International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 11 Issue 2 ǁ February 2023 ǁ PP. 19-33

Process Optimization for Abrasive Water Jet Contour Cutting of Porcelain

Ramesh Nayak B[1], Nayan P[2], Rohan Badari[3], Soumya S[4], S. Srinivas[5]
[1]*Associate Professor, Dept. of Industrial Engineering and Management, B. M. S. College of Engineering, Bengaluru, Karnataka, India*
[2]*Student, Dept. of Industrial Engineering and Management, B. M. S. College of Engineering, Bengaluru, Karnataka, India*
[3]*Student, Dept. of Industrial Engineering and Management, B. M. S. College of Engineering, Bengaluru, Karnataka, India*
[4]*Student, Dept. of Industrial Engineering and Management, B. M. S. College of Engineering, Bengaluru, Karnataka, India*
[5]*Professor, Dept. of Mechanical Engineering, B. M. S. College of Engineering, Bengaluru, Karnataka, India*
Corresponding Author:1

Abstract
Abrasive water jet machining is one of the most popularly used non-conventional machining processes in the industry. Due to its ability to smoothly cut materials which are hard, brittle and heat sensitive, the AWJM process is one of the best non-conventional alternatives to machine materials such as ceramics, polymer composites, and other materials with a high strength-to-weight ratio. In this study, the analysis and optimization for the input parameters such as working pressure, nozzle speed and abrasive flow rate are conducted with the surface roughness and material removal rate as the outputs. The Taguchi L27 orthogonal array method is employed for the modelling, analysis and optimization of the selected input variables. Further, Analysis of Variance (ANOVA) is used for identifying the percentage contribution of each input parameter on the surface roughness and material removal rate.
This study deals with the process optimization for abrasive waterjet contour cutting for the material porcelain, to minimize the surface roughness and maximize the material removal rate. Further, the effects of the working pressure, abrasive mass flow rate and nozzle speed were investigated, allowing for the process to attain better surface finish and higher machining rates. On the basis of Taguchi-based optimization and analysis of variance, the following conclusions were made:
1. Surface roughness achieved a minimal value of 2.004 μm for the input parameters AFR = 400 g/min, WP = 125 MPa, and N S= 100 mm/min, at levels 3, 2, and 1 respectively.
2. The optimal values of factors for maximizing MRR were found to be AFR = 400 g/min, W P = 125 MPa, and NS = 300 mm/min.
3. By conducting ANOVA study, it was found that the most influential and significant parameter for SR was nozzle speed, followed by abrasive mass flow rate, each contributing 42.37 % and 19.87 % respectively. Working pressure was found to be insignificant.
4. For the MRR, it was found that the most influential factor was nozzle speed, contributing 85.42 % to the material removal rate, followed by abrasive mass flow rate, which contributed 4.86 %. Both nozzle speed and abrasive mass flow rate were found to be significant, and WP was found to be insignificant.
5. Increasing the nozzle speed and decreasing the abrasive mass flow rate lead to lower surface roughness and decrease in contour cutting performance. However, lower nozzle speed combined with high abrasive mass flow rate improved the quality of surface roughness considerably.
6. Increasing the nozzle speed and abrasive mass flow rate increases higher rates of material removal.
Keywords:*Abrasive Mass Flow Rate, Working Pressure, Nozzle Speed, Surface Roughness, Material Removal Rate.*

Date of Submission: 23-01-2023 Date of acceptance: 06-02-2023

I. INTRODUCTION

In the current global scenario, there is a fierce competition amongst manufacturing companies that are trying to capture the market. This has led to a rise in the amount of research on advanced technologies and manufacturing processes, new materials, and methods to utilize them in efficient, economical and eco-friendly ways. Non-conventional machining techniques fill this need in the market by providing an innovative alternative to traditional machining processes. Non-conventional machining techniques are defined as a group of subtractive machining processes which remove excess material from a work piece through the use of mechanical, electrical, chemical and thermal energy or a combination of any of these. They are popularly used to machine materials which are difficult to cut using traditional machining processes, to cut complex shapes and profiles into hard, brittle materials like ceramics and ceramic composites, and materials with a high strength-to-weight ratio [1]. Non-conventional machining techniques include Abrasive Jet Machining, Water Jet Machining, Ultrasonic Machining, Electrical Discharge Machining, Electron Beam Machining, LASER Beam Machining and many others [2]. Although these techniques have some limitations, they possess a greater potential than conventional methods of machining. However, they require thorough study and research in order to fully utilize them in practical applications [3].

1.1. Abrasive Water Jet Machining

Abrasive water jet machining (AWJM) is an advanced and powerful machining process that can cut a wide range of engineering materials like metals, on metals, ceramics, composites etc. It incorporates abrasive particles such as Aluminium oxide, silica sand, silicon carbide, or garnet into the water jet with the purpose of removing material.

