Experimental Investigation And Optimization Of Process Parameters In WEDM On Machining Of H13 Steel Using Response Surface Methodology

Arunbharathi R[1] , Ashoka Varthanan P [2], Abinash Raju R [3], Akilesh M [4]
[1]Assistant Professor, Dept of Mechanical Engineering
[2]Professor, Dept of Mechanical Engineering
[3, 4]Dept of Mechanical Engineering
[1, 2, 3, 4] Sri Krishna College of Engineering and Technology, Coimbatore, Tamilnadu, 641008, India

Abstract- *The main objective of the present work is to optimize the process parameters of wire electrical discharge machining process on machining AISI H13 die steel by considering the significant effect of input parameters viz. pulse on time, peak current, pulse off time and wire tension in order to get the desired outcome such as maximizing material removal rate, better surface finish and reduced kerf width. H13 steel was selected as the specimen based on the wide usage in industrial applications like making of hot punches and dies for blanking, bending, swaging and forging operations and other applications. In this work, a brass wire of 250μm diameter was used as wire tool electrode and De-ionized water as the dielectric fluid. 30 experimental runs were carried out on the specimen based on the full factorial central composite design using response surface methodology. The performance characteristics viz., Material Removal Rate, Surface Roughness and Kerf Width were measured and analyzed using Minitab software analytically as well as graphically in order to evaluate the performances of the wire electrical discharge machining process. Mathematical model was developed for predicting the values of responses in terms of interactive and higher order input process parameters. The Analysis of variance (ANOVA) was performed to find the significant process parameters for material removal rate, surface roughness and Kerf width. The adequacy of the above proposed model was also tested using ANOVA. Response surface plot for the responses are plotted by considering the significant parameters. Finally optimal combination of process parameters were obtained through desirability function approach for this multi-objective optimization problem to maximize material removal rate, better surface finish and reduced kerf width by using Response Optimizer plot.*

Keywords- Desirability Function, H13 Steel, Kerf Width, Response Surface Methodology

I. INTRODUCTION

WEDM process is usually used in combination with CNC and will only work when a part is to be machined completely through. The melting temperature of the parts to be machined is an significant parameter for this process rather than strength or hardness. The surface quality and material removal rate (MRR) of the machined surface by wire EDM will depend on different machining parameters such as applied peak current, pulse on time, pulse off time, wire tension and wire materials. WEDM process is commonly conducted on immersed condition in a tank fully filled with dielectric fluid; nevertheless it also can be conducted in dry condition. During the WEDM process, the material is eroded ahead of the wire by using the channel of plasma generated by electric sparks between two conductive materials (i.e. electrode and the work piece), this channel of plasma converted into thermal energy at a temperature range of 8000 to 12000ºC at a pulsating direct current supply of 20000 to 30000 Hz. The electrode and work piece are separated by a small gap being immersed in dielectric fluid, an electric spark is produced in between this small gap and the work piece material is eroded, as the pulsating current is turnedoff, the plasma breaks down which leads to sudden reduction in the temperature and the eroded material is flushed away with the help of dielectric fluid in the form of microscopic debris. With each electric spark discharge a small crater is formed on both the work piece and the electrode which is a prime decider in the final surface quality. As there is no direct contact between the work piece and the wire electrode, eliminating the mechanical stresses during machining.

II. LITERATURE REVIEW

Aniza Alias et al [1], has reported that, improper electrical parameters settings can affect the processing efficiency and surface roughness due to arcing phenomenon that lead by discharge focal point. Objective of the paper is to find the influence of three different machine rates which are 2 mm/min, 4 mm/min and 6 mm/min with constant current (6A) with WEDM of Titanium Ti-6Al-4V. The effects of various process parameters on the cutting width, material removal rate, surface roughness and surface topography are also discussed.

Farnaz Nourbakhsh et al [2], investigated the influence of zinc-coated brass and high speed brass wire on the performance of wire electro-discharge machining of titanium alloy. The process parameters including cutting speed, wire rupture and surface integrity are obtained by considering input parameters like pulse width, servo voltage, pulse current and wire tension. A Taguchi L18 design of experiment has been used. It was also found that the cutting speed raise with peak current and pulse off time. Surface roughness was found to raise with pulse width and fall with pulse interval. The Analysis of Variance table is carried out for all process parameters to determine the significant ones. Compared with high-speed brass wire, zinc-coated brass wire results in elevated cutting speed and even surface finish. Also, SEM photographs validated that uncoated wire produces a surface finish with more cracks, craters and melted drops.

