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Performance improvement on WEDMof O_2 steel through desirability approach

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Abstract— Wire Electrical discharge machining is a popular advanced machining method of cutting, shaping materials that conducts electricity. Since it involves thermo-electrical mechanism of material removal and the number of controlling process parameters are many, it is recognized as a stochastic process. WEDM is environmentally safe, user friendly and easy to automate. O_2 steel, a cold worked, difficult to machine material due to its toughness, wear resistance and high strength at elevated temperatures is used in making mechanical press-tool, drawing dies and punches. In this work the machining performance of O_2 steel is improved with multi-response criteria based on the desirability approach. Experimental tests were carried out through a L_{16} orthogonal array design, at four levels. The influence of input factors, spark duration, off time, wire speed and gap voltage were analyzed on the performances of surface roughness and material removal rate. The optimum cutting conditions are obtained by desirability function approach. Analysis of variance is applied to sort the effect from pooled data. A regression model was developed for surface roughness and material removal rate. Confirmation experiment was carried out for the recommended optimal machining parameters. Good improvements were obtained.

Keywords— *WEDM; O_2 tool steel; desirability; ANOVA*

I. Introduction

Wire electro discharge machining involves metal erosion by spark discharges [1].Two metal electrodes, one being the tool(Cu-Zn) and the other being the workpiece (O2 steel) are immersed in a di-electric(Distilled water). A series of voltage pulses, usually of rectangular form of frequency 5kHz,is applied between the two electrodes, which are separated by a small gap(0.01-0.5mm),rexulting in dielectric breakdown to plasma channel of 10 µm radius. On this the electrons together with the neutral atoms of dielectric collide, creating positive ions and are accelerated towards work. The kinetic energy in the form of heat reaches 8000^o to 10000^o C, causing the work piece to melt locally and evaporate instantly.

II. Literature Review

Luo et al [2] recommended short pulse duration and low current for EDM to provide better surface finish. Ho et.al. [3] noted that optimal machining performance involves analytical and statistical methods. Hewidy et al [4] WEDMed Inconel 601 and identified that the increase in the peak current leads to arcing, which decreases discharge numbers the machining efficiency and also, subsequently decreases the volume of material removal. Kanlayasiri and Boonmung [5] proved that the surface roughness can be improved by decreasing both pulse duration and discharge current. Muthuraman et.al. [6,7,8] applied desirability approach, response surface methodology and grey relational analysis to evaluate parametric optimization of wire EDM on WC-Co composites. From the literature study it was noticed, optimization is a systematic approach to study the parametric influence. It reduces the number of trials required to select proper process parameters and ranges that helps in efficient WEDM. The present study undertakes multi parametric optimization by desirability approach on cold worked WEDMed O_2 steel.

III. Material and Method

O_2 steel is a tough material that is difficult to machine economically by conventional methods. In this work, it is Wire EDMed on an Electronica sprint cut WEDM machine. For conducting the experiments, 4 factors at 4 levels with 16 experimental runs as recommended by Taguchi orthogonal array was selected. Table I displays the chemical composition of O_2 steel. Table II shows the Parameters, its levels and ranges selected.

TABLE I. CHEMICAL COMPOSITION OF O_2 STEEL

Elements	C	Si	Mn	Cr	V	Ni	Mo
% of Wt	0.80	0.5	1.3	0.4	0.2	0.3	0.3

TABLE II. PARAMETER LEVELS AND RANGES OF L16 EXPT.

Control Factors	Symbol	Level			
		1	2	3	4
Pulse-on	A	122	125	128	131
Off-time	B	44	47	50	53
Wire	C	1	2	3	4
Voltage	E	10	13	16	19

From work-piece of size, 75 mm x 75 mm x 12.43mm, a length of 12mm and width 12.5 mm was cut. A 0.25mm diameter copper-zinc wire was used as the tool electrode. The surface roughness was measured by Talysurf surftronic 3+ at 0.8 mm cut-off value. The material removal rate is evaluated from Eq.1

$$MRR = ktv \qquad mm^3/min \qquad (1)$$

Where,

t = thickness of work-piece mm = 12.43 mm

k = Kerf width= (d+2 Δg) = 0. 35 mm

d = diameter of wire = 0.25 mm

Δg=wire-work spark gap = 0.05 mm

v = Cut Length/Machining time mm/min

Table III presents the input parameters in coded units and two output responses obtained.

