Study of Material Removal rate (MRR) for DSS 2205 Steel in WEDM

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Abstract:

The influence of various process parameters of Wire EDM that is wire electro discharge machining on material removal rate, MRR of DSS 2205 stainless steel is performed in the current study The optimization of MRR with considering various process parameters like pulse on time (P_{on}), Pulse off time (P_{off}), Wire Feed Rate (WF) and Voltage Gap (VG) is done using Taguchi methodology along with L_{27} orthogonal array. The optimality ($P_{on}3P_{off}1WF2VG1$) of the system for maximized MRR is determined in the Current investigation. The present work also describes the significance and interactions of the process parameters by analysis of variance (ANOVA) method. Finally the changes in form of improvement in material removal rate at the optimal state are compared with the initial condition.

Keywords: WEDM, MRR, DSS 2205, ANOVA.

Introduction:

The wide application areas of DSS 2205 steel have proved its importance in many fields of manufacturing industry. The main characteristics which have made DSS 2205 steel useful are its high general, localized and stress corrosion resistance properties in addition to high strength and excellent impact toughness [1]. In present scenario the demand of high-speed machining with higher accuracy and precision is increasing for improving productivity. In this respect WEDM, wire electro discharge machining process proves almost to be an indispensable solution because WEDM can perform this operation very easily as it is an electro erosion process [2-3]. Any material which has conductive properties can be cut by a wire electrode which follows a predetermined path of required configuration [4, 5].

Nomenclature

MRR	material removal rate
P_{on}	pulse on time
P_{off}	pulse off time
WF	wire feed
VG	voltage gap
R_a	surface roughness
Mm	millimeter
Min	minute
µs	microsecond
µm	micrometer

In Wire EDM, the erosion is done by melting and evaporation of the surface material by the generated heat in the plasma channel. A series of discrete sparks are generated between the wire electrode and work piece material through Di-electric that is deionizer water, which erodes the work-piece to produce desired complex shape [6-10]. Metal removal rate is one of the important performance variables of WEDM. The MRR has not given the due importance in the literature in case of WEDM of DSS 2205 stainless steel. Thus enough scope is there to analyze and optimize the process parameters during WEDM of DSS 2205 Stainless steel. In this current study 27 no. of experiments were conducted using taguchi L_{27} orthogonal array. These experiments were carried out considering pulse on time, pulse off time, wire feed and gap voltage as control parameters and material removal rate (MRR) as the output variable. DSS 2205 Stainless steel (22 % chromium5% Nickel) [11] is taken as the work piece material due to its wide applications in oil and gas exploration, transport storage and chemical processing, paper machines and automobile industry. The present study summarizes the Taguchi optimization technique in order to optimize the process parameters for maximum MRR in WEDM for DSS 2205 stainless steel. It is found that, pulse on time is the most influencing parameter in controlling MRR whereas pulse off time and voltage gap produces less influence.

1. Taguchi Method

Taguchi technique is a powerful tool to design high quality systems [12]. Taguchi pioneered the use of robust design for product and process design that focuses on minimizing variation and/or sensitivity to noise [13]. In Taguchi technique, three stages such as system design, parameter design, and tolerance design are employed. The present study employs parameter design to obtain the optimal condition of the process parameters for maximization of MRR of DSS 2205 Stainless steel. The design based on orthogonal array is used to minimize the cost and time by reducing number of experiments [14]. To measure the performance of the response variable, Taguchi uses signal to noise (S/N) ratio approach [15]. For the case of maximization, higher the better (HB) criterion is used. Furthermore analysis of variance is done to find the significant process parameter. With the help of ANOVA and S/N ratio analysis, the optimal process condition is predicted.

2. Details of experiment

Work piece material

DSS 2205 Stainless steel is taken as the work piece material which is 22% chromium and 5 % Nickel stainless steel having good corrosion resistance properties. The composition of DSS 2205 Stainless steel is obtained by chemical test and shown inTable 1.

Table 1. Chemical Composition of DSS 2205 Stainless Steel

Cr	Ni	Mo	C	N	Mn	Si	P	S	Fe
22.0 – 23.0	4.5 – 6.5	3-3.5	0.3 max	0.14-0.20	2.0 max	1.0 max	0.030 max	0.020 max	Balance

Design of experiment:

Design of experiment is a tool to achieve maximum amount of conclusive information from minimum amount of work, money, time and energy. Taguchi method uses orthogonal array to reduce the number of experiments. The choice of orthogonal array depends on number of parameters and their levels [17-18]. This is a four-parameter-three level experiment. Design factors and their levels are shown in Table 2. In the present case, L_{27} orthogonal array is selected having 27 rows corresponding 27 numbers of experiment and 20 degrees of freedom. The factors and their interactions are assigned to their respective positions.

