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"Effect of varying process parameters on surface roughness in AWJ machine" Using Analysis of Variance (ANOVA)

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Abstract — *As abrasive water jet (AWJ) machine starts to be used in industry, getting high quality surface has become a major requirement. The most significant characteristic of the abrasive water jet cutting technology is cold cutting, which does not have a thermic effect on the material. Being a non-traditional machine, AWJ is holding several deficiencies, which limits its extensive applications. One of the deficiencies is striation marks presented on AWJ cutting surface.*

The objective of the our experimental investigation is to conduct research of the machining parameters impact on surface roughness of the machined parts, and derive conclusions referring to the manner in which certain machining parameters affect surface roughness.

Keywords- *Traverse speed, Abrasive flow rate, Standoff distance, Surface roughness, Regression model and response surface, ANOVA.*

I. INTRODUCTION

The technique of cutting materials using high pressure waterjets was first time patented in 1968 by Dr. Norman Franz, researcher at University of Michigan, USA. In 1979 Dr. Mohamed Hashish added abrasive particles to increase cutting force and ability to cut hard materials including steel, glass and concrete (abrasive WJ).The non-traditional AWJ machining technique, based on high-pressure abrasive-waterjets, was first commercialized in 1983.

Water Jet Machining (WJM) and Abrasive Water Jet Machining (AWJM) are two non-traditional or non-conventional machining processes. They belong to mechanical group of non-conventional processes like Ultrasonic Machining (USM) and Abrasive Jet Machining (AJM). In these processes (WJM and AJWM), the mechanical energy of water and abrasive phases are used to achieve material removal or machining.

However in all variants of the processes, the basic methodology remains the same. Water is pumped at a sufficiently high pressure, 200-400 MPa (2000-4000 bar) using intensifier technology. An intensifier works on the simple principle of pressure amplification using hydraulic cylinders of different cross-sections as used in "Jute Bell Presses". When water at such pressure is issued through a suitable orifice (generally of 0.2- 0.4 mm dia), the potential energy of water is converted into kinetic energy, yielding a high velocity jet (1000 m/s). Such high velocity water jet can machine thin sheets/foils of aluminum, leather, textile, frozen food etc.

In pure WJM, commercially pure water (tap water) is used for machining purpose. However as the high velocity water jet is discharged from the orifice, the jet tends to entrain atmospheric air and flares out decreasing its cutting ability. In AWJM, abrasive particles like sand (SiO2), glass beads are added to the water jet to enhance its cutting ability by many folds.

II. LITERATURE REVIEW

The prediction of the depth of cut was developed on the material stainless steel. It was developed through the empirical formula.

The theoretical and experimental results were compared on the various hard materials like glass and ceramic. The research work was that the by changing the process parameters like change in the pressure, nozzle tip distance on the different thickness of glass plates there effect is studied in detailed. It was detailed study by plotting the graphs and was concluded that the as the pressure increases the material removal rate also increases.

The effects of the various parameters was been study and the effects on the work piece by changing the process parameters. The process analysis was been done by studying the effect on the surface of the hard materials like aluminum, ceramic and stainless steel.

III. EXPERIMENTAL DETAILS

Material Selection:

AWJM is capable of machining geometrically complex and hard material components that are precise and difficult to machine such as heat treated tools steels, composites, glasses, ceramics, super alloys, carbides , steels etc. I have selected the material Material type: SS316L and Thickness of the w/p: 45mm & 20 mm for experiment as it is been widely used Dairy Equipment's, Pharmaceutical, Beverages, Brewery, Thermal management system.

Design of Experiment based on 2^3 ANOVA method:

In the experiment which is being carried out have three factors they are traverse speed, abrasive flow rate standoff distance are the control factors on the machine AWJM, Water jet S3060 at the IDMC Limited, Vithal Udyognagar. The nozzle diameter is 1.1mm, abrasive material aluminium oxide with WJ grade 80 mesh, impact angle is perpendicular for the every readings in the experiment.