Jaganjeet Singh et al [3], described the optimization of the WEDM process using Taguchi methodology. It was found that the Taguchi's factor design is a simple, organized, reliable, and more effective tool for optimization of the machining parameters. The effects of different machining parameters such as pulse-on time, pulse-off time, peak current, servo voltage, wire tension and wire feed has been studied though machining of H13 hot work steel. An attempt has been made to improve the machining conditions for surface roughness based on (L18 Orthogonal Array) Taguchi methodology.

Max Schwade [4], stated that EDM is time consuming especially for the application of new materials or in the case of unfavorable machining conditions. Due to the large number of influencing factors and their interdependencies it is difficult to foretell the machining conditions only by interpretation of the used generator parameters. In this study the actual physical values for current and voltage as well as pulse on-time and off-time of each discharge was found by monitoring the electrical process signals.

G. Harinath Gowd [5], optimized the wire EDM process parameters for machining SS304. After conducting pilot experiments and literature survey, the influencing parameters were identified. The effect of input parameters such as pulse-on time, pulse-off time, wire tension and water pressure on surface roughness and material removal rate while machining the stainless steel 304 material is analysed.

Sivaprakasam et al [6], examined the characteristics viz. material removal rate (MRR), Kerf width (KW) or cutting width and surface roughness (SR) utilising response surface methodology with central composite design (CCD) of wire electrical discharge machining by considering three controllable factors such as servo voltage, capacitance and feedrate. The experiments are carried out on titanium alloy (Tie6Ale4V). Analysis of variance (ANOVA) was executed to find out the significant impact of each factor. The model evolved using genetic algorithm (GA) was used to determine the optimal machining conditions using multi-objective optimization technique.

Ugrasen et al [7], has established statistically significant machining parameters and the percentage contribution of these parameters on accuracy, surface roughness and MRR. Each experiment has been made using L16 orthogonal array under different cutting conditions of pulse-on, pulse-off, current, and bed speed. Among various process parameters voltage and flush rate were persistent. Based on this analysis, process parameters are optimized. ANOVA is performed to calculate the relative magnitude of the each factor on the objective function. Evaluation and comparison of responses was done using artificial neural network.

III. EXPERIMENTAL DETAILS

3.1 Experimentation.

The experiments were carried out on a five axis Electronica Sprintcut 734 CNC Wire cut machine. Sprintcut 734 provides full flexibility to the operator in choosing parameter values with in a wide range. The WEDM setup is shown in Fig. 1. A brass wire of 250μm diameter is used as the tool material. De-ionized water is used as the dielectric fluid.

Fig. 1 Wire EDM setup for experimentation

3.2 Work Piece

In this work, H13 hot work tool steel is used for the experimentation. The material has high hot tensile strength, hot wear-resistance, toughness, good thermal conductivity and insensitiveness to hot cracking. H13 type grade is suitable for experimentation, resistance to softening up to 600ºC, combined with good stability in hardening and high toughness, making it suitable not only for hot die applications but also plastic moulds. The composition of metal is shown in Table 1. In this work H13 tool steel plate of 100mm x 50mm x 15mm is used. The machined work pieces with cut pieces is shown in Fig. 2.

Table 1 Composition of workpiece material

Element	C	Mn	P	Cr	Vn	Mb
%age	0.316	0.338	0.0125	4.956	1.09	1.285

Fig. 2 Machined work piece with cut pieces

3.3 Design of experiments with CCD:

Using the response surface methodology, the different combinations of input parameters to conduct the experiments and their corresponding responses are tabulated in Table 2. The central composite design is adopted for creating 30 runs.