Table 2. Selected Parameters and their Range

Factors	**Unit**	**Levels**		
Pulse on	µs	4	6	8
Pulse off	µs	8	10	12
Wire feed	mm/min	6	8	10
Voltage Gap	V	50	55	60

Machining operation

A CNC operated wire cut EDM of TOOL MASTER 6S was used for this present work. The experimental setup is shown in Fig. 1. During the machining operation variable parameters are pulse-on time, pulse- off time, wire feed and gap voltage and some parameters are kept constant which are shown in Table 3.

Fig. 1. Pictorial view of WEDM (TOOL MASTER 6S)

Table 3. Constant parameters during machining

Parameter	Value
Wire Material	Brass wire, 0.025 mm Dia
Shape cut	10 x 7 mm^2
Thickness of the work piece	10 mm
Location of work piece on table	Center of table
Drive	AC servo Motor
Dielectric used	De ionized water

MRR measurement

For the present study, MRR is taken as response variable. For efficient evolution of WEDM process, larger MRR is regarded as the best machining performance. The kerf width is measured after the machining operation to calculate the material removal rate of DSS 2205 stainless steel. The thickness and kerf width of the work-piece is measured with Vernier caliper (MITUTOYO). MRR is calculated by the following formula,

MRR (mm^3/min) = [total cutting length (mm) × thickness of work piece (mm) × kerf width (mm)] ÷ total time taken (min.).

3. Results and discussions

Signal to noise ratio analysis

To achieve the optimal set of conditions, Taguchi advocates the use of signal-to-noise ratio than simple averages of results as the former can capture the variability of results within the trial conditions. Hence, in the present work S/N ratio analysis for MRR is done using higher the better criterion as MRR is to be maximized. The estimated S/N ratio is calculated as:

$$\text{S/N ratio for HB} = -10\log\left(\frac{1}{n}\sum\frac{1}{y^2}\right) \quad (1)$$

Where y is the observed data and n is the number of observations. Table 4 shows the MRR values along with corresponding S/N ratio values. The average of S/N ratio of each level of the factors of T_{on}, T_{off}, WF and VG is given in Table 5 and total average value of S/N ratio of all the 27 experiments is also listed in this Table. Delta value is also calculated and ranks are assigned according to those delta values. The parameter having higher delta value will have greater influence over the response parameter. Hence, pulse on time is the most influencing parameter whereas P_{off} and VG also have some sort of influences on MRR of DSS 2205stainless steel.

Table 4. Values of MRR and their corresponding S/N Ratio

S. No.	MRR (mm^3/min)	S/N Ratio (dB)	S. No.	MRR (mm^3/min)	S/N Ratio (dB)	S. No.	MRR (mm^3/min)	S/N Ratio (dB)
1	4.3979	12.8649	**10**	6.9227	16.8055	**19**	7.9820	18.0422
2	3.9585	11.9506	**11**	5.8845	15.3942	**20**	10.3026	20.3000
3	3.6175	11.1682	**12**	7.5099	17.5127	**21**	9.2359	19.3096
4	3.5822	11.0830	**13**	4.7976	13.6205	**22**	8.7561	18.8462
5	2.8527	9.1051	**14**	6.5040	16.2636	**23**	8.1000	18.1697
6	3.7496	11.4797	**15**	5.7695	15.2228	**24**	7.2849	17.2485
7	2.5792	8.2297	**16**	5.9140	15.4376	**25**	7.2886	17.2529
8	3.3462	10.4910	**17**	5.5857	14.9416	**26**	6.5496	16.3243

9	3.0418	9.6626	**18**	4.4249	12.9181	**27**	7.9340	17.9898

Table 5. Response Table for S/N Ratio

Level	P_{on}	P_{off}	WF	VG
1	10.66	15.92	14.69	15.68
2	15.33	14.56	14.77	14.93
3	18.16	13.69	14.72	13.56
Rank	1	2	4	3
Delta	7.49	2.23	0.08	2.12

