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An investigation of different abrasives using abrasive water jet machining of steel

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Abstract* — Surface roughness (R_a) and material removal rate characteristics of an abrasive water jet machined surface of steel were studied. Garnet and aluminium oxide were used as an abrasive material with 80mesh. Taguchi's design of experiments and analysis of variance (ANOVAs) Analysis was used to determine the effect of machining parameters on surface roughness and material Removal Rate. It was found that traverse speed and types of abrasive materials are the most significant control factor in influencing material removal rate and surface roughness respectively. The experimental result shows that aluminium oxide type abrasive materials perform better than garnet in terms of both machining characteristics. Increasing in traverse speed and abrasive flow rate may result in better material removal rate characteristics. Decreasing the traverse speed and increased abrasive flow rate may result better surface smoothness.

Keywords- Abrasive water jet cutting, process parameters, abrasive type, DOE

I. INTRODUCTION

Stainless steel is the name given to a group of corrosion resistant steels. Their remarkable resistance to corrosion is due to a chromium-rich oxide film which forms on the surface. It is a strongly durable material used in various manufacturing industries due to its properties and ability to resist corrosion effect. [1]

Abrasive water jet machining (AWJM) process is one of the non-conventional and versatile processes that have been widely used in various industry related applications. In this cutting technique, a thin, high velocity water jet accelerates abrasive particles that are directed through an abrasive water jet nozzle and strike on the material to be cut. Advantages of abrasive water jet cutting machine include the ability to cut all types of materials, no thermal distortion, little cutting forces, more flexibility and being environmentally friendly. Because of these capabilities, this cutting technique is more cost-effective than conventional and some non- conventional machining processes. [2] The cut geometry depends on the type of abrasive grit and cutting parameters. Different types of abrasives are used in AWJM like garnet, olivine, aluminium oxide (Al_2O_3), silica-sand, glass bead, silicon carbide (SIC), zirconium, etc. But a survey shows that 90% of the AWJM is done using garnet as an abrasive. The hardness of the abrasive particles is an important characteristic which strongly influences the cut geometry and that the depth of jet penetration depends strongly on the ratio of the hardness of the target material to the hardness of the abrasive. [3, 4]

In this study, it was found that the most significant control factors are types of abrasives, traverse speed, stand-off distance which has major effect on cutting quality. A few experimental investigations have been undertaken with the aim of analyzing the effect of process parameters on cut quality. Experiments were conducted in varying traverse speed, abrasive flow rate, standoff distance and types of abrasives were analyzed and optimized with consideration of work piece surface roughness with using Design of experiments (DOE) and Analysis of variance (ANOVA).

II. EXPERIMENTAL SETUP

The experiments were conducted on abrasive water jet machine, KMT at Ram engineering company. All the machining procedures were done using single-pass cutting, some factors were kept constant during investigation. This machine used 350Mpa water pressure, abrasive size (80 Mesh), orifice diameter, nozzle diameter and impact angle were kept constant throughout the investigation. During the experiments, the nozzle was frequently checked and changed, if the nozzle worn out significantly. An 8mm thick stainless steel-304 was used as work piece material. Technical specification of abrasive water jet machine is given in table 1. SS-304 has selected as work material due to lower carbon which minimize the carbide precipitation and is widely used in industries and some household applications fabrication of electric components, screw, machine parts, and automobile spare parts. Chemical composition of SS-304 is given in table 1.

Table 1 technical specification of abrasive water jet machine

Parameters	Specification
Table size (X/Y/Z)	3000X 3000X 250 mm
Ultra high pump	50 HP
Water pressure	3500 Bar (350 Mpa)

Orifice diameter	0.30 mm
Nozzle diameter	0.70 mm
Dimension of pump	870X 900X 1800 mm

In this study, cutting parameters such as abrasive types, traverse speed, abrasive flow rate, and stand-off distance were analyzed and optimized with consideration of material removal rate and surface roughness. Mass of material investigated based on mass difference, surface roughness measure with surface roughness tester mitutoyo see fig 1. Garnet and aluminium oxides were used as an abrasive see fig 2.Abrasive types were selected based on difference in hardness and both have same grit size of 80 mesh.

