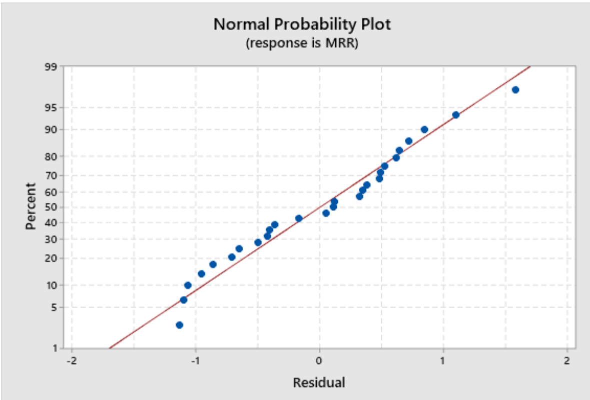

Figure 4. Normal Probability plot for MRR.

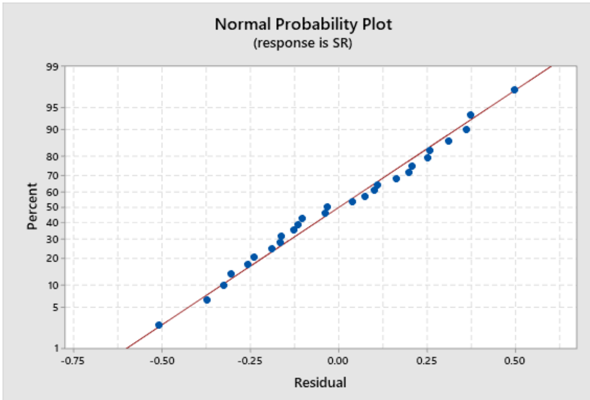

Figure 5. Normal Probability plot for SR.

The normal probability plot, shown in Figures 4 and 5, demonstrates that the error terms follow a normal distribution. The original plot is reflected in the characteristics exhibited by the residuals. To form reasonable assumptions, consider predicted components, and other features, as random and unstructured. Make sure the residual plot shows an uneven or scattered pattern before making conclusions. The normal probability plot shows the normal distribution of the data and separate response components. There was no discernible shift in the variance of the residuals compared to the fitted values. The assumption that the error terms possess a normal distribution is supported by the normal probability plot of the residuals approximating a linear relationship [13].

Interaction and Contour Plots of Surface Roughness

After machining, the surface quality of the cut surface has a significant impact on the strength of the material. This is particularly important to keep in mind when working with alloys. For abrasive water jet machined surfaces, the conventional default representation for average roughness measurements for machined surface finishes has become the average roughness measurements themselves. Predicting the surface roughness as a function of the most relevant parameters during abrasive waterjet cutting of alloys was the primary focus of this study.

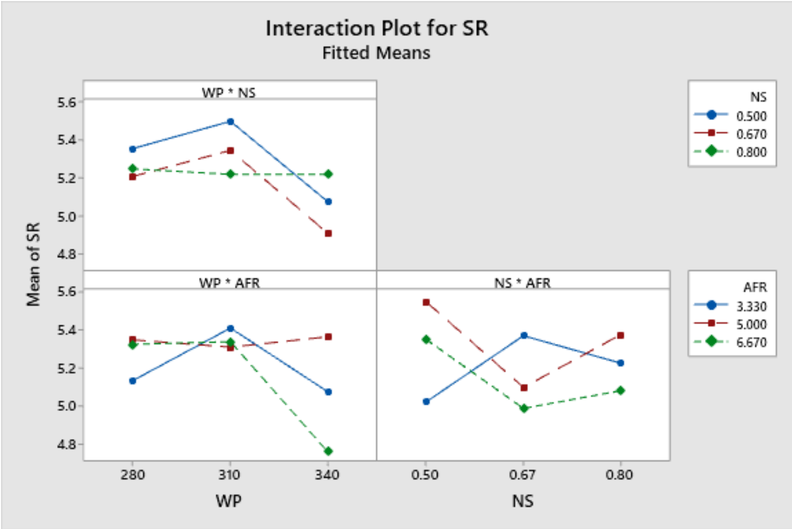

Figure 6. Interaction plot for SR.

