International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-10, August 2019

Machinability Optimization of Abrasive Water Jet Cutting Process on AA6082 Aluminium Alloy

C. Joel, T.Jeyapoovan

Abstract**: *Aluminium alloys are extensively used nowadays in various manufacturing industries due to its special properties and high strength. In this study, AA6082 aluminium alloy is taken into consideration by studying the machinability properties using the abrasive water jet cutting process. RSM technique is used for conducting the experiments by varying the input factors such as stand-off distance, abrasive feed and nozzle transverse speed. The effect of hardness and surface roughness is investigated. The correlation between the input parameters and the corresponding output was tested by analysis of variance to check the 95% confidence level.***

Keywords* : *Aluminium alloy 6082, Abrasive Water Jet Cutting, Hardness, Roughness, RSM

I. INTRODUCTION

Abrasive water jet cutting process is extensively used in current scenario due to its advanced manufacturing process. This process was produced by high-pressure water to a narrow nozzle by means of a force which is referred to as high-speed water jet beam. For cutting all type of material, the particles of abrasives were added into water results in the high-speed abrasive jet beam. It was successfully achieved by means of controlling the input parameters which significantly affects the manufacturing cost in surface roughness [1].

A study was done by investigating the titanium alloys using abrasive water jet cutting process by analyzing the kerf profile, surface roughness and taper angle [2]. Niranjan et al [3] study was focused on the study of depth of penetration on Z91 magnesium alloy and optimal parameter. Surface roughness is analyzed with different transverse speeds and studied the morphology of cut surfaces. Marin et al [4] work focused on controlling the input parameters of abrasive water jet machining through evolutionary algorithm and optimization of water jet machining was analyzed using modelling and simulation. A study was also focused to envisage the surface roughness using abrasive water jet machining process in 7075 aluminium alloy through genetic expression programming [5]. Similarly, the outcome of input constraints was focused on using GA and simulated annealing for an estimate of surface texture using the abrasive water jet process [6]. By introducing the cryogenic liquid nitrogen in the abrasive cutting process, the output parameters such as material removal rate, depth of cut and surface integrity were determined in AA5083-H32 aluminium alloy. The cut surface was also investigated using scanning electron microscopy and studied its microstructural observations [7]. Subsequently, the influence of milling depth and physical characteristics of the material was investigated by Vijay et al [8] on 6061 and 2024 aluminium alloys. It was projected that the machinability index and mechanical properties were influenced as a significant part in determining the output parameters. The machinability studies were also focused on studying the depth of cut by varying the input parameters in 6061 aluminium alloys and studied its surface morphology [9]. Moreover, the cutting process was also studied by studying the surface roughness, kerf taper angle using the design of experiments. RSM technique is used to identify the optimal value based on the input parameters [10]. The studies on abrasive jet water cutting were analyzed with respect to many material combinations. However, the machinability study in AA6082 aluminium alloy is very limited. In this current study, by using RSM technique, surface roughness and hardness measurements are discussed.

Manuscript published on 30 August 2019.
***Correspondence Author(s)**

C.Joel, Assistant Professor, Department of Mechanical Engineering, Easwari Engineering College, Ramapuram, Chennai, India.
Dr.T.Jeyapoovan, Professor, Department of Mechanical Engineering, Hindustan Institute of Technology and Science, Chennai, India.

II. AA6082 ALUMINIUM ALLOY

Aluminium alloy 6082 is intense corrosion resistance with the maximum yield strength of the 6000 series alloys and also called as a structural alloy. The mechanical properties of AA6082 Aluminium alloy are tabulated in Table I.

Table- I : Mechanical Properties of AA6082 Aluminium alloy

Sl.No	Properties	Value
1	Young's modulus	71 GPa
2	Thermal Expansion	23.1 µm/m-K
3	Density	2.71 g/cm^3
4	Yield strength	280 MPa
5	Ultimate tensile strength	140 to 330 MPa

The composition of AA6082 Aluminium alloy is tabulated in Table II. Aluminium alloy 6082 is widely used in the construction of the high-stress application of trusses, bridges and cranes. Also mainly used in automotive applications.

