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Experimental investigation of abrasive waterjet machining of Nickel based superalloys (Inconel 625)

A C Arun Raj*[1], S Senkathir, T Geethapriyan[1], J Abhijit[1]
[1]Department of Mechanical Engineering, *SRM Institute of Science and Technology*, Kattankulathur, India

*Corresponding author: arunraj.c@ktr.srmuniv.ac.in

Abstract. This work explores abrasive waterjet machining (AWJM) process to improve the machining capabilities of conventional water jet machine by adding abrasive particles to the water jet. The addition of abrasive particles can turn the water jet into a modern machining tool for all materials. The experimental data of cutting parameters for hard-to-machine metal Inconel 625 is obtained. Inconel 625 is machined using an abrasive water jet and the effect of water pressure, abrasive flow rate, stand-off distance, surface quality has been studied and the response parameters are investigated. Experiments were conducted, based on Taguchi's L18 orthogonal array and the process parameters were optimized using Grey relational analysis. Further, the morphological study is made using scanning electron microscope (SEM) on the samples that were machined at optimized parameters. It is observed from the experiment that Stand-off distance is the most influencing parameter among the input parameters.

1. Introduction

Abrasive water jet machining is broadly used in many industrial applications [1]. AWJM is a non conventional machining process where the material is removed by impact erosion of high-pressure high velocity of water and entrained high velocity of grit abrasives on a work piece there are so many process parameters that affect the quality of cutting, which are traverse speed, hydraulic pressure, standoff distance, abrasive flow rate, and types of abrasives [2]. Important quality parameters are Material removal rate, surface roughness, kerfs width, tapering of the kerfs. A focused stream of abrasive particles is carried by high-pressure fluid which is made to impinge on the work surface through a nozzle and work material is ejected by erosion by converting pressure energy of carrier gas or air to its kinetic energy and hence high-velocity jet erodes the work piece [3,4]. In this study, the process parameters are analyzed and the most influential factor for obtaining good surface finish is determined by grey rational analysis.

2. Experimental Work

Inconel 625 has been selected as the test material because of its outstanding resistance to chloride pitting and crevice corrosion cracking. It possesses high strength properties and resistance to elevated temperatures. Abrasive water jet machining has proven to be an effective technology for altering the variety of

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engineering materials. In this study, experimental analysis on cutting performance of AWJM on INCONEL 625 is studied. The parameters and the levels were selected primarily based on the literature review of some studies based on water jet machining. Full factorial experimental analysis and a confirmation test is done. The results obtained in the present work are compared successfully with the published literature. In machining we used three different SOD For each experimental run, the machining parameter was set to the predefined levels according to the orthogonal array. The machining process has both constant and variables parameters, according to orthogonal array to find the output parameters of MRR, SR, ROUNDNESS Once the experiment is done, calculate the MRR and find the SR by surface roughness tester and roundness by machine vision system. Then the S/N ratio, normalized S/N ratio and grey relation grade are calculated by the formula. Give the rank to the grey relational and get optimized value from the rank the highest value is optimized value. INCONEL 625 is used as the work piece which has 10 mm thickness. In L18 table the pressure, stand- off distance, surface quality and abrasive flow rate values of 3 levels were varied keeping abrasive size as constant. After the experiment is done, MRR, SR, ROUNDNESS is recorded. And then S/N ratio, normalized S/N ratio, grey relational grade and optimized value is found out based on choosing the highest value among the other.

Table 1. Input parameters.

Input Parameters	**Level 1**	**Level 2**	**Level 3**
Surface Quality	3	4	-
Pressure (Psi)	37000	40000	43000
Standoff distance (mm)	0.5	1	1.5
Abrasive flow rate (Kg/min)	0.200	0.285	0.320

3. Selection of performance measure

3.1. Material Removal Rate (MRR)

In AWJM material removal rate takes place due to brittle fracture of the work piece due to the impact of high-velocity abrasive grains [8]. The material removal rate is an important parameter that needs to be considered while cutting operations as it has an impact on the good finish of the material.

3.2. Circularity by Machine Vision.

Roundness measuring machine (RMM) and coordinate measuring machine (CMM) are employed by the help of machine vision (camera), work holding tools, lighting device and also image processing software the roundness has been calculated.

