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Optimization of Surface Roughness for AISI A2 on WEDM Using Response Surface Methodology

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Abstract*—AISI A2 offers a variety of advantages over its counterparts such as stability after hardening, compressive strength, non deforming properties, toughness and wear resistance. Due to these properties it is gaining application in manufacturing of bending and stamping dies, roll threading dies, plastic mould dies, cams and rolls. As newer, more exotic materials are developed, and more complex shapes are presented, conventional machining operations reach their limitations; hence the increased use of non-conventional machining methods in manufacturing continues to grow at an accelerated rate. In this study, an attempt has been made to machine AISI A2 using wire electric discharge machining. The objective is to investigate the influence of process parameters namely pulse on time (T_{on}), pulse off time (T_{off}), peak current (I_p) and servo voltage (S_v) on surface roughness. To investigate parametric influence on response parameter, a Central Composite design approach of response surface methodology (RSM) is used to plan and analyze the experiments. The mathematical relationships between WEDM input process parameters and response parameter are established to determine optimal values of surface roughness mathematically. The Analysis of variance (ANOVA) is performed to obtain statistically significant process parameters. Interaction effects of process parameters on output responses are analyzed using statistical and graphical representations.*
Keywords— AISI A2, Wire EDM, RSM, Surface Roughness, CCD, ANOVA.

I. INTRODUCTION

The objective of this paper is to analyze the effect of different input process parameters like pulse on time (T_{on}), pulse off time (T_{off}), peak current (I_p) and servo voltage (S_v) of Wire EDM on output response namely surface roughness using response surface methodology (RSM), in particular the central composite design (CCD). The mathematical models so produced have been analyzed and optimized to give the values of process parameters producing the optimal values of the output responses.

II. LITERATURE REVIEW

In 2000 Gokler, M.I. and Ozanozgu, A.M. [1] selected the most appropriate offset and cutting parameter combination for Wire Electrical Discharge Machining process to get the required surface roughness value of the machined workpieces. A group of experiments have been conducted on 1040 steel material of thicknesses 40, 70 and 80 mm, and on 2379 and 2738 materials of thicknesses 40 and 60 mm. The surface roughness value of the testpieces has been calculated by using a surface roughness tester. The corresponding charts and tables have been made for 1040, 2379, 2738 steel materials. In 2004 Hascalyk, A. and Cayda, U. [2] presented an experimental research of the machining characteristics of AISI D5 steel in the wire electrical discharge machining process. During the experiment the parameters such as Pulse Duration, Open Circuit Voltage, Dielectric Fluid Pressure and Wire Speed were changed to see their effect on the Metallurgical Structure and Surface Roughness. Taking the experimental results into consideration, it was observed that intensity of process energy affected surface roughness and amount of recast as well as the wire speed, the microcracking and dielectric fluid pressure does not seem to have much of influence. In 2008 Ramakrishnan, R. and Karunamoorthy, L. [3] described the growth of Artificial Neural Network (ANN) models and the Multi Response optimization technique to envisage and select the best cutting parameters of Wire Electrical Discharge Machining (WEDM) process. To envisage the performance characteristics viz. Surface Roughness, Material Removal Rate Artificial Neural Network models were formed using the Back-Propagation algorithms. Inconel 718 was selected as the work material to conduct the experiments. Experiments were done as per the