Parameter Selection for 45mm thickness:

Table 1 Parameter selection for 45mm thickness

Control Parameters	Level		Observed Values
	Min	max	
Speed(mm/min) (A)	30	50	Surface Roughness (Ra)
Abrasive flow rate(gm./min) (B)	600	700	
Stand of distance (mm) (C)	3	5	

Observation table:

Table 2 Observation table for 45mm thickness

No.	Speed (mm/min) (A)	Abrasive flow rate(gm./min) (B)	Tip distance (mm) (c)	Surface roughness (Ra value) (xi)
1	30	600	3	2.83
2	50	600	3	3.72
3	30	700	3	3.05
4	50	700	3	3.75
5	30	600	5	2.76
6	50	600	5	3.12
7	30	700	5	2.73
8	50	700	5	3.88
9	40	650	4	3.61
10	40	650	4	3.04
11	40	650	4	3.43
12	40	650	4	3.49

Effect estimate summary:

Table 3 Effect estimate summary

Factor	Effect estimate (Fy)	Sum of square (Sy)	% Contribution(Cy)
A	0.775	1.2013	74.57%
B	0.245	0.1200	7.45%
C	-0.215	0.0925	5.74%
AB	0.15	0.045	2.79%
AC	-0.02	0.0008	0.04%
BC	0.12	0.0288	1.79%
ABC	0.245	0.1225	7.60%

Analysis of variance for AWJ

Table 4 Analysis of variance for AWJ

Source of variation	Sum of square (Sy)	Degree of freedom(Fy)	Mean square (Sy)	Fo
A	1.2013	1	1.2013	3838.02
B	0.1200	1	0.1200	383.39
C	0.0925	1	0.0925	295.53
AB	0.045	1	0.045	143.77
AC	0.0008	1	0.0008	25.56
BC	0.0288	1	0.0288	92.01
ABC	0.1225	1	0.1225	391.37
Error(Fe)	0.0025	8	0.000313	
Total(Ft)	1.6084	15		

Regression model:

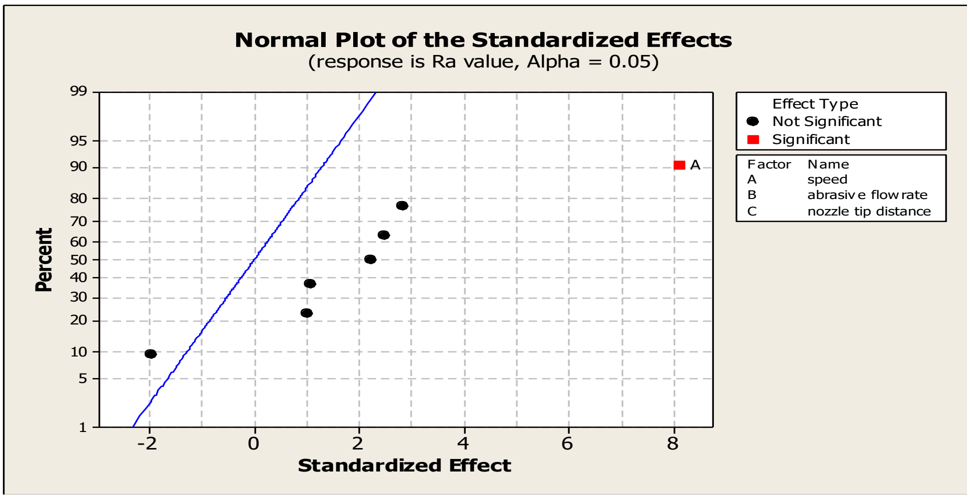
βY =β0+(β1x1/2) +(β2x2/2) +(β3x3/2) +(β12x12/2) +(β13x13/2) +(β23x23/2) +(β123x123/2)
Here,
β0= sum of average of response
β1 = Effect of parameter "A" on Ra value
β2 = Effect of parameter "B" on Ra value
β3 = Effect of parameter "C" on Ra value
β12 = Effect of parameter "AB" on Ra value
β13 = Effect of parameter "AC" on Ra value
β23 = Effect of parameter "BC" on Ra value

Y=3.23+(0.775/2)x1+(0.245/2)x2-(0.215/2)x3+90.15/2)x1x2-(0.02)x1x3+(0.12/2)x2x3+(0.245/2)x1x2x3

