OPTIMIZING OUTPUT CHARACTERISTICS OF ABRASIVE WATER JET MACHINING FOR STAINLESS STEEL 316.

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ABSTRACT

This paper aims toward Achieving fine surface roughness and kerf width for stainless steel SS316 by optimizing input parameters of AWJM such as Traverse speed and Standoff distance.Abrasive water jet machining (AWJM) is a non-conventional metal removal process as well as one of the best manufacturing processes suitable for machining on very hard material.The Taguchi design of experiment, the signal-to-noise ratio, and analysis of variance are employed to analyze the effect of the input parameters by adopting L9 Taguchi orthogonal array (OA). In order to achieve the minimum surface roughness (SR) and kerf width, two controllable factors, i.e. the parameters of each at three levels are applied for determining the optimal combination of factors and levels. The main aim is to achieve fine surface roughness and kerf width by optimized Traverse speed and standoff distance.

KEYWORDS: *AWJM, SS316, Traverse Speed, Standoff distanced, Surface Roughness (SR), Traverse Speed, Taguchi Design, Analysis of Variance.*

1. INTRODUCTION

Abrasive water jet machining (AWJM) is a non-conventional machining process that employs high-pressure water for producing high velocity stream, entrained with abrasive particles for a wide variety of materials ranging from soft to hard [1]. In the abrasive water jet machining, there is a mixture of garnet 80 mesh (abrasive) and water, which helps to cut the material simply and provides the good surface finishing. The abrasive water jet machine is more powerful than a pure water jet machine [3]. It was discovered that the kind of abrasive materials, standoff distance and cutting speed were the huge control factors and the cutting introduction was the immaterial control factor in controlling the Ra. Hocheng (1994) they has completed work on the kerf development of a ceramic plate cut by a water jet cutting [4].Taguchi method arranges a special design of orthogonal array (OA) to study the entire input parameter in much less experiments. Taguchi's philosophy which was originated by Dr. Taguchi, it is an efficient tool for designing high quality manufacturing systems [2].

AWJM is superior to many other cutting techniques in processing various materials, such as no thermal distortion on the work piece, high machining versatility to cut virtually any material and small cutting forces. This technology has found extensive applications in industry, particularly in contouring or profile cutting and in processing difficult-to-cut materials such as ceramics and marbles, and layered composites [6]. AWJM is successfully applied in the past for cutting of wide variety of materials ranging from conventional steels to ceramic materials. The intensity and the efficiency of the cutting process depend on several AWJM process parameters such as traverse rate, standoff distance, angle of impact etc. [Hashish et al., 1983]. Many investigations have been conducted to understand the effects of the process variables on the cutting performance measures, such as the top kerf width, kerf taper and surface roughness. Kerf geometry is a characteristic of major interest in abrasive water jet cutting [7].The amount of heat generated during the process is negligible, so its effect is not negative. However, this factor may be of significance when other materials for example, rubber or steel, are cut. Although abrasive water jet cutting uses considerable amounts of electricity, water and abrasives, it has very little impact on the natural environment [8]. It may generate loud noise and a messy working environment. It may also create tapered edges on the kerf, especially when cutting at high traverse rates [3]. AWJM is complicated dynamical and stochastic process with incomplete information about mechanism and side effects character. It's complicated appearance in large amount and parameters multiform determining process behaviour in large number of relations among parameters, and their interactions. Their complicacy its incomplete knowledge functioning mechanisms and large amount of factors entering to the process [9].

As the above literature review shows; there is a huge potential for getting fine surface roughness and kerf width the effectiveness of process parameters of AWJM.

2. OBJECTIVE

1. To get optimized surface roughness and kerf.
2. To achieve fine kerf width and surface roughness.
3. To avoid burr formation while machining.
4. To avoid heat affected zone in stainless steels.

3. EXPERIMENTAL SET UP AND SELECTION OF PROCESS PARAMETERS

As discussed in the literature review, a large number of variables are involved in the AWJM and virtually all these variables affect the cutting results. Therefore only those parameters are selected which shows a considerable influence on objectives of the study i.e. Surface roughness, Bottom kerf width and top kerf width. These parameters are nozzle traverse speed and Standoff distance. The rest of the parameters are kept constant which are given in Table 1.

Table 1: Constant parameters.