TABLE III. CODED EXPERIMENTAL PLAN WITH OUTPUT RESPONSES

Sl	Input Parameters				Output	
	A	B	C	D	MRR	Ra
1	1	1	1	1	0.728	3.7
2	1	2	2	2	0.522	3.7
3	1	3	3	3	0.393	2.9
4	1	4	4	4	0.365	3.0
5	2	1	2	3	0.599	2.4
6	2	2	1	4	0.486	3.5
7	2	3	4	1	0.481	2.2
8	2	4	3	2	0.433	3.3
9	3	1	3	4	0.586	3.5
1	3	2	4	3	0.460	3.4
1	3	3	1	2	0.515	3.6
1	3	4	2	1	0.478	3.5
1	4	1	4	2	0.607	3.7
1	4	2	3	1	0.509	3.3
1	4	3	2	4	0.427	3.2
1	4	4	1	3	0.513	3.4

Derringer and Suich [9] described procedure of desirability method as, find S/N, normalize and evaluate individual desirability. Assign a suitable weighting factor, estimate the composite desirability results and calculate the total loss function. Then determine the optimal parameter and its level combination, perform analysis of variance (ANOVA), identify the significant parameters and select the optimal level of machining parameters, finally the confirmation test need be done. Using Eq.2 and Eq.3, the calculated results are presented in Table IV.

For Larger-the better approach,

$$d_i = \begin{cases} 0, y_j \le y_{\min} \\ \left(\dfrac{y_j - y_{\min}}{y_{\max} - y_{\min}} \right)^r, y_{\min} \le y_j \le y_{\max}, r \ge 0 \\ 1, y_j \ge y_{\min} \end{cases} \qquad (2)$$

$$d_G = \sqrt[w]{\left(d_1^{w1} \times d_2^{w2} ....d_i^{wi} \right)} \qquad (3)$$

Where, di is individual desirability, dg is composite desirability, $Y_{i..}$ is the estimated response.

IV. RESULT AND DISCUSSION

The signals to noise ratio, individual desirability as well as the composite desirability were evaluated and the results are presented in Table IV. The analysis and graph were done using Minitab software version.16.

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TABLE.IV DESIRABILITY ANALYSIS OF O2 STEEL

Ex. No.	S/N ratio		Individual Desirability Di		Composite Desirability dg	Rank
	Ra	MRR	Ra	MRR		
1	-11.50	-2.76	1.00	1.00	1.00	1
2	-11.43	-5.65	0.98	0.52	0.71	4
3	-9.46	-8.11	0.54	0.11	0.24	14
4	-9.80	-8.75	0.62	0.00	0.00	15
5	-7.82	-4.45	0.18	0.72	0.36	13
6	-11.01	-6.27	0.89	0.42	0.61	7
7	-7.01	-6.36	0.01	0.40	0.02	15
8	-10.48	-7.27	0.77	0.25	0.44	11
9	-11.03	-4.64	0.89	0.69	0.78	3
10	-10.83	-6.75	0.85	0.34	0.53	10
11	-11.25	-5.76	0.94	0.50	0.68	5
12	-10.96	-6.41	0.87	0.39	0.58	9
13	-11.53	-4.34	1.00	0.74	0.86	2
14	-10.48	-5.87	0.77	0.48	0.61	8
15	-10.18	-7.39	0.70	0.23	0.40	12
16	-10.63	-5.80	0.80	0.49	0.63	6.
AVERAGE COMPOSITE DESIRABILITY=0.53						

Expt.1 ranks first with highest composite desirability of 1,with A1B1C1D1.The average composite desirability for all levels were evaluated and is displayed in Table V. Pulse off time ranks first with high delta values, followed by wire speed. Gap voltage ranks third and pulse on time ranks fourth.

TABLE. V AVERAGE COMPOSITE DESIRABILITY ANALYSIS

Level	On Time	Off Time	Wire Speed	Voltage
1	0.49	0.75	0.73	0.55
2	0.35	0.61	0.51	0.67
3	0.65	0.33	0.52	0.44
4	0.62	0.41	0.35	0.45
Delta	0.3	0.42	0.38	0.23
Rank	3	1	2	4

The response graph of mean composite desirability is presented in Fig.1,

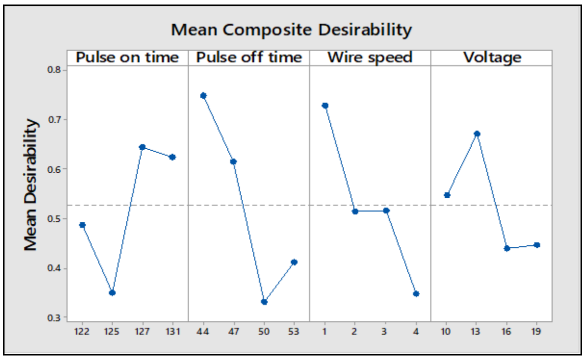

FIG.I RESPONSE GRAPH OF COMPOSITE DESIRABILITY

The analysis of variance was performed to identify the significance of each parameter at a confidence interval of 95% and to evaluate the percent contribution. The analysis was done with coded units for "maximum the better". The result is presented in Table VI.