Table 2 Design of Experiments and its Responses

Std order	Ton	Toff	IP	WT	Responses		
					MRR	KW	SR
Unit	(µs)	(µs)	(amps)	(N)	(mm^3/ min)	(mm)	(µm)
12	125	58	190	8	8.3292	0.279	2.20
8	125	58	210	6	9.4567	0.287	3.25
19	120	54	200	7	8.1218	0.273	2.52
2	125	50	190	6	12.725	0.285	2.56
10	125	50	190	8	12.470	0.289	2.41
15	115	58	210	8	5.0908	0.286	2.67
17	120	54	200	7	8.2913	0.275	2.94
13	115	50	210	8	7.7532	0.284	3.04
20	120	54	200	7	8.2913	0.275	2.94
1	115	58	190	6	7.0343	0.269	1.87
3	115	58	190	6	4.8655	0.263	1.72

3.4 Monitoring of Output Responses

3.4.1 Material removal rate

The metal removal rate (mm^3/min) is calculated from the cutting speed data directly displayed by the machine tool with the help of the Eq. 1. Values of the cutting speed are noted for certain distance from the initiation of cut along a particular axis. This is done to ensure that readings are to be noted only when the cutting is properly stabilized. The offset of the wire is set at zero.

Material removal rate = cutting speed × kerf width × height mm^3/min. (1)

3.4.2 Surface roughness

Surface roughness of the workpiece was measured using MITUTOYO made surface roughness tester SJ-201P instrument having stylus radius of 3mm and its resolution is 0.1µm and it is shown in Fig. 3. It is a shop–floor type surface roughness measuring instrument, which traces the surface of various machine parts and calculates the surface roughness based on roughness standards, and displays the results in µm.

Fig. 3 Surface Roughness Tester

3.4.3 Kerf width

Kerf width occurs during machining is measured using the tool maker microscope. It determines the dimensional accuracy of the finishing part, is of extreme importance. The internal corner radius to be produced in WEDM operations is also limited by the kerf.

IV. RESULTS AND DISCUSSION

The experiments were framed and conducted by employing response surface methodology (RSM). The selection of appropriate model and the development of response surface models have been carried out by using Minitab 17 software. The regression equations for the selected model were obtained for the response characteristics, viz., Material Removal Rate, Kerf Width and Surface Roughness. These regression equations were developed using the experimental data and were plotted to investigate the effect of process variables on various response characteristics. The analysis of variance (ANOVA) was implemented to statistically analyze the results.

4.1 Analyis of Variance

Analysis of variance is carried out to statistically analyze the results. ANOVA checks the values of R^2 as it explains the ratio of the variability explained by the model to the total variability inherent in the observation data of experiments. It also shows adequate precision which calculates signal to noise ratios. A ratio greater than 4 shows that the model to be fit. Process variables having p-value < 0.05 are considered significant terms for the given response parameters. The backward elimination process eliminates the insignificant terms to adjust the fitted quadratic models and in the present work backward elimination process with α to exit = 0.05 is used to eliminate the insignificant terms.

4.1.1 ANOVA for Surface Roughness

Surface roughness is an important process criterion, which dictates the condition of the surface component which has to be machined. The Analysis of Variance of surface roughness is given in Table. 3. Based on analysis of variance as shown in Table. 3 the Values of 'Prob.> F' less than 0.05 indicates that model terms are significant at 95% confidence level. F-value of model is 12.62 and the associated p-value is lower than 0.05 and it indicates that the model is significant. The p-value for lack of fit is 0.494 suggesting that this model adequately fits the data. From ANOVA results, it could be observed that factors Ton, Toff and IP are significant and the other interaction factors are non-significant. Almost 84% of the total variation in the response data could be contributed to factors T_{on} and IP.