Taguchi's L9 Orthogonal Array. The responses were optimized using the Multi Response Signal-To-Noise (MRSN) ratio in addition to the Taguchi's parametric design approach. In 2010 Datta, S. and Mahapatra, S.S. [4] derived the mathematical model to represent process behavior of the Wire Electrical Discharge Machining operation. Experiments have been performed with six process parameters namely Pulse Duration, Discharge Current, Wire Speed, Pulse Frequency, Dielectric Flow Rate and Wire Tension to be varied at three different levels. Data related to the process responses namely Surface Roughness, Material Removal Rate and kerf have been calculated for each of the experimental run; which relate to the randomly chosen various combination of factor setting. This data has been utilized to fit into a mathematical model (Response Surface Model) for each of the response, which can be presented as a function of the above said six process parameters. In 2012 Amitesh, G. and Jatinder, K. [5] investigated the effect of machining parameters on Material Removal Rate and Cutting Speed on machining of Nimonic 80A using brass wire as the tool electrode during the Wire Electrical Discharge Machining process. Research indicated that Material Removal Rate (MRR) and Cutting Speed (CS), both increased with increase in Peak Current (Ip) and Pulse-on-Time, however decreased with increase in Spark Gap Set Voltage (Sv) and Pulse-off-Time (Toff). In 2013 El-Taweel, T.A. and Hewidy, A.M. [6] presented a study of optimum value selection of the Wire Electric Discharge Machining conditions for CK-45 steel. Duty Factor, Feeding Speed, Wire Tension, Water Pressure and Wire Speed have been taken as the main factors affecting Wire EDM performance criteria. The process performances namely Tool Wear Rate, Material Removal Rate and Surface Roughness were calculated. Response Surface Methodology was used to develop the experimental models. The Wire EDM process has shown its competence to machine the CK-45 steel material under the acceptable Material Removal Rate and fine Surface Finish. In 2014 Shashikant, Roy, A.K. and Kumar, K. [7] determined the parameters that result in the best dimensional accuracy in Electrical Discharge Machining. Pulse on Time, Discharge Current, Pulse off Time and Gap Voltage were taken as machining parameters for the purpose of blind hole operation on EN 19 tool steel. The CCD Design of Experiment of Response Surface Methodology used to check the effect of machining parameters on the overcut. Machining parameters optimized for the purpose of minimum overcut. Confirmation tests performed to predict the optimum process parameters and results were checked. It was found that the Discharge Current had greatest effect over the overcut followed by the Gap Voltage; however the effect of the other two input parameters namely Pulse off Time and Pulse on Time was very low. In 2015 Chaudhari, R.M. and Salot V.P. [8] used AISI 52100 as the work piece material. The input parameters selected for optimization were pulse off time, pulse on time, wire feed and voltage. Wire tension, dielectric fluid pressure, cutting length and resistance were taken as fixed parameters. The experimental purpose Taguchi L32 has been used. For each experiment surface roughness, material removal rate and kerf width was calculated by using the contact signal to noise ratio measuring system. By using the multi objective optimization approach Grey Relational Analysis, in order to optimize input parameters in the wire EDM of AISI 52100. Analysis of Variance (ANOVA) was also helpful to identify most important factor. The goal of optimization was maximization of the material removal rate, minimization of surface roughness and the kerf width.

III. EXPERIMENTAL METHODOLOGY

3.1 Machine tool

In this research work, SR is response characteristics. This response characteristic is investigated under varying conditions of input process parameters, which are namely pulse on time (T_{on}) ,pulse off time (T_{off}), peak current (I_p) and servo voltage (S_v). The experiments were performed on Electronica make ELEKTRA Sprintcut 734 CNC Wire cut machine as shown in figure 3.1. ELEKTRA Sprintcut 734 provides full freedom to operator in choosing the parameter values with in a wide range. A brass wire of 0.25 mm diameter is used as the cutting tool material. De-ionized water is used as dielectric, which flush away metal particle from the workpiece.

Figure 3.1 WEDM Setup for experimentation

3.2 Workpiece

AISI A2 steel is an air hardened cold work steel. It is a 5% Chromium steel that provides high degree of hardness after heat treatment with good dimensional stability. It is heat treatable and will provide hardness in the range of 57-62 HRC. It offers good toughness with medium wear resistance and is comparatively easy to machine. It is used in various applications which require good degree wear resistance as well as good toughness. AISI A2 steel is characterized by:

- Good machinability
- Good wear resistance
- Better stability after hardening
- Better compressive strength
- High hardenability
- Better non-deforming properties

Table 3.1 gives the chemical composition of the material AISI A2.

Table 3.1 Chemical composition of AISI A2

Element	C	Mn	Si	Cr	Ni	Mo	V
% age	1.01	0.62	0.25	4.77	0.34	1.02	0.28

The work material used is in rectangular form of dimensions 210mm x 160mm x 27mm as shown in figure 3.2.

Figure 3.2 AISI A2 Workpiece Material

3.3 RSM and design of experiment

Response surface methodology is a collection of the statistical and mathematical methods which are useful for the modeling and optimization of engineering science problems. Response surface methodology explores the relationships between controllable input parameters and obtained responses. There are in total 21 experiments carried out according to design of experiments. The average values of SR (µm) are shown in Table 3.2.