Y=3.23+0.3875x1+0.1225x2-0.1075x3+0.075x1x2-0.01x1x3+0.06x2x3+0.1225x1x2x3

Significant parameter's graph:

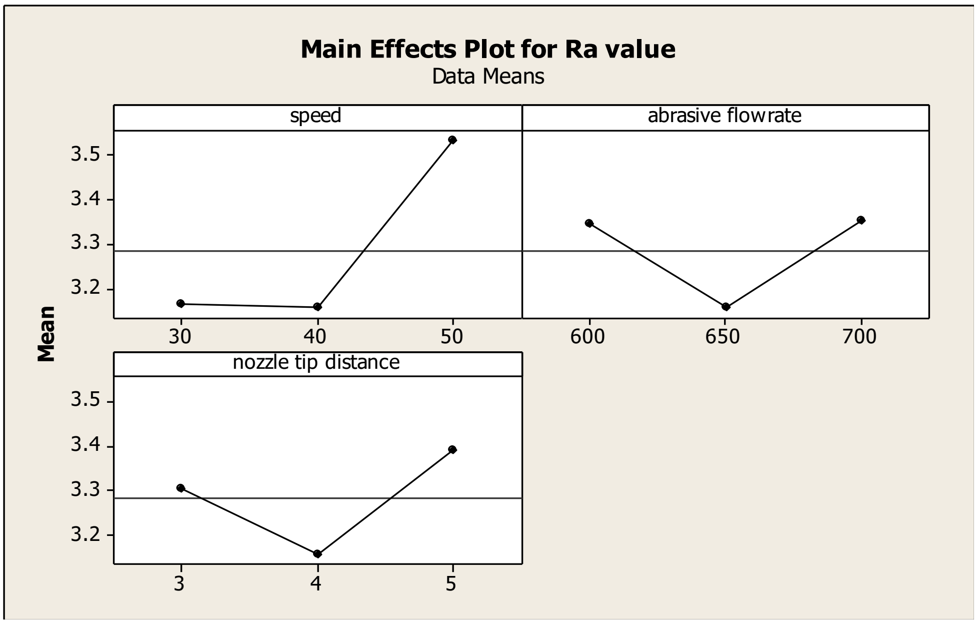
Graph no 1



From graph we can say that "A" is the significant parameter from all other parameter, effect of parameter "A" is Maximum on the response Ra value.

Main effect graph for 45 mm thickness:

Graph no 2



From main effect graph, we can say that speed is the significant parameter and with the incresing speed till (40 mm/min) Ra value not more affected but after (40 mm/min) speed Ra value will increse rapidly.

Same in abrasive flow rate, by increasing abrasive flow rate Ra value decreases but after (650 gm/min) flow rate Ra value will increase. But not affected as much as speed.

Here when tip distance at minimum level (3mm) then Ra vlue more but with incresing tip distance Ra value decrease till (4mm) after that Ra value again increases. But not affected as much as speed.

Parameter Selection for 20 mm thickness:

Table 5 Parameter selection for 20mm thickness

Control Parameters	Level		Observed Values
	Min	Max	
Speed(mm/min) (A)	80	120	Surface Roughness (Ra)
Abrasive flow rate(gm./min) (B)	500	600	
Stand of distance (mm) (C)	3	5	

Observation table:

Table 6 Observation table for 20mm thickness

No.	Speed (mm/min) (A)	Abrasive flow rate(gm/min) (B)	Tip distance (mm) (C)	Surface roughness (Ra value) (XI)
1	80	500	3	4.19
2	120	500	3	4.61
3	80	600	3	4.31
4	120	600	3	4.70
5	80	500	5	4.10
6	120	500	5	4.36
7	80	600	5	4.05
8	120	600	5	4.85
9	100	550	4	4.32
10	100	550	4	4.39
11	100	550	4	4.41
12	100	550	4	4.23

Effect estimate summary:

Table 7 Effect estimate summary

Factor	Effect estimate (Fy)	Sum of square (Sy)	% Contribution(Cy)
A	0.4675	0.4371	72.52
B	0.1625	0.0528	8.76
C	-0.1125	0.0253	4.19
AB	0.1275	0.0325	5.39
AC	0.0625	0.0078	1.29
BC	0.0575	0.006	1.09
ABC	0.1425	0.0406	6.73