Table 3 Analysis of Variance of Surface roughness

Source	DF	Adi SS	Adi MS	F-value	P-value
Model	15	6.87227	0.45815	12.62	0
Blocks	1	0.00641	0.00641	0.18	0.681
Linear	4	6.52083	1.63021	44.89	0
Ton	1	2.07682	2.07682	57.19	0
Toff	1	0.1944	0.1944	5.35	0.036
IP	1	4.2336	4.2336	116.58	0
WT	1	0.01602	0.01602	0.44	0.517
Square	4	0.21538	0.05383	1.48	0.26
Ton*Ton	1	0.00943	0.00943	0.26	0.618
Toff*Toff	1	0.00034	0.00034	0.01	0.924
IP*IP	1	0.1336	0.1336	3.68	0.076
WT*WT	1	0.10643	0.10643	2.93	0.109
2-way Interaction	6	0.12965	0.02161	0.6	0.73
Ton*off	1	0	0	0	1
Ton*IP	1	0.02103	0.02103	0.58	0.459
Ton*WT	1	0.0484	0.0484	1.33	0.268
Toff*IP	1	0.0196	0.0196	0.54	0.475
Toff*WT	1	0.03423	0.03423	0.94	0.348
IP*WT	1	0.0064	0.0064	0.18	0.681
Error	14	0.50839	0.03631		
Lack-of-fit	10	0.37519	0.03752	1.13	0.494
Pure	Error	4	0.1332	0.0333	
Total	29	7.38067			
Model	Summary				

S	R-sq	R-sq(adj)	R-sq(pred)		
0.19056	93.11%	85.735%	63.29%		

4.1.2 ANOVA for Material Removal Rate

From ANOVA results given in Table. 4, it could be observed that factors T_{on}, T_{off} and IP are significant, in addition to that one higher order term T_{on}^2 and the other interaction factors are non-significant. It was observed from the F and P values that the factors T_{on} and T_{off} are most significant for MRR. This can also be observed from the values of percent contribution obtained for each source, which quantifies the contribution of a parameter towards the variation in response. Almost 88% of the total variation in the response data could be contributed to factors T_{on} and IP.

Table 4 Analysis of Variance for Material Removal Rate

Source	DF	Adi SS	Adi MS	F-value	P-value
Model	15	234.09	15.606	41.89	0
Blocks	1	1.189	1.189	3.19	0.096
Linear	4	226.36	56.592	151.89	0
Ton	1	137.62	137.62	369.38	0
Toff	1	75.413	75.413	202.4	0
IP	1	13.243	13.243	`35.54	0
WT	1	0.083	0.083	0.22	0.644
Square	4	3.859	0.965	2.59	0.082
Ton*Ton	1	2.858	2.858	7.67	0.015
Toff*Toff	1	1.498	1.498	4.02	0.065
IP*IP	1	0.22	0.22	0.59	0.455
WT*WT	1	0.192	0.192	0.51	0.485
2FI	6	2.68	0.447	1.2	0.362
Ton*off	1	1.332	1.332	3.57	0.08
Ton*IP	1	0.175	0.175	0.47	0.505
Ton*WT	1	0.191	0.191	0.51	0.485
Toff*IP	1	0.516	0.516	1.39	0.259
Toff*WT	1	0.458	0.458	1.23	0.286
IP*WT	1	0.007	0.007	0.02	0.89
Error	14	5.216	0.373		
Lack-of-fit	10	5.192	0.519	86.56	0
Pure	Error	4	0.024	0.006	
Total	29	239.31			
Model	Summary				
S	R-sq	R-sq(adj)	R-sq (pred)		
0.610405	97.82%	95.48%	85.66%		

4.1.3 ANOVA for Kerf Width

From ANOVA results found in Table. 5, it could be observed that factors Pulse on time, Pulse off time, Current, Wire Tension and two higher order term T_{on}^2, WT^2 are significant and the other interaction factors are non-significant. It was observed from the F and P values that the factors Ton and IP are most significant for kerf width. This can also be observed from the values of percent contribution obtained for each source, which quantifies the contribution of a parameter towards the variation in response.

