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Study the Effect of Cutting Parameters of Abrasive Water Jet Process on Aluminum Alloy 5083

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ABSTRACT

The most common type of abrasive water jet is known as a valuable and advanced non-traditional machining operation due to its no heat-affected zone, best in removing material, very environmentally friendly, and no mechanical stresses. This paper gives an idea about Abrasive water jets in terms of applications, advantages, and limitations. Also illustrates the influence of the parameters on the material removal rate. The effect of feed rate, pressure, and stand-off distance were worked, at three levels for material removal rate (MRR) to machining Aluminium alloy type-5083 by using a tool consisting of a mixture of 70% water and 30% abrasives of red garnet. The distance of the standoff has the most significant impact on the rate of material removal, which is subsequently followed by the feed rate and finally the pressure. The findings demonstrated that the Taguchi model is capable of making accurate predictions regarding the machining reactions, with a rate of material removal of 93.3%.

1. Introduction

Many materials are hard-to-machine that are not suitable to be machined using traditional machining therefore the development of advanced manufacturing processes or non-traditional machining because of improved chemical, mechanical, and thermal properties. The non-traditional method is classified as chemical, thermal, and mechanical processes. This paper used the mechanical process that includes a water jet, ultra-sonic, and abrasive water jet machining but it was the Abrasive water method. In general abrasive water jet machining, fine abrasive particles impinge with very high velocity on the work surface, erosion of the workpiece by particles. Whether the material is brittle, hard, or composite, this method will work very well. In a process called "abrasive water jet machining," a stream of water containing abrasive particles is used to smooth out the material being worked on. Variables on an abrasive water jet machine include the standoff distance, and workpiece Machining occurs by abrasive particles in water, Cutting is the most popularly used Abrasive water operation for various industrial applications [1]. Some advantages of Abrasive water jet technology (machining super alloys and refractory materials, machine thin and very thin materials, machined materials hardening, Availability of raw material, reducing the failure rate, low cost, Maintenance costs are low, no change to the tool and precision of machining is excellent. Generally its applications (deburring of cross holes, are especially useful for machining thermally sensitive materials, cutting and drilling soft and brittle materials, and used for grooving turning, milling, and drilling. There are