Total means/N Ratio = 14.73 dB

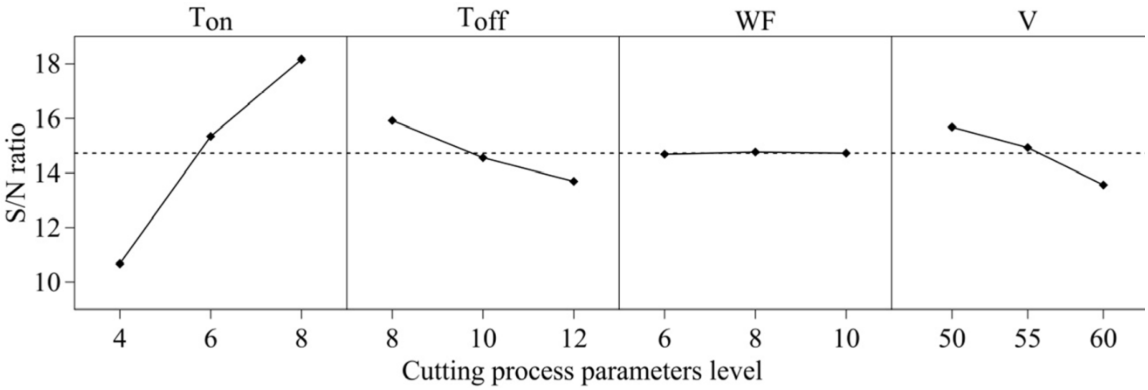

Fig. 2. Main effect plot for signal to noise ratio

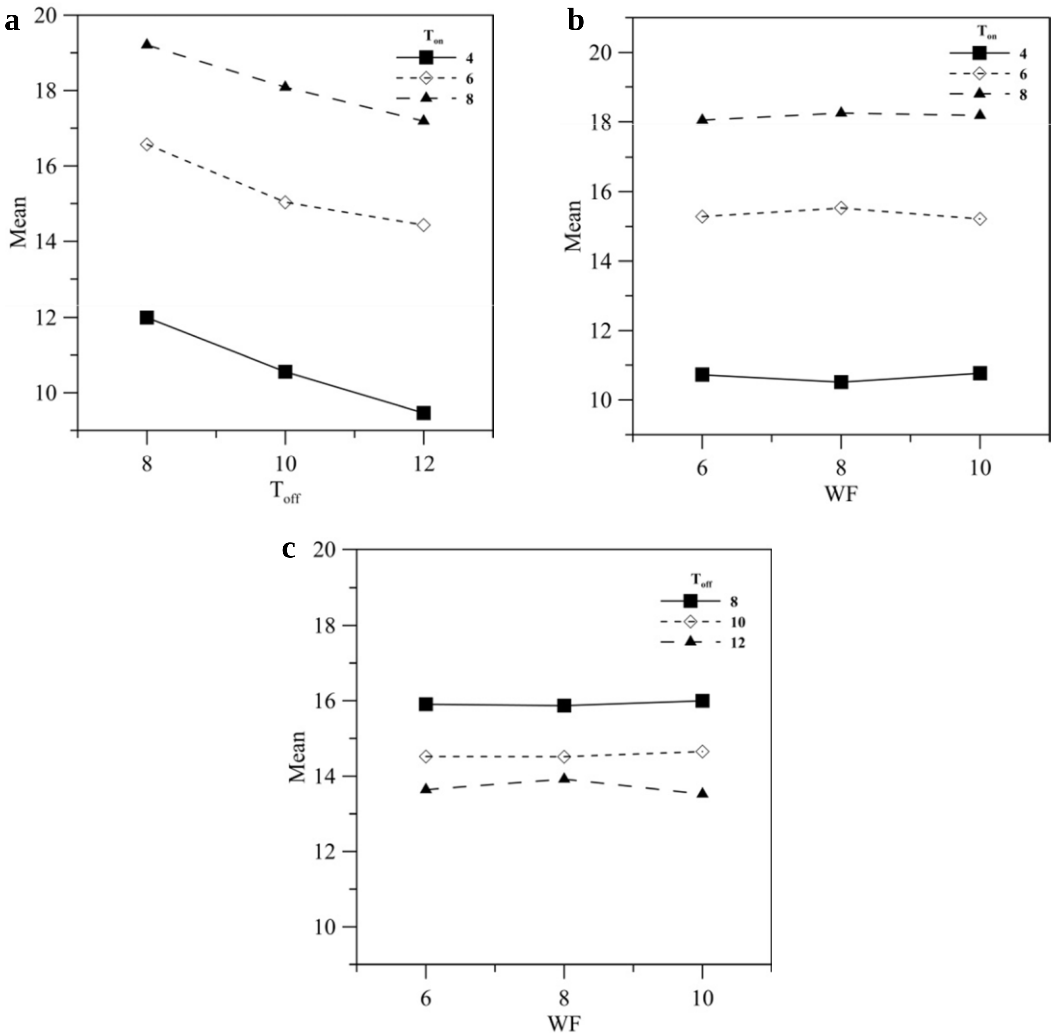

Fig. 3. Interaction plots for mean S/N ratio (a) T_{on}vs T_{off}, (b) T_{on}vs WF and (c) T_{off} vs WF