Table 5 Analysis of Variance for Kerf width

Source	DF	Adi SS	Adi MS	F-value	P-value
Model	15	0.004011	0.000267	17.88	0
Blocks	1	0.000001	0.000001	0.09	0.768
Linear	4	0.003518	0.00088	58.8	0
Ton	1	0.001926	0.001926	128.77	0
Toff	1	0.00033	0.00033	22.07	0
IP	1	0.001107	0.001107	74.01	0
WT	1	0.000155	0.000155	10.37	0.006
Square	4	0.000342	0.000086	5.72	0.006
Ton*Ton	1	0.000206	0.000206	13.76	0.002
Toff*Toff	1	0.000016	0.000016	1.06	0.321
IP*IP	1	0.000034	0.000034	2.28	0.153
WT*WT	1	0.000109	0.000109	7.26	0.017
2-way Interaction	6	0.000149	0.000025	1.66	0.202
Ton*off	1	0.000033	0.000033	2.21	0.159
Ton*IP	1	0.000003	0.000003	0.2	0.658
Ton*WT	1	0	0	0	0.949
Toff*IP	1	0.000023	0.000023	1.51	0.24
Toff*WT	1	0.000023	0.000023	1.51	0.24
IP*WT	1	0.000068	0.000068	4.55	0.051
Error	14	0.000209	0.000015		
Lack-of-fit	10	0.000173	0.000017	1.89	0.282
Pure	Error	4	0.000036	0.000009	
Total	29	0.004221			
Model	Summary				
S	R-sq	R-sq(adj)	R-sq(pred)		
0.003867	95.04%	89.72%	69.26%		

4.2 Mathematical Model

RSM is a statistical technique for calculating and representing the cause and effect relationship between true mean responses and input control variables. The main objective of RSM is to use a set of designed experiments to find an optimal response. In this work, response surface modelling was utilized for determining the relations between the various WEDM process parameters on the responses, i.e., Material Removal Rate (MRR), Surface Roughness (SR) and Kerf Width (KW).

4.2.1 Effect of Process Parameters on MRR

The regression coefficients of the second order equation are acquired by using the experimental values. The mathematical equation for the material removal rate as a function of four input process variables was developed using experimental data and is shown in Eq. 2.

MRR = 174 - 2.41 Ton + 0.31 Toff - 0.307 IP - 6.45 WT + 0.01291 Ton*Ton + 0.01461 Toff*Toff + 0.00090 IP*IP + 0.084 WT*WT 0.01442 Ton*Toff + 0.00209 Ton*IP + 0.0219 Ton*WT - 0.00449 Toff*IP + 0.0423 Toff*WT + 0.0021 IP*WT. (2)

The response surface is plotted to study the effect of process variables on the material removal rate and is shown in Fig. 4a-4c. From Fig. 4a the material removal rate is found to have an rising trend with the increase of pulse duration and at the same time it decreases with the increase of pulse off time. From Fig. 4b the material removal rate is found to have an increasing trend with increase in pulse on time and kerf width.

Fig. 4c shows that the material removal rate increases with increase in peak current.