Analysis of variance for AWJ:

Table 8 Analysis of variance for AWJ

Source of variation	Sum of square (Sy)	Degree of freedom(Fy)	Mean square (Sy)	Fo
A	0.4371	1	0.4371	34968
B	0.0528	1	0.0528	4224
C	0.0253	1	0.0253	2024
AB	0.0325	1	0.0325	2600
AC	0.0078	1	0.0078	624
BC	0.006	1	0.006	528
ABC	0.0406	1	0.0406	3248
Error(Fe)	0.0001	8	0.0000125	
Total(Ft)	0.6028	15		

Summarization of Significant Parameters:

From above table no 8 we we can say that "A" is the significant parameter from all other parameter, effect of parameter "A" is Maximum on the response Ra value.

Table 9 *Summarization of Significant Parameters on Response of AWJ*

Parameters	Effect
Speed (mm/min) A	++ (significant)
Abrasive flowrate (gm/mm) B	+
Nozzle tip distance (mm) C	+

Regression model:

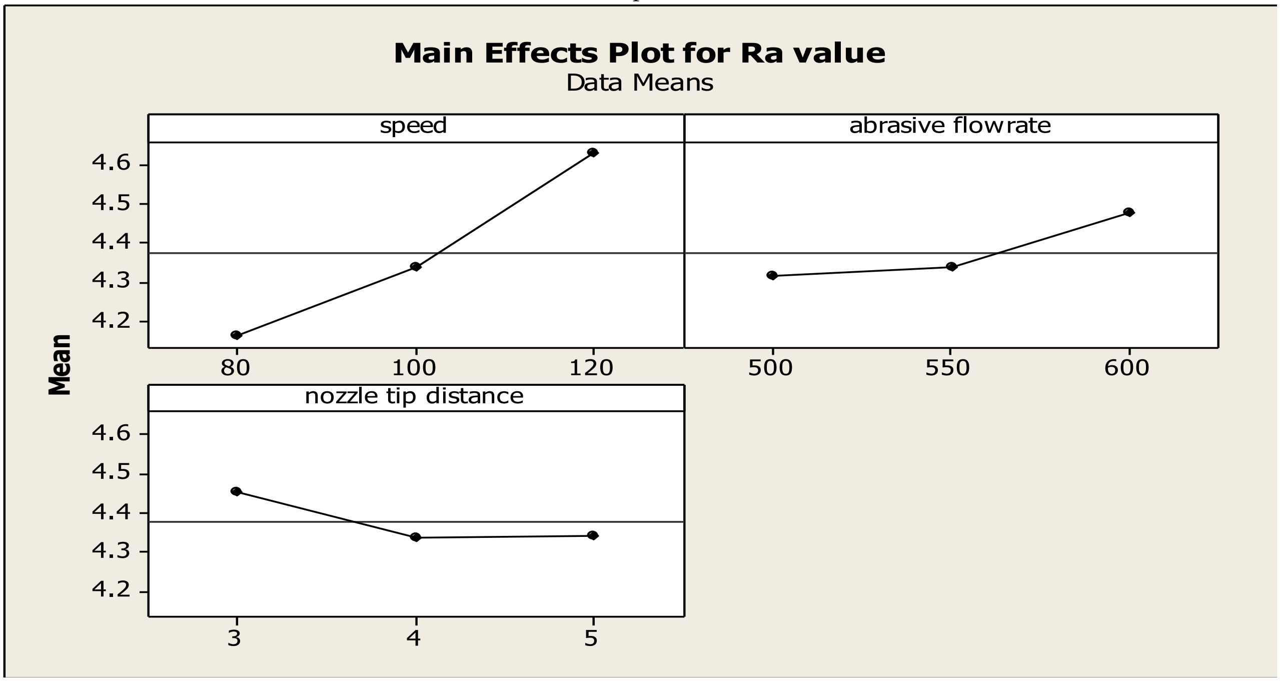
βY= β0+(β1x1/2) +(β2x2/2) +(β3x3/2) +(β12x12/2) +(β13x13/2) +(β23x23/2) +(β123x123/2)