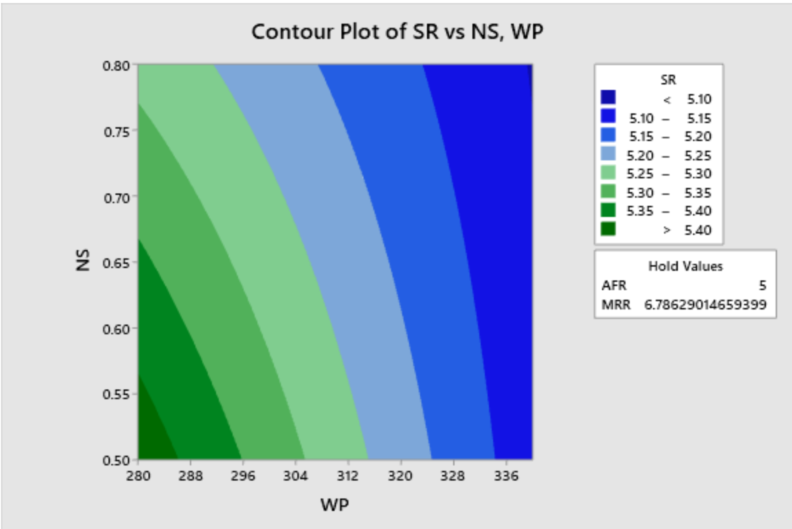

Figure 7. Contour interaction plot of WP and NS for SR.

From Figure 6, it is also evident that with increasing nozzle speed, the surface roughness increases as well. This may increase the cutting amount and the exposure time the cutting surface has with the primary cutting stream. Initially, the abrasive water stream penetrates into the cut surface and finishes cutting. There is a specific amount of time and contact needed for those actions to occur. When the speed of cutting is high, the work surface does not have sufficient time for improvement after the penetration portion of the process has occurred [20].

The jet's pressure has a clear effect on the surface finish, as depicted in Figure 7. As the pressure increases, the water's surface becomes increasingly defined. Due to the rise in water pressure, brittle abrasives fracture into smaller particles. The smaller size of the abrasives enables further contributions to the surface, resulting in a smooth finish. Furthermore, the higher water pressure allows particles to move at greater speeds, contributing to an even smoother machined surface finish. The bonding force of any material can only be compromised by a sufficiently high number of hits per area at a given power [21]. Increasing the volumetric flow of the abrasive will smooth the surface, as a higher abrasive flow creates a greater number of impacts and available cutting edges per area. The feed rate affects both the total kinetic energy and the amount of abrasive particles that strike. As more abrasives are added to the stream, the jet will have proportionately higher cutting power.

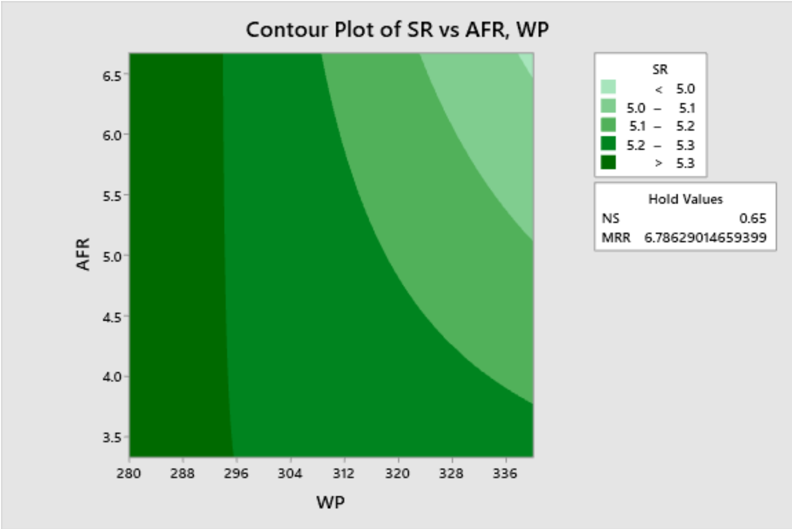

Figure 8. Contour interaction plot of WP and AFR for SR.