The basic principle of abrasive water jet machining is to apply a high-speed jet of abrasive particles to the work surface via a nozzle, which is carried out at high-pressure. It uses the kinetic energy of the water to erode the particles at the surface. Small fragments of material loosen after successive collisions, exposing a new surface layer to the jet. Depending on the type of material, the mechanism of erosion may be rapid plastic deformation, or cutting action through crack propagation and chipping [4]. Pandya Jay Bakulchandra et al. [5] attempt to study the effect of standoff distance, abrasive flow rate and water pressure on kerf geometry and material removal rate using ceramic tiles. The experiment was done using Taguchi method and analyzed using Minitab. Using Taguchi method, it was concluded that water pressure has more effect on the kerf geometry and MRR when compared to abrasive mass flow rate and standoff distance. Confirmatory experiments validated the results to be accurate. M Sreenivasa Rao et al. [6] analyzed the effect of standoff distance, working pressure and nozzle diameter on kerf width and surface roughness using glass plates. The MRR was optimized using Taguchi Method. Through the experimental study it was concluded that the water pressure has maximum effect on the surface roughness whereas the kerf width is affected by standoff distance and nozzle diameter. The kerf width is directly proportional to the nozzle diameter. As the nozzle diameter increases, the kerf width increases. Similarly, the kerf width is directly proportional to the standoff distance as well. ANOVA was conducted to find significant parameters. J. Wang et al. [7] in their experimental research study attempted to find the optimal process parameters to enhance the cutting performance of AWJ, and the material used was 87% alumina ceramic tile, as well as a phenolic fabric polymer matrix composite. The experiment was conducted for single pass cutting, multi-pass cutting, and even for alternating jet traversal direction. For the single pass cutting experiment, the authors considered the working pressure, nozzle speed, standoff distance, and the abrasive mass flow rate, and the jet impingement angle as the variable parameters. Depth of cut and surface roughness were considered as the responses. The study revealed that the jet impingement angle had a significant impact on the depth of cut for the alumina ceramic tile but was not as significant for the polymer matrix composite. It was reported that using the optimum jet angle of 80^o-85^o enhanced the depth of cut by 30% as compared to a 60^o impingement angle, or about 8% when compared to a perpendicular impingement angle. For the polymer matrix composite, depth of cut was reported to increase up to 25% as the impingement angle increased from 50^o to 80^o. From 80^o to 90^o, however, no significant change was observed. The increase in the depth of cut was attributed to the fact that an impingement angle of less than 90^o compensates for the drag angle of the jet in the bottom cutting region of the kerf, which leads to an increase in the energy component of the particle in the cutting direction. For the surface roughness, an increase in the jet impingement angle from 50^o to 70^o was reported to have a significant impact (50% decreases) on the surface roughness. Further, the jet impingement angle was found to have no effect on the other kerf characteristics. Venkata Lakshmi Mrudhula et al. [8] attempt to find the optimal process parameters for cutting granite. The variable inputs considered were working pressure and material thickness. The response variables were MRR and surface roughness. The experimental results were analyzed using Origin software and best-fit curves were obtained for water pressure, MRR, and surface roughness. ANOVA was carried out for both curves, and mathematical correlations were developed for both the curves using Origin software. The correlations were reported to be useful for predicting optimal working pressure values for any thickness of granite. Ajit Dhanawade et al [9] investigated the optimal characteristics for cutting PZT ceramic using AWJM. Input parameters considered were standoff distance, working pressure, and nozzle speed. The responses measured were kerf taper angle and depth of cut. Response surface method was used to design the experiments, and ANOVA was used to identify the most influential parameters. It was reported that the depth of cut was most affected by the working pressure, followed by traverse rate and standoff distance. An increase in the kinetic energy of the water jet was found to be directly proportional to the depth of cut. It was also found that increasing the standoff distance led to flaring of the water jet which decreased the cutting ability of the jet. An increase in the traverse speed was reported to decrease the depth of cut due to lesser abrasive particles impinging the work surface in the same time frame. With respect to the kerf wall characteristics, traverse speed and working pressure were found to be the most influential parameters. Certain defects such as inter-granular fractures, striations, and wear tracks were reported. These were attributed to the low impingement angle of the AWJ, jet deflection, as well as the low kinetic energy of the AWJ. Further, using the Design Expert v10 software, optimal values for the input parameters were calculated using desirability function. Vaibhav Jain et al [10] investigated the optimization of Granite cutting using Taguchi Technique and AWJM. Process parameters which were considered were travel speed, stand-off distance and water jet pressure on the material removal rate of Granite. ANOVA was used to analyze the results and Traverse speed was found to be the most significant parameter which affected the Material Removal Rate.

Nomenclature

AWJM	Abrasive Water Jet Machining
WP	Working Pressure
NS	Nozzle Speed
AFR	Abrasive Mass Flow Rate
JIA	Jet Impingement Angle
SOD	Stand Off Distance
SR	Surface Roughness
MRR	Material Removal Rate
ANOVA	Analysis of Variance
KTA	Kerf Taper Angle
w_t	Top kerf width
w_b	Bottom kerf width
OA	Orthogonal Array

Table 1: Chemical composition of porcelain

Compound Name	Chemical Formula	Percentage
Silicon Dioxide	SiO_2	69%
Aluminium Oxide	Al_2O_3	21%
Sodium Oxide	Na_2O	3%
Potassium Oxide	K_2O	2.5%
Magnesium Oxide	MgO	1.5%
Calcium Oxide	CaO	1.5%
Ferric Oxide	Fe_2O_3	1%
Zirconium Dioxide	ZrO_2	Up to 2%

Table 2: Physical properties of Porcelain

Density	2400 Kg/m^3
Ultimate Tensile Strength	29 N/m^2
Brinell hardness	7 Mohs
Melting point	2200 K
Thermal Conductivity	1.5 W/mK
Heat Capacity	1050 J/g K

Table 3: Machine specifications

AWJ Machine Specifications	
Name/model	OMAX MAXIEM 1515
Maximum Pressure	345 MPa
Maximum Nozzle Speed	8000 mm/min
Table size (L x B)	2235 mm x 1727 mm
XY Cutting Envelope	1575 mm x 1575 mm
Z - axis travel	150 mm

1.2. Material

Porcelain is a material made from well-chosen porcelain clay or pottery stone through technological processeslike proportioning, moulding, drying and firing. For the past 30 years there has been a lot of change in the method of making the porcelain. Nowadays porcelain is made by using clay, feldspar or flint and silica, which are all characterized by small particle size.

Porcelain has more mechanical resistance, low porosity and high density which gives high durability, inequity, soft touch and aesthetic look.

The composition of clay being used varies from where it is extracted and how it is being treated. All clay vitrifies which means it develops glassy qualities only at very high temperatures unless they are mixed with other different materials whose verification level is much lower. Clay has this property to keep its shape when heated, called refractory property. So, porcelain has low porosity like glass and it has the ability to stay in the same shape when heated like clay. Feldspar which is mainly made of Aluminium silicate and flint which is a type of hard quartz which functions as a fluxing agent in the manufacturing of porcelain.

Porcelain is an amorphous solid which means that the atoms in the solid are not locked in 3D crystal but are randomly arranged, so that means that if you hit a porcelain hard it cannot dissipate all the energy through all the rows of the atoms because they are not connected to each other and it will break and shatter which makes it brittle but hard.

Due to these properties, porcelain is very difficult to cut using traditional processes. AWJM is a very good alternative to cut the material.

Average chemical composition and physical properties of porcelain stoneware tiles (by percentage of mass) are shown in the table 1 and 2.

II. EXPERIMENTAL SETUP

The machine used for the study is the OMAX MAXIEM 1515 AWJ cutting machine with a 30 HP direct drive pump which supports a pressure capacity of 100 MPa to 345 MPa. The machine is also equipped with gravity feed type abrasive hopper, pneumatic control valve for X-Y-Z coordinate controlled motion over a cutting table of dimensions 1575×1575×150 mm, and nozzle speed ranging from 1 mm/min to 8000 mm/min. The type of abrasive used was 80 mesh garnet and the nozzle used was a tungsten carbide focusing nozzle of 0.76 mm diameter, and the orifice diameter was 0.35 mm and orifice material was sapphire. The specification of the Abrasive Water Jet Machine is as shown in the table 3.

As discussed in references, there are several input parameters categorized as hydraulic parameters, cutting parameters, abrasive parameters, and so on, each with several sub-parameters under them. However, it becomes difficult to consider all the process parameters for the purpose of experimentation. Therefore, this study focuses on three easy to vary parameters which have a significant impact on the outputs considered, which are the surface roughness and the material removal rate. The following table shows the input parameters considered, along with their values and ranges.

In this paper, the input variables considered are working pressure, nozzle speed, and abrasive mass flow rate. The responses measured are the material removal rate and the surface roughness. The design of experiments chosen is the Taguchi method, and the most influential parameters are verified by the use of ANOVA. Optimization of the input parameters is carried out to maximize the material removal rate and minimize the surface roughness.