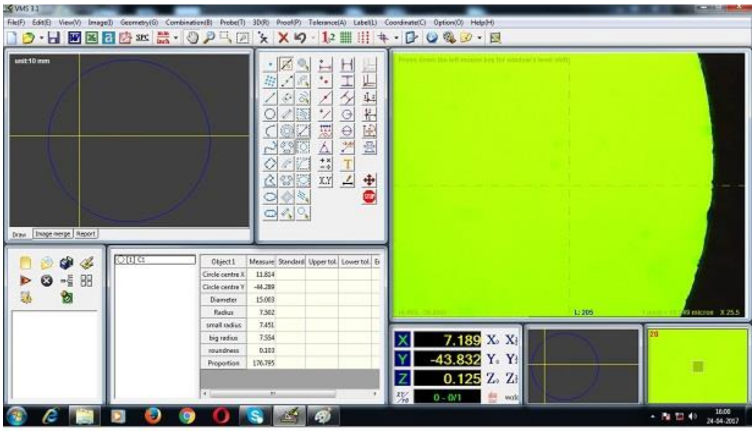

Figure 1. Measurement of roundness

4. Optimizations

4.1. Taguchi Optimization

Material Removal Rate, Surface Roughness, and Circularity were found based on the given input parameters. The surface roughness is better for the third work piece and MRR is higher for eight work piece and finally the circularity error is minimum for fifth work piece has been observed.

Table 2. L18- Orthogonal array with circularity, SR and MRR

.Orifice dia. (mm)	Water Pressure (psi)	SOD (mm)	Cutting quality	Avg. Speed (mm/min)	Total time	Circularity	MRR $*10^{-3}$	Surface Roughness (µm)
12	37000	0.5	3	36.72	4.05	0.0905	8.753	2.6837
14	37000	1	3	42.58	3.29	0.097	12.94	1.5917
16	37000	1.5	3	43.95	3.38	0.096	13.128	1.5621
12	40000	0.5	3	41.97	3.54	0.109	12.5	2.3558
14	40000	1	3	47.58	3.13	0.0176	14.337	1.1597
16	40000	1.5	3	50.20	2.96	0.1025	12.094	2.8682
14	43000	0.5	3	53.98	2.75	0.1025	16.326	3.0073
16	43000	1	3	56.96	2.61	0.104	17.249	1.5834
12	43000	1.5	3	47.69	3.12	0.097	14.327	2.7531
16	37000	0.5	4	36.34	4.10	0.097	10.610	2.0642
12	37000	1	4	30.09	4.95	0.096	9.19	1.744
14	37000	1.5	4	35.44	4.20	0.1095	10.25	1.6105
14	40000	0.5	4	38.42	3.87	0.1	11.268	2.4725
16	40000	1	4	41.44	3.59	0.1015	12.199	2.1903
12	40000	1.5	4	34.16	4.36	0.1065	9.975	1.8363
16	43000	0.5	4	46.78	3.18	0.0975	13.841	2.0465
12	43000	1	4	38.62	3.85	0.101	14.20	1.7431
14	43000	1.5	4	43.42	3.43	0.1075	12.7	2.4261

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Table 3. Grey Relation analysis with circularity, SR and MRR

Grey relation coefficients			Grey Relation AL grade	Rank
SR	MRR	Circularity		
0.392	0.999	0.536	0.642	12
0.961	1	0.444	0.802	3
1	1	0.455	0.818	2
0.477	1	0.337	0.605	15
0.645	1	1	0.882	1
0.356	1	0.387	0.581	17
0.333	1	0.387	0.573	18
0.971	1	0.374	0.782	4
0.378	1	0.443	0.607	14
0.59	1	0.444	0.678	10
0.799	1	0.456	0.752	6
0.936	1	0.333	0.756	5
0.44	1	0.411	0.617	13
0.535	1	0.396	0.644	11
0.725	1	0.354	0.693	8
0.599	1	0.439	0.679	9
0.8	1	0.401	0.734	7
0.435	1	0.346	0.594	16

4.2 Grey Rational Analysis

Optimization of multiple response characteristics is more complex compared to optimization of single performance characteristics. The multi-response optimization of the process parameters viz., material removal rate(MRR), Surface roughness(SR), circularity error on abrasive water jet machining on Inconel 625 using Orthogonal Array with grey relational analysis is studied.