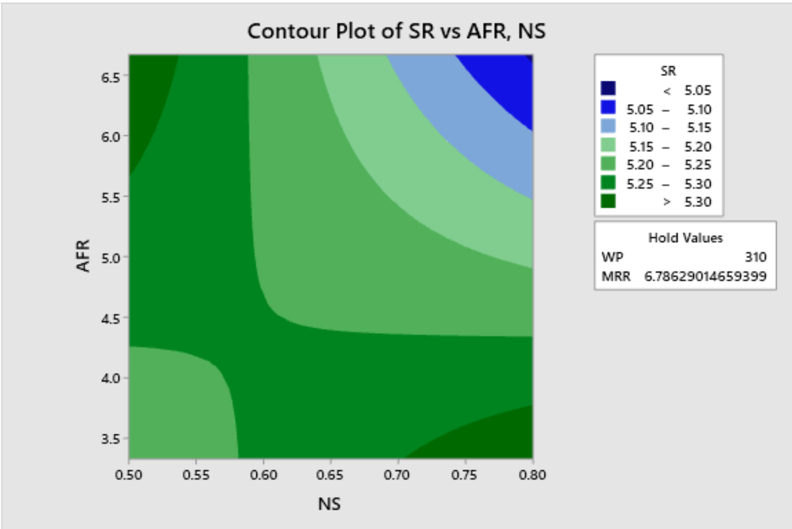

Figure 9. Contour interaction plot of NS and AFR for SR.

The amount of surface roughness produced is proportional to the abrasive feed rate and the water jet pressure (Figure 8). The time it takes to cut materials may vary significantly depending on how quickly the material is introduced. As abrasive feed rates increase and fresh particles enter the cutting zone, the abrasive particles have less time to cut through the material [12]. When the abrasive feed rate is increased, the time available for abrasive elements to penetrate the material decreases, regardless of whether the particles possess higher cutting energy. Consequently, the surface becomes rougher than it was. When there is a greater standoff distance between the two objects, the abrasive elements travel a longer distance. Increasing the distance between the abrasive elements may reduce their cutting capacity, potentially leading to a less defined shape of the material. Due to increased collisions and the greater distance traveled, the cutting effectiveness of abrasive particles diminishes as their travel distance increases [15].

On the other hand, when the flow rate is increased, abrasives tend to collide with one another, causing them to lose some kinetic energy. As one moves further away from the nozzle entrance, the surface appears more uneven. When the waterjet pressure is raised, the necessary energy is transferred to the abrasive particles, resulting in an increase in the particles' momentum and a reduction in striations. The capacity of the jet to penetrate deeper and provide a smoother finish on the cut surface is enhanced when momentum is transferred [22]. The waterjet with high pressure may cause a fracture, and because it continues to cut, it might also cause the fractured portion to elongate even more. With a slower nozzle speed you can make a complete cut for relatively ductile materials, it should improve spirit and texture while controlling the MRR, thus making for a striation-free area altogether. Depending upon the fragile material, it may be necessary to adopt a higher jet nozzle speed for surface quality. As seen in Figure 9, the combination of higher water jet levels and a lower jet traverse speed may work to improve the results and as a result, improve quality attributes [23].

Interaction and Contour Plots of Material Removal Rate

In every machining process, the rate at which material is removed from the workpiece is an essential determinant of the overall efficiency of the operation. It was determined that the feed rate was the most relevant of all the parameters. It was discovered that an increase in feed rate led to an improvement in material removal rate (MRR). The sharp increase in throughput drastically reduces the amount of time necessary to finish the procedure. The time required to complete the procedure is determined by the feed rate.

When the jet pressure is increased, the kinetic energy of the abrasive particles is also enhanced. The higher kinetic energy of the particles improves cutting capability, allowing for the removal of a greater volume of processed material. Figure 10 shows that higher jet pressure increases the material removal. This may be due to the jet diverging and the increased distance between the workpiece and the jet, which results in abrasive particles receiving less kinetic energy.

