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An Efficient Optimization of Materiel Removal Rate For Wire Cut Electro Discharge Machining In S2 Steel Using Response Surface Methodology

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Abstract:

S2 is a shock- resisting steels. The harden ability of group S steels can be controlled by varying their composition instead of adjusting the melting procedures and grain size. These steels can obtain optimum hardness at higher austenitizing temperatures. The tempering resistance of group S steels can be mins. Wire Electric Discharge Machine (WEDM) seems a good option for machining the complicated shapes on medium strength steel. this paper, identify the effects of various enhanced by addition of silicon, which also forms a microstructure to resist.S2 tool steels are slowly preheated at 760ºC (1400ºF). Temperature is then increased to 927ºC (1700ºF) followed by holding the steel sections at that temperature for 10 to 30 process parameters of WEDM such as pulse on (Ton) ,pulse off (Toff), peak current (IP), servo voltage (SV) for analysis the material removal rate (MRR) while machining S2 mild steel material. Central Composite Design is used to plan and design of experts. The output response variable being material removal rate will be measured for all the number of experiments conducted. As the lowest value of MRR indicates the poor cutting rate, the optimum parameter level combination would be analyzed which gives desired material removal rate. These optimized values of various parameters would then be used in performing machining operation in order to obtain desirable outputs.

***Keywords*- S2 Steel, Wire EDM, Process Parameters, RSM Technique, Material Removal Rate.**

I. INTRODUCTION

The main objective of this paper is to study different parameters likes (Ton,Toff,IP,SV) of WEDM operations using response surface methodology, in particular central composite design (CCD), to develop empirical relationships between different process parameters and output responses namely MRR. The mathematical models so developed are analyzed and optimized to yield values of process parameters producing optimal values of output responses.

J.F. Liu et. al. (2016) this study focuses on the development of a predictive model incorporating massive random discharges to provide insights into white layer (WL) formation mechanism in EDM. Key findings are as follows: A new FEA model with massive random discharging characteristics has been developed and implemented to simulate solid white layer formation and heat affected zone (HAZ) formation and the corresponding austenite marten site phase transformation. The predicted geometry and marten site distribution of solid WL and HAZ in both surface and subsurface are comparable to the experimental observations. The developed FEA model across from micro scale individual discharge to massive random discharges is capable of predicting the macro scale accumulated thermal damage in an EDM process.

Vikas et. al. (2014) the article concludes the effect of the different input parameters like Pulse ON time, Pulse OFF time, Discharge Current and Voltage over the surface roughness for an EN41 material. It was found out that the discharge current had a larger impact over the surface roughness parameter. The effect of the other parameters was significantly less and can be ignored. The interaction plots also showed negligible effect over the Surface Roughness value. The entire result was calculated at 95 % confidence level and the experimental value so obtained was found very close to the predicted value and hence, the entire work is validated.

Jangra Kamal et al. (2010) presented the optimization of performance characteristics in WEDM using Taguchi Grey relational analysis. Process parameters were investigated using mixed L18 orthogonal array.GRA was applied to determine optimal process parameters for optimization of multiple performance characteristics which were investigated during rough cutting operation in D-3 tool steel.

U.Natarajan et al. (2011) focuses RSM for the multiple response optimization in micro-end milling operation to achieve maximum metal removal rate (MRR) and minimum surface roughness. Aluminium block of 60×40×16 mm is used as the work piece material and carbide end mill cutter of diameter 1 mm as the cutting tool.

SR. Sadeghi et al. (2011) investigated the effect of discharge current, pulse interval, open circuit voltage and servo voltage on MRR and SR. It was observed that discharge current and pulse interval are the most influencing parameters for MRR and SR.

Neeraj Sharma et al. (2013) investigated the effect of parameters on cutting speed and dimensional deviation for WEDM using HSLA as work piece. It is seen that the most prominent factor for cutting speed and dimensional deviation is pulse-on time, while two-factor interactions play an important role in this analysis. Response surface methodology was used to optimize the process parameter for cutting speed and dimensional deviation. The central composite rotatable design was used to conduct the experiments. The analysis of variance was used for the investigation of significant factors.

In the present study S2 steel is chosen for parametric investigation and optimization of material removal rate by using response surface methodology and WEDM.