Figure 1: Abrasive Water Jet Machine

Table 4: Working Conditions

Input Parameters	Details	Notation	Units	Values/Ranges
Variable Parameters	Working Pressure	WP	MPa	100, 125, 150
	Nozzle Speed	NS	mm/min	100, 200, 300
	Abrasive Mass Flow Rate	AFR	g/min	200, 300, 400
Constant Parameters	Standoff Distance	-	mm	1.5
	Orifice Diameter	-	mm	0.35
	Nozzle Diameter	-	mm	0.76
	Abrasive Type	-	-	Garnet
	Abrasive Size	-	Mesh no.	80
	Jet Impact Angle	-	Degrees	90^o
	Material Thickness	-	mm	11
	Target Material	-	-	Porcelain

Table 5: Contour cutting path dimensions for Taguchi experiments

Profiles	Inner Arc Radius					Outer Arc Radius					Straight Cut						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dimensions (mm)	30	30	10	25	5	20	10	10	10	5	20	30	25	25	25	7.5	7.5

Table 6: Contour cutting path dimensions for confirmatory experiments

Profiles	Inner Arc Radius					Outer Arc Radius					Straight Cut						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dimensions (mm)	10	10	10	10	30	25	25	20	10	10	50	12.5	12.5	10	10	8	7

2.1 Design for the cutting path

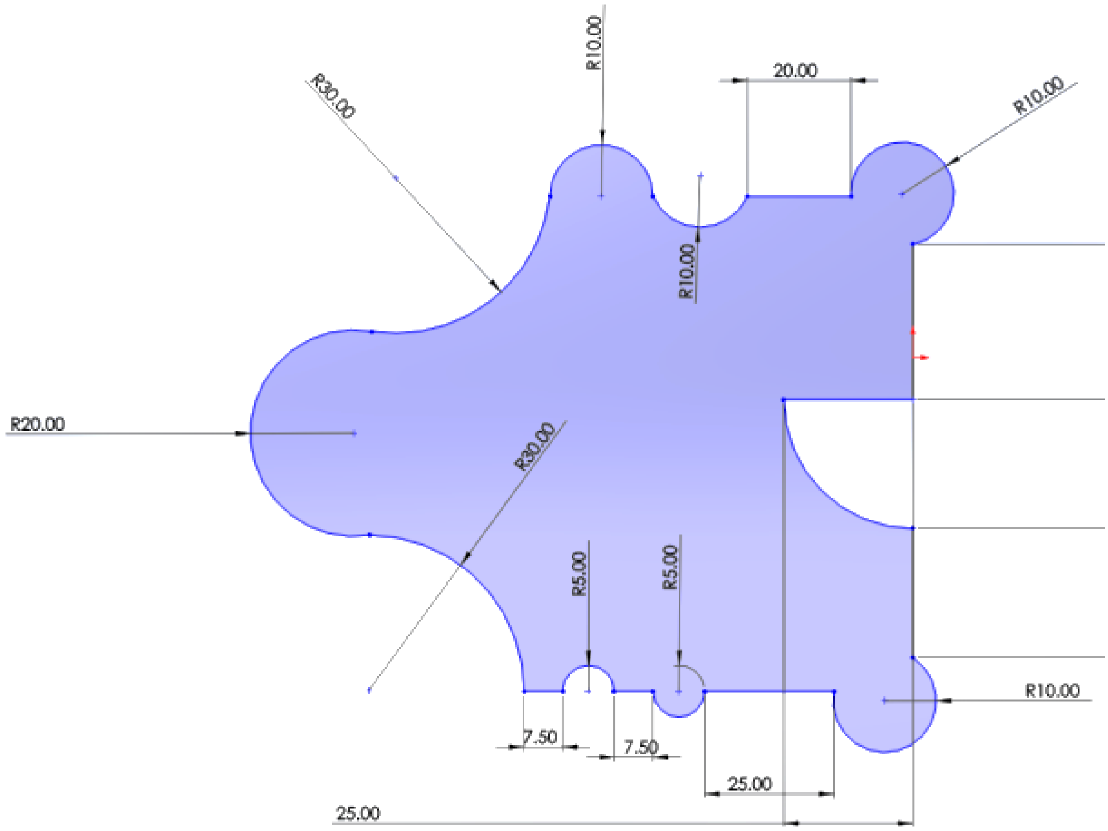

Figure 2: Contour cutting for Taguchi L27 experiments

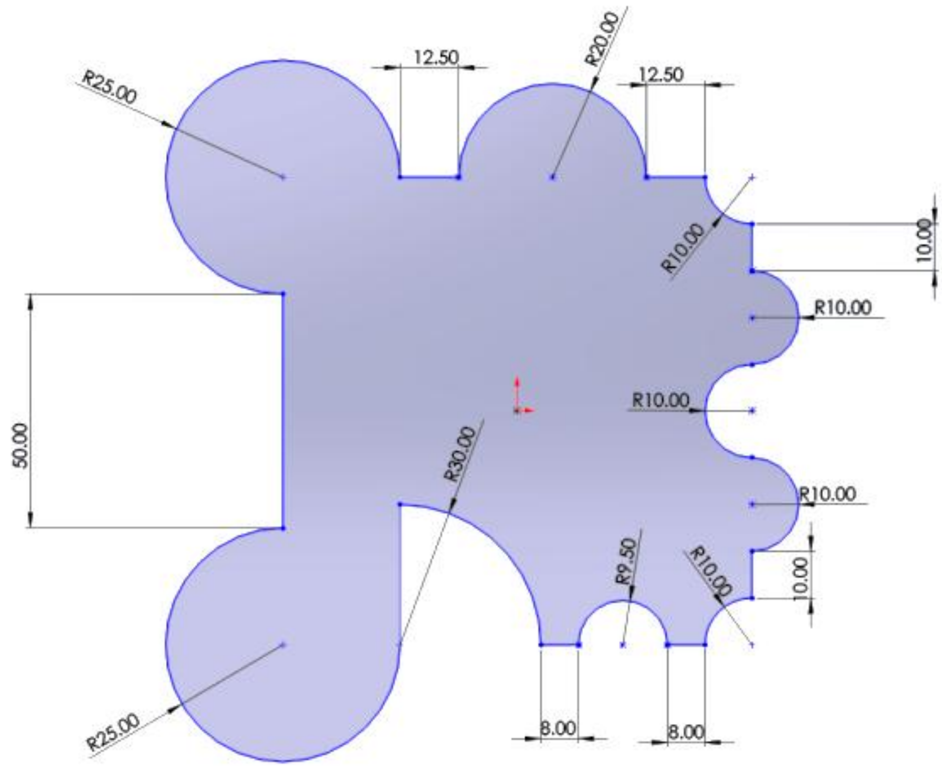

Figure 3: Contour cutting for confirmatory experiments

2.2. Design of Experiment

A standardized Taguchi L_{27} orthogonal array was used in this project to accommodate the input variables selected for the AWJ contour cutting of porcelain. Each input parameter has 3 levels, and there are 3 input parameters. Taguchi method was used since it provides a better insight into the interaction of parameters and provides systematic predictions to help and analyze the process effectively with the minimum number of experiments.