Fig. 1 Surface roughness tester

Fig. 2 Abrasive Grits

Design of experiments (DOE) is the powerful tool and can used in variety of experimental situation. Design of experiments approach (DOE), Taguchi method and ANOVA were used to optimized parameters and analyze cutting parameters with consideration of material removal rate of work material and surface roughness. The L9 Orthogonal Array methodology was selected to plan the experiments. Three factors are chosen the design becomes a 3 level 3 factorial Taguchi design. Total 18 nos. of experiments has been carried out with two different abrasives. The MINITAB16 software helps to develop the experimental plan for L9 Orthogonal Array. The values of the parameters that have varied during the execution of experiments are shown in Table 2.

Table 2 Abrasive water jet machine parameters and their levels

Symbol	Input Parameters	Level 1	Level 2	Level 3
A	Traverse speed (mm/min)	50	100	150
B	Abrasive flow rate (gm/min)	250	350	450
C	Stand-off distance (mm)	2	3	4

III. ANALYSIS AND DISCUSSION OF EXPERIMENTAL RESULT

Effect of process parameters and matching parameters is conducted in table. The nine experiments were done on the abrasive water jet machine with garnet and aluminium oxide abrasives based on the Taguchi method and it summarized in the following table.

Table 3 Design Layout and Experimental Results

Ex. no.	Traverse speed (A)	Abrasive flow rate (B)	Stand-off distance (C)	MRR (Garnet) gm/s	SR (Garnet) µm	MRR (Al. oxide) gm/s	SR (Al. oxide) µm
1	50	250	2	0.0426	2.893	0.0490	2.875
2	50	350	3	0.0480	2.952	0.0488	2.860

3	50	450	4	0.0500	2.953	0.0530	2.869
4	100	250	3	0.0838	3.235	0.0550	3.195
5	100	350	4	0.0944	3.305	0.0600	3.334
6	100	450	2	0.0890	2.979	0.1020	2.980
7	150	250	4	0.1190	3.635	0.0590	3.506
8	150	350	2	0.1160	3.599	0.1230	3.460
9	150	450	3	0.1220	3.484	0.1340	3.405

Analysis of Variance tables 4 shows the effect of parameter on MRR. The significant parameters can be easily identified .Traverse speed is a most significance factor for MRR and it has p-value<0.05. Abrasive flow rate and stand of distance has less effect on MRR. Percentage contribution of residual error is 3.84%. It strengthens the analysis as it is on minimum side. Maximum % percentage contribution of Traverse speed has 91.6%.

The ANOVA table for material removal rate for stainless steel 304 is given below:

Table 4 ANOVA for MRR (Garnet)

Source	DF	Seq SS	Adj SS	Adj MS	F value	P	% Con.
A	1	0.0071002	0.0071002	0.0071002	119.172	0.000112	91.6%
B	1	0.0003466	0.0003466	0.0003466	5.817	0.060729	4.47%
C	1	0.0000056	0.0000056	0.0000056	0.094	0.771387	0.07%
Error	5	0.0002979	0.0002979	0.0000596			3.84%
Total	8	0.0077502					

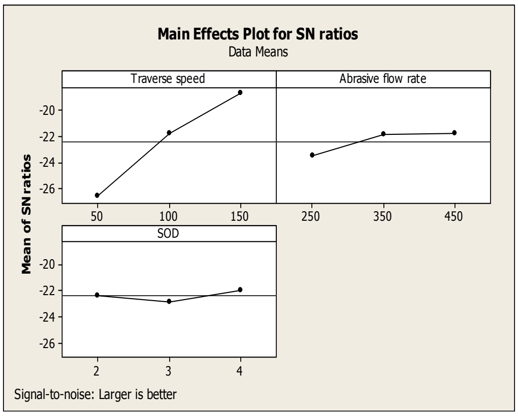

Fig.3 Main effect plot for MRR (garnet)