Constant Parameters	value
Orifice diameter	0.35mm
Nozzle diameter/mixing tube diameter	0.762mm
Nozzle length	101.65mm
Abrasive type	Silicon carbide
Abrasive size (grit no)	80 mesh size
Water pressure	2750 bar
Abrasive flow rate	0.30 kg/min

Experiments were also conducted to find out maximum value of nozzle traverse speed for the through cut. It comes out to be 100 mm/min at threshold levels of other two input variables for through cutting. The higher levels of water pressure and abrasive flow rate and lower level of nozzle traverse speed are selected at the threshold levels permitted by the machine tool as input.

Table 2 indicates variable process parameters and their levels selected.

4. DESIGN OF EXPERIMENTS AND EXPERIMENTATION

There are various strategies that ensure an appropriate choice of runs. One of the strategies is the Taguchi's orthogonal scheme. This approach can drastically reduce the number of trials required to gather the necessary data. A L9 orthogonal was selected for the experimentation which takes into account three factors at their three levels as shown in table 3. In total, 9 runs were undertaken in this experimental investigation. These experiments were conducted three times at the same setting.

In order to quantitatively evaluate experimental results, a measurement of the Surface roughness and kerf characteristics such as top kerf width and bottom kerf width was made. The measurement of kerf taper, top kerf width and depth of cut was carried out from the end of the kerf prior to separating the specimens to measure the smooth depth of cut. It was anticipated that in AWJ contouring the two kerf walls might not be symmetrical due to the jet tail back effect.

Table 2: Variable process parameters and their levels.

Parameters	Level 1	Level 2	Level 3
Nozzle Transverse speed (mm/min)	125	155	195
Standoff Distance (mm)	4	5	6

Table 3: Data summary for Surface roughness, Top and Bottom kerf width.

Experiment No.	Traverse Speed (mm/min)	Stand Off Distance (mm) (μm)	Surface Roughness(Ra) (mm)	Top Kerf Width (mm)	Bottom Kerf Width
1	125	4	0.34	0.761	0.700
2	125	5	0.56	0.771	0.683
3	125	6	0.77	0.770	0.671
4	155	4	1.81	0.780	0.646
5	155	5	1.26	0.776	0.653
6	155	6	1.55	0.773	0.660
7	195	4	1.38	0.800	0.646
8	195	5	1.61	0.821	0.630
9	195	6	1.85	0.823	0.590

5. RESULTS AND DISCUSSION:

After conducting the experiments with different settings of input parameters i.e. Nozzle Standoff distance and nozzle transverse speed, the values of output parameter i.e. surface roughness, top kerf width, Bottom kerf width are recorded and these are plotted as per Taguchi's design of experiments methodology. The analysis of the results obtained has been performed according to the standard procedure recommended by Taguchi. The analysis of response data is done by software "MINITAB 16" specifically used for the design of experiment applications. The detailed description of the analysis is given as under in this section.

5.1 EFFECT OF PROCESS PARAMETER ON THE SURFACE ROUGHNESS

General Linear Model: Surface Roughness versus Traverse speed and Standoff distance:

As analyzed with ANOVA Surface roughness is greatly affected by Traverse speed (89%), it shows greater variance with respect to traverse speed

Method

Factor coding (-1, 0, +1)

Factor Information

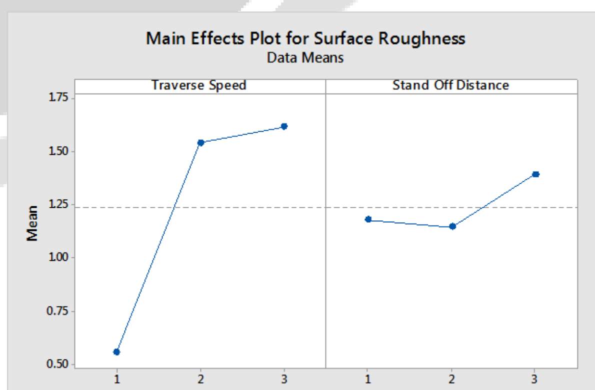
Factor	Type	Levels	Values
Traverse Speed	Fixed	3	1, 2, 3
Stand Off Distance	Fixed	3	1, 2, 3