Table 6: Taguchi L27 Orthogonal Array

Exp. No.	AFR, g/min	WP, Mpa	NS, mm/min	SR, µm	S/n ratio, SR	MRR, mm^3/min	S/n ratio, MRR
1.	200	100	100	2.351	-7.4251	1897.6182	65.564
2.	200	100	200	2.42	-7.6763	2676.4115	68.551
3.	200	100	300	2.532	-8.0693	3161.5385	69.998
4.	200	125	100	2.391	-7.5716	1586.3686	64.008
5.	200	125	200	2.45	-7.7833	2562.5216	68.173
6.	200	125	300	2.578	-8.2257	4485.6016	73.036
7.	200	150	100	2.498	-7.9518	1546.2074	63.785
8.	200	150	200	2.481	-7.8925	2486.5951	67.912
9.	200	150	300	2.807	-8.9648	4566.6667	73.191
10.	300	100	100	2.225	-6.9466	2299.2305	67.231
11.	300	100	200	2.395	-7.5861	3283.8240	70.328
12.	300	100	300	2.977	-9.4756	4350.4931	72.77
13.	300	125	100	2.225	-6.9466	1656.6508	64.385
14.	300	125	200	2.298	-7.2270	3150.9525	69.969
15.	300	125	300	2.602	-8.3061	5215.1874	74.345
16.	300	150	100	2.261	-7.0860	1827.3360	65.236
17.	300	150	200	2.564	-8.1784	3037.0627	69.649
18.	300	150	300	2.662	-8.5042	3945.1677	71.921
19.	400	100	100	2.059	-6.2731	1827.3360	64.236
20.	400	100	200	2.243	-7.0166	3492.6221	70.863
21.	400	100	300	2.371	-7.4986	4458.5799	72.983
22.	400	125	100	2.004	-6.0380	2038.1825	66.184
23.	400	125	200	2.226	-6.9505	3454.6588	70.768
24.	400	125	300	2.43	-7.7121	4242.4063	72.552
25.	400	150	100	2.105	-6.4650	2068.3034	66.312
26.	400	150	200	2.402	-7.6115	3853.2733	71.716
27.	400	150	300	2.231	-6.9700	4674.7535	73.395

The Taguchi L27 trials were carried out, and the MRR and Surface Roughness were measured. Table 6 displays the orthogonal array along with the values obtained for the responses, and their corresponding signal to noise ratios.

The signal to noise ratios were calculated by using the larger is better formula for MRR (3), and the smaller is better formula for SR (4):

Larger is better (maximize the response):

$$S/_{N} = -10\, log_{10} \frac{1}{n} \sum_{i=1}^{n} \frac{1}{Y_{ijk}^{2}} \qquad (1)$$

Smaller is better (minimize the response):

$$S/_N = -10\,log_{10}\frac{1}{n}\sum_{i=1}^{n}Y_{ijk}^2 \qquad (2)$$

Where, n is the number of replications,
$Y_{ijk}$is the response value of the i^{th} input in the j^{th}experiment in the k^{th} trial

III. RESULTS AND DISCUSSION

The Taguchi L_{27} orthogonal array experiments were conducted as shown in table 8, and statistical tests were performed on the performance characteristic-response data to identify and examine the contribution of the input factors on the responses. Surface plots were graphed in order to examine the behavior of the output response with respect to relationship of factors. ANOVA was conducted to determine the percent contribution of the factors to each of the responses.

Figures 4-7 show the variation of means of responses versus the levels of the input factors and also the variation of the mean signal to noise ratios versus the levels of input factors.