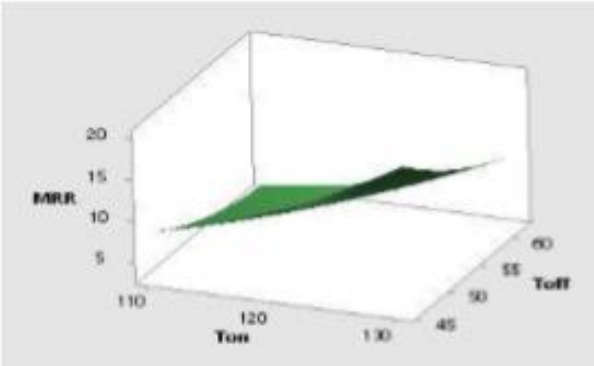

Fig. 4a Combined effect of Ton and Toff on MRR

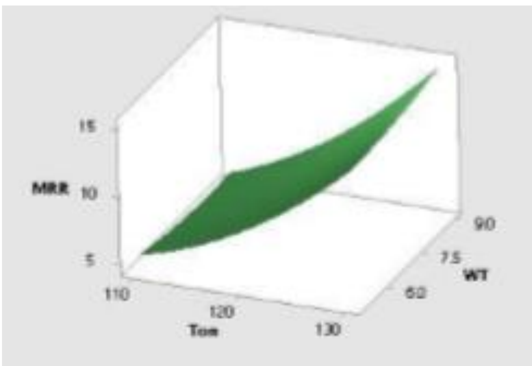

Fig. 4b Combined effect of Ton and WT on MRR

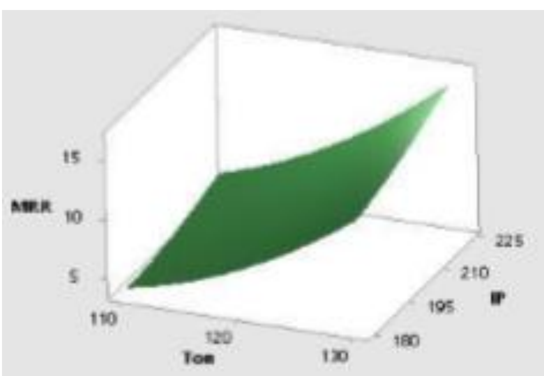

Fig. 4c Combined effect of Ton and IP on MRR

4.2.2 Effect of Process Parameters on KW:

The regression equation for the kerf width as a function of four input process variables was developed using experimental data and is shown in Eq. 3.

$$KW = 2.395 - 0.02229\ Ton + 0.00482\ Toff - 0.00788\ IP - 0.0811\ WT + 0.000110\ Ton*Ton - 0.000048\ Toff*Toff + 0.000011\ IP*IP + 0.001990\ WT*WT - 0.000072\ Ton*Toff + 0.000009\ Ton*IP - 0.000012\ Ton*WT + 0.000030\ Toff*IP + 0.000297\ Toff*WT + 0.000206\ IP*WT. \quad (3)$$

The response surface is plotted to study the effect of process variables on the kerf width and is shown in Fig. 5a-5c. From Fig. 5a the kerf width is found to have an rising trend with the increase of pulse duration and at the same time it decreases slowly with the increase of pulse off time. It is observed from Fig. 5b that the kerf width increases slightly with increase in peak current. The Fig. 5c shows that kerf width not varied with increase in wire tension.

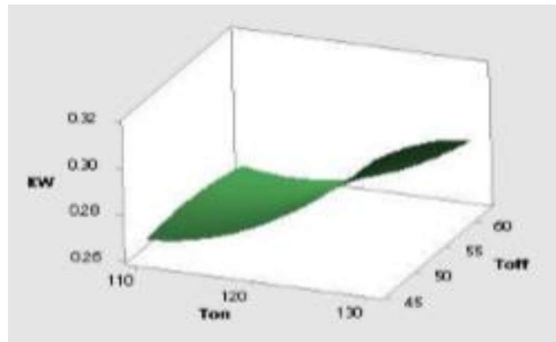

Fig. 5a Combined effect of Ton and Toff on KW

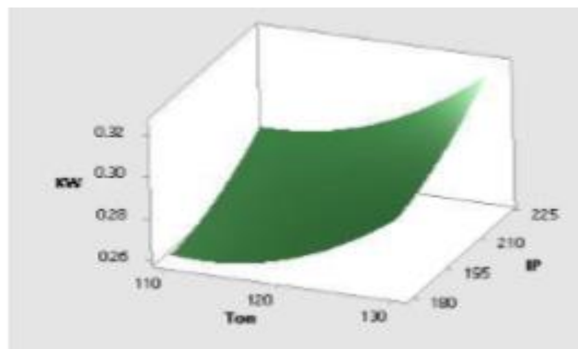

Fig. 5b Combined effect of Ton and IP on KW

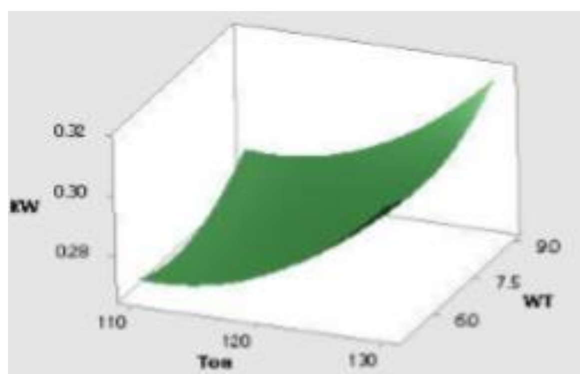

Fig. 5c Combined effect of Ton and WT on KW

4.2.3 Effect of Process Parameters on SR

The regression equation for the kerf width as a function of four input process variables was developed using experimental data and is shown in Eq. 4.