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many limitations (not all materials can be cut, slow materials removal and nozzle damage due to wear.F. Kartal and H. Gökkaya [2] determine the most important abrasive water jet turning operational parameters, like nozzle feed rate nozzle diameter, AFR, standoff distance, and spindle speed for cutting AISI 1050 steel workpiece as output material removal rate and surface roughness, using Taguchi design L18 orthogonal. As a result of the experimental studies, the nozzle feed rate was the most significant impact on surface roughness and AFR proved best significant impact on material removal rate.S. Arun et al. [3] Find the optimal combination of process parameters by employing Taguchi's method of design analysis. In addition, the analysis of variance was utilized so that we could determine which factor was the most important. The rate of material removal and the surface roughness of Inconel 718 were both affected by the process variables standoff distance, transverse speed, and average feed rate (AFR). These variables were examined to see how they had an effect. According to the results of the analysis of variance, the traversal speed of the machine is the most important variable in the process in terms of surface roughness and the rate of material removal. Both the impact of the AFR and the standoff distance are irrelevant. M. A. Khaan and K. Gopta [4] The cutting of the super alloy type Ni-Fe-Cr using abrasive water jet technology was examined. The trials varied the standoff distance, transit speed, and pressure factor amounts. Impact angle, AFR, and orifice diameter were the set parameters. Abrasive garnet, size 80. By assessing the rate of material removal and surface roughness, the study's final result evaluated productivity and surface quality. According to the findings, travel speed is the most important process parameter, and material removal rates are satisfactory at high pressure and low travel speed's. Maniah et al. [5] detected the effect of standoff distance, feed rate, and mass flow rate on surface roughness during machining aluminum metal matrix composite type(Ni, Al, Mg, SiC, and BaN) by abrasive water jet technology. The input parameters were standoff distance at three levels (5, 3.25, and 0.5) mm, feed rate (150, 135, and 90) mm/min, and mass flow rate at (750, 300, and 100) mg/min. The results showed the optimum parameters were 0.5 mm standoff distance, 135 mm/min feed rate, and 350 mg/min mass flow rate. Also, especially mass flow rate feed rate was most significant on surface roughness. The best surface roughness was produced by reducing the feed rate and adding a standoff distance. C. Jol and T. Jeypoovan[6] investigated machinability for aluminum alloy type AA7075 using the abrasive water jet technology. The main parameters like standoff distance, AFR, and nozzle speed to obtain optimum output material removal rate and hardness. The cutting parameters at three levels of standoff distance (4, 3, and 2) mm, AFR were (350, 300, and 250) g/mm, and nozzle speed L.Cano [7]The objectives of this work are to study the effect of abrasive water jet technology parameters (standoff distance, pressure, and feed rate) on material removal rate. And by adjusting abrasive water jet parameters, you can get the best machining conditions and get the best quality at the highest value of material removal rate. There are many factors and elements that affect how materials are shaped by abrasive water jets. This study focuses on the process factors that have an impact on the plain water jet (PWJ) milling of pockets. The impact of many machining process factors on the PWJ milling process parameters has been studied in the literature, including water jet traverse speed, water jet pressure, stand-off distance, and abrasive flow rate. The method of water jet milling is assessed The examination of the experimental data reveals that increasing the jet traversal speed improves surface roughness but has the opposite effect on cut depth. Monika Kulisz [8] This study investigates the effects of changing the abrasive waterjet cutting settings on the surface layer of the workpiece. According to the results analysis, machining does not result in a strengthening effect, or a rise in micro hardness. Additional surface finish procedures can be required because to the imperfections that are normally present on workpieces cut with greater jet feed rates vf. Additionally, it was discovered that chamfering happened at all vf speeds. Factorial analysis of variance was used to assess the statistical significance of each variable for the 2D surface roughness parameters, Ra/Rz/RSm (ANOVA). Artificial neural network (ANN) modeling, which used the multi-layered perceptron and radial basis function to predict the surface, was used to validate the results.

2. Mechanism of Abrasive Water Jet

An unconventional technology called an abrasive water jet uses high-speed water jets with abrasive granules to erode materials. The main component of an abrasive water jet is the abrasive particles, which move at speeds of (900) m/s. The stream makes contact with the workpiece's surface, and the abrasive's erosive force quickly removes the material. In this instance, the abrasive functions like a saw and creates a fine groove in the material of the workpiece [10]. Water is ejected via a nozzle at high velocity at a pressure of up to 400 MPa. In an abrasive water jet, water is mixed with abrasives using a nozzle that has been particularly designed for the purpose. As water is transported to the abrasives, the latter's speeds quickly rise. It produces a concentrated spray of highly-accelerated abrasive particles that escape from the nozzle and cut the work surface [11]. The schematic for the abrasive water jet machine is shown in Figure 1. The abrasive water jet machined surface has three distinct zones. These are the initial damage zone, the rough cutting region, and the smooth cutting region [12].

3. Elements of Abrasive Water Jet Machine

An abrasive water jet machine consists of various equipment as the following as shown in figure (1):

- Hydraulic Pump Unit: (Electric motor, hydraulic pump, intensifier, accumulator, and tubing.

- Water Feeding Unit: nozzles are made from tungsten carbide and synthetic sapphire. And 200 hours of operation, which are damaged by particles of dirt.- Abrasive Feed Unit: there are two particles (dry abrasive delivery and abrasive slurry feed).

- Nozzle: The two major configurations (single-jet feed and multiple-central feed).

- Worktable: There are readily accessible forms and sizes in a wide range, from little to quite huge.

- Drain and Catcher System (The workpiece is moving while the nozzle is stationary, and the nozzle is moving while the workpiece is still.).