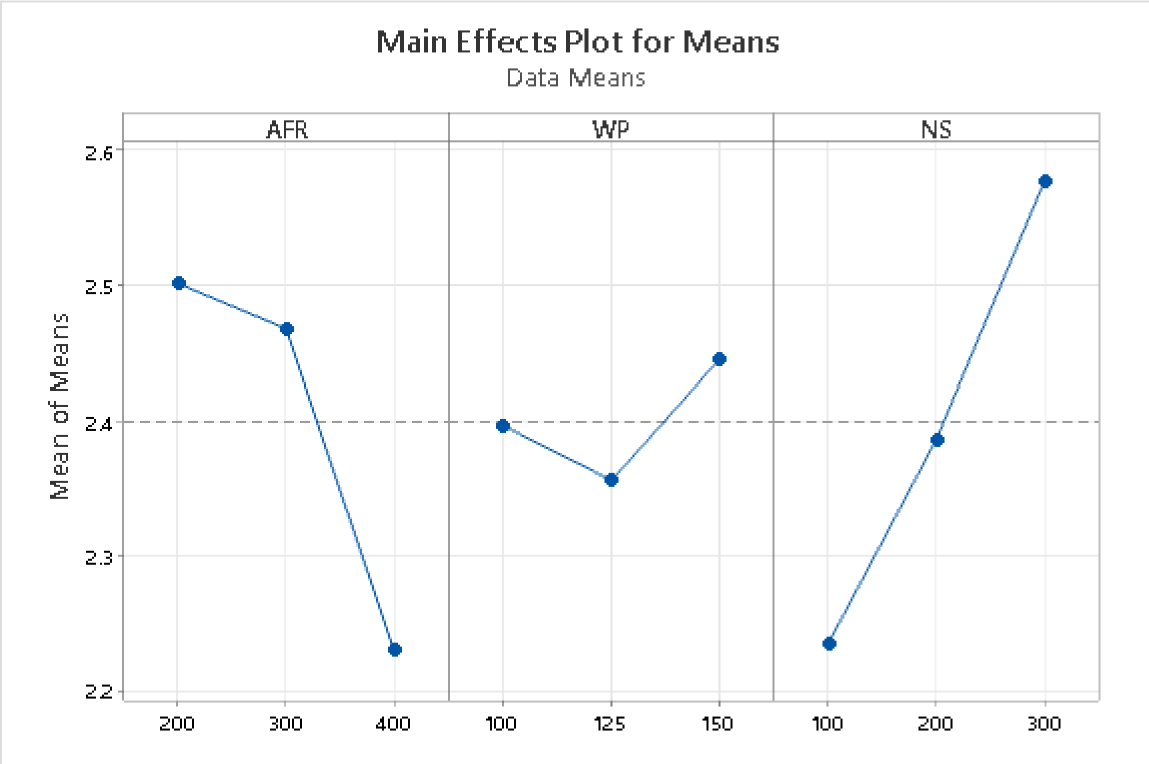

Figure 4: Main effect plots for means for SR

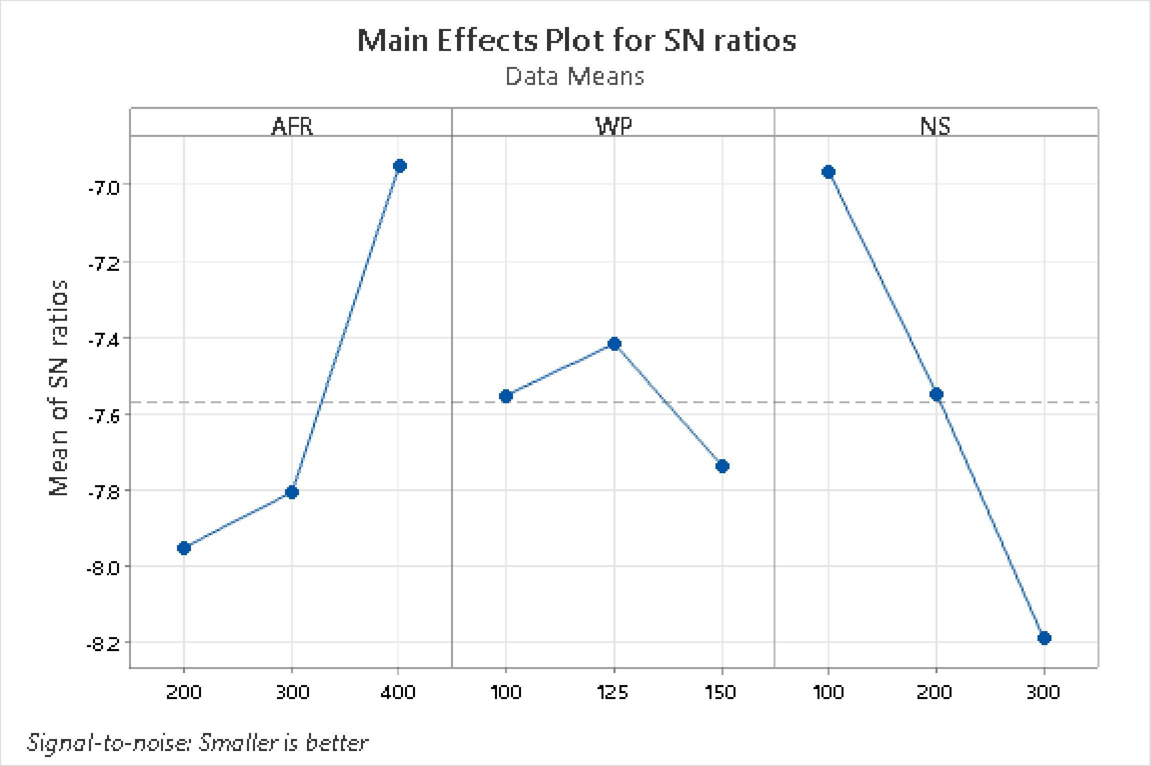

Figure 5: Main effect plot for mean of signal to noise for MRR

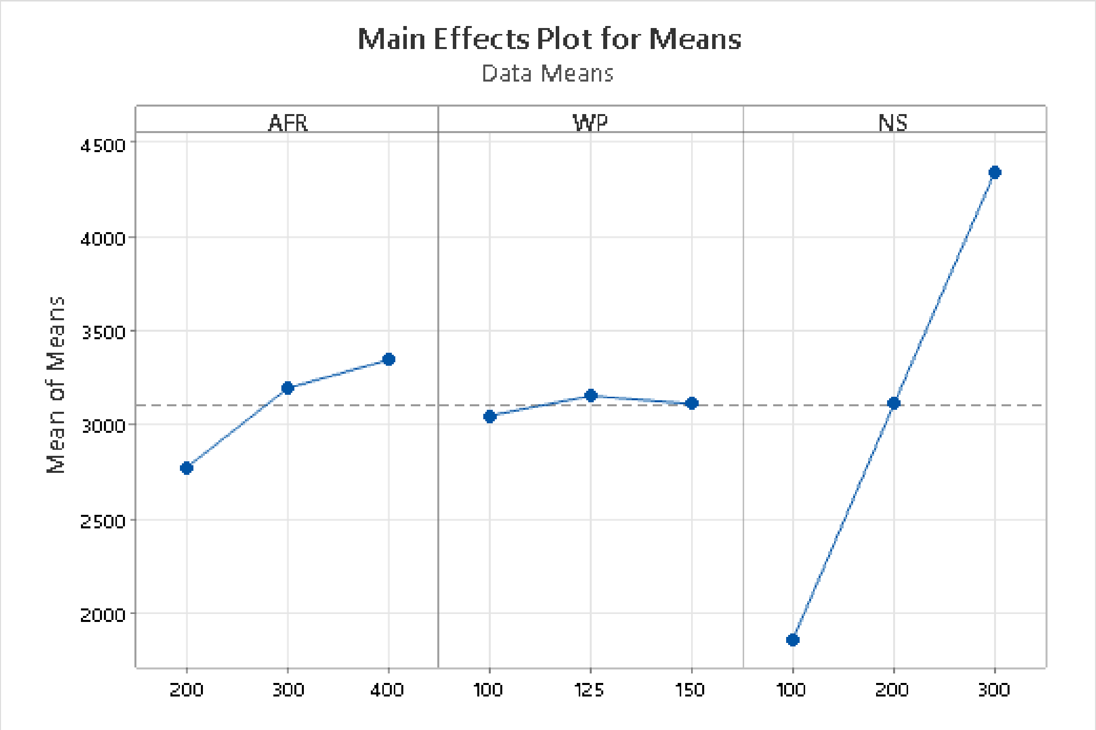

Figure 6: Main effect plot for mean of means for MRR

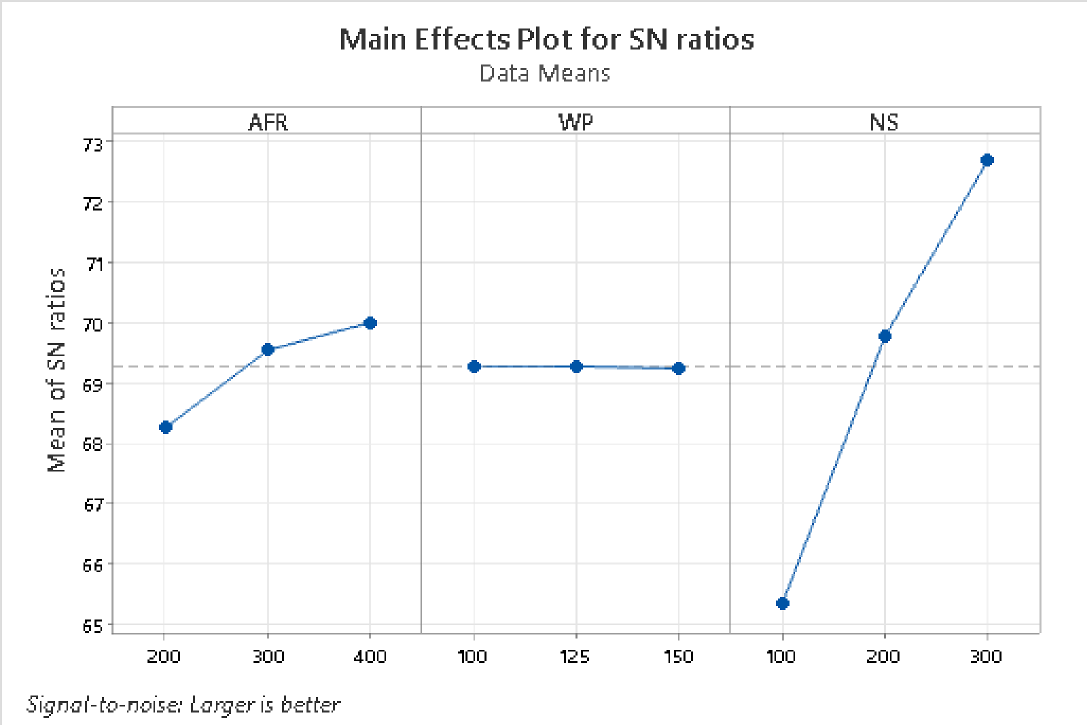

Figure 7: Main effect for means of signal to noise ratio for MRR

The response tables for SR and MRR are given in table 7, with the optimal values marked in bold

Table 7: Mean signal to noise ratio response for SR and MRR

Levels	Surface Roughness			Material Removal Rate		
	AFR	WP	NS	AFR	WP	NS
1	-7.951	-7.552	**-6.967**	68.25	**69.28**	65.33
2	-7.806	**-7.418**	-7.547	69.54	69.27	69.77
3	**-6.948**	-7.736	-8.192	**70**	69.24	**72.69**
Delta	1.003	0.318	1.225	1.75	0.05	7.36
Rank	2	3	1	2	3	1

3.1 Surface Plot Analysis of SR

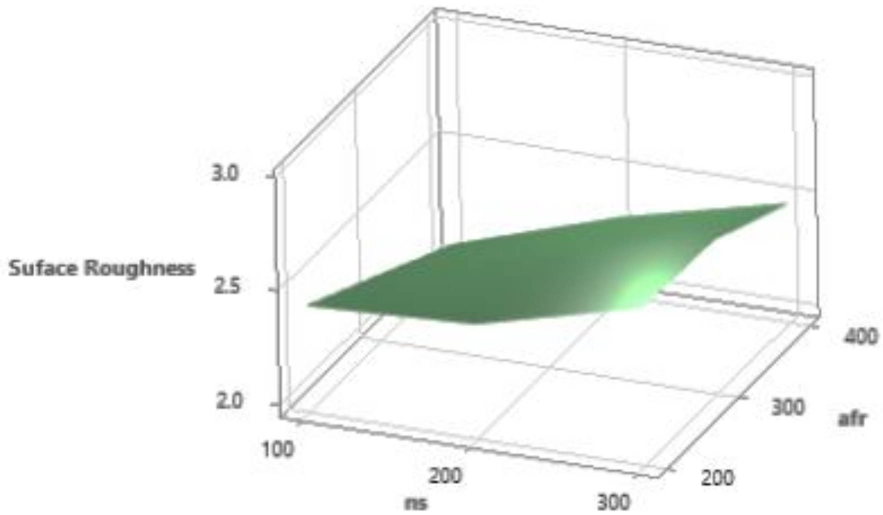

Figure 8: Surface plot of NS and AFR vs SR

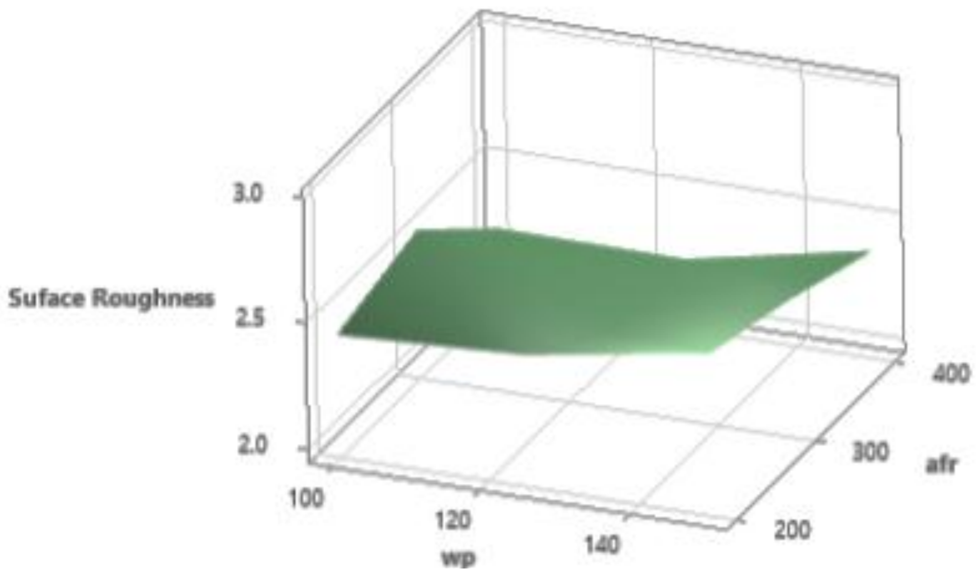

Figure 9: Surface plot of WP and AFR vs SR

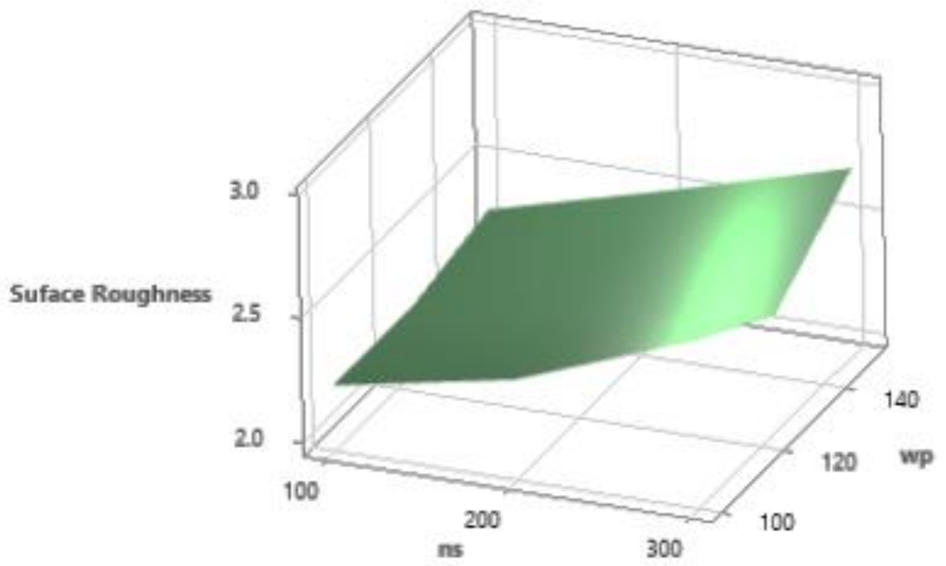

Figure 10: Surface plot of NS and WP vs SR

From Figures 8-10, it is evidently clear that surface roughness improves when lower values of working pressure and nozzle speed are used. There is also a clear increase in the surface roughness when nozzle speed increases beyond 200 mm/min. It is also observed that in the optimal value, the working pressure is 125 MPa, which is not the lowest level. This contradiction may be attributed to the dominant effect of the abrasive mass flow rate and low nozzle speed. Increase in AFR leads to more abrasive particles impinging on the target surface within the same time frame thereby improving the surface roughness by giving a smoother finish. A higher nozzle speed leads to the jet moving across the surface of the target material faster and thereby allowing fewer number of abrasive particles to erode the surface of the target material within the same time frame. In fig.9, the variation of surface roughness with respect to working pressure seems to be almost flat. This can be explained by the dominant effect of AFR.