TABLE. VI ANOVA OF MEAN COMPOSITE DESIRABILITY

SOURCE	DF	SS	MS	F	%
On time	3	0.22	0.07	2.92	20.55
Off time	3	0.43	0.14	5.64	39.69
Wire speed	3	0.29	0.10	3.80	26.74
Voltage	3	0.14	0.05	1.85	13.02
Error	3	0.08	0.03		
Total	15	1.17		14.2	100.0

It is noticed, pulse off time is most important parameter, followed by wire speed with their percent contribution significantly higher (39.69% and 26.74%, respectively).Hence, optimization trials for improvement should discount these parameters as they sharply alter the outcome. Pulse on time is next in significance with 20.55% contribution. Since, the gap voltage (13.02%) is comparatively of lesser significance, it could be varied for test trials.

Given an increase in pulse off time, the spark issuance time for actual machining reduces. Increasing on-time initially increase machining but consequently heating effect ensues; MRR as well smoothness decreases. Wire speed increase yield better finish by means of uniformity of surface dimension but MRR suffers. Increasing Gap voltage increases wire electrode-work piece gap; the sparking distance increases and MRR suffers. Considering the above factors, keeping lower levels of all four parameters for the material, and the parameter range is recommended by multi parametric optimization through the desirability approach.

Fig. II shows the pie diagram of relative contribution from the input parameters.

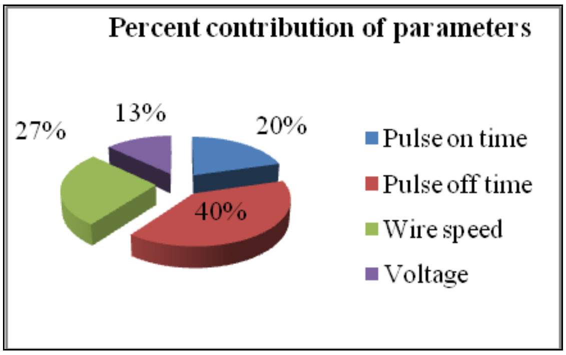

FIG.II INFLUENCE OF PARAMETER ON RESPONSES

Fig.III depicts the composite desirability is maximum at exp.1

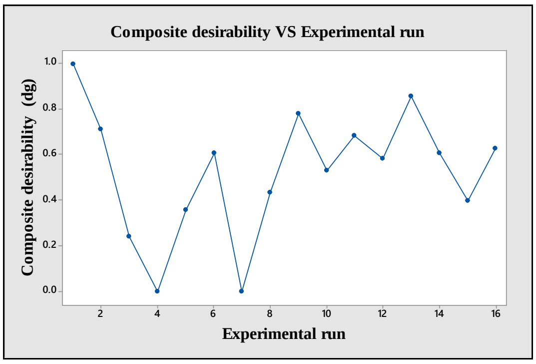

FIG.III COMPOSITE DESIRABILITY VS EXPERIMENTAL RUN

For performance improvement, first the process average of composite desirability was evaluated from Table IV as 0.53. This corresponds to Expt.No. 10 (Initial) which had a MRR of 0.46 mm^3/min and Ra of 3.48μm. Maximum desirability of 1 (Predicted)has occurred during Expt.No 1 which yielded MRR of 0.728 mm^3/min and Ra of 3.76μm. The process mean composite desirability suggested terms A3B1C1D2 from Fig. I (optimal) tested thrice for confirmation, the average MRR and Ra results obtained are presented in Table VII.

TABLE VII. RESULT OF CONFIRMATION EXPERIMENT ON O_2 STEEL BY DESIRABILITY APPROACH

Output Response	Confirmation Experiment Results		
	Initial	Predicted	Optimal
Level	A3B2C4D3	A1B1C1 D1	A3B1C1 D2
Ra	3.48	3.75	3.54
MRR	0.46	0.73	0.53
Dg	0.53	1	0.689

Confirmation experiment showed an increase in surface roughness by 7.75% and improvement in material removal rate is 26%. Hence this combination of parameter T_{ON}: 122µs, TOFF: 44µs, WS: 1 and V: 13 volt is preferred for faster cutting.

A response surface regression equation for predicting performance was made with,

S = 0.1602; R-Sq = 93.4%; R-Sq (adj) = 87.1%,

$$Dg = 0.52675 - 0.03906\,A + 0.22232\,B + 0.20215\,C + 0.14585\,D \quad (4)$$

Where,

Dg is composite desirability function, A,B,C and D are on-time, off-time, wire speed and gap voltage respectively.

