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Modeling of Abrasive Water Jet Matching Parameters When Cutting High Thickness St37 Sheets

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Abstract. Cutting large thickness steel sheets faces a lot of limitations specially when using flame cutting such as burning surface and changing in the mechanical properties. Abrasive water jet machining (AWJM) can replace this method to avoid these limitations. This paper studies the most significant process parameters such as water pressure (P), traverse speed (Ts), and abrasive particles flow rate (Abr) as inputs on surface roughness (Ra), waviness (Wa), and kerf taper angle (Ɵ) as outputs when cutting steel 37 with 55mm thickness. The experiments were designed by Taguchi method. Taguchi analysis with signal to noise ratio (smaller is better) is used to determine the preferred levels of the input variables. A validation specimen is machined at the preferred levels which confirmed the correctness of Taguchi results. A prediction modelling using artificial neural network (ANN) is built between inputs and outputs to predict surface roughness, waviness and kerf angle for various inputs. The validation shows that the average total percentage error is 3.89%. The results show that the most significant parameter is the traverse speed on all outputs.

Keywords: Abrasive water jet machining (AWJM); steel 37(st.37); Surface roughness (Ra); surface waviness (Wa); kerf taper angle(Ɵ); Taguchi design method.

1. INTRODUCTION

AWJM process is one of the distinctive advanced machining which has proven its ability in processing variety of developed materials and different thicknesses. AWJM utilizes a high-water pressure to accelerate the abrasive particles which erode the workpiece material. AWJM is considered a good alternative to flame cutting for different thicknesses because the disadvantages of flame cutting which can be avoided by AWJM such as burning the surface, changing of the material properties, and formation of burning material layer. So, surface integrity produced by AWJM process is very important response to study. The importance of surface integrity appears at applications of friction, lubrication, and insertion of mechanical parts. So, the most of the researchers study the effect of many process parameters on surface properties that affect its quality such as roughness, waviness, and kerf taper ratio or angle.

It was found that the traverse speed (Ts) had the biggest influence on surface roughness (Ra) for AISI 309 stainless steel [1]. **V. Chaturvedi and D. Singh**, [2] concluded that the traverse speed was the most significant factor and the standoff distance was the least one on surface roughness using VIKOR with single to noise ratio method for AISI 304 stainless steel sheet 20 mm thickness. **C.R. Sanghani, et al**, [3] showed that taper ratio and surface roughness increases with the increase of traverse speed, stand-off jet distance and abrasive flow rate and with the reduction in water pressure for AISI 304 stainless steel. **N. Yuvaraj and M. P. Kumar**, [4] concluded thatthe most effective parameters are jet pressure and impingement angle on surface roughness for D2 steel 80 mm thickness using the simos-grey relational method and ANOVA test.

N. Yuvaraj and M. Pradeep Kumar,[5]studied the effect of a jet impact angle and water pressure at two levels of each of them and showed that the jet angle of 70° is keeping the surface integrity of D2 steel better than normal jet impact angle of 90°. **ChithiraiPon Selvan, et al,**[6]built an ANN model to predict depth of cut and surface roughness. This model built according to experimental work on cutting mild steel. Taguchi’s method of design of experiments was used to select input process parameters by varying water pressure, traverse speed, abrasive mass flow rate and standoff distance**.**

Influence of three parameters (traverse speed, standoff distance, and water pressure) on surface finish of austenitic steel (AISI 316L) was investigated. Full factorial experimental design was applied [7]. EN24 steel with a range of thickness was machined by AWJM. Water jet pressure, nozzle speed, and standoff distance had been varied at three levels. The speed was the most significant on surface roughness and kerf wall inclination [8]. **M. Zohoor and S. H. Nourian,** [9] showed that the traverse speed and nozzle diameter were significant factors on the kerf quality and geometry on Hardox steel. The parameters used were nozzle diameter, traverse speed, water pressure, and abrasive flow rate. Top width of cut and kerf taper angle were measured and analyzed. ANOVA was employed to get the most effective parameters.