3.2 Surface Plot Analysis for MRR

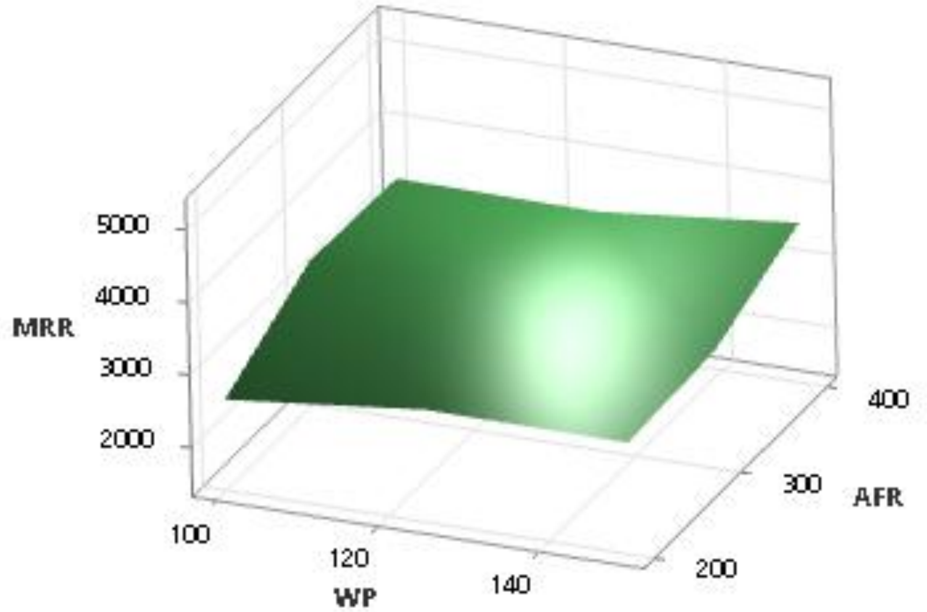

Figure 11: Surface Plot of AFR and WP vs MRR

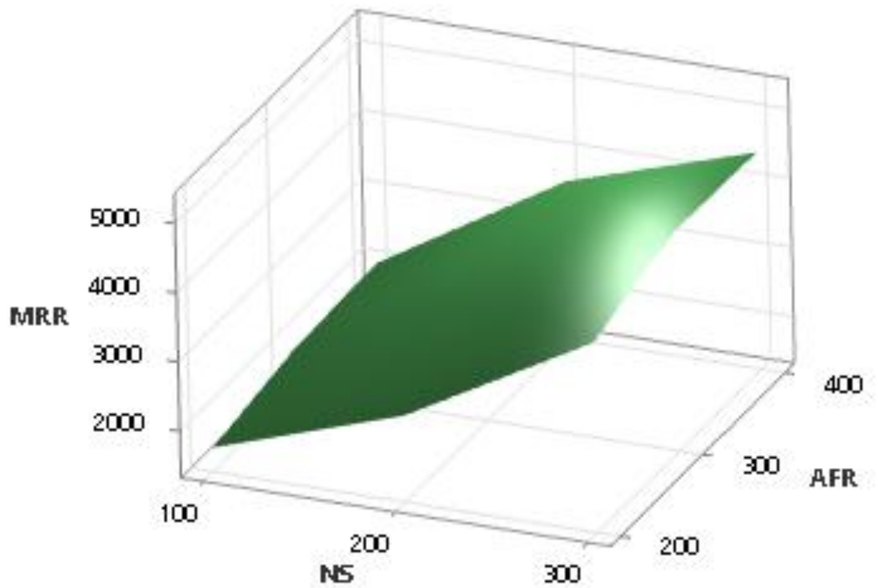

Figure 12: Surface Plot for AFR and NS vs MRR

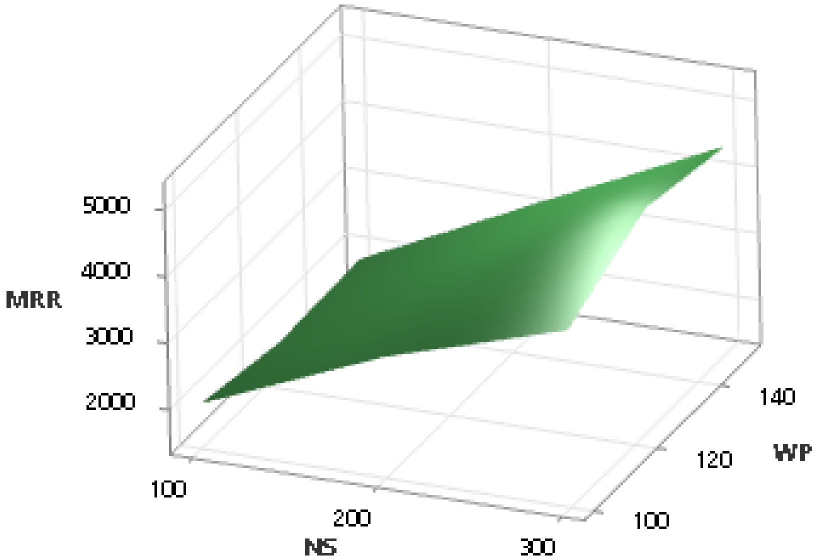

Figure 13: Surface Plot of WP and NS vs MRR

From Figure11, it is observed that the working pressure is relatively flat. This could be due to the dominant effect of AFR. From Figure 12, it is seen that a higher nozzle speed coupled with a higher AFR contributes to the maximum amount of material removal, since more abrasive particles can impinge the work surface for a similar machining time. From Figure13, it can be seen that MRR increases almost linearly with a combined increase in water pressure and nozzle speed. However, it is also noted that MRR varies almost linearly with the nozzle speed, and that high values of nozzle speed are better for obtaining a high MRR.

It would be expected that a higher working pressure would yield a better MRR, however, the optimal value of working pressure is at 125 MPa. This could be due to the dominant effect of nozzle speed and the cumulative effect of nozzle speed and abrasive flow rate which allows for a higher rate of particles to erode the target material at similar jet velocities.