Table 3.2 Design of experiment and SR

Std	Run	T_{on}	T_{off}	I_p	S_v	SR
1	6	125	50	150	15	2.45
2	11	125	50	70	15	1.85
3	21	125	30	150	35	3.15
4	17	105	50	70	35	0.89
5	18	125	30	70	35	2.69
6	8	105	30	150	15	2
7	10	105	50	150	35	0.9
8	14	105	30	70	15	1.9
9	5	98	40	110	25	1.65
10	16	129	40	110	25	2.7
11	20	115	23	110	25	2.2
12	2	115	57	110	25	1.21
13	3	115	40	40	25	1.8
14	13	115	40	180	25	2.32
15	12	115	40	110	8	2.25
16	1	115	40	110	42	1.6
17	4	115	40	110	25	2.01
18	9	115	40	110	25	2.02
19	15	115	40	110	25	2.04
20	7	115	40	110	25	2.01
21	19	115	40	110	25	2.02

IV. RESULT AND DISCUSSION

4.1 Analysis of surface roughness

According to fit summary obtained from analysis, it is found that the quadratic model is statistically significant for SR. The results of quadratic model for SR in the form of ANOVA are presented in Table 4.1. If F value is more corresponding, p value must be less and corresponding resulting in a more significant coefficient. Non significant terms are removed by the backward elimination for fitting of SR in the model. Alpha out value is taken as 0.05 (i.e., 95 % confidence level). It is found from the Table 4.1 that F value of model is 3524.59 and related p value is < 0.0001, results in a significant model. The lack of fit is a measure of failure of model to represent data in experimental domain at which the points are not included in regression variations in model that cannot be accounted for by the random error. If there is the significant lack of fit, as indicated by the low probability value, response predictor is discarded. Lack of fit is non significant and its value is 0.5801. From Table 4.1 it is found that R^2 of model is 0.9998, which is very close to 1. It means that 99.98 % variation can be explained by the model and only .02% of the total variation cannot be explained, which is the indication of good accuracy. The predicted R^2 is in the logical concurrence with adjusted R^2 of 0.9986. Figure 4.1 shows normal probability plot of residuals for SR. Most of residuals are found around straight line, which means that the errors are normally distributed. Adequate precision compares significant factors to non significant factors, i.e., signal to noise ratio. According to results obtained from software, ratio greater than 4 is desirable. In this, adequate precision is 239.89. So signal to noise ratio is significant. By applying multiple regression analysis on experimental data, empirical relation in terms of actual factors is obtained as follows, equation 4.1.

$$\mathbf{SR} = +\ 9.56945 - 0.18910*Ton + 0.24368*Toff - 0.030487*Ip - 0.10814*Sv + 0.000867941*Ton^2 - 0.00108767*Toff^2 + 0.00000829373*Ip^2 - 0.000326422*Sv^2 - 0.00119926*Ton*Toff + 0.000296875*Ton*Ip + 0.00165074*Ton*Sv - 0.00191469*Toff*Sv - 0.000071875*Ip*Sv \quad (4.1)$$

Table 4.1 ANOVA for response surface of Surface Roughness

Pooled ANOVA for Response Surface Reduced Quadratic Model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	DF	Mean Square	F Value	p-value Prob > F	
Model	6.113	13	0.470	3524.59	< 0.0001	significant
A-Ton	0.601	1	0.601	4510.85	< 0.0001	
B-Toff	0.490	1	0.490	3672.92	< 0.0001	
C-Ip	0.306	1	0.306	2295.67	< 0.0001	
D-Sv	0.215	1	0.211	1583.32	< 0.0001	
AB	0.048	1	0.048	361.71	< 0.0001	
AC	0.112	1	0.112	845.53	< 0.0001	
AD	0.091	1	0.091	685.32	< 0.0001	
BD	0.105	1	0.105	793.91	< 0.0001	
CD	0.006	1	0.006	49.56	0.0002	
A^2	0.086	1	0.086	648.04	< 0.0001	
B^2	0.182	1	0.182	1370.76	< 0.0001	
C^2	0.002	1	0.003	22.42	0.0021	
D^2	0.016	1	0.016	123.46	< 0.0001	
Residual	0.0009	7	0.0001			
Lack of Fit	0.0003	3	0.0001	0.742	0.5801	not significant
Pure Error	0.0006	4	0.0002			
Cor Total	6.114	20				
Std. Dev.	0.012		R-Squared			0.9998
Mean	1.983		Adj R-Squared			0.9995
C.V. %	0.582		Pred R-Squared			0.9986
PRESS	0.008		Adeq Precision			239.89

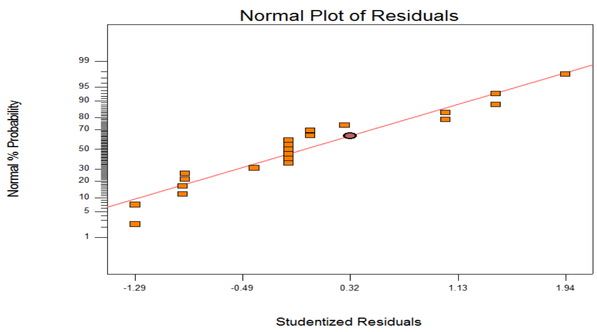

Figure 4.1 Normal probability plot of residuals for SR

4.2 Effect of process parameters on SR

The combined effect of two control factors on response variables is called interaction effect. For interaction plot, two parameters vary keeping the other two process parameters constant at their central value and observe effect on response characteristics. This plot is called three-dimensional surface plot. So the significant interactions are shown in figure 4.2-4.6.