II. METHODOLOGY

A. Machine Tool And Workpiece

In this research work, MRR is response characteristics. These response characteristics are investigated under the varying conditions of input process parameters, which are Pulse on Time (Ton),Pulse off Time (Toff), Servo gap voltage (SV), Peak current (IP). The experiments were performed on Electronica make ELEKTRA Sprintcut 734 CNC Wire cut machine. ELEKTRA Sprintcut 734 provides full freedom to the operator in choosing parameter values with in a wide range. A brass wire of 0.25 mm diameter is used as the tool material. Deionized water is used as the dielectric, which flush away the metal particle from the rectangular work piece of S2. The chemical composition of S2 is as follo

Table - of 1 Composition S2

Carbon %	Manganese %	Phosphorus %	Sulphur %	Silicon %	Copper %	Nickel %	Vanadium %	Moly %	Iron
0.524	0.346	0.01891	0.01645	0.9864	0.25	0.30	0.456	0.349	96

B. Examining The Output Response

The MRR (mm³/min) is calculated from the cutting speed (directly displayed by the machine tool)*height of work piece removed *breadth of work piece removed [8].

I.e. MRR = cutting speed* length * height of work piece removed.

Values of the MRR are noted at a distance of 5 mm, 5 mm, and 5 mm from the initiation of cut along a particular axis. This is done to ensure that readings are to be noted only when the cutting process is properly stabilized. The offset of the wire is set at zero.

Response surface methodology and design of experiment

RSM is a compilation of mathematical and statistical techniques useful for the modeling and analysis of problems in which output factors are influenced by several input parameters and the main aim is to optimize this output parameters. Graphical representation of the procedure for RSM is as follows:

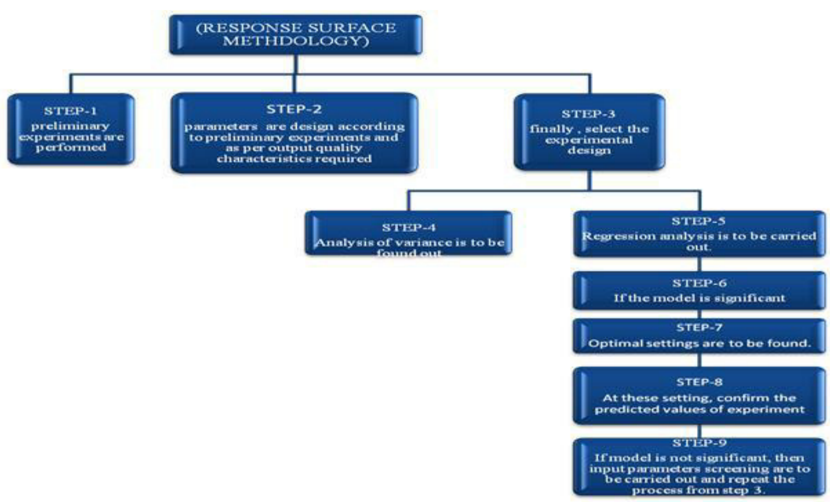

Fig.1 Graphical representation of procedure for RSM

Table 2: Different levels of Process parameters with coded form and unit

Sr. no.	Parameters	Coded form	Min. value	Max. Value
1	T_{on} (μs)	A	100	120
2	T_{off} (μs)	B	20	60
3	IP (A)	C	50	180
4	SV(V)	D	20	100

Table 4: (Design of experiments and results for wire EDM output response)

Std	Run	A:T_{on} μs	B:T_{off} μs	C:IP A	D: SV V	MRR mm³/mn
1	11	120	60	180	20	162.5
2	10	120	60	60	20	132.09
3	9	120	20	180	80	155.8
4	20	102	60	60	80	68.12
5	17	120	20	60	80	135.15
6	7	102	20	180	20	138.33
7	19	102	60	180	80	98.3
8	4	102	20	60	20	117.68
9	12	95.8639	40	120	50	115.62
10	14	126.136	40	120	50	153.89
11	15	111	20	120	50	150.45
12	2	111	73.6359	120	50	124.44
13	5	111	40	19.0924	50	97.99
14	8	111	40	220.908	50	138.33
15	16	111	40	120	20	132.9
16	1	111	40	120	100.454	104.6
17	3	111	40	120	50	131.5
18	18	111	40	120	50	130.5
19	21	111	40	120	50	130.5
20	13	111	40	120	50	130.5
21	6	111	40	120	50	130.5

Work piece	S2 Mild Steel
Electrode (tool)	0.25mm Ø, Brass wire
Work piece height	10.2 mm
Dielectric Conductivity	20mho
Dielectric temperature	20-24⁰C

Table 5: Sequential Model Sum of Squares [Type I]