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Traverse Speed	2	2.0889	1.04443	16.92	0.011
Stand Off Distance	2	0.1075	0.05373	0.87	0.485
Error	4	0.2469	0.06172		
Total	8	2.4432			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.248428	89.90%	79.79%	48.85%



Regression Equation

Surface Roughness = 1.2367 - 0.680 Traverse Speed_1 + 0.303 Traverse Speed_2 + 0.377 Traverse Speed_3 - 0.060 Stand Off Distance_1 - 0.093 Stand Off Distance_2 + 0.153 Stand Off Distance_3

5.2 EFFECT OF PROCESS PARAMETER ON THE TOP KERF WIDTH:

General Linear Model: Top Kerf Width versus Traverse Speed and Stand Off Distance

Method

As analyzed with ANOVA kerf width is also greatly affected by Traverse speed (93%), it shows greater variance with respect to traverse speed, and standoff distance shows minimum effects on kerf width.

Factor coding (-1, 0, +1)

Factor Information

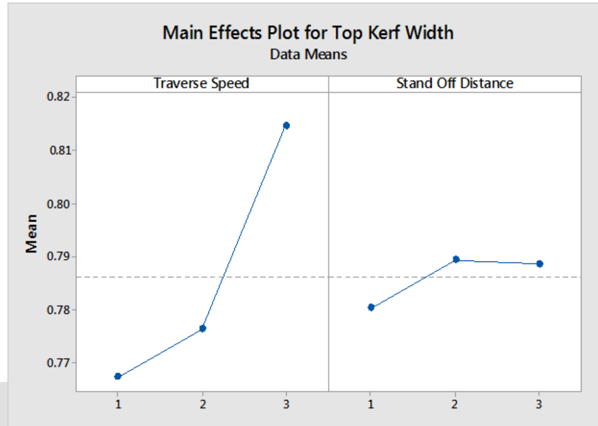
Factor	Type	Levels	Values
Traverse Speed	Fixed	3	1, 2, 3
Stand Off Distance	Fixed	3	1, 2, 3

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Traverse Speed	2	0.003791	0.001895	29.26	0.004
Stand Off Distance	2	0.000151	0.000075	1.16	0.399
Error	4	0.000259	0.000065		
Total	8	0.004201			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0080485	93.83%	87.66%	68.77%



Regression Equation

Top Kerf Width = 0.78611 - 0.01878 Traverse Speed_1 - 0.00978 Traverse Speed_2 + 0.02856 Traverse Speed_3 - 0.00578 Stand Off Distance_1 + 0.00322 Stand Off Distance_2 + 0.00256 Stand Off Distance_3

5.2 EFFECT OF PROCESS PARAMETER ON THE TOP KERF WIDTH:

General Linear Model: Bottom Kerf Width versus Traverse Speed and Stand Off Distance

Method

Factor coding (-1, 0, +1)

Factor Information

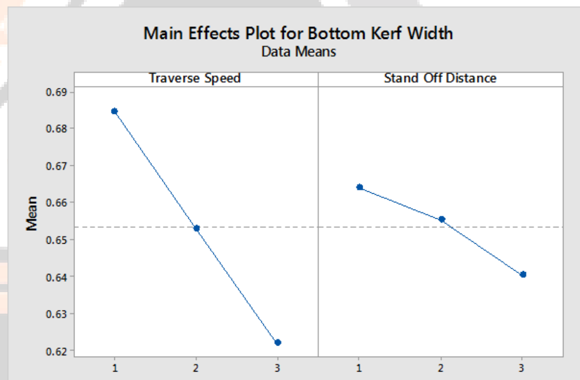
Factor	Type	Levels	Values
Traverse Speed	Fixed	3	1, 2, 3
Stand Off Distance	Fixed	3	1, 2, 3

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Traverse Speed	2	0.005891	0.002945	8.88	0.034
Stand Off Distance	2	0.000860	0.000430	1.30	0.368
Error	4	0.001326	0.000332		
Total	8	0.008078			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0182102	83.58%	67.16%	16.87%



Regression Equation

Bottom Kerf Width = 0.65322 + 0.03144 Traverse Speed_1 - 0.00022 Traverse Speed_2 - 0.03122 Traverse Speed_3 + 0.01078 Stand Off Distance_1 + 0.00211 Stand Off Distance_2 - 0.01289 Stand Off Distance_3

6. CONFIRMATION TESTS

Data about the confirmatory experiments performed at the optimum settings of process parameters are is presented in table 9. It is important to mention that predicted mean values as shown in table 9 are calculated using MINITAB 16.