Here,
β0= sum of average of response
β1 = Effect of parameter "A" on Ra value
β2 = Effect of parameter "B" on Ra value
β3 = Effect of parameter "C" on Ra value
β12 = Effect of parameter "AB" on Ra value
β13 = Effect of parameter "AC" on Ra value
β23 = Effect of parameter "BC" on Ra value

=4.3963+(0.4675/2)x1+(0.1625/2)x2-(0.1125/2)x3+(0.1275/2)x1x2-(0.0625/2)x1x3+(0.0575/2)x2x3+(0.1425/2)x1x2x3
=4.3963+0.23375x1+0.08125x2-0.05625x3+0.06375x1x2+0.03125x1x3+0.02875x2x3+0.07125x1x2x3

Main effect graph for 20 mm thickness:

Graph no 3



From main effect graph, we can say that speed is the significant parameter and with the increasing speed, Ra value also increases.

Same in abrasive flow rate, by incresing abrasive flow rate Ra value increases but not much affected like speed.

Here when tip distance at minimum level (3mm) then Ra vlue more but with incresing tip distance Ra value decrease till (4mm) after that Ra value again increases at some increment. Which is also not affect like speed.

Images of the workpiece of 45mm:

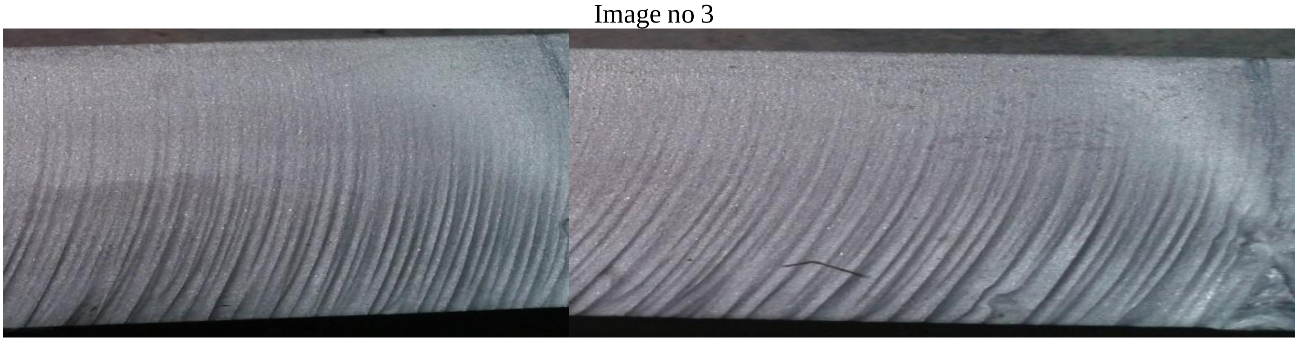
Image no 1

First Optimal result

Image no 2

Second Optimal result

Image no 3



Increased surface roughness due to striation marks

Conclusion and Result Analysis

We have conducted experiments on stainless steel material having thicknesses 45mm and 20mm respectively. During our investigation we considered three process parameters nozzle traverse rate or cutting speed, abrasive flow rate and nozzle tip distance for optimization. We have taken a pressure and other parameters as constant. The value of pressure we have taken as 380Mpa, nozzle diameter 1.1mm and orifice diameter 0.38mm.

We have used two optimization methods which is Analysis of Variance(ANOVA).After completing our Design of Experiments using above method we measured different Ra value for different combination of three process parameters.

We obtain the result for 45 mm thickness workpiece by ANOVA method that Cutting speed or Nozzle traverse rate has the most significant effect on Surface roughness of the workpiece. As cutting speed increases the value of surface roughness also increases, on the other side increased value of abrasive flow rate increase shearing action of the jet which results in lower value of the surface roughness. Same results were obtained after the experimentation of 20mm thickness workpiece. In the experimentation of 20mm thick workpiece we observed one thing that the reduced thickness of the workpiece results in nearly same striation marks on full length of the workpiece. From that we can say that the reduced thickness of the workpiece has not more effect of the process parameters.

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