AWJ parameters were investigated such as speed and abrasive flow rate on cut width on steel 11523 of different thicknesses (5 to 20 mm). It was proved that the machining speed influences primarily the cut width and the deviation from the perpendicular line,[10]. **J. Kechagias, et al,** [11] stuided the effect of sheet thickness, nozzle diameter, standoff distance, and traverse speed when cutting TRIP 800 HR-FH and TRIP 700 CR-FH steel sheets on kerf geometry. According to ANOVA kerf geometry affected mainly by nozzle diameter. An Explicit Finite Element Analysis (FEA) was conducted and (AWJM) Process Parameters (impact angle, operational pressure and traverse rate) were studied to provide data to optimize (AWJM) process. It was concluded that material removal rate increase by (1% – 3%) with increasing the Pressure by (4% – 5%). But also showed drawbacks as surface roughness and damage When the impact angle is 90^{o} [12].

So, the objective of this paper is to study the influence of the traverse speed, water pressure, and abrasive particles flow rate as input parameters on the output responses that characterize the surface integrity for steel 37 coupled with designing of multi prediction modelling to predict surface roughness, waviness and kerf angle for various inputs.

2. EXPERIMENTAL WORK

2.1 Experimental plan

In the present experimental work, the influence of three process parameters namely water pressure (p), traverse speed (Ts), and abrasive mass flow rate (Abr) on surface roughness, waviness, and kerf taper angle are investigated, when machining steel 37 material with 55 mm thickness by AWJM. According to Taguchi design method, the parameters have five different levels as illustrated in table 1, and with constant parameters used during this work are illustrated in table.2, there are 25 experiments as illustrated in table.3. KMT STREAMLINE PRO-2 machine was used in machining the specimens. The data received from experiments are analyzed using Minitab 2019. The prediction modeling is designed by Artificial Neural Network (ANN) using MATLAB software.

Table 1: The levels of parameters

The factor	Level 1	Level2	Level3	Level4	Level5
Water pressure (bar)	3000	3500	4000	4500	5000
Traverse speed (mm/min)	5	10	15	20	25
Abrasive particles flow rate (g/min)	200	250	300	350	400

Table.2: The constant parameters

Abrasive material	Garnet
Abrasive material size	#80
Orifice diameter	0.25 mm
Jet impingement angle	90◦
Standoff distance	2 mm
Material type	Steel 37
Nozzle length	152.4 mm
Nozzle diameter	0.76 mm
Workpiece thickness	55 mm

Table 3: The Taguchi trials

Trial No.	Pressure(P)bar	Traverse speed (Ts) mm/min	Abrasive particles mass flow (Abr) g/min
1	3000	5	200
2	3000	10	250
3	3000	15	300
4	3000	20	350
5	3000	25	400
6	3500	5	250
7	3500	10	300
8	3500	15	350
9	3500	20	400
10	3500	25	200
11	4000	5	300
12	4000	10	350
13	4000	15	400
14	4000	20	200
15	4000	25	250
16	4500	5	350
17	4500	10	400
18	4500	15	200
19	4500	20	250
20	4500	25	300
21	5000	5	400
22	5000	10	200
23	5000	15	250
24	5000	20	300
25	5000	25	350

2.2 Selection of work piece material

In the present investigation, steel 37 material is selected. This material which known as structural steel is used in a lot of manufacture parts for machines and welded structure parts. The chemical composition of steel 37 is illustrated in table .4. For this experimental work, the specimens were machined having size of 30×30×55 as shown in Fig .1.

Table 4: Chemical composition of steel 37

The element	The percentage %
Iron (Fe)	99.2
Carbon (c)	0.165
Silicon (Si)	0.0341
Manganese (Mn)	0.973
Phosphorus (P)	0.0092

Fig.1: Samples of the specimens machined by AWJM

2.3 Surface roughness (Ra)

Surface roughness is measured by using surface roughness meter (Surtronic 3+ stylus profilometer) as shown in Fig. 2. For measuring roughness, stylus is traversed in the same direction of traverse speed at 15 mm from the top surface of workpiece (smooth zone). The measurement process is repeated three times for each side of the workpiece, then the average is taken to analysis.

