CR Investigation of Sub-zero Treated SKD 11 on WEDM: A Taguchi Approach

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Abstract

Using Taguchi's parameter design, significant process parameters affecting the response characteristics are identified as pulse-on-time, pulse-off-time, servo voltage and wire feed. It has been observed that a combination of optimal parameters for each response characteristics is different. In this study, the process parameters namely the pulse-on-time, pulse-off-time, servo voltage and wire feed are optimized with considerations of performance characteristics, such as cutting speed. To validate the study, confirmation experiment has been carried out at optimum set of parameters and predicted results have been found to be in good agreement with experimental findings.

Keywords: WEDM, Sub-zero treated, SKD 11, Cutting rate

I. INTRODUCTION

Wire electrical discharge machining (WEDM) is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles. The process of WEDM is shown in Figure 1. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously traveling wire electrode made of thin copper, brass or tungsten of diameter 0.05–0.3 mm, which is capable of achieving very small corner radii (Ho et al., 2003). WEDM is an extremely accurate machining process. It can produce a smooth surface finish because the wire is able to go through the entire part and the accuracy can be achieved until ±0.0001 inches. Few researchers worked on WEDM and explained below:

Datta and Mahapatra (2010) optimized the process parameters using response surface methodology (RSM) coupled with gray-taguchi technique on D2 tool steel as work material in WEDM process. It was observed that six process parameters such as discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate are most significant parameters for cutting operation.

Parashar et al. (2010) presented the statistical and regression analysis of overcut using design of experiments is proposed for WEDM operations. Experimentation was planned as per Taguchi's L'32 (21 X 44) mixed orthogonal array. Each experiment has been performed under different cutting conditions of gap voltage, pulse ON time, pulse OFF time, wire feed and dielectric flushing pressure. Stainless steel grade 304L was selected as a work material to conduct the experiments. From experimental results, the overcut was determined for each machining performance criteria. Sadeghi and Razavi (2011) experimentally investigated the influence of several process parameter such as the discharge current, pulse interval, open circuit voltage and servo voltage on the MRR and SR of WEDM by using taguchi method. In this experiment the AISI DS/DIN 1.2601 steel is used as a working material. The mathematical modeling was carried out using regression analysis and the analysis of variance techniques and the mathematical relationship between the parameter and their related outputs. Somashekhar et al. (2011) presented a study on new approach for the optimization of the Micro-WEDM process with multiple performance characteristics based on the statistical-based analysis of variance (ANOVA) and grey relational analysis (GRA).

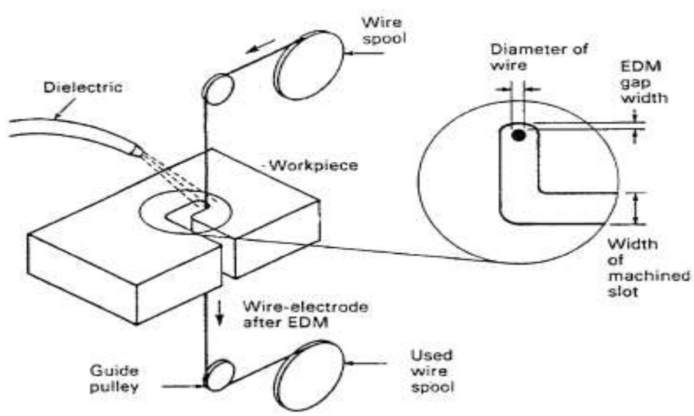

Fig. 1: WEDM Process (Kuriakose et al., 2003)

Analysis of variance was used to study the significance of process parameters on grey relational grade (GRG) which showed capacitance to be the most significant factor. A GRG obtained from the GRA is used to optimize the Micro-WEDM process.

Sharma et al. [2013a, 2013b] investigated the effect of process parameter on cutting rate in WEDM using response surface methodology (RSM). In this study the high strength low alloy steel is used as a work material. It was found that the cutting rate increases with increase in pulse on time and peak current. The cutting rate decreases with increase in pulse of time and servo voltage and the wire mechanical tension has no significant effect on cutting rate. Gupta et al. (2012) investigated the effect of parameters on Overcut for WEDM using HSLA as work piece. They revealed that kerf width decreases with increase in pulse on time, pulse off time, spark gap voltage and peak current. Khanna and Singh (2013) optimized the process parameters of WEDM while machining D-3 tool steel. Sharma et al. (2015) investigated the recast layer and un-machined area of NiTi alloy on WEDM. It has been found that some un-machined area observed which can be minimized or eliminated by trim cutting. A number of researchers (Sharma et al., 2014a; 2014b; 2014c) utilized planning of experimentation to reduce the experiments and analysis the process parameters.