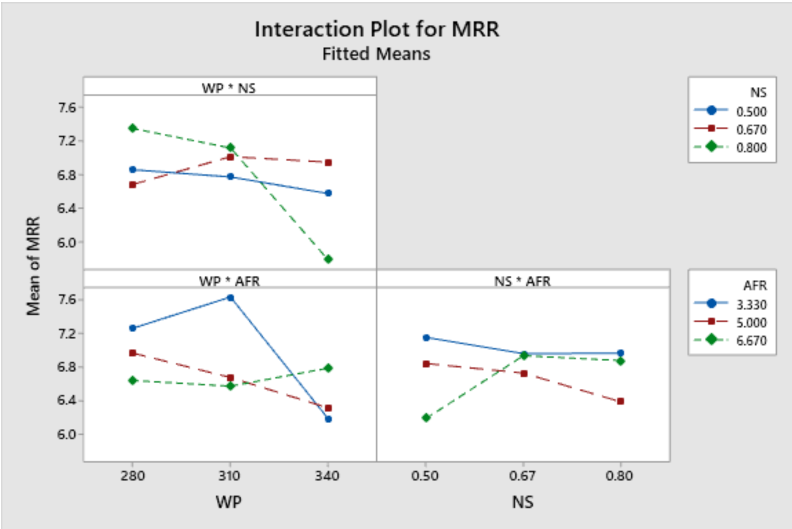

Figure 10. Interaction plot for MRR.

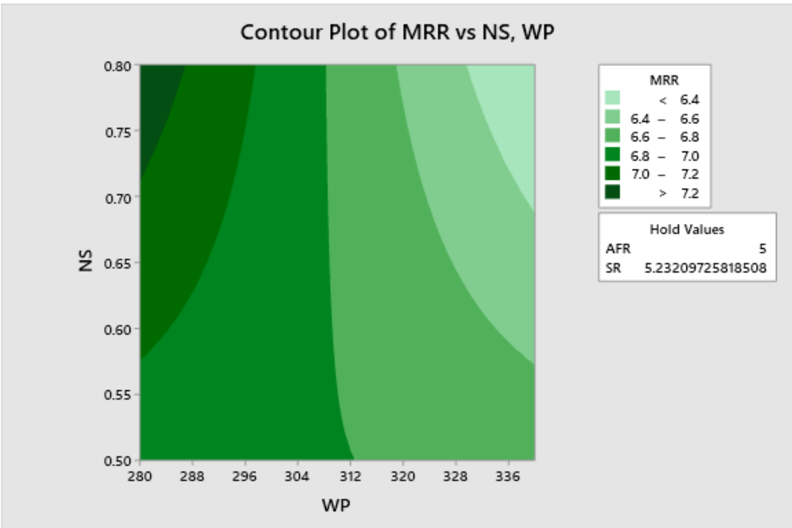

Figure 11. Contour interaction plot of WP and NS for MRR.

Due to its crucial role in determining the final outcome of the machining operation, it is one of the most significant factors to consider. Among those tested, the feed rate was the most relevant factor. It was shown that the MRR improved with a higher abrasive feed rate, leading to the conclusion that these two factors are related (Figure 11). Increasing the feed rate has resulted in reduced processing time for the goods. Since the feed rate dictates how long the procedure takes to complete, it is an important variable. Both the water pressure and the kinetic energy of the abrasive elements increase as the pressure rises. Abrasive elements with higher kinetic energy are more effective cutters, allowing for greater material removal simultaneously [22].

Figure 12 shows that as jet pressure and abrasive rate increase, the MRR decreases. One possible explanation is that the kinetic energy of the abrasive particles is reduced and the jet diverges as the distance between the workpieces increases. The metal removal rate is positively correlated with the abrasive feed rate and negatively correlated with the nozzle speed when these two parameters interact at lower levels [2]. Conflicting forces between the abrasive feed rate and the nozzle speed lead to this occurrence. The rate of metal removal slows slightly as the pressure of the water jet increases, resulting in a decrease in the amount of material removed. However, the amount of material being removed decreases when the nozzle speed increases. When material removal increases for any input factor, the value decreases, as can be observed when considering both water pressure and nozzle speed together [15].