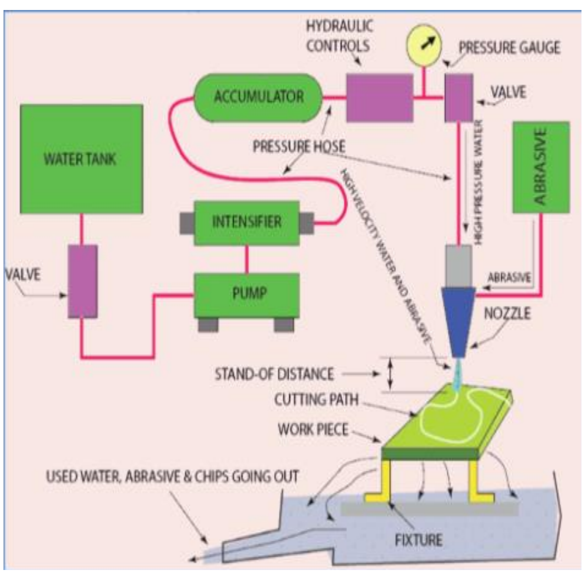

Figure 1. Abrasive water jet element [1].

4. Experimental work

-Tool

Abrasive water jet machines utilize the kinetic energy of abrasive particles carried in water as a cutting tool by impinging on the surface of the workpiece at a high velocity through a nozzle.

- Workpiece

Materials for workpieces are chosen based on their chemistry, mechanical characteristics, and allowed stresses. Because of the reduced kinetic energy of the abrasive particles caused by the hard material's resistance, the rate of material removal drops. And in this work select Aluminum alloy type-5083 according to cost and application with dimension (100*100*5) mm to cut gear with dimension form as shown in figure (2a&b).

Input	
Diametral Pitch	5.08
Number of Teeth	16
Pressure Angle	20
Fillet Arc Angle	0
Precision	0.051 mm
Bore Hole Diameter	0.0 mm
Annotations	True
Output	
Outer Diameter	9.0 cm
Pitch Diameter	8.0 cm
Base Diameter	7.518 cm
Root Diameter	6.75 cm
Addendum	5.0 mm
Dedendum	6.051 mm
Whole Depth	1.105 cm

5- Material Removal Rate

It defines as the volume of material that was removed divided by the machining time. The instantaneous material removal at which a specified material area of cross-sectional is removed. Experimentally determining the rate of material removal is done by dividing the difference in mass between the workpiece before and after machining by the amount of time spent cutting [1]:

MRR= ((Wb-Wa)/t)……………………………….. (1)

Where:
Wa= after machining,weight,
Wb= before machining, weight,
t = machine time.

Table 1. Technical specifications of the AWJ machine.

Maximum SOD	10 mm
Maximum feed rate	1200 mm/min
Maximum jet pressure	413 MPa
Maximum abrasive feed rate	1 kg/min
Table size	2000 x 3000 mm

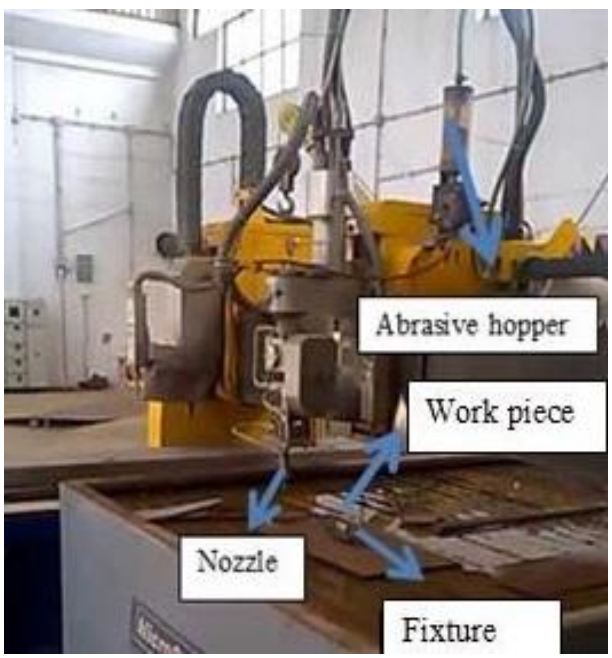

Figure 3. Abrasive water jet element.

6. Design of Experiment (DOE)

Experimental design is done by the Taguchi method using a package program (Min Tab) with three parameters for three levels as table 2.