II. EXPERIMENTAL SET-UP

A Wire EDM machine (Sprintcut ELPULS 40A DLX) was used as the experimental machine in this study. A brass Wire with a diameter of 250 µm was used as an electrode to erode a work piece of Sub-zero treated SKD11 steel (flat plate). Table 1 shows the Chemical Composition of SKD11 steel (Weight By %). The SKD11 steel plate 300 x 140 x 28 mm size has been used as a work piece material for the present experiments. This SKD11 steel plate is sub-zero treated before experiments. The sub-zero treatment is the process of treating work-pieces to sub-zero temperatures (i.e., below –100°C) to remove residual stresses and improve wear resistance on steels.

Table – 1
Chemical Composition of SKD11 steel (Weight By %)

C	P	S	Si	Mn	Cr	Mo	Cu	Ni	V	Fe
1.4-1.6	0.02 - 0.03	0.01-0.03	0.2-0.4	0.4-0.6	11-13	0.8-1.2	≤0.25	≤0.25	0.2-0.5	balance

The Sub-zero treated SKD11 steel provides better mechanical properties or greater resistance to wear. These are used to make mould, dies etc.

Table – 2
Optimal ranges of significant process parameters

Real factor	Parameter Name	Unit	Lower Limit	Upper Limit
T_{on}	Pulse on Time	µs	107	122
T_{off}	Pulse off time	µs	30	45
SV	Servo Voltage	V	30	60
WF	Wire Feed	m/min	5	11

Table 2 shows the ranges of significant process parameters. Apart from the parameters mentioned above following parameters were kept constant at a fixed value during the experimentation

1) Work piece : SKD11 STEEL
2) Electrode(tool) : 0.25mm Ø, Brass wire
3) Work piece height : 28mm
4) Cutting length : 7mm
5) Dielectric Conductivity : 20mho
6) Dielectric temperature : 20-24^{0}C

The sub-zero treated SKD11 is used for the experimentation. This is mounted on Electronica Sprintcut WEDM machine tool. Figure 2 shows the specimens cut during experimentation work on WEDM.

Fig. 2: Specimens cut during Experimentation

III. RESULTS AND DISCUSSIONS

Experiments were performed according to L_{16} orthogonal array and results were given in Table 3. After conducting the experiments with different Settings of input factors i.e. pulse on time, Pulse off time, Servo Voltage and Wire Feed the values of output variables CS were recorded and plotted as per Taguchi design of experiments methodology. The analysis of the results obtained has been performed according to the standard procedure recommended by Taguchi.

A. Response Analysis of Raw data or of S/N data

The main effects can be studied by the level average response analysis of raw data or of S/N data. The analysis is done by averaging the raw and/or S/N data at each level of each parameter and plotting the values in graphical form. The level average responses from the raw data help in analyzing the trend of the performance characteristic with respect to the variation of the factor under study. The level average response plots based on the S/N data help in optimizing the objective function under consideration. The peak points of these plots correspond to the optimum condition (Roy, 1990).

Table – 3
Taguchi's L_{16} Standard Orthogonal Array (Jangra et al., 2014) for Cutting rate

Experiment No.	*Column*				*CR (mm/min)*				*SN Ratio*
	1	*2*	*3*	*4*	*R 1*	*R 2*	*R 3*	*Mean value*	
1	107	30	30	5	0.71	0.62	0.65	0.66	-3.6499
2	107	35	40	7	0.58	0.59	0.58	0.58333	-4.6825
3	107	40	50	9	0.39	0.41	0.43	0.41	-7.7650
4	107	45	60	11	0.28	0.25	0.26	0.26333	-11.6185
5	112	30	40	9	1.08	1.01	1.05	1.04667	0.3863
6	112	35	30	11	1.22	1.29	1.23	1.24667	1.9072
7	112	40	60	5	0.59	0.61	0.59	0.59667	-4.4886
8	112	45	50	7	0.57	0.59	0.57	0.57667	-4.7849
9	117	30	50	11	1.29	1.24	1.29	1.27333	2.0943
10	117	35	60	9	1.11	1.08	1.08	1.09	0.7464
11	117	40	30	7	1.6	1.62	1.6	1.60667	4.1181
12	117	45	40	5	1.29	1.25	1.28	1.27333	2.0965
13	122	30	60	7	2.09	2.06	2.07	2.07333	6.3329
14	122	35	50	5	2	2.02	2.02	2.01333	6.0780
15	122	40	40	11	1.69	1.64	1.66	1.66333	4.4176
16	122	45	30	9	1.79	1.75	1.76	1.76667	4.9419