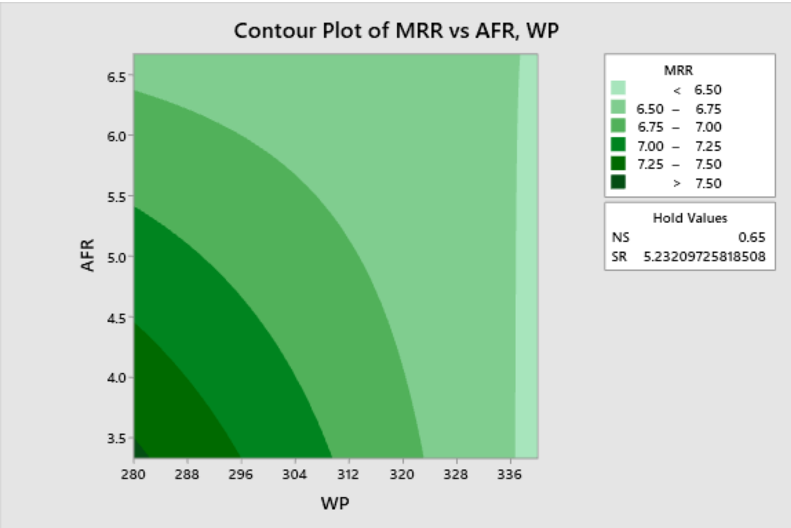

Figure 12. Contour interaction plot of WP and AFR for MRR

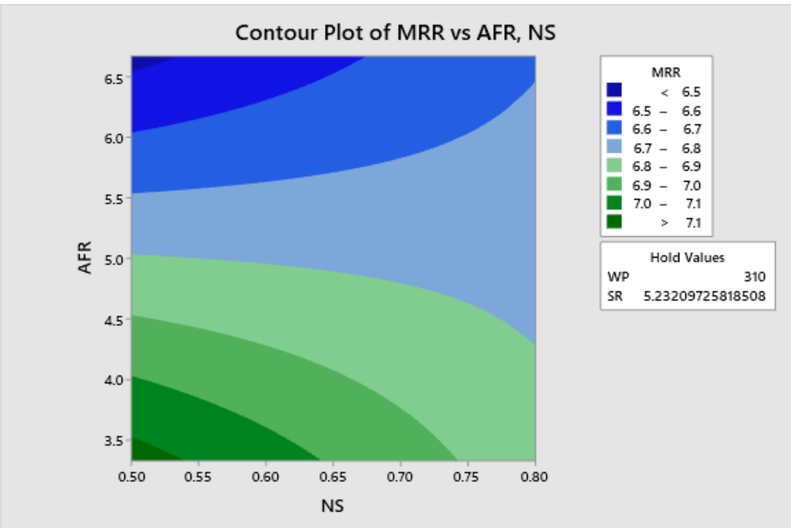

Figure 13. Contour interaction plot of NS and AFR for MRR.

Table 4. AWJM Process Parameter results.

Solution	AF	WP	NS	SR Fit	MRR Fit	Composite Desirability
1	6.67	340	0.80	5.04461	6.29748	0.861199

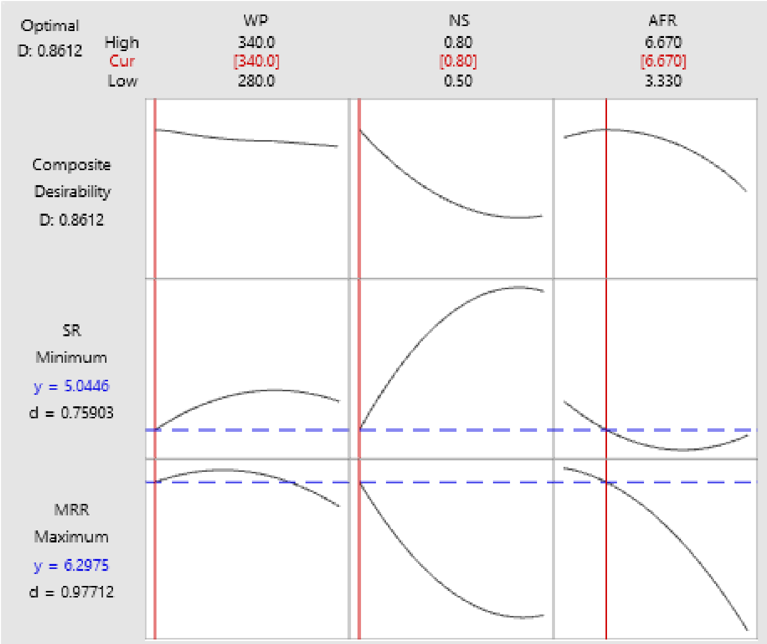

Figure 14. Response optimization plot of AA6082-T6 alloy.