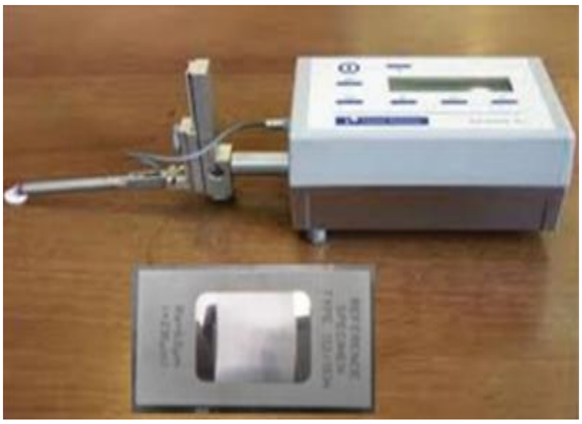

Fig. 2: **Surtronic 3+ stylus profilometer**

2.4 Surface waviness (Wa)

Surface waviness is measured using Axiom Too 600 coordinate measuring machine (CMM) which is shown in Fig.3, according to the definition of Waviness arithmetic mean height value (Wa). CMM takes the coordinates of 30 points along 10 mm at the middle of the machined surface at 50 mm from the top surface of workpiece (the rough zone) as shown in Fig.4 for all four sides of the specimen. According to the definition of waviness, it calculated as the mean deviation of the axis that perpendicular to the reference surface and the average of the four sides was taken to analysis.

Fig.3:Axiom Too CMM

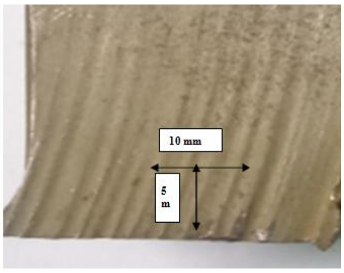

Fig.4: Schematic diagram for waviness location

2.5 Kerf taper angle(Θ)

Axiom Too 600 CMM is used to measure the top width (X_1) and bottom width (X_2) of specimen as shown at Fig.5 each of them three times along the specimen and take their average (X'_1), (X'_2). Then the taper angle was calculated according to equation.1.

$$\tan(\Theta) = (X'_2 - X'_1)/2t \qquad \text{Equ.1}$$

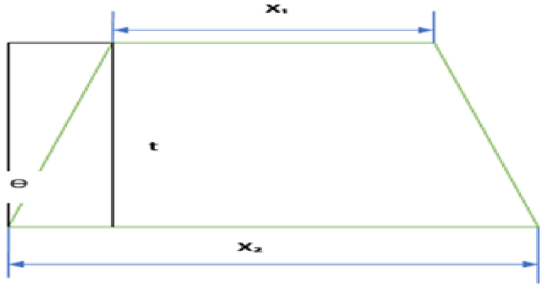

Fig.5: Schematic diagram for taper angle measurement

3. RESULTS AND DISCUSSION

3.1 ANOVA analysis

The results are analyzed by ANOVA using Minitab 2019 software to determine the most significant parameter on the output, and the effecting percent of all input process parameters on output parameter. The results are illustrated in table.5.

Table .5: ANOVA results

Response	Source	DF	Contribution%	SS	MS	F	P
Surface roughness	P	4	8.04	0.01410	0.003524	2.54	0.095
	Ts	4	54.24	0.09504	0.023761	17.09	0.000
	Abr	4	28.20	0.04942	0.012355	8.89	0.001
	Error	12	9.52	0.01668	0.001390		
	Total	24	100				
Surface waviness	P	4	4.86	1.3297	0.33242	5.50	0.009
	Ts	4	81.64	22.3497	5.58742	92.37	0.000
	Abr	4	10.85	2.9701	0.74253	12.28	0.000
	Error	12	2.65	0.7259	0.06049		
	Total	24	100				
Kerf taper angle	P	4	9.65	0.06745	0.016862	11.96	0.000
	Ts	4	70.77	0.49445	0.123611	87.68	0.000
	Abr	4	17.15	0.11982	0.029956	21.25	0.000
	Error	12	2.42	0.01692	0.001410		
	Total	24	100				