Table –II: Chemical composition of the AA6082 Aluminium alloy

Element	Mn	Fe	Mg	Si	Cu	Zn	Ti	Al
%	0.45	0.25	0.70	0.9	0.05	0.10	0.05	Bal.

DOI: 10.35940/ijitee.J9360.0881019

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

III. EXPERIMENTAL DETAILS

AA6082 aluminium alloy is considered for conducting the experiment with a block size of 500 mm x 50 mm x 50 mm. S3015 Abrasive Water Jet cutting system (Fig 1) is presented with gravity feed category abrasive hopper and X-Y movements are controlled by pneumatically at 3000 mm x 1500 mm and transverse speed varies from 1 mm/min to 7000 mm/min.

A Box-Behnken three parameters, three design level matrix was carefully chosen and tabulated in Table III. Seventeen sets coded conditions are tabulated in an experimental design matrix (Table IV) and containing twelve points of full repetition 3-factorial design and five centre points. The lower and upper bounds of the constraints were added as +1 and −1, correspondingly.

Table-III: Experimental levels and factors

No.	**Factors**	**Unit**	**Notation**	**Levels**		
				-1	**0**	**1**
1	Abrasive feed	Feed/mm	A	250	300	350
2	Stand-off distance	mm	B	1	1.5	2
3	Nozzle transverse speed	mm/min	C	50	55	60