An enhanced abrasive feed empowers the involvement of more cutting edges during machining, which is crucial when working with fragile materials to achieve an effective cut and better surface quality. However, in the case of a ductile alloy such as aluminium, it is preferable to keep the abrasive flow rate at a modest level. This approach reduces the likelihood of electrified abrasives becoming entrenched in the material, risking texture damage [14]. A moderate abrasive flow rate enhances nozzle life and texture by allowing full participation of cutting edges, while its interaction with a lower jet nozzle speed is clearly illustrated in Figure 13, showing improved results. This improvement is evident in the observations made. A lower water pressure value causes abrasive particle rebound, shortening nozzle life and increasing the MRR, while a higher water pressure produces jet divergence, leading to energy loss in the jet [23].

Process Parameter Optimization

By experimenting with different combinations of input variables, Response Optimizer can find the optimal configuration for enhancing the quality of either a single response or a batch. Minitab generates an optimisation graphic in addition to computing the optimal solution. Using this interactive visualization, you are able to adjust the values of the input variables to do sensitivity studies and maybe improve upon the original result. The program will optimize the model parameters by first recasting the design requirements as a constrained minimization issue, and then using optimization strategies to find a solution to the constrained minimization problem.

From the optimization plot of Figure 14, the results of the study very well present the ideal input parameters for machining AA6082-T6 aluminum alloy using AWJM. These are three main parameters: WP, NS, and AFR where MRR is maximized and SR minimized. The optimal conditions are obtained as seen in the following data presented in Table 4 as, water jet pressure of 340 MPa; nozzle speed of 0.8 mm/sec; abrasive feed rate of 6.67 g/sec.

From the graphs, it can be inferred that the factors lead to the maximum MRR, which is a value of 6.29 g/min, and the minimum, which is a value of 5.04 Ra. In the optimization plot, the nozzle speed and abrasive feed rate exhibit a greater effect on MRR and SR. The nozzle speed relative to MRR tends to increase up to a certain point and then stabilize. The rate of abrasive feed is also directly proportional to MRR; however, improving the feed rate results in increased material removal. A high feed rate of abrasives, combined with an optimized nozzle speed, facilitates machining with maximum material removal. Surface roughness behaves differently. Although surface roughness generally decreases with an increase in nozzle speed, the effect of abrasive feed rate on SR is quite complex, as an increase in feed rate beyond a certain stage can lead to increased surface roughness. Therefore, a critical balance of these parameters is required to achieve the best quality surface while maintaining high material removal rates. This value represents the overall performance of the chosen parameters in serving the two conflicting objectives of maximizing the material removal rate and reducing surface roughness. The desirability score is relatively high for the composite, meaning that the best combination of water jet pressure, nozzle speed, and abrasive feed rate chosen for AWJM on AA6082-T6 provides optimal performance. This study confirms that water jet pressure, nozzle speed, and abrasive feed rate are key parameters in optimizing machining. Future studies may involve finer adjustments of these parameters or determine their effects on other materials [24].

The surface morphology of the AA6082 alloy, which can be seen in Figure 15, is the subject of this research. The rate of material removal was inconsistent concerning the input parameters due to the unequal obstacles. Additionally, it was found that there is dimple development in the aluminum alloy that had a homogeneous distribution of the reinforced particles. It was confirmed that it exhibited great ductility after observing fine dimples in the material.

A relationship is explained using the graph (Figure 16 a) between Abrasive Feed Rate, Material Removal Rate, and Surface Roughness. The results clearly show that with increases in the feed rate values, MRRs exhibit a regular trend of rising up but not entirely linear, whereas as the rise goes in the values of feed rate, the SRs rise sharply. For instance, when the AFR stood at 6.67 g/sec and the water jet pressure was set at 280 MPa (Experiments 1, 3, and 4), MRR peaked at 6.345 g/min (Experiment 3) and then dropped low with increased pressure. In Experiment 2, MRR reduces to 4.779 g/min at 340 MPa. This means, although the abrasive feed rate increases, with higher feed rates and pressures, suboptimal MRRs might be attained due to possible interference between grains. Surface Roughness (Ra) tends to be higher for higher feed rates of abrasives, particularly in Experiment 13 where Ra peaks at 7.642 μm for feed rate 6.67 g/sec and pressure 340 MPa. This would imply that although a higher AFR may result in higher material removal rates, the surfaces turned out to be more rugged, as seen for Experiments 9 and 13, which have Ra values of 6.884 μm and 7.642 μm, respectively. Hence, this in turn calls for optimization of AFR for the purpose of good material removal with minimized roughness [25].