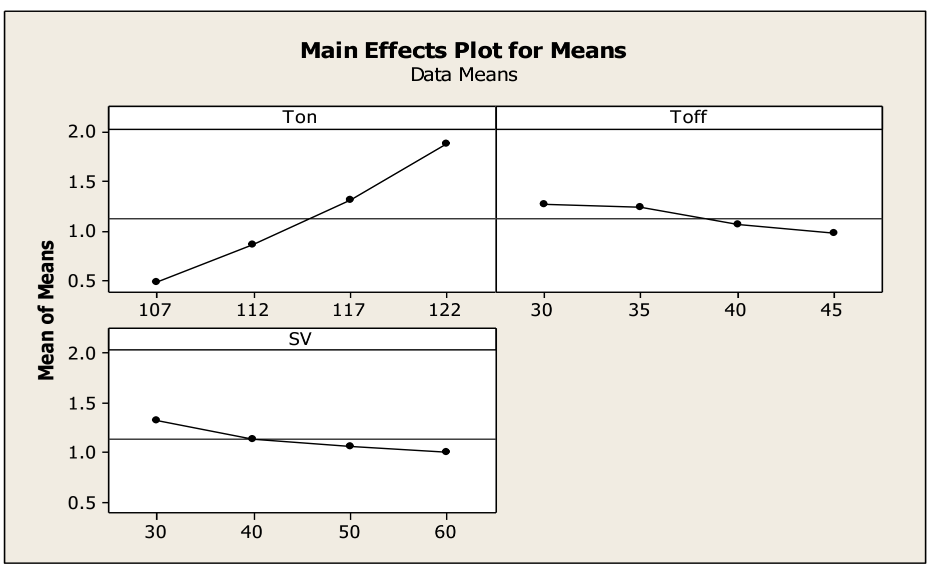

Fig. 3: Effects of Process Parameters on Cutting rate (Means)

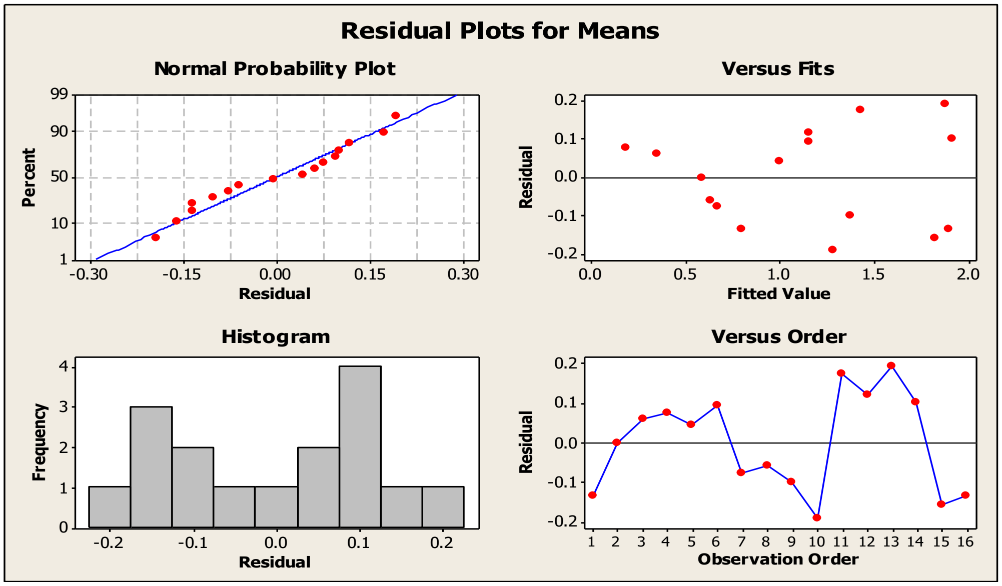

Fig. 4: Residual Plots for Means (CR)

The percentage contribution of various process parameters on the selected performance characteristic can be estimated by performing analysis of variance test (ANOVA). Thus, information about how significant the effect of each controlled parameter is on the quality characteristic of interest can be obtained. The total variation in the result is the sum of variation due to various controlled factors and their interactions and variation due to experimental error.