$$SR = -91.2 + 0.459\, Ton + 0.257\, Toff + 0.441\, IP + 2.39\, WT\ \ 0.00074\, Ton*Ton - 0.00022\, Toff*Toff - 0.000698\, IP*IP - 0.0623\, WT*WT + 0.00000\, Ton*Toff - 0.000725\, Ton*IP - 0.01100\, Ton*WT - 0.00087\, Toff*IP\ \ 0.0116\, Toff*WT + 0.00200\, IP*WT. \quad (4)$$

The response surface is plotted to study the effect of process variables on the surface roughness and is shown in Fig. 6a-6c. From Fig. 6a the surface roughness is found to have an rising trend with the increase of pulse duration and at the same time it declines slightly with the increase of pulse off time. It is observed from the Fig. 6b that the surface roughness increases with increase in peak current. The Fig. 6c shows that the surface roughness increases first and decreases with increase in wire tension.

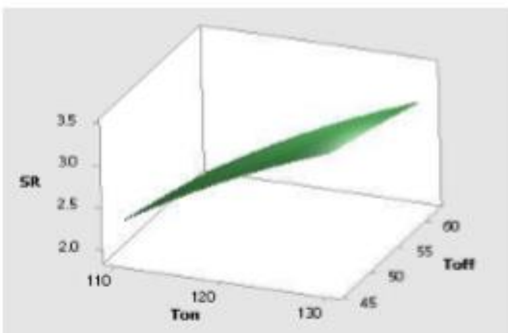

Fig. 6a Combined effect of Ton and Toff on SR

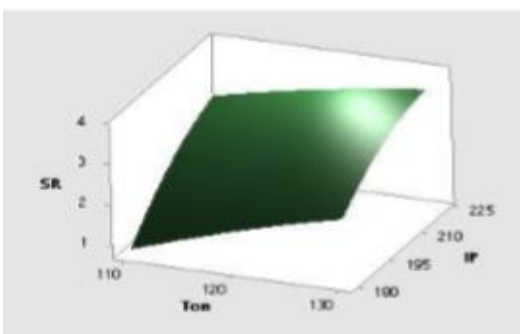

Fig. 6b Combined effect of Ton and IP on SR

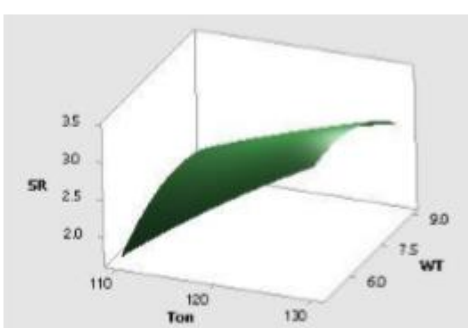

Fig. 6c Combined effect of Ton and WT on SR

V. CONCLUSIONS

Experimental investigation on wire electrical discharge machining of H13 tool steel is performed with a view to correlate the process parameters with the responses such as material removal rate, kerf width and surface roughness. The process has been successfully modeled using response surface methodology (RSM) and model acceptability checking is also carried out using Minitab software. The central composite design is adopted for designing the experiments. The second-order response models have been checked with analysis of variance. Finally, an attempt has been made to identify the optimum machining conditions to provide the best possible responses within the experimental constraints. This study can help researchers and industries for developing a robust, reliable knowledge base and early prediction of MRR, kerf width and surface roughness without experimenting with WEDM process for H13 steel.

- The present study develops MRR models for four different parameters namely pulse current, pulse on, pulse off and wire tension for WEDM process on H13 steel using response surface method. Ton and Toff are the most significant factors for material removal rate. The value of MRR increases with an increase of pulse on time and decreases with increase in pulse off time. WT has no significant effect on MRR.
- For kerf width, all the four parameters considered in this experiments are significant. Among these, pulse on time and peak current are the most significant. KW increases with increase in pulse on time and gradually increased with the increase in peak current.
- For surface roughness, pulse on time and peak current are the factors that most significant. Surface roughness value increases with increase in pulse on time and peak current and decreases slowly with increase in pulse off time.
- Finally, the obtained results are optimized to maximizing material removal rate and minimizing kerf width and surface roughness using desirability approach. The optimum parameter of combination setting is pulse on time 120 µs, pulse off time 46 µs, peak current 180 Amps and wire tension 8 N for maximizing MRR and minimizing SR and KW.

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