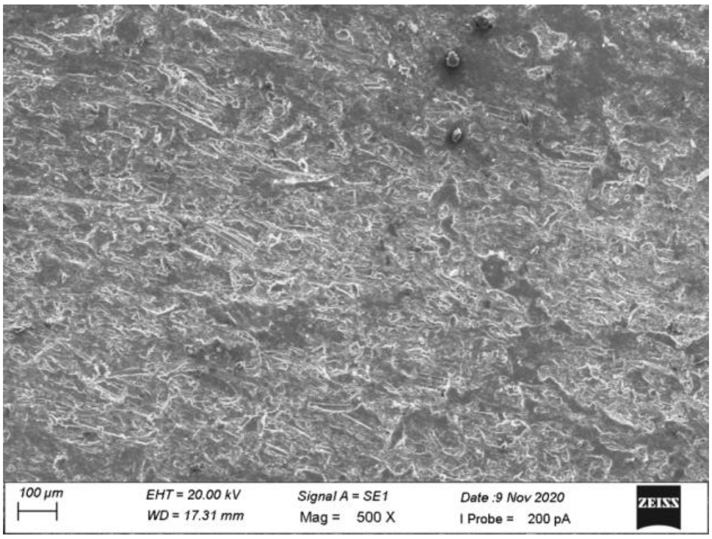

Figure 15. SEM Images of AA6082-T6 alloy.