3.3 ANOVA Study

The ANOVA study is a statistical test which can provide information about the contribution of each input factor as well as the combination of the factors on the responses. A confidence level of 95% was selected for this study.

The significance of a factor is determined by its p-value in the ANOVA table. If the p-value of the factor is <0.05, then it is said to be statistically significant. If it's p-value is > 0.05, then the factor is considered to be statistically insignificant.

Table 2: ANOVA for SR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
AFR	2	0.39257	0.39257	0.196285	15.03	0.002	Significant
WP	2	0.03627	0.03627	0.018134	1.39	0.304	Non-Significant
NS	2	0.52623	0.52623	0.263114	20.15	0.001	Significant
AFR*WP	4	0.04794	0.04794	0.011984	0.92	0.499	Non-Significant
AFR*NS	4	0.10321	0.10321	0.025801	1.98	0.191	Non-Significant
WP*NS	4	0.03125	0.03125	0.007814	0.6	0.674	Non-Significant
Residual Error	8	0.10446	0.10446	0.013058			
Total	26	1.24192					

Table 3: ANOVA for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
AFR	2	1579445	1579445	789722	4.88	0.041	Significant
WP	2	50138	50138	25069	0.15	0.859	Non-significant
NS	2	27759507	27759507	13879754	85.78	0	Significant
AFR*WP	4	584412	584412	146103	0.9	0.506	Non-significant
AFR*NS	4	501422	501422	125355	0.77	0.571	Non-significant

WP*NS	4	726475	726475	181619	1.12	0.41	Non-significant
Residual Error	8	1294389	1294389	161799			
Total	26	32495788					

From the ANOVA study it was found that AFR and NS are significant for both the responses, whereas the working pressure and all the interactions were found to be insignificant.

3.4 Confirmatory Experiments

The validation of the optimal parameters obtained from the Taguchi L_{27} OA method was established using confirmatory experiments.

Three trials of confirmatory experiments were carried out for each combination of optimal parameters.

An average surface roughness of 2.19μm was obtained using the input factors as AFR = 400 g/min, WP = 125 MPa, NS = 100 mm/min. The surface roughness displayed relative values to the results obtained using the Taguchi L_{27} OA experiments.

An average MRR of 4485.602 mm^3/min was obtained using the optimal input factors as AFR = 400 g/min, WP = 125 MPa and NS = 300 mm/min.

The optimal combination of parameters resulted in a low surface roughness and a high MRR respectively, and the values were found to be satisfactory (within 10% error) when compared to predicted Taguchi values.

IV. CONCLUSION

This study deals with the process optimization for abrasive waterjet contour cutting for the material porcelain, to minimize the surface roughness and maximize the material removal rate. Further, the effects of the working pressure, abrasive mass flow rate and nozzle speed were investigated, allowing for the process to attain better surface finish and higher machining rates. On the basis of Taguchi-based optimization and analysis of variance, the following conclusions were made:

1. Surface roughness achieved a minimal value of 2.004μm for the input parameters AFR= 400 g/min, WP= 125 MPa, and NS= 100 mm/min, at levels 3, 2, and 1 respectively.
2. The optimal values of factors for maximizing MRR were found to be AFR= 400 g/min, WP= 125 MPa, and NS= 300 mm/min.
3. By conducting ANOVA study, it was found that the most influential and significant parameter for SR was nozzle speed, followed by abrasive mass flow rate, each contributing 42.37% and 19.87% respectively. Working pressure was found to be insignificant.
4. For the MRR, it was found that the most influential factor was nozzle speed, contributing 85.42% to the material removal rate, followed by abrasive mass flow rate, which contributed 4.86%. Both nozzle speed and abrasive mass flow rate were found to be significant, and WP was found to be insignificant.
5. Increasing the nozzle speed and decreasing the abrasive mass flow rate lead to lower surface roughness and decrease in contour cutting performance. However, lower nozzle speed combined with high abrasive mass flow rate improved the quality of surface roughness considerably.
6. In contrast, increasing the nozzle speed and abrasive mass flow rate provided higher rates of material removal.

REFERENCES

[1]. D. Petkovic, M. Madic, G. Radenkovic "Selection of the Most Suitable Non-Conventional Machining Processes for Ceramics Machining by Using MCDMs" Science of Sintering, 47, 2015,pp 229-235.

[2]. T. Younas, M. Manzoor and J. Kumari, "Non-conventional machining processes as expedient alternatives for conventional machining processes," 07-08 August 2017 IEEE 3rd International Conference on Engineering Technologies and Social Sciences (ICETSS), 2017, pp. 1-5.

[3]. C.A. Niranjan & Satyanarayana, Srinivas & Ramachandra, Mamtha, "Effect of process parameters on depth of penetration and topography of AZ91 magnesium alloy in abrasive water jet cutting" Journal of Magnesium and Alloys, vol 6,2018, pp 366-374.

[4]. Jennifer Milaor Llanto, Majid Tolouei-Rad, Ana Vafadar and Muhammad Aamir "Impacts of Traverse Speed and Material Thickness on Abrasive Waterjet Contour Cutting of Austenitic Stainless Steel AISI 304L" School of Engineering, Edith Cowan University,Applied Sciences,vol, 11, 2021.

[5]. Pandya Jay Bakulchandra, Ronak S. Ramijiyani "Investigation on Water Jet Abrasive Machining During Cutting of Ceramic Tile",International Journal of Advance Research and Innovative Ideas in Education, Vol-3, Issue-5, 2017, pp 1802-1812.

[6]. D.V. Srikantha, Dr. M. SreenivasaRao "Metal Removal and Kerf Analysis in Abrasive jet drilling of Glass Sheets, Procedia Materials Science, vol 6, 2014, pp 1303 – 1311.

[7]. J. Wang, T. Kuriyagawa and C. Z. Huang "An Experimental Study to Enhance the Cutting Performance in Abrasive Waterjet Machining" Machining Science and Technology, vol 7, 2003, pp 191-207.

[8]. A Venkata Lakshmi Mrudhulam, Dr. Ch V S Parameswara Rao and Dr. S N MalleswaraRao Singu "Experimental Evaluation of Optimal Parameters for Abrasive Water Jet Machining Process of Granite", International Journal of Engineering Trends and Applications (IJETA), Volume 4, Issue 2,2017, pp 15-19.

[9]. Ajit Dhanawade, Ravi Upadhyai, Arunkumar Rouniyar and Shailendra Kumar "Experimental Study on Abrasive Water Jet Machining of PZT Ceramic", Journal of Physics: Conf. Series 870, 2017.

[10]. Vaibhav Jain, Kishan Fuse, Anand Bhesdadiya "Optimization of Granite Cutting in Abrasive Water Jet Machining using Taguchi Technique", Proceedings of the International Conference on Industrial Engineering and Operations Management, Pilsen, Czech Republic, 2019.