The main effect plot and interaction plots are shown in Fig. 2 and Fig. 3 respectively. The main effect plot gives the optimal combination of process parameter for maximum MRR. The combination of levels having highest S/N ratio value is taken as optimal condition. Hence the optimal process parameter combination is $P_{on}3P_{off}1WF2VG1$. Themain effect plot also gives the idea of significance of the process parameter. The line having highest inclination in main effect plot is the most significant parameter. In this case P_{on} is the most significant parameter. Interaction plots are concerned, estimating an interaction means determining the non-parallelism of parameter effects. From the Fig. 3, it can be seen that there is some interaction among the interacting parameters.

Analysis of variance (ANOVA)

ANOVA is a statistical technique to investigate the significance of individual process parameters and their interactions on the system response under consideration. The respective percentage contribution of the parameters and their interactions are calculated through ANOVA. It also consist F-ratio to find the significance of process parameters. ANOVA results for WEDM process parameters of DSS 2205 stainless steel is shown in Table 6. From this table, it is observed that parameters P_{on}, P_{off} and VG are significant parameters. However, parameter P_{on} has maximumcontribution in controlling MRR characteristics of the DSS 2205 stainless steel. Moreover, it is found that parameter P_{off} and VG have moderate contribution. None of the interactions have considerable contribution within the experimental range considered in the study.

Table 6. Results of ANOVA For MRR

Source	Degree of freedom	Sum of square	Mean Square	F ratio	% contribution
P_{on}	2	257.630	128.815	1810.57*	85.14
P_{off}	2	22.725	11.363	159.71*	7.51
WF	2	0.029	0.014	0.20	0.01
VG	2	20.835	10.418	146.43*	6.89
P_{on} x P_{off}	4	0.366	0.092	1.29	0.12
P_{on} x WF	4	0.311	0.078	1.09	0.10
P_{off} x WF	4	0.282	0.071	0.99	0.09
Error	6	0.427	0.071		
Total	26	302.605			100

*Significant parameters ($F_{0.005,2,6}$ = 14.544)

Confirmation test

To verify the accuracy of the predicted optimality, confirmation test is an important step. It is performed by comparing the performance at the optimal condition to that of the initial condition. For the present analysis, $P_{on}2P_{off}2WF2VG2$ is taken as the initial condition. The predicted value, of the S/N ratio at the optimal level is calculated as:

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{o} (\bar{\gamma}_i - \gamma_m) \quad (2)$$

Where γ_m = total mean S/N ratio, $\bar{\gamma}$ = mean S/N ratio at the optimal level, o is the number of the main design parameters that significantly affect the WEDM process parameter. Table 7 shows the comparison of the estimated S/N ratio with the optimal S/N ratio using the optimal parameters. The increase of the S/N ratio from initial to the optimal condition is about 4.16dB which means MRR is increased by 26%. This implies that the prior design and analysis for optimizing the WEDM process parameters are suitably applied.

Table 7 Results of validation test

	Initial condition	Optimal condition	
		Prediction	Experimentation
Level	$P_{on}2P_{off}2WF2VG2$	$P_{on}3P_{off}1WF2VG1$	$P_{on}3P_{off}1WF2VG1$
MRR (mm^3/min)	6.414		10.3026
S/N ratio (dB)	16.14	20.29	20.30

Improvement of S/N ratio = 4.16 dB

4. Conclusions

In the present study, Taguchi orthogonal array is successfully used to optimize the process parameters viz. P_{on}, P_{off}, WF, VG of WEDM in order to maximize the MRR of DSS 2205 stainless steel. ANOVA analysis is done to investigate the significance of the process parameters and their interactions. Finally confirmation test is performed to validate the results through optimization. The following conclusions can be drawn from the above study,

i. Optimal combination of process parameters for maximum MRR is $P_{on}3P_{off}1WF2VG1$ i.e. higher level of pulse on time, middle level of wire feed along with lower level of pulse of time and gap voltage.

ii. The ANOVA result indicates that pulse-on time (P_{on}) is the most influencing parameter whereas pulse off time (P_{off}) and voltage gap (VG) are found to be quite remarkable parameters to control the MRR.

iii. The confirmation test reveals that MRR of DSS 2205 stainless steel developed at optimal condition is 26% greater than that developed with the initial condition.

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