The interaction effect of pulse on time (Ton) and pulse of time (Toff) on surface roughness (SR) is shown in the figure 4.2. From the figure it is observed that as the value of Ton is increased from 105 to 125 µs and Toff constant at 30 µs the surface roughness value increased from 1.804 to 2.774 µm. When the value of Toff is increased from 30 to 50 µs and Ton constant at 105 µs the surface roughness value decreased from 1.804 to 1.462 µm.

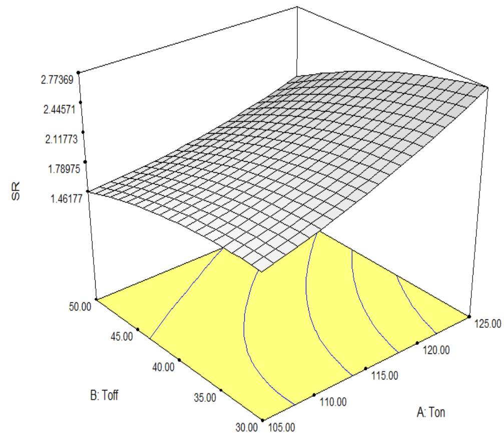

Figure 4.2 Interaction effect of Ton and Toff on SR

The increase in surface roughness due to increase in pulse on time is due to the fact that a high value of Ton causeslonger duration of spark to occur which leads to higher discharge energy which penetrates deep inside the material. This removes large chunks of material from the work piece producing large craters. Large craters are clear indicator of large surface roughness. The decrease in surface roughness due to increase in pulse of time is due to the fact that larger value of pulse off time increases the gap between the two consecutive sparks which results in impingement of lower discharge energy leading to the removal of fine particles of materials from work piece surface, craters obtained are shallow. Hence, lower surface roughness is obtained.

The interaction effect of pulse on time (Ton) and peak current (Ip) on surface roughness (SR) is shown in the figure 4.3. From the figure it is observed that as the value of Ton is increased from 105 to 125 µs and Ip constant at 70A the surface roughness value increased from 1.727 to 2.219 µm. When the value of Ip is increased from 70 to 150A and Ton constant at 105 µs the surface roughness value increased from 1.727 to 1.784 µm. The increase in surface roughness due to increase in pulse on time is due to the reason cited earlier. The increase in surface roughness due to increase in peak current is due to the fact that a larger value of peak current increases the temperature of discharge channel. The energy obtained at large level of Ip has larger heat energy that penetrate deep inside the material and larger piece of material are removed, which produces larger crater on work piece surface. Hence, surface roughness increases.

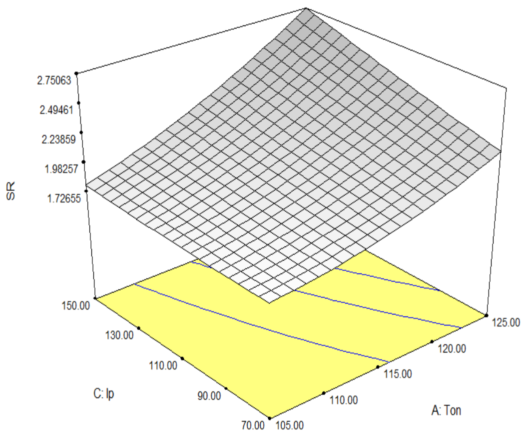

Figure 4.3 Interaction effect of Ton and Ip on SR

The interaction effect of pulse on time (Ton) and servo voltage (Sv) on surface roughness (SR) is shown in the figure 4.4. From the figure it is observed that as the value of Ton is increased from 105 to 125 µs and Sv constant at 15V the surface roughness value increased from 2.065 to 2.465 µm. When the value of Sv is increased from 15 to 35V and Ton constant at 105 µs the surface roughness value decreased from 2.065 to 1.353 µm. The increase in surface roughness due to increase in pulse on time is due to the reason cited earlier. The decrease in surface roughness due to increase in servo voltage is due to the reason that a high value of servo voltage increases the gap between two consecutive sparks. Higher the servo voltage longer is the discharge waiting time which results in lower discharge energy, which produces shallow crater on work piece and hence lower surface roughness is obtained.