Sequential Model Sum of Squares [Type I]						
Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob> F**	
Mean vs Total	341950.1	1	34195			
Linear vs Mean	8582.14	4	2145.54	31.70	<0.0001	
2FI vs Linear	380.42	6	63.40	0.90	0.5292	
Quadratic vs 2FI	699.69	4	174.92	392.31	<0.0001	Suggested
Cubic vs Quadratic	1.88	2	0.94	4.69	0.089	Aliased
Residual	0.80	4	0.020			
Total	351605.0	21	16743.09			
Lack of Fit Tests						
Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
Linear	1081.99	12	90.17	450.83	<0.0001	
2FI	701.56	6	116.93	584.64	<0.0001	
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Cubic	0	0				Aliased
Pure Error	0.80	4	0.20			
Model Summary Statistics						
Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	8.23	0.8880	0.8600	0.7912	2018.3	
2FI	8.38	0.9273	0.8547	0.5991	3874.5	
Quadratic	0.67	0.9997	0.9991	0.9888	108.08	Suggested
Cubic	0.45	0.9999	0.9996		+	Aliased

III. RESULT AND DISCUSSION

There are 21 experiments in total carried out according to the design of experiments. The average values of MRR (mm³/min) are shown in Table 4. For analysis of data, checking the goodness of fit of model is required. The model adequacy checking includes test for significance of regression model, test for significance on model coefficients, and lack of fit test .For this purpose, ANOVA is performed.

A. Analysis of Material Removal Rate-

To decide about the adequacy of the model, three different tests viz. sequential model sum of squares, lack of fit tests and model summary statistics were performed for material removal rate and characteristics of WEDM process. The two tables display two different tests to select an adequate model to fit various output characteristics. The sequential model sum of squares test in each table shows how the terms of increasing complexity contribute to the model.

It can be observed that for all the responses, the quadratic model is appropriate. The “lack of fit” test compares the residual error to the pure error from the replicated design points. The results indicate that the quadratic model in all the characteristics does not show significant lack of fit, hence the adequacy of quadratic model is confirmed. Tables show the selection of adequate model for material removal rate. The p value should be less than 0.5.the value of p is less than 0.5 in case of quadratic. Which shows that quadratic model is suggested. In order to statistically analyze the results, ANOVA was performed. Process variables having p-value < 0.05 are considered significant terms for the requisite response characteristics. The insignificant parameters were pooled using backward elimination method. The pooled version of ANOVA for material removal rate indicates that (A), (C), (D), the interaction terms (AB, AC, AD, BD) and the quadratic terms (B^2, $C^{2,}$ D^2) are significant parameters affecting material removal rate.

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The Model F-value of 2395.96 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A,B,C,D,AB,AD,BC,BD,A^2,B^2,C^2,D^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 2.36 implies the lack of fit is Non significant relative to pure error there is a 21.29% chance that a "Lack of Fit F- value" this large could occur due to noise. Not significant lack of fit is good we want the model to fit. The "Pred R-Squared" of 0.9980 is in reasonable agreement with the "Adj R-Squared" of 0.9993. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. My ratio of 205.574 indicates an adequate signal. This model can be used to navigate the design space.

(insignificant identified from ANOVA) of some terms of thequadratic equation have been omitted.

MRR=+319.52714-4.02653* Ton-2.35798* Toff+0.42030* Ip-0.45151* Sv+0.018001* Ton * Toff+0.011152* Ton * Sv+2.00938E-003 * Toff * Ip-0.015018* Toff * Sv+0.018077* Ton2 +6.03826E-003* Toff2 - 1.22305E-003*Ip2-4.66042E-003* Sv2

Table 6: Pooled ANOVA for Material Removal Rate

	Sum of	D.F	Mean	F	p-value	
Model	9662.24	12	805.187	2395.96	< 0.0001	significant
$A\text{-}T_{on}$	732.296	1	732.296	2179.06	< 0.0001	
$B\text{-}T_{off}$	338.26	1	338.26	1006.55	< 0.0001	
C-IP	2109.52	1	2109.52	6277.23	< 0.0001	
D-SV	400.445	1	400.445	1191.59	< 0.0001	
AB	34.7883	1	34.7883	103.518	< 0.0001	
AD	30.0411	1	30.0411	89.3921	< 0.0001	
BC	46.513	1	46.513	138.407	< 0.0001	
BD	269.068	1	269.068	800.653	< 0.0001	
A^2	32.0404	1	32.0404	95.3412	< 0.0001	
B^2	87.1792	1	87.1792	259.416	< 0.0001	
C^2	289.708	1	289.708	862.074	< 0.0001	
D^2	262.908	1	262.908	782.325	< 0.0001	
Residual	2.68848	8	0.33606			
Lack of Fit	1.88848	4	0.47212	2.3606	0.2129	not significant
Pure Error	0.8	4	0.2			
Cor Total	9664.93	20				

B. Effect of Process Parameter (one factor) and 3-D Surfaces on MRR

The effect of single and two control factors or process parameters on the response variables is called the interaction effect. For the interaction plot, the single and two parameters vary keeping other two process parameters at the central value and observe the effect on the response characteristics. This plot is called the three-dimensional surface plot (i.e., 3D surface plot). So the significant interactions are shown in Figs. 3 (a, b, c, d)