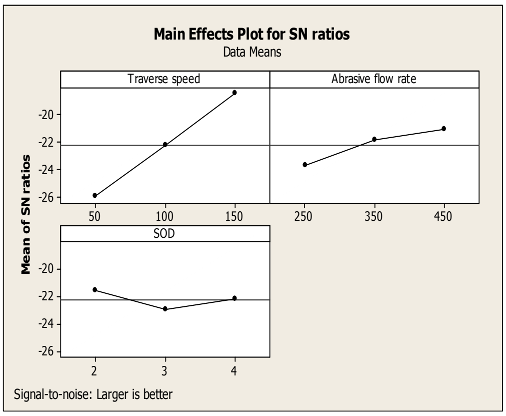

fig.4 Main effect plot for MRR (Al.oxide)

Fig. 3 and 4 shows the main effect plot of MRR at different parameters like traverse speed, abrasive flow rate and stand of distance in Abrasive water jet machining process of SS304. From the figures, it can be seen that maximum MRR (Garnet and Al.oxide) obtained are at traverse speed of 150 mm/min, abrasive flow rate of 450 gm/min for both abrasives and stand of distance of 4mm and 2mm respectively.

Analysis of Variance tables 5 shows the effect of parameter on MRR. The significant parameters can be easily identified .Traverse speed is a most significance factor for MRR and abrasive flow rate is also significant factor for MRR, it has p-value<0.05. Stand of distance has less effect on MRR. Percentage contribution of residual error is 4.98%. It strengthens the analysis as it is on minimum side. Maximum % percentage contribution of Traverse speed has 82.5%.

The ANOVA table for material removal rate for stainless steel 304 is given below:

Table 5 ANOVA for MRR (Al.oxide)

Source	DF	Seq SS	Adj SS	Adj MS	F value	P	% Con
A	1	0.0072245	0.0072245	0.0072245	82.8042	0.000268	82.5%
B	1	0.0009830	0.0009830	0.0009830	11.2671	0.020181	11.23%
C	1	0.0001092	0.0001092	0.0001092	1.2519	0.314042	1.24%
Error	5	0.0004362	0.0004362	0.0000872			4.98%
Total	8	0.0087530					

Analysis of Variance tables 6 shows the effect of parameter on SR. The significant parameters can be easily identified .Traverse speed is a most significance factor for SR and it has p-value<0.05. Abrasive flow rate and stand of distance has less effect on SR. Percentage contribution of residual error is 5.22%. It strengthens the analysis as it is on minimum side. Maximum % percentage contribution of Traverse speed has 87.6%.

The ANOVA table for surface roughness for stainless steel 304 is given below:

Table 6 ANOVA for SR (Garnet)

Source	DF	Seq SS	Adj SS	Adj MS	F value	P	% Con.
A	1	0.614400	0.614400	0.614400	83.8198	0.001250	87.6%
B	1	0.020068	0.020068	0.020068	2.7378	0.158904	2.86%
C	1	0.029681	0.029681	0.029681	4.0492	0.100356	4.23%
Error	5	0.036650	0.036650	0.007330			5.22%
Total	8	0.700799					

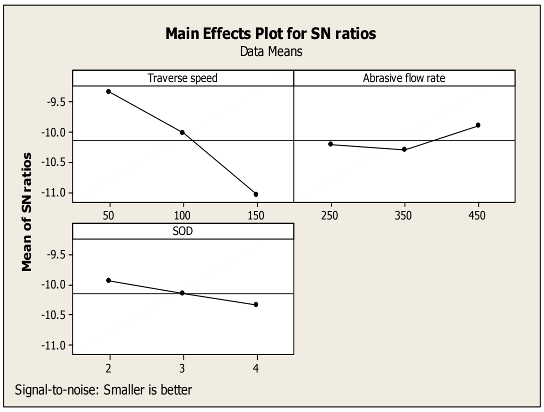

Fig.5 Main effect plot for SR (garnet)

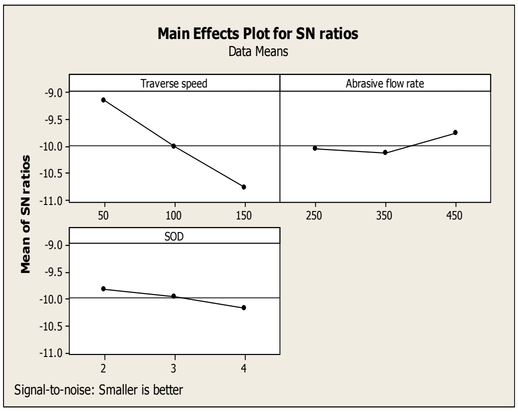

fig.6 Main effect plot for SR (Al.oxide)

Analysis of Variance tables 7 shows the effect of parameter on SR. The significant parameters can be easily identified .Traverse speed is a most significance factor for SR and it has p-value<0.05. Abrasive flow rate and stand of distance has less effect on SR. Percentage contribution of residual error is 4.37%. It strengthens the analysis as it is on minimum side. Maximum % percentage contribution of Traverse speed has 88.2%.