Table 2. Technical specifications of the AWJ machine.

No.	Parameters	Level 1	Level 2	Level 3
1	Standoff distance	1	2	3
2	Feed rate	50	70	90
3	Pressure	225	250	275

7. Measurement

The Arduino (Mega2560) is installed in a plastic case measuring (20 cm * 20 cm), which contains 52 digital inputs and 16 analog inputs. The Arduino is programmed by the system (ID) to transmit data to the computer as in figure 1. The thermocouples

8-Results and Discussions

Standoff Distance Influence on material removal rate

Determine from Figure (4) the material removal rate reduces as the standoff distance increases, accounting for pressure. For example, Table shows that the material removal drops from 10.05 to 6.39 g/min when the standoff distance is raised from 1 to 3 mm (3). By decreasing the density and kinetic energy that reach the workpiece as the standoff distance increases, the jet's diameter increases, dissipating the energy needed to strike the workpiece's surface. This results in a reduction in the depth of the cut, which lowers the rate of material removal. Additionally, while the Standoff distance does not significantly affect the process's characteristics, it is preferable to provide a higher value to avoid harm to the nozzle's front during the reflection of the abrasives and water stream.

Pressure Influence on material removal rate

When the standoff distance is taken into account, it can be observed in Figure 4. that the material removal rate rises as the pressure increases. More specifically, According to Table 1, raising the pressure from 225 to 275 MPa results in a rise in the material removal rate from 10.05 to 6.39g/min. As pressure rises, kinetic energy also rises, explaining why this is the case, which in turn results in a rise in jetting velocity. An increase in the jetting velocity has a direct impact on the collision of abrasive particles with the material being targeted, which results in deeper penetration and a greater material removal rate (MRR).

Feed Rate Influence on material removal rate

Observe from Figure 4. that the material removal rate drops as the feed rate goes up, even when the standoff distance is taken into account; specifically, the material removal rate drops from 10.05 to 6.39g/min when the feed rate goes from 50 to 90 mm/min, as the table below shows 3. Because there is less time for the abrasive water jet to make contact with the workpiece when the feed rate is increased, there is a corresponding reduction in the number of abrasive particles that cause cutting (AWJ). Therefore, an increase in the feed rate will result in a reduction in the cutting depth, and therefore, a reduction in the rate at which material is removed from the workpiece. The phenomenon is connected to the length of time that the erosion process takes.

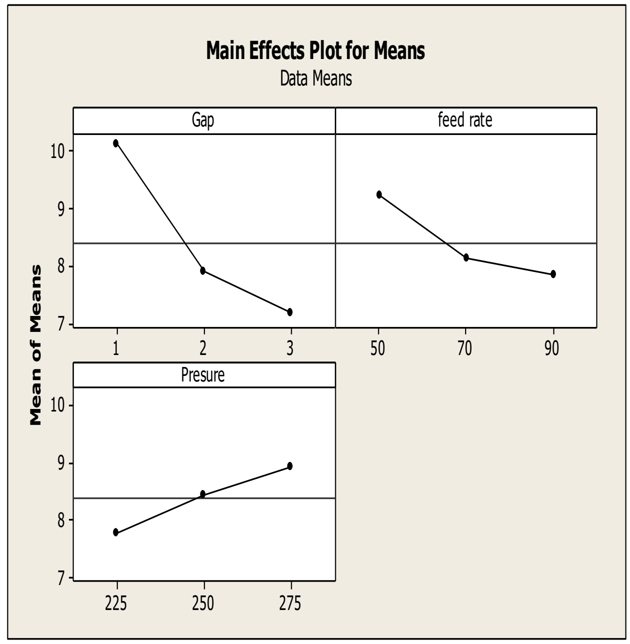

Figure 4. The influence of SOD(mm), Feed rate(mm/min), and Pressure(mpa) on MRR (g/min).