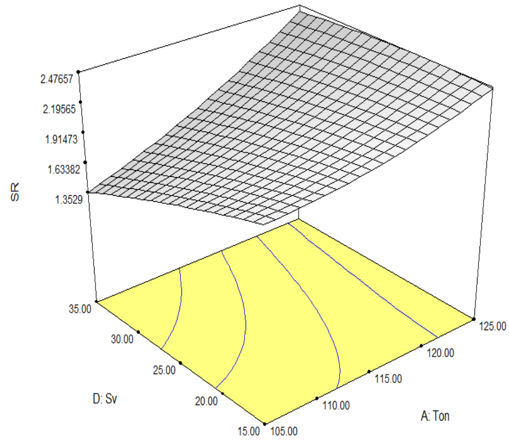

Figure 4.4 Interaction effect of Ton and Sv on SR

The interaction effect of pulse of time (Toff) and servo voltage (Sv) on surface roughness (SR) is shown in the figure 4.5. From the figure it is observed that as the value of Toff is increased from 30 to 50V and Sv constant at 15V the surface roughness value decreased from 2.202 to 1.969 µm. When the value of Sv is increased from 15 to 35V and Toff constant at 30 µs the surface roughness value decreased from 2.202 to 2.169 µm. The decrease in surface roughness due to increase in pulse of time and servo voltage is due to the reasons cited earlier.

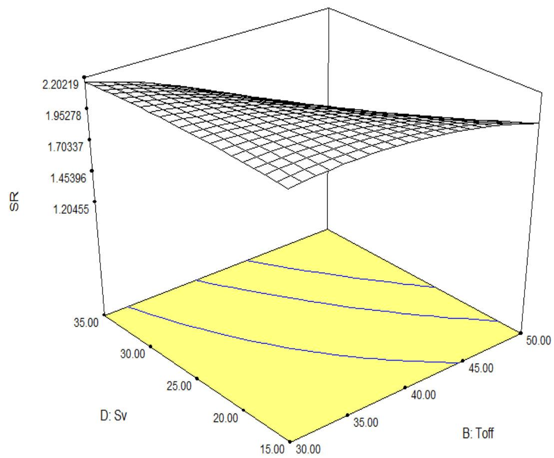

Figure 4.5 Interaction effect of Toff and Sv on SR.

The interaction effect of peak current (Ip) and servo voltage (Sv) on surface roughness (SR) is shown in the figure 4.6. From the figure it is observed that as the value of Ip is increased from 70 to 150A and Sv constant at 15V the surface roughness value decreased from 2.016 to 2.368 µm. When the value of Sv is increased from 15 to 35V and Ip constant at 70A the surface roughness value decreased from 2.016 to 1.691 µm. The increase in surface roughness due to increase in peak current and decrease in surface roughness due to increase in servo voltage is due to the reasons cited earlier.

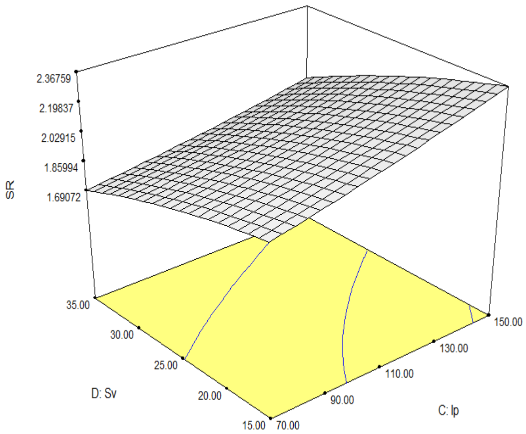

Figure 4.6 Interaction effect of Ip and Sv on SR.

V. CONCLUSION

In this paper, the effect of process parameters on SR is investigated. It is concluded that:

1. Main effect of pulse on time, pulse off time, peak current and servo voltage and interaction effect of pulse on time and pulse of time, pulse on time and peak current, pulse on time and servo voltage, pulse of time and servo voltage, peak current and servo voltage and second order of pulse on time, pulse off time, peak current and servo voltage found to be significant from the ANOVA of surface roughness.
2. Surface Roughness (SR) of the machined surface increased with increase in pulse on time because the discharge energy becomes more intense with increasing pulse on time, whereas with increase in pulse off time and servo voltage surface finish increases. On increasing the value of peak current, surface roughness of the machined surface increases whereas on decreasing the peak current surface roughness decreases.
3. For the response parameter, the predicted value of the response is in close agreement with experimental results.

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