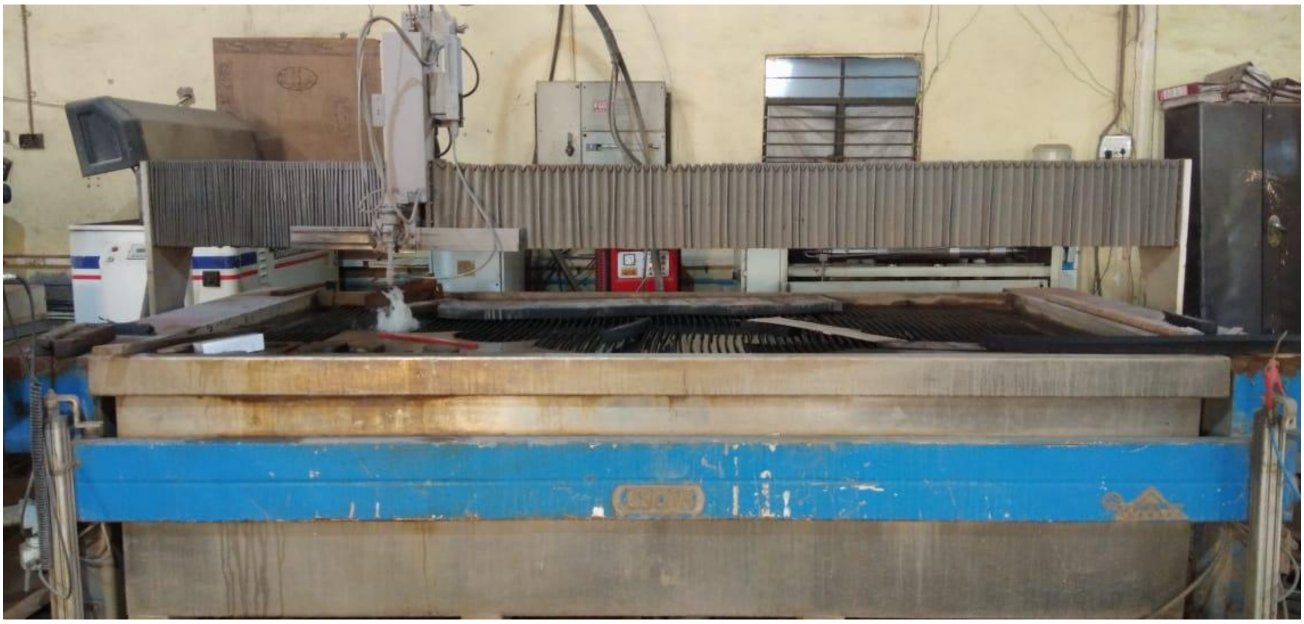


Fig. 1: Abrasive Water Jet Cutting Machine

Fig. 2: Work samples

Fig 2 shows the experimental samples of 17 specimens measuring 50mm x 50mm x 20mm. These specimens were cut from the block size of 500 mm x 50 mm x 50 mm thorough Abrasive Water Jet cutting system by adopting the experimental levels and factors tabulated in Table III.

IV. RESULTS AND DISCUSSION

The relation among hardness and surface roughness of the abrasive water jet is a function of the cutting parameters such as abrasive feed (A), stand-off distance (B) and nozzle transverse speed (C) is stated as:

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Hardness & Surface Roughness = f {A, B, C} (1)

A polynomial regression model with second order equation was used for forming a mathematical relationship between the machining parameters and the interface effects of all three parameters were developed based on the hardness and surface roughness. For the three factors, the second-degree response surface is expressed as follows:

Hardness & Surface Roughness =

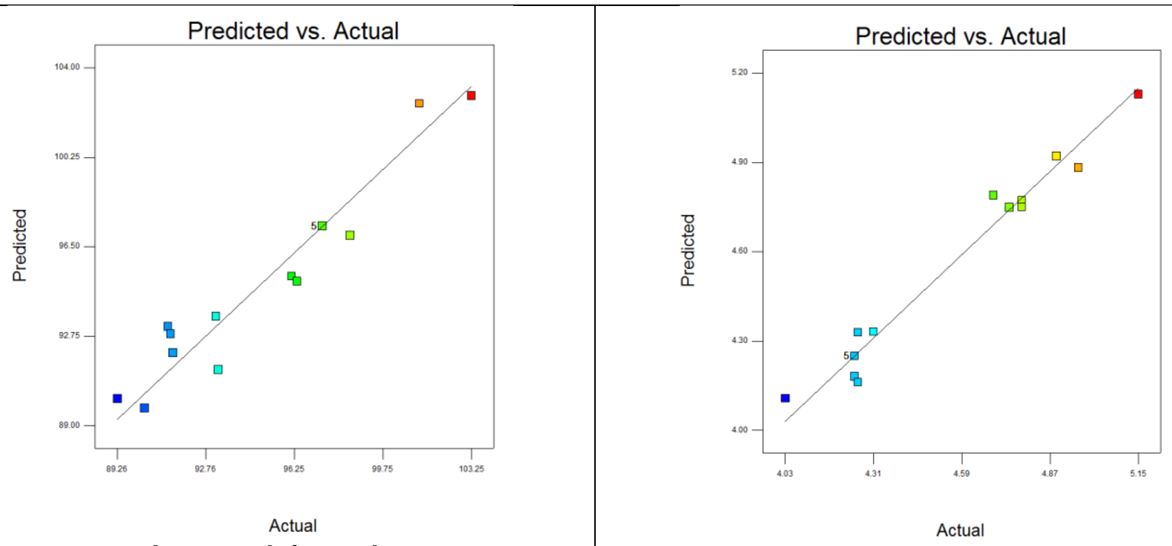
$b_0 + b_1(A) + b_2(B) + b_3(C) + b_{11}(A^2) + b_{22}(B^2) + b_{33}(C^2) + b_{12}(AB) + b_{13}(AC) + b_{23}(BC)$ (2)

where b_0 is the average of the responses, and $b_1, b_2, b_3, \ldots, b_{23}$ are regression coefficients which were designed by DOE Software.

The importance of every coefficient was calculated by *t*-test, *p* values and the impact of model terms at 95% confidence level.