From the ANOVA results, it is found that the most significant factor is the traverse speed on the roughness (Ra), the waviness (Wa), and the kerf taper angle (Ө).For the surface roughness, the most significant parameter is the traverse speed with impact ratio 54.24% followed by the abrasive mass flow rate with impact ratio 9.52%. the water pressure is not significant on the surface roughness. For the surface waviness, all the process parameters are significant. The most significant parameter is the traverse speed with impact ratio 81.64% followed by abrasive mass flow rate with impact ratio 10.85% then the water pressure with impact ratio 4.86%.For the kerf taper angle, all the process parameters are significant. The most significant parameter is the traverse speed with impact ratio 70.15% followed by the abrasive mass flow rate with impact ratio 17.15%, then the water pressure with impact ratio 9.65%.

3.2 Taguchi analysis with signal to noise ratio (S/N)

Taguchi analysis with the Signal to Noise ratio (S/N) (smaller is better) is used to determine the preferred levels of the input variables that used in Taguchi design. This preferred combination of levels is used to get the best values according the target output using Minitab 2019 software. The preferred levels are shown in Fig.6.

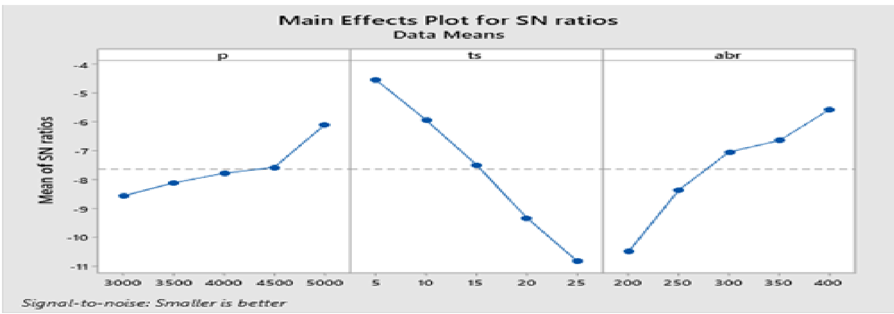

Fig.6: Preferred levels using (S/N) ratio

The preferred levels are 5000 bar, 5 mm/min, and 400 g/min as a water pressure, traverse speed, and abrasive mass flow rate respectively. A validation specimen is machined at the preferred levels and measuring the surface roughness, waviness, and kerf taper angle. It is found that the values of measuring data are 2.25µm, 0.007mm, and 0.075º respectively which confirm the correctness of the Taguchi analysis results.

4. MODELLING USING ANN

MATLAB software with ANN tool box is used to design neural networks to establish a relationship between input variables and output variables and also to predict surface roughness, waviness and kerf angle for various inputs. The general specification of the design networks is illustrated in table.6. The different structures of networks with their mean square error are illustrated in table.7, with Max_fail is 1000 (validation checks) and 100,000 epochs in training step. The recommended network design is based on the mean square error.

Table.6: The general specifications of the design of networks

Specification	Type
Network type	Feed- forward back propagation
Training function	TRAINLM
Adapting learning function	LEARNGDM
Performance function	Mean square error (MSE)
Number of neurons	10
Transfer function	Logsig, Tansig
Number of hidden layers	From 1:10

Table. 7: The different designs of prediction models

No of network.	Transfer function	Network design	MSE (Total)
1	Tansig	3x10x3	0.0885
2	Tansig	3x10x10x3	0.1030
3	Tansig	3x10x10x10x3	0.1512
4	Tansig	3x10x10x10x10x3	0.0551
5	Tansig	3x10x10x10x10x10x3	0.5693
6	Tansig	3x10x10x10x10x10x10x3	0.1215
7	Tansig	3x10x10x10x10x10x10x10x3	0.0590
8	Tansig	3x10x10x10x10x10x10x10x10x3	0.3216
9	Tansig	3x10x10x10x10x10x10x10x10x10x3	0.1154
10	Tansig	3x10x10x10x10x10x10x10x10x10x10x3	0.2532
11	Logsig	3x10x3	0.2256
12	Logsig	3x10x10x3	0.1238
13	Logsig	3x10x10x10x3	0.1081
14	Logsig	3x10x10x10x10x3	0.1760
15	Logsig	3x10x10x10x10x10x3	0.0776
16	Logsig	3x10x10x10x10x10x10x3	0.3670
17	Logsig	3x10x10x10x10x10x10x10x3	0.2099
18	Logsig	3x10x10x10x10x10x10x10x10x3	0.4160
19	Logsig	3x10x10x10x10x10x10x10x10x10x3	0.1741
20	Logsig	3x10x10x10x10x10x10x10x10x10x10x3	0.0535