Response Optimization: Bottom Kerf Width, Top Kerf Width and Surface Roughness

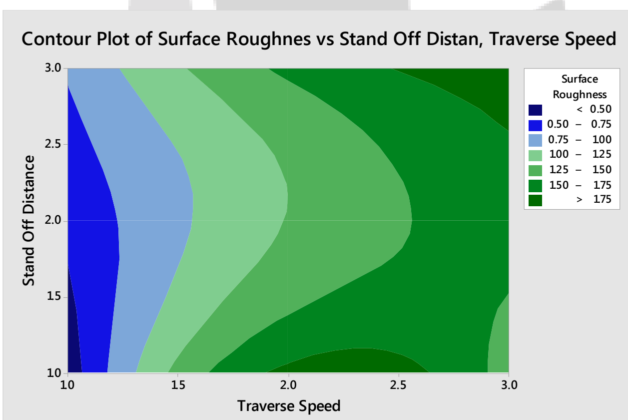
Parameters

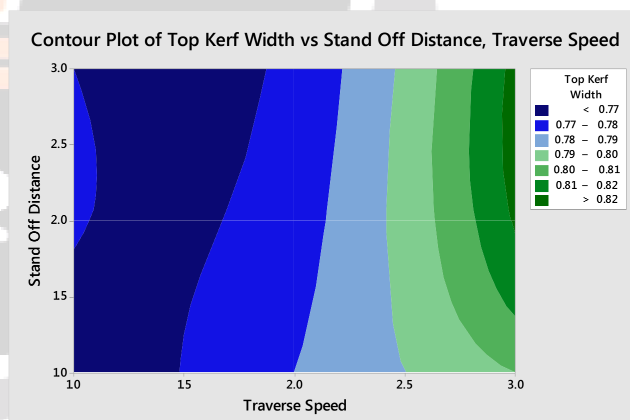
Response	Goal	Lower	Target	Upper	Weight	Importance
Bottom Kerf Width	Maximum	0.59	0.700		1	1
Top Kerf Width	Minimum		0.761	0.823	1	1
Surface Roughness	Minimum		0.340	1.850	1	1

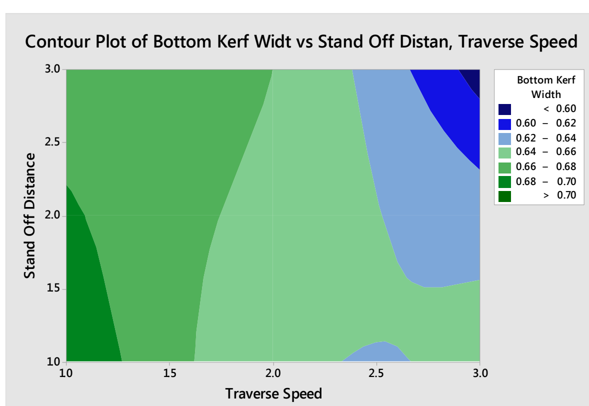
7. CONCLUSIONS

Present work explored the abrasive water jet machining of SS316 using Taguchi's design of experiments and subsequent analysis. From the work, following inferences can be drawn:

- For top Surface Roughness, nozzle transverse speed has emerged as most significant parameter with a percent contribution of 89.90% followed by Standoff distance.
- For top kerf width, nozzle transverse speed has emerged as most significant parameter with a percent contribution of 93.83% followed by Standoff distance.
- For bottom kerf width, nozzle transverse speed has emerged as most significant parameter with a percent contribution of 83.58% followed by Standoff distance.
- Optimal settings of process parameters for minimum Surface roughness, top kerf width and bottom kerf width are nozzle transfer speed and standoff distance at lowest levels of 125 mm/min and 4mm respectively.







Solutions

Solution	Traverse Speed	Standoff Distance	Bottom Kerf Width Fit	Top Kerf Width Fit	Surface Roughness Fit	Compose Desirability
1	1	1	0.695444	0.761556	0.496667	0.947800
2	1	2	0.686778	0.770556	0.463333	0.880836

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