Using Eq.4, the predicted results were compared with the experimental values and were found to be closer. A higher desirability indicates favorable conditions. Fig. IV and V depicts the graph of predicted and experimental desirability. The tendency and pattern remains the same and are closer with less error. Hence, this equation can be used for predicting the multi quality characteristics

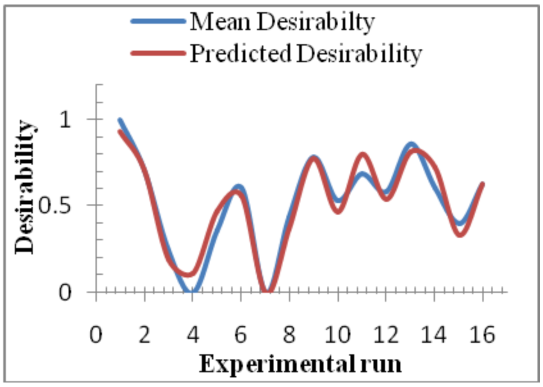

FIG.IV PREDICTED AND EXPERIMENTAL DESIRABILITY GRAPH

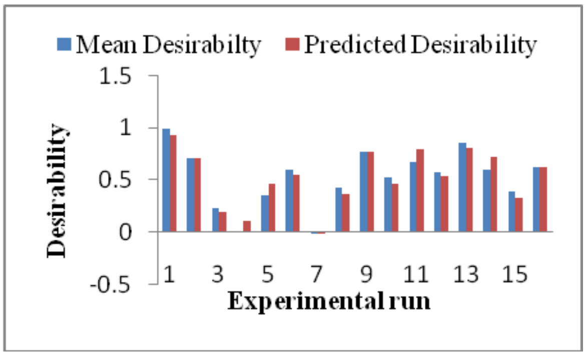

FIG.V HISTOGRAM OF PREDICTED AND EXPERIMENTAL DESIRABILITY

V. Conclusion

In this study, cold worked O_2 steel was machined by WEDM. Desirability approach was used to find multi quality characteristics. Parameters at levels, A1B1C1D1 resulted in maximum desirability. Analysis of variance was carried out. The percent contribution of off-time was highest followed by wire speed and on-time. Statistically gap voltage is of least significance in this multi parametric optimization. The confirmation experiment showed the material rate improvement by 26%, accompanied by an increase in roughness of 7.5%.Regression equation was derived that could reasonably predict the outcome, with R^2 value of 93.4% and R^2adj of 87.1%. The graph comparing predicted and experimental was plotted and were found closer with less error. The

WEDM performance of O_2 steel can be improved by multi-parametric optimization techniques like desirability.

References

[1] J.A.McGeough,"Advanced Machining Methods",Springer Science and Business Media, Technology and Engineering,1988,p.p145--146.

[2] Y. F. Luo, “Rupture failure and mechanical strength of the electrode wire used in wire EDM”, Journal of Materials Processing Technology, Vol. 94 (2-3), 1999, pp. 208-215.

[3] S.T Ho,S. Newman. Rahimifard,R.D. Allen.,“State of the art in wire electrical discharge machining (WEDM)”, International Journal of Machine Tools and Manufacture, Vol. 44, 2004, pp. 1247–1259.

[4] M.Hewidy,T.A.El-Taweel,and M.El-Safty,“Modeling the machining parameters of wire electrical discharge machining of Inconel 601 using RSM”, Journal of Materials Processing Technology,Vol. 169,2005,pp. 328–336.

[5] K.Kanlayasiri,S. Boonmung, “Effects of wire-EDM machining variables on surface roughness of newly developed DC 53 die steel: design of experiments and regression model”, Journal of Materials Processing Technology, Vol. 192-193, 2007, pp. 459-464.

[6] V.Muthuraman and R. Ramakrishnan,“Multi Parametric Optimization of WC-Co Composites using Desirability Approach’’,Elsevier Procedia Engineering, Vol. 38, 2012, pp. 3381-3390.

[7] V.Muthuraman,R.Ramakrishnan,K.Sundaravadivuand B.Arun,"Predicting surface roughness of Wedmed WC-Co composite using box-behnken response surface method”, Advanced Materials Research, Vols.383-390,2012, pp. 3223-3228.

[8] V.Muthuraman, R.Ramakrishnan and M.Puviyarasan, “Optimization of WEDM Parameters on Machining WC-Co Composite with Multiple Quality Characteristics", International Journal of Applied Engineering Research, ISSN 0973-4562 Vol. 9 No.26,2014, pp. 8947-8954.

[9] G.Derringer and R.Suich, "Simultaneous optimization of several response variables”, Journal of Quality Technology, Vol. 12,1980, pp. 214–219.