Comparison of Predicted and Measured reading of material removal rate

The observed values for the material removal rate are compared with the anticipated values in Figure, which are shown in Table 3, which depicts the measured values and the expected values for the material removal rate (5). The actual findings of the material removal rate were not too far off from what the design model had indicated. The independent value had a predictive accuracy of 93.3% when it came to the rate of material removal. In other words, it was able to find 93.3% of the variance in the phenomena, in addition to providing us with critical information that helped us interpret this change. This indicates that there is a good level of determination between the dependent variables of the anticipated value and the measured value. It is possible to incorporate the residual percentage of the determination.

Table 3. Measured and predicted values of MRR

Source of variance	Degree	Sum of squares	Variance	P(%)
Gap (mm)	2	14.298	7.149	70.71
Feedrate (mm/min)	2	3.18	1.59	15.71
Pressure (Mpa)	2	2.07	1.04	10.24
Error,e	20	0.673		3.32
Total	26	20.221		100

Table 4. Measured and predicted readings of material removal rate.

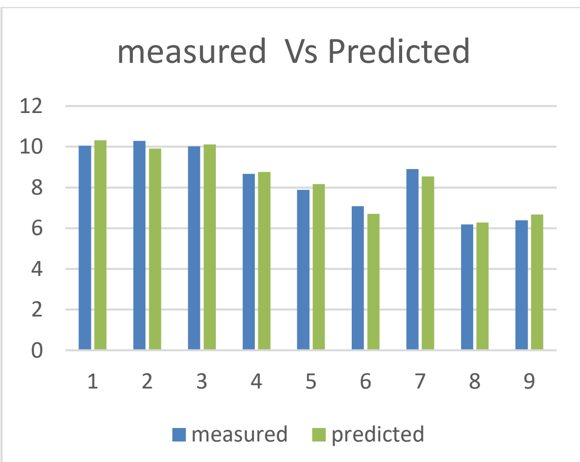

Figure 5. This compares the measured values of the material removal rate with the expected values.

Analyses of Variance (ANOVA)

The analysis of variance, or ANOVA, is one of the most effective analytical procedures for establishing the relative contribution of various process parameters to the final product. The F-ratio is utilized in the analysis of MRR to determine crucial process parameters. The analysis was carried out with a degree of confidence equal to or greater than 93.3%. The ANOVA for the MRR of a workpiece is displayed in Table 4, and it varies based on the Taguchi design. It was discovered that the feed rate (F) has the most significant impact on MRR, with a factor of 21.47, followed by the pressure (P) with a factor of 4.26, and then the standoff distances (SOD) with a factor of 2.05.

No	Gap	Feed rate	Pressure	MRR	PMEAN (1)
1	1	50	225	10.05	10.326
2	1	70	250	10.29	9.916
3	1	90	275	10.02	10.116
4	2	50	250	8.67	8.766
5	2	70	275	7.89	8.166
6	2	90	225	7.08	6.706
7	3	50	275	8.91	8.536
8	3	70	225	6.18	6.276
9	3	90	250	6.39	6.666

Model of Regression

These parameters were utilized in the process of developing the mathematical model and obtai *6* the mathematical relation between the input parameters. On the other hand, these parameters were used to correlate the material removal rate in the regression equation, as stated in the following sentence:

MRR = 7.91 - 1.48 G - 0.0345 f + 0.0234 P……….. (2)

The purpose of the regression is to get a mathematical representation of the relationship between the input variable and the output variable. This will allow the value of the dependent variable to be predicted given a certain value for the independent variable. Because it takes into account three different variables at once, this model is what statisticians refer to as a "multiple regression model."

8. Conclusions

It may be summed up in one sentence According to the findings, the material removal rate increased from 10.05 to 6.39 grams per min when the pressure was raised from 225 to 275 MPa, when the feed rate was lowered from 90 to 50 mm/min, and when the standoff distance was shortened from 3 to 1 mm. The distance of the standoff has the most significant impact on the rate of material removal, which is subsequently followed by the feed rate and finally the pressure. The best reading for the material removal rate was 10.05 grams per minute when the pressure was 275 mega Pascal's, the feed rate was 50 millimeters per minute, and the standoff distance was 1 millimeter for both. The findings demonstrated that the Taguchi model is capable of making accurate predictions regarding the machining reactions, with a rate of material removal of 93.3%.

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