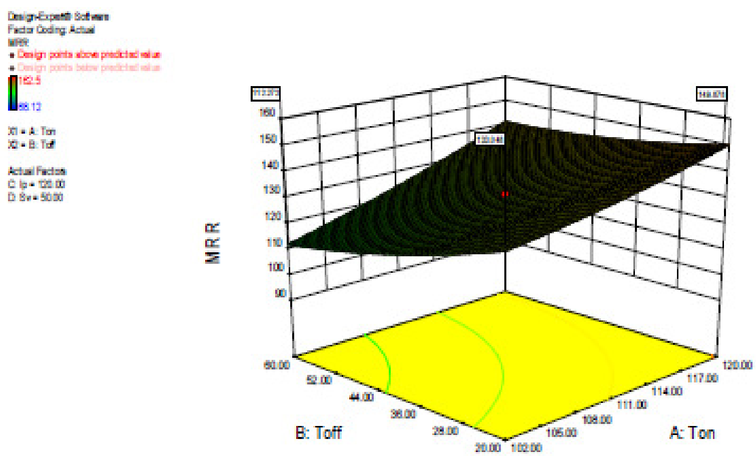

Fig shows interation effect of T_{on} and T_{off}

After thorough study of various literatures it can be say From Figure 4 that the material removal rate is generally shows increasing effect with the increase of pulse on time and at the same time it decreases with the pulse off time on decreasing of Toff. At small value of Toff means, there will be more time duration for which current is on i.e. more number of discharges per second which implies that metal erosion will be more, hence faster MRR results. This is due to the fact that a high value of TON and lower value of TOFF means that discharge will act for longer time, which results to a more discharge energy. Large discharge energy will cause violent sparks resulting in faster removal of metal. Hence metal removal rate increases. It is observed from Figure 4 shows that MRR achieves a maximum value of 152.5 mm3/min.

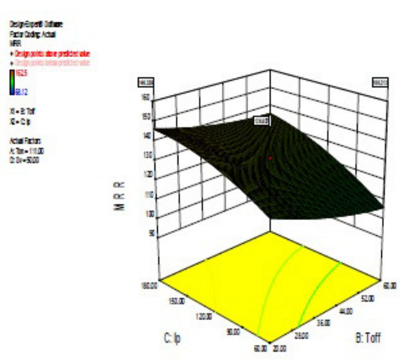

Fig 4: Interaction effect of IP and Toff

It is seen from Figure that material removal rate increases with increase in the peak current values and simultaneously decrease with turn off time. Various researchers state that the higher is the peak current setting, the larger is the discharge energy. This generally leads to increase in material removal rate. But, the sensitivity of the stronger than that of peak current setting on the cutting performance is the pulse on time. While the peak current setting isobserved from the figure 5 MRR is max.(146.63 too high, wire breakage may occur frequently. It ismm3/min).

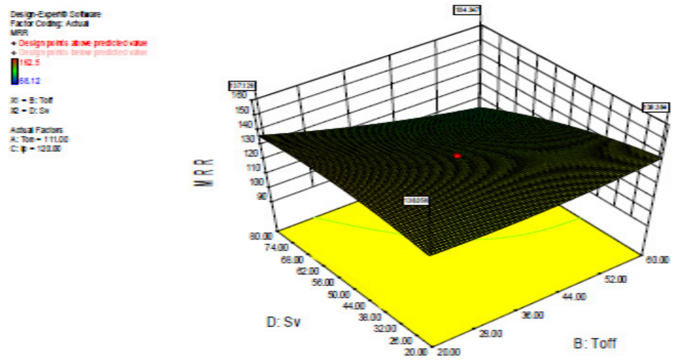

Figure shows the 3D interaction plot of Toff and SV on MRR.

It is observed from Figure 6 that material removal rate decreases with increase in spark gap set voltage and turn off time. With increase in spark gap set voltage the average discharge gap gets widened resulting into a lower material removal rate.

CONCLUSION

In this paper, effect of process parameters on MRR is investigated.It is concluded that:. Response surface methodology (RSM) was applied for developing the mathematical models in the form of multiple regression equations correlating the dependent factors with the independent factors like (pulse on time, pulse off time, spark gap set voltage, peak current) in WEDM machining of S2 steel. It was found experimentally that increasing the pulse on time and peak current, the cutting rate increases, whereas increasing the pulse off time and servo voltage decreases the cutting rate. The higher discharge energy associated with the increased pulse on time, peak current and lesser pulse off time and servo voltage leads to more powerful explosions which increase the cutting rate. Using the model equations, the response surfaces have been plotted to study the effects of process parameters on the performance characteristics. From the experimental data of RSM, empirical models were developed and the confirmation experiments were performed, which were found within 95% confidence interval.

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