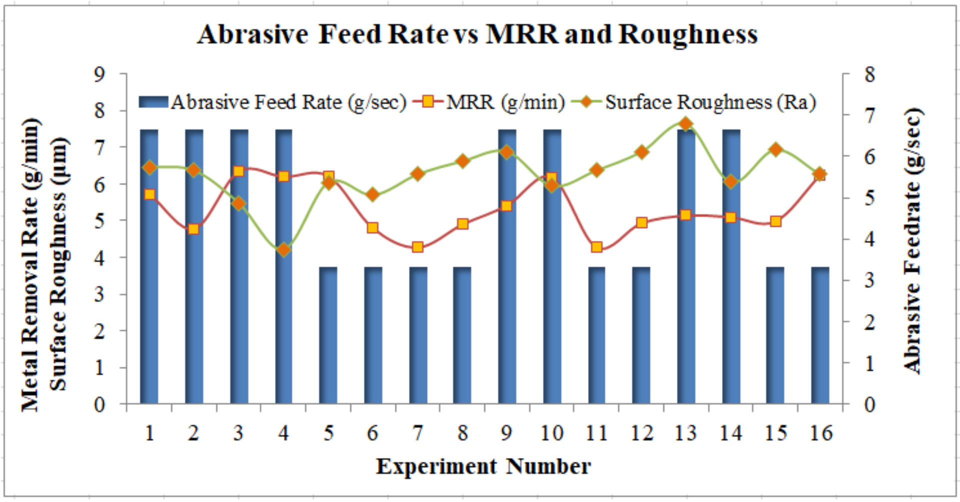

Figure 16. (a) Correlations of Abrasive feed rates and Outcomes of MRR and SR

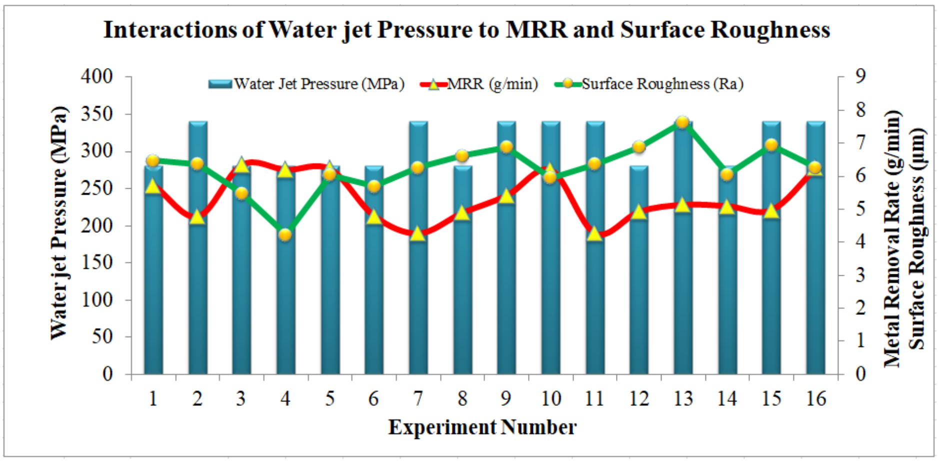

Figure 16. (b) Correlations of Abrasive feed rates and Outcomes of MRR and SR.

Figure 16 b presents the effect of WJP on MRR and SR while considering the interaction between different pressures and nozzle speeds. The data indicate that as WJP increases, MRR also tends to rise with some fluctuations. For instance, at a WJP of 340 MPa in experiment no. 9, with the nozzle speed maintained at 0.5 mm/sec, the MRR is recorded at 5.415 g/min. Conversely, when the same pressure is applied but the nozzle speed is increased to 0.8 mm/sec in Experiment 10, the MRR rises to 6.183 g/min. This demonstrates that nozzle speed significantly influences MRR; slower speeds provide more time for abrasive particles to impact the surface of the material, thereby increasing the removal rates. However, surface roughness exhibits an unpredictable trend concerning variations in water jet pressure. For example, in Experiment 9 at a pressure of 340 MPa with a nozzle speed of 0.5 mm/sec, the SR value is 6.884 µm; yet in Experiment 10, using the same pressure but with a nozzle speed of 0.8 mm/sec, the SR is comparatively lower at about 5.951 µm. This suggests that the longer time allowed by the nozzle can result in coarser surfacing. In Experiment 13, with a WJP of 340 MPa and a feed rate of 6.67 g/sec, the surface roughness reaches its highest recorded value of 7.642 µm. This may be attributed to high abrasive feed rates, which, coupled with elevated WJP, lead to more intense interaction between the abrasive particles and the material, resulting in a rougher surface [26]. The figures presented indicate that abrasive feed rate, water jet pressure, and nozzle speed vary linearly with both MRR and SR. High abrasive feed rates and high water jet values enhance material removal but generally come at the expense of increased surface roughness. One of the major requirements in industrial applications is to maintain surface quality, and efficiency cannot be compromised [27].

CONCLUSION

This research highlights the use of AWJ to optimize cutting parameters for AA6082-T6 Aluminum alloy, an important industrial material due to its significant strength and resistance to corrosion. Investigations provide evidence that using DOE enhances machining performance with higher MRR and lower SR. Under optimal cutting conditions, such as a nozzle speed of 0.8 mm/sec, an abrasive feed rate of 6.67 g/sec, and a water jet pressure of 340 MPa, the experiments yielded an MRR of 6.29 g/min and an SR of 5.04 Ra, showing efficient machining results. The optimization results demonstrate that the abrasive feed rate and nozzle speed are the key factors influencing MRR and SR, making them critical parameters for achieving optimum results in AWJM. This non-thermal cutting method eliminates the risk of heat-induced defects, such as phase changes or thermal damage that occur in most conventional processes. Moreover, as AWJM is a non-contact process, tool wear is avoided, reducing the product's running costs while extending equipment life, further enhancing its value and reliability for industrial applications. The development and optimization of processes by AWJM represent social and industrial benefits. This technology increases manufacturing efficiency by ensuring faster and more accurate machining with less waste, leading to cost savings and a reduced environmental impact. Further opportunities in this research area include exploring other high-performance materials for which AWJM can simplify machining for large-scale industries. This may involve composites or advanced alloys for aerospace, automotive, or biomedical sectors. Optimizing other process parameters, such as nozzle diameter, abrasive particle size, and standoff distance, will enhance the accuracy and efficiency of the machining operation.

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