Table- IV: Design matrix and Experimental Results

Experiment No.	Std order	Run order	Coded Value			Actual Value			Hardness (BHN)	Roughness (Ra)
			A	B	C	A	B	C		
1	1	3	-1	-1	0	250	1	55	90.33	4.25
2	2	25	1	-1	0	350	1	55	93.15	4.31
3	3	18	-1	1	0	250	2	55	103.25	5.15
4	4	22	1	1	0	350	2	55	91.45	4.26
5	5	17	-1	0	-1	250	1.5	50	96.14	4.78
6	6	14	1	0	-1	350	1.5	50	93.25	4.26
7	7	28	-1	0	1	250	1.5	60	91.25	4.69
8	8	13	1	0	1	350	1.5	60	89.26	4.74
9	9	23	0	-1	-1	300	1	50	91.36	4.03
10	10	6	0	1	-1	300	2	50	101.20	4.89
11	11	12	0	-1	1	300	1	60	96.36	4.78
12	12	4	0	1	1	300	2	60	98.45	4.96
13	13	26	0	0	0	300	1.5	55	97.36	4.25
14	14	16	0	0	0	300	1.5	55	97.36	4.25
15	15	10	0	0	0	300	1.5	55	97.36	4.25
16	16	9	0	0	0	300	1.5	55	97.36	4.25
17	17	5	0	0	0	300	1.5	55	97.36	4.25



Correlation graph for Hardness

Correlation graph for Surface Roughness

Fig 3: Predicted Vs Actual factor for Hardness and Surface Roughness

The model was developed by the coefficients and the final experimental relationship established to evaluate the hardness and surface roughness are given below:

Coded Factors:

Hardness = +97.36-1.73A+2.89B-0.83C-3.66AB+0.23AC-1.94B-3.59A^2+0.78B^2-1.29C^2 (3)

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

$$\text{Roughness}=+4.25-0.16A+0.24B+0.15C-0.24AB+0.14AC-0.17BC+0.097A^2+0.14B^2+0.27C^2 \quad (4)$$

Actual Factors:

$$\text{Hardness} = +97.36-1.73A+2.89B-0.83C-3.65AB+0.23AC-1.94BC-3.59A^2+0.78B^2-1.29C^2 \quad (5)$$

$$\text{Roughness} = +4.25-0.16A+0.24B+0.15C-0.24AB+0.14AC-0.17BC+0.09A^2+0.14B^2+0.27C^2 \quad (6)$$

The impact of every coefficient was calculated using Student's *t*-test and *p* values, the values are enumerated in Table 4. The standards of "Prob>*F*" less than 0.05 shows that the designed model relations are substantial. For hardness, *A*, *B*, AB, BC and A^2 are important models. The table values more than 0.10 shows that the model terms are non-important are found as C, AC, B^2 and C^2 with 0.9287 as an R-square value. Similarly, for output of surface roughness, the significant model terms are found to be less than 0.10 with an R-square value of 0.9754. The effects of many linear regression constants for the second-order response surface model were tabulated in Table 5. Analysis of variance technique was applied to verify the capability of the established experimental relationship. In this experimental analysis, the preferred level of sureness was measured to be 95%. The predicted values were best matched with its investigational value, as shown in Fig 3. It is stated that the designed model is satisfactory.