Table – 4
Analysis of Variance for Means (CR)

Source	*DF*	*SS*	*MS*	*F*	*P*
Ton	*3*	*4.34727*	*1.44909*	*22.54*	*0.015*
Toff	*3*	*0.23077*	*0.07692*	*1.20*	*0.443*
SV	*3*	*0.22157*	*0.07386*	*1.15*	*0.456*
WF	*3*	*0.03751*	*0.01250*	*0.19*	*0.894*
Residual Error	*3*	*0.19290*	*0.06430*		
Total	*15*	*5.0300*	*S = 0.2536; R-Sq = 96.2%; R-Sq(adj) = 80.8%*		

Table – 5
Pooled Analysis of Variance for Means (CR)

Source	*DF*	*SS*	*MS*	*F*	*P*
Ton	*3*	*4.3473*	*1.44909*	*37.74*	*0.000*
Toff	*3*	*0.2308*	*0.07692*	*2.00*	*0.215*
SV	*3*	*0.2216*	*0.07386*	*1.92*	*0.227*
Residual Error	*6*	*0.2304*	*0.03840*		
Total	*15*	*5.0300*	*S = 0.1960; R-Sq = 95.4%; R-Sq(adj) = 88.5%*		

It can be observed from Table 4 and 5 that the pulse on time affects the cutting rate very significantly. Moreover, the different input parameters used in the experimentation can be ranked in the order of increasing cutting rate as wire feed, servo voltage, pulse off time, pulse on time. From the Figure 3, the highest cutting rate has been recorded with Pulse on time (at level 4). In WEDM, the pulse on time is most significant factor for increasing the cutting rate, pulse off time is the 2^{nd} significant factor and servo voltage is the 3^{rd} significant factor and wire feed is the 4^{th} significant factor. It is also clear from the figure that the cutting rate increases as the pulse on time is increased. But when the pulse off time is increased, the cutting rate decreases. This is because the fact that by increasing the pulse on time, the time for which spark is produced in the gap is increased and hence the cutting rate is increased. By increasing the pulse off time, the time for which spark is absent, is increased and hence the cutting rate decreases. From the figure 3, the cutting rate is remains constant approximately when wire feed increases. But when the servo voltage is increased, the cutting rate decreases.

In order to estimate the contribution of each factor towards the variation of machining performance in terms of cutting rate for wire electrical discharge machining of SKD11 (sub-zero treated), Analysis of Variance test was conducted on the results obtained from the experimentation. The ANOVA test summary for Cutting rate has been recorded for average response (Table 4 and 5). Hence the cutting rate is mainly influenced by the pulse on time and pulse off time, which has also been suggested by many other researchers. It can also be concluded that the cutting rate increases with the increase in Pulse on time and wire feed and it decreases with the increase in Pulse off time and servo voltage.

With regarding to the S/N response, the values of S/N ratio have been found to be highest for those factor levels that correspond to highest average response. Hence, these factor levels can be termed as optimum from the point of view of average response as well as S/N response. As S/N response takes into account both the magnitude as well as the variation in response, the factor levels that correspond to highest S/N ratio are termed as optimum. The analysis of results showed that "$A_4B_1C_1$" is the optimal parameter setting for the Maximization of Cutting rate. Hence, it can be concluded from this discussion that "input parameters settings of Pulse on Time at 122, Pulse off time at 30µs and Servo voltage at 30 V have given the optimum results for Cutting rate; when SKD11 (sub-zero treated) was machined with WEDM". Table 7 gives the results of confirmation test i.e. predicted value and experimental value.

Table – 7
Predicted Optimal Values and Results of Confirmation Experiments

Performance Measures/ Responses	*Optimal Set of Parameters*	*Predicted Optimal Value*	*Predicted Confidence Intervals at 95% confidence level*	*Actual Value*
Cutting rate	$A_4B_1C_1$	*2.19458 mm/min*	CI_{POP} : 2.0117 < μ_{cr} <2.3777; CI_{CE} : 1.8627 < μ_{cr} < 2.2.5267	*2.02 mm/min*

IV. CONCLUSIONS

From this research it is found that all the selected parameters i.e. Pulse on time, Pulse off time, Servo voltage, and Wire Feed significantly affect the Cutting speed in Wire Electric discharge machining of Sub-zero treated SKD11. With regarding to the average response, Pulse on time has emerged as most significant followed by Pulse off time. Servo voltage and Wire feed can be termed as less significant for cutting rate. It has been concluded from the results that “input parameter setting of Pulse on time at 122µs, Pulse off time at 30µs, and Servo voltage 30V have given the optimum results for cutting rate; when Sub-zero treated SKD11 was machined with WEDM.

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