It is found that the network with structure (3x10x10x10x10x10x10x10x3, Tansig) as shown in Fig.7, has the least total average error percent which equal 3.89% with training error percent is 3.6% and validation error percent is 4.67%. The total error percent in estimation at training and validation for waviness, kerf taper angle, and surface roughness are 7.35%, 3.61%, and 0.72% respectively as shown in Fig.8.

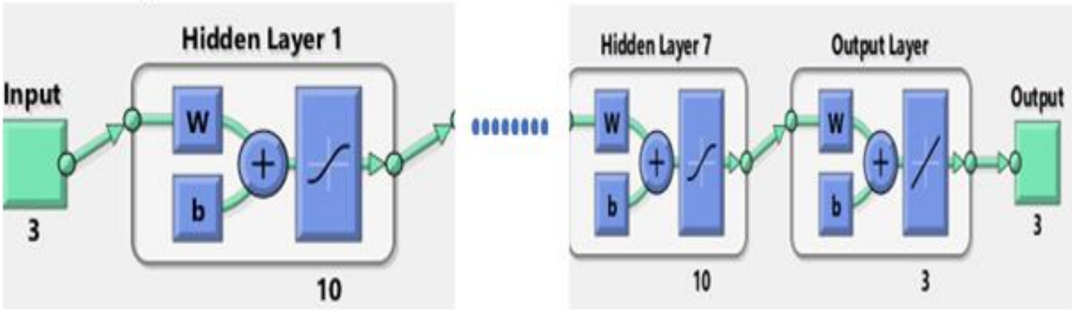

Fig. 7: The network structure

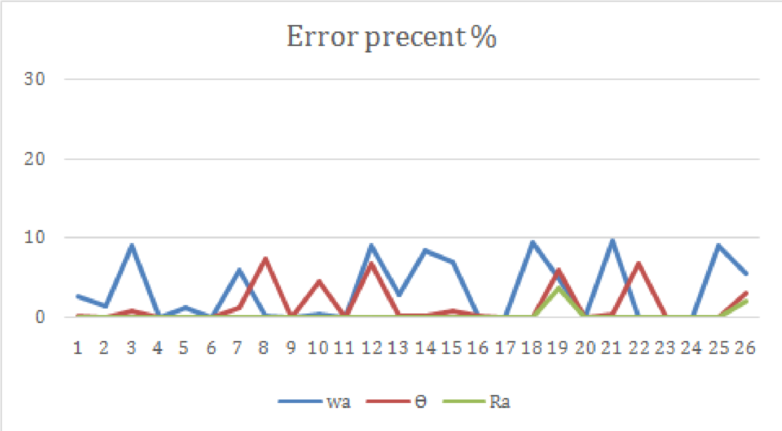

Fig. 8: Percentage error for the outputs

5. CONCLUSION

From the present work it can be concluded the following:

1. Traverse speed is the most significant factor that affects surface roughness, waviness, and kerf angle.
2. Abrasive flow rate is the second factor that affects the roughness, waviness, and kerf angle.
3. Water pressure is the third factor that effect the waviness and kerf angle and no significant on surface roughness.
4. Taguchi analysis with the Signal to Noise ratio (S/N) (smaller is better) has the ability to determine the preferred levels of the input variables which used to get the best values of the target output (roughness, waviness, and kerf angle).
5. After applying of ANN to predict surface roughness, waviness and kerf angle for various inputs, it was found that the total average error percent equal 3.89%. The total percentage error in estimation at training and validation for waviness, kerf taper angle, and surface roughness are 7.35%, 3.61%, and 0.72% respectively.

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