Table -V: Analysis of Variance for Hardness

ANOVA for Hardness						**ANOVA for Surface Roughness**					
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value**	**Source**	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value**
Model	229.82	9	25.54	10.13	0.003	Model	1.74	9	0.19	30.86	<0.000
A-A	24.01	1	24.01	9.52	0.017	A-A	0.21	1	0.21	33.74	0.000
B-B	66.99	1	66.99	26.57	0.001	B-B	0.45	1	0.45	71.32	<0.000
C-C	5.49	1	5.49	2.18	0.183	C-C	0.18	1	0.18	29.23	0.001
AB	53.44	1	53.44	21.19	0.002	AB	0.23	1	0.23	36.04	0.000
AC	0.20	1	0.20	0.08	0.785	AC	0.08	1	0.08	12.97	0.008
BC	15.02	1	15.02	5.96	0.044	BC	0.12	1	0.12	18.46	0.003
A^2	54.30	1	54.30	21.54	0.002	A^2	0.04	1	0.04	6.39	0.039
B^2	2.54	1	2.54	1.01	0.349	B^2	0.09	1	0.09	14.14	0.007
C^2	7.05	1	7.05	2.80	0.138	C^2	0.31	1	0.31	49.03	0.000
Residual	17.65	7	2.52			Residual	0.04	7	6.26E-003		
Lack of Fit	17.65	3	5.88			Lack of Fit	0.04	3	0.015		
Pure Error	0.00	4	0.00			Pure Error	0.00	4	0.00		
Cor Total	247.47	16				Cor Total	1.78	16			
Std. Dev.	**1.59**		**R-Squared**		**0.9287**	**Std. Dev.**	**0.079**		**R-Squared**		**0.9754**
Mean	95.43		Adj R-Squared		0.8370	Mean	4.49		Adj R-Squared		0.9438
C.V. %	1.66		Pred R-Squared		0.1411	C.V. %	1.76		Pred R-Squared		0.6066
PRESS	282.38		Adeq Precision		10.755	PRESS	0.70		Adeq Precision		16.828