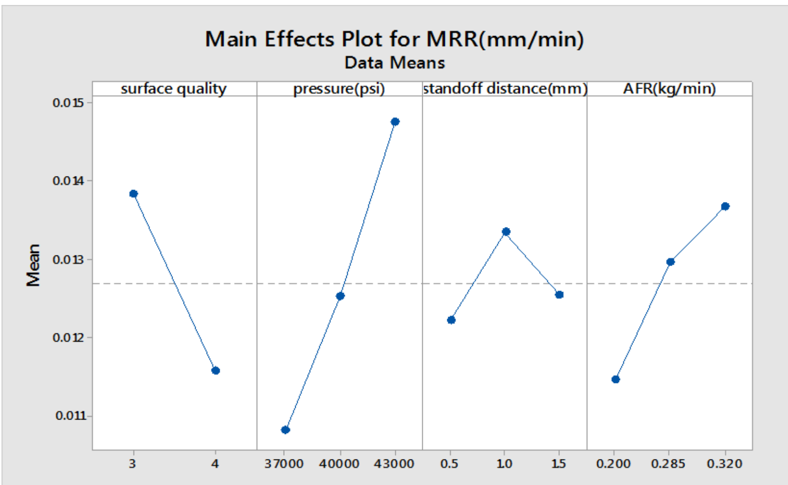

Figure 2(a). Effect of process parameters

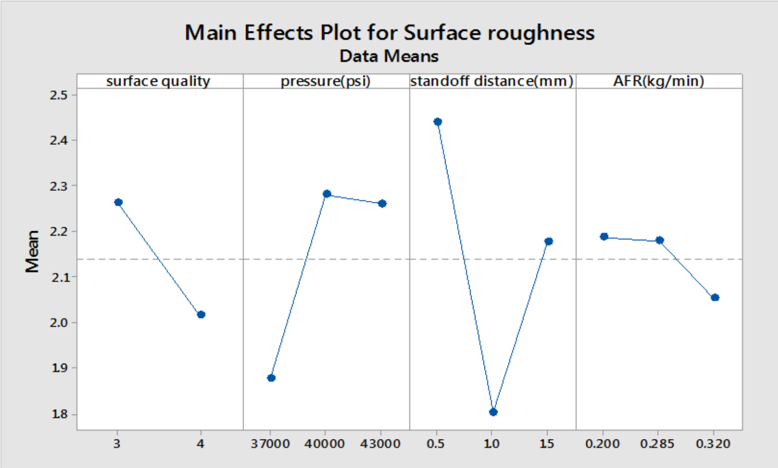

Figure 2(b). Effect of process parameters

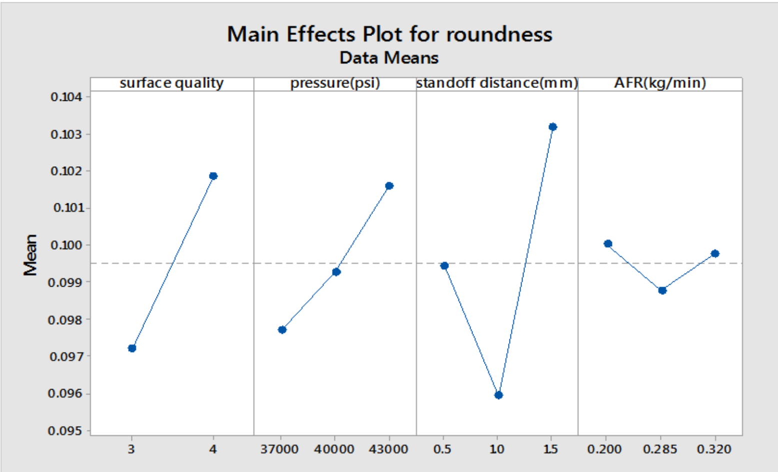

Figure 2(c). Effect of process parameters

5. Results and Interpretations

5.1. *Effect of process parameters on MRR*

From Fig.2 (a) the process parameters of surface quality, water pressure, SOD and abrasive flow rate on MRR is analyzed. The effect of surface quality on MRR was tested at standard machining and high quality machining. In this test is observed that when surface quality increases the MRR decreases. The tests were repeated with different parameters in the test range. Therefore, it is concluded that surface quality has effect on MRR. The effect of water pressure on MRR was tested in range of pressures from 37,000 to 43,000 psi. In this range it was found that when water pressure increases MRR increases. Therefore it is concluded that water pressure has major effect on MRR. The effect of SOD on MRR was tested in range between 0.5 to 1.5 mm. in this range it was found that MRR keeps on varying its range. From the results, it was found that SOD has no effect on MRR. The effect of abrasive flow rate on MRR was tested in the range between 0.200 to 0.320 kg/min. It was found that when abrasive flow rate increases MRR increases. From the test it was found that abrasive flow rate has major effect on MRR