The ANOVA table for surface roughness for stainless steel 304 is given below:

Table 7 ANOVA for SR (Al.oxide)

Source	DF	Seq SS	Adj SS	Adj MS	F value	P	% Con.
A	1	0.520381	0.520381	0.520381	100.857	0.000167	88.2%
B	1	0.017281	0.017281	0.017281	3.349	0.126753	2.93%
C	1	0.025873	0.025873	0.025873	5.014	0.075281	4.39%
Error	5	0.025798	0.025798	0.005160			4.37%
Total	8	0.589333					

IV. Effects of both abrasives on MRR and SR

Garnet and aluminium oxide abrasive grit are used as an abrasives. Hence the material removal rate for garnet abrasive is little much less compare to the aluminium oxide abrasives and the graphs represent the difference of the MRR with both abrasives.

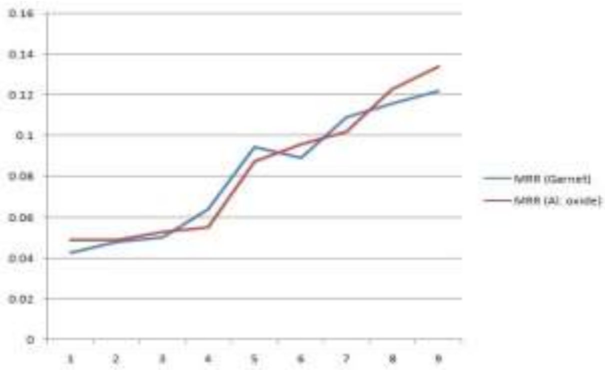

Fig.7 Effects of MRR on factors

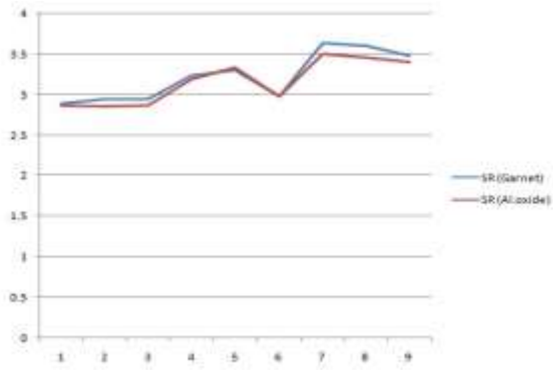

fig.8 Effects of SR on factors

From the figure we illustrate that material removal rate of aluminium oxide grit is little much higher compare to garnet abrasive grit due to higher hardness of abrasive particles.

Here, Garnet and aluminium oxide abrasive grit are used as an abrasives. Hence the surface roughness for garnet abrasive is little much less compare to the aluminium oxide abrasives and the graphs represent the difference of the SR with both abrasives.

V. CONCLUSION

Following are the important conclusions of the research work from experimental work.

- Traverse speed is the most influence parameter for material removal rate. Increase in traverse speed, there are increase in material removal rate.
- Higher abrasive flow rate give increase MRR and less influence on surface roughness. Abrasive flow rate is less significant control factor for MRR.
- MRR increases with the increase in SOD (2 to 4 mm) up to certain limit and further increase in SOD beyond the limit results in decrease in MRR and increases surface roughness with increase in SOD.
- MRR and surface roughness were influenced by traverse speed, abrasive flow rate and SOD in decreasing order.
- Traverse speed is a most significant control factor for MRR and SR and abrasive flow rate and SOD are equally significant control factor for the both parameters.
- Aluminum oxide abrasive grit gives better surface finish compare to garnet abrasive grit.

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