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

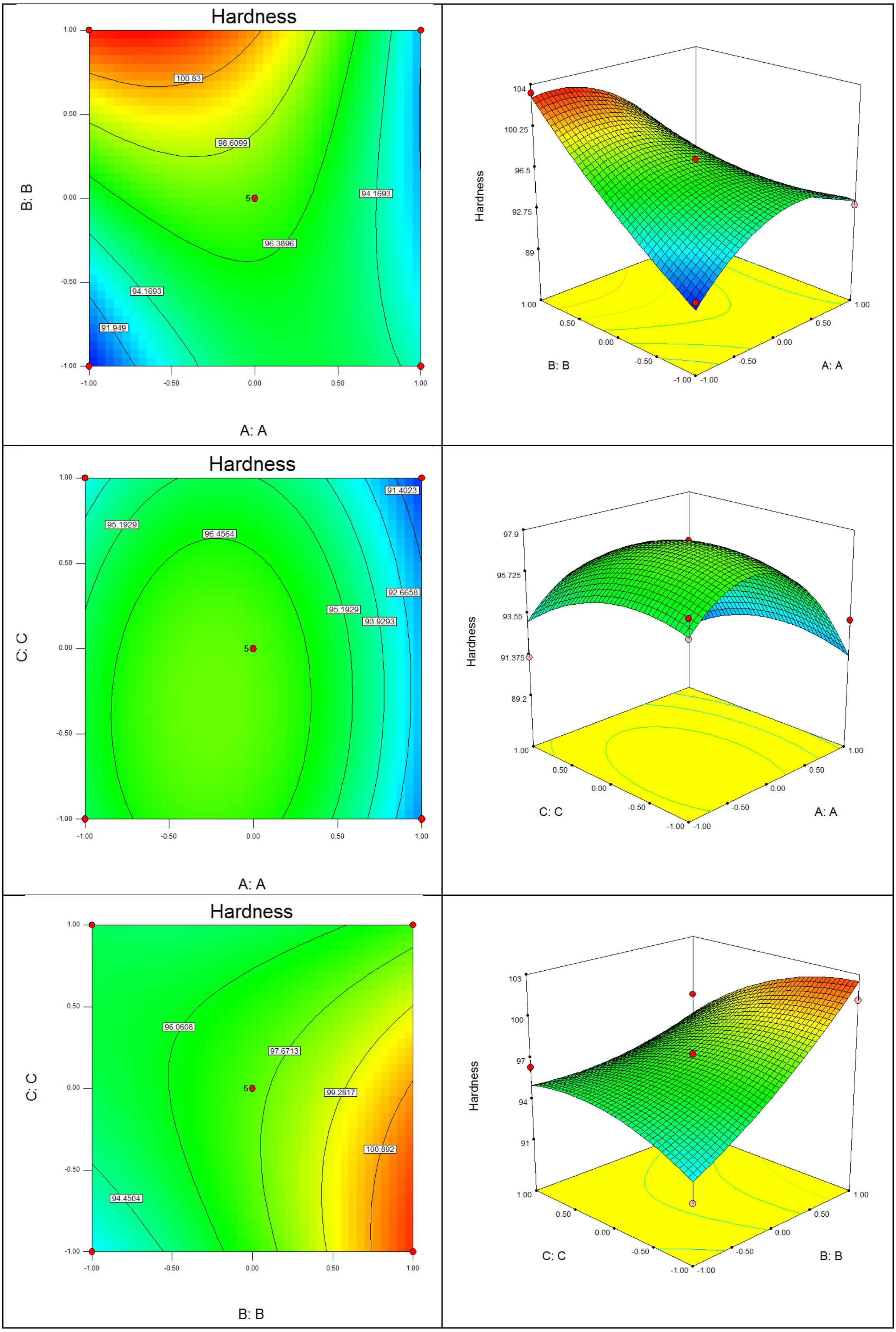


Fig 4: Contour plot for Hardness

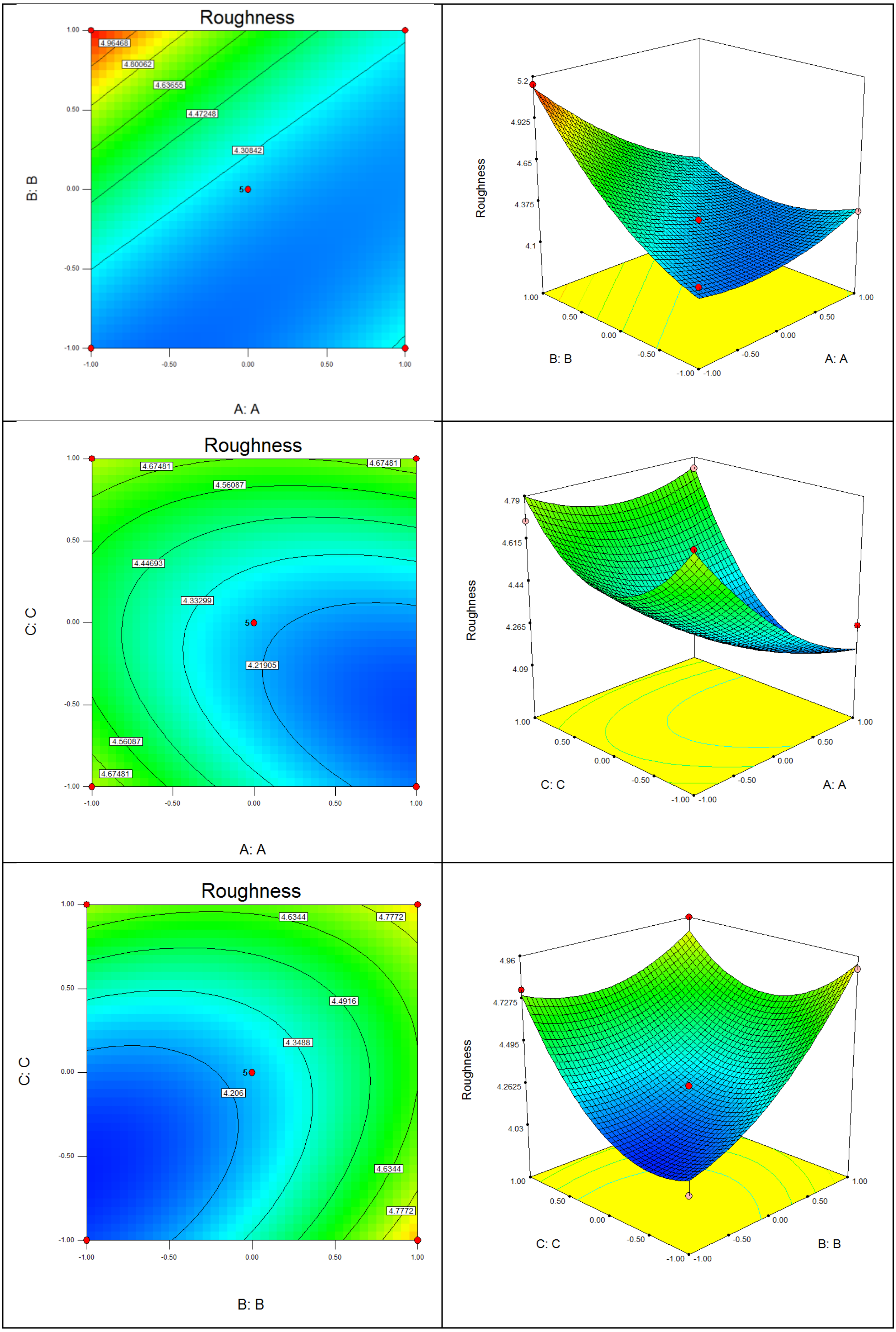


Fig 5: Contour plot for Surface Roughness

Table-VI : Regression coefficients for surface models

Hardness		Surface Roughness	
Factor	**Coefficient Estimate**	**Factor**	**Coefficient Estimate**
Intercept	97.36	Intercept	4.25
A-A	-1.73	A-A	-0.16
B-B	2.89	B-B	0.24
C-C	-0.83	C-C	0.15
AB	-3.66	AB	-0.24
AC	0.23	AC	0.14
BC	-1.94	BC	-0.17
A^2	-3.59	A^2	0.10
B^2	0.78	B^2	0.14
C^2	-1.29	C^2	0.27

By using the RSM approach, the maximum hardness is found as 103 and minimum surface roughness as 4.03. The consequence of cutting constraints based on abrasive feed, stand-off distance and nozzle transverse speed is discussed by means of contour plots as shown in Figure 4 and 5. When abrasive feed is increased from 250 to 300 feed/mm, the hardness also increases and then decreased when it increases to 350 feed/mm as shown in Figure 4. At high feed and nozzle transverse speed, the hardness value is increased to a maximum extent and then decreased. When stand-off distance increases, the hardness value also increased gradually to a maximum value. Similarly, in the case of surface roughness, stand-off distance and nozzle transverse speed gradually increased when the input parameter increased from lower to a higher level. However, the abrasive particle is decreased with increase in abrasive feed rate values.

V. CONCLUSION

An experiential relationship was established to envisage the hardness and surface roughness using abrasive water jet cutting machine in AA 6082 aluminium alloy. The input parameters are varied as per the Box-Behnken design using the RSM approach.

- The maximum hardness of 103 BHN is attained under the cutting conditions of 250 feed/mm, 2 mm of stand-off distance and 55 mm/min nozzle transverse speed.
- In case of surface roughness, the minimum value is achieved under input parameters of 300 feed/mm abrasive feed, 1 mm stand-off distance and 50 mm/min nozzle transverse speed which is found as 4.03
- The established empirical relation can be meritoriously used to calculate the hardness and surface roughness of the abrasive water jet cutting process at 95% confidence level.