5.2. Effect of process parameters on Surface roughness

From Fig.2 (b) the process parameters of surface quality, water pressure SOD and abrasive flow rate on Surface Roughness is analyzed. The effect of surface quality on surface roughness was tested in standard and high quality machining. But in this test it is found that surface roughness keeps on decreasing. When surface quality increases surface roughness increases and we can get smooth finish. In this test the water pressure ranges between 37,000 to 43,000 psi. Here the surface roughness increases with increase in water pressure but at one stage it remains constant and again increases. Here the stand -off distance varies from 0.5 to 1.5 mm. During this test we could observe that the SR decreases with increase in SOD and also at one point it increases. SOD has major effect on surface roughness with the highest value. The effect of AFR on surface roughness was tested in the range between 0.200 to 0.320 kg/min. Here the surface roughness remains constant upto some limit after that it decreases with increase in AFR.

5.3. Effect of process parameters on Roundness

From Fig.2 (c) the process parameters of surface quality, water pressure SOD and abrasive flow rate on Surface Roughness is analyzed. The range of surface quality for this test is standard machining and high quality machining. During this test it was found that roundness increases with increase in surface quality. The water pressure range varied between 37000 psi to 43000psi. Here also the roundness increases with increase in pressure. The stand-off distance varies between 0.5mm to 1.5 mm. Here the roundness varies its value. The effect of SOD on roundness has major effect on roundness. Here the test range is between 0.200 kg/min to 0.320 kg/min. In this test, it was found that roundness value increases and decreases with increase in AFR.

Table 4. Average Grey Rational Grades

	Level 1	**Level 2**	**Level 3**	**Max-Min**
Water Pressure	0.7413	0.6703	0.6615	0.071
SOD	0.6326	0.766	0.6748	0.1337
Cutting Quality	0.6991	0.683	-	0.061
Orifice dia.	0.6721	0.704	0.697	0.0319

5.4. SEM Analysis

Scanning Electron Microscope uses a focused electron beam to produce images. By using this, we are able to get the poor and good finish component and also useful in determining the composition. Scanning electron microscope (SEM) analysis is carried out for the work piece. It has a magnification 500µm. The below fig. 3(a) shows the surface of the work piece that has good surface finish and free from burr sand stress. Fig. 3(b) shows the presence of burr and stress in the machined surface. It has a magnification of 100 µm.

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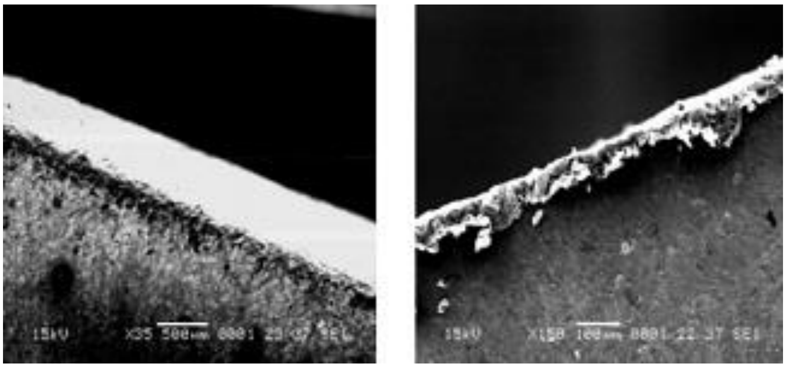

Figure 3. Output from SEM (Scanning Electron Microscope)

6. Conclusions

The input parameters have been varied and their effect on MRR, SURFACE ROUGHNESS, and CIRCULARITY has been studied.L18 orthogonal array has been used and Taguchi Optimization is used for determining the multi response optimization of parameters. From this study, it has been observed that stand-off distance is the most influencing parameters among the input parameters. Specimen 5 has been ranked 1 which has the optimum value of 0.882. From table 3, comparing the 3 levels of operation it is observed that Stand of Distance has the highest max-min value thus it is concluded to be the most influential factor.

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