REFERENCES

1. Caydas¸ U, Hasc¸alik A (2008) A study on surface roughness in abrasive waterjet machining process using artificial neural networks and regression analysis method. J Mater Process Technol 202(1):574–582
2. A. Alberdi, T. Artaza, A. Suárez, A. Rivero, F. Girot, “An experimental study on abrasive waterjet cutting of CFRP/Ti6Al4V stacks for drilling operations, Int J Adv Manuf Technol (2016) 86:691–704 DOI 10.1007/s00170-015-8192-x
3. C A Niranjan, S Srinivas, M Ramachandra, Effect of process parameters on depth of penetration and topography of AZ91 magnesium alloy in abrasive water jet cutting, Journal of Magnesium and Alloys 000 (2018) 1–9
4. Marin Gostimirovic, Vladimir Pucovsky, Milenko Sekulic, Dragan Rodic, Vlastimir Pejic, Evolutionary optimization of jet lag in the abrasive water jet machining, The International Journal of Advanced Manufacturing Technology
5. Kök M, Kanca E, Eyercioglu O (2011) Prediction of surface roughness in abrasive waterjet machining of particle reinforced MMCs using genetic expression programming. Int J Adv Manuf Technol 55(9–12):955–968
6. Azlan MZ, Habibollah H, Safian S (2011) Genetic algorithm and simulated annealing to estimate optimal process parameters of the abrasive water jet machining. Eng Comput 27:251–259
7. Yuvaraj Natarajan, Pradeep Kumar Murugasen, Lenin Raj Sundarajan, Rajadurai Arunachalam Experimental Investigation on Cryogenic Assisted Abrasive Water Jet Machining of Aluminium Alloy, International Journal of Precision Engineering and Manufacturing-Green Technology
8. Vijay Kumar Pal, Puneet Tandon, Identification of the role of machinability and milling depth on machining time in controlled depth milling using abrasive water jet Int J Adv Manuf Technol (2013) 66:877–881
9. Prabhuswamy N R, S Srinivas, Aref Vasli, Sheshashayan M V, Venkatesh S, Yash Roongta, Machinability Studies of Aluminium 6061 cut by Abrasive Water Jet, Materials Today: Proceedings 5 (2018) 2865–2870
10. Parikshit A. Dumbhare, Shikha Dubey, Yogesh V. Deshpande, Atul B. Andhare, Purushottam S. Barve, Modelling and multi-objective optimization of surface roughness and kerf taper angle in abrasive water jet machining of steel Journal of the Brazilian Society of Mechanical Sciences and Engineering (2018) 40:259

AUTHORS PROFILE

JOEL.C received the Bachelor of Engineering degree in Mechanical Engineering in the year 2004 from M.I.E.T Engineering College, Bharathidasan University, Trichy, Tamilnadu and Master of Engineering degree in Computer Aided Design in the year 2008 from Hindustan Engineering College, Anna University, Chennai, Tamilnadu, India. He is pursuing his Doctoral degree in the area of Abrasive Water jet Machining at Hindustan Institute of Technology & Science, Chennai. He is currently working as an Assistant Professor in Department of Mechanical Engineering at Easwari Engineering College, Chennai since June 2017. He has more than 10 years teaching experience and he has guided many undergraduate student projects. He has published 4 research papers in peer reviewed International and National Journals and Conferences. At undergraduate and postgraduate level, he has handled more than 14 subjects in the areas such as Design of Transmission systems, Design of machine Elements, Engineering Graphics, Manufacturing Technology, Process planning & cost Estimation, Strength of Materials, etc. He has also organized various symposiums, workshops, national conferences.

Dr. T. JEYAPOOVAN is a professor in the department of Mechanical engineering, Hindustan Institute of Technology and Science, Padur, Chennai. He has a B.Tech. degree in Mechanical Engineering from College of Engineering, Trivandrum, an M.S. degree in Software System from Birla Institute of Technology and Science, Pilani and an M.E. degree in Computer Aided Design from Sathyabama Institute of Science and Technology, Chennai. He has completed Ph.D from Anna University, Chennai. His title of research is “Characterization of machined surfaces using Vision System”. He has over 30 years of teaching experience and specializes in Computer Aided Design and Manufacturing. His area of research includes image and signal processing, Vibration analysis, Rapid prototyping, Low cost Automation and Computer Integrated Manufacturing. He has seven publications in international journals and many publications in conferences. He has authored many textbooks for engineering students which includes Engineering Drawing and Graphics, A First course in Programming with C and Computer Numerical Control Machines. These books are prescribed in many Indian Universities in their syllabus. He is a member of ISTE, IET and IEEE (Robotics and Automation).