International Journal of Advanced Academic Studies

E-ISSN: 2706-8927
P-ISSN: 2706-8919
IJAAS 2019; 1(2): 01-04
Received: 01-08-2019
Accepted: 05-09-2019

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Parametric optimization for maximization of MRR in WEDM of D_2 steel material

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Abstract
The present work is planned to optimize the material removal rate (MRR) in wire electrical discharge machining (WEDM) of D2 tool steel. Machining parameters namely pulse on time, pulse off-time, voltage gap and wire feed have been chosen for the present investigation to perform experimental runs. The experiments have been conducted using L16orthogonal array of Taguchi method. The effects of machining parameters on MRR has been determined by utilizing signal-to-noise ratio and graphical main affects plot. The optimum parametric condition has been acquired for looking for maximizing MRR by using Taguchi method. Confirmatory experiments have also been conducted to verify the predicted parametric setting. From the present investigation, it is found that Taguchi method is robust to study, analyze and optimize processing conditions in WEDM.

Keywords: Wire electrical discharge machining, D_2 tool steel, taguchi method, material removal rate

Introduction
Wire electric discharge machining (WEDM) is a non-conventional kind of precision machining process which using an electrical spark and thermal-erosion process between the electrode cathode and the working piece anode are immersed in a dielectric fluid liquid [1]. The spark and thermal-erosion manufacturing process of WEDM is a great value in machining of mould materials, so as to accomplish the required shapes and sizes with improved productivity, better surface and dimensional accuracy [2]. Since, it has progressively exceptional advantages, the WEDM has been widely applied in modern metal industry for producing complex shapes, cavities in moulds and dies, which are difficult to manufacture by traditional machining techniques [3]. In the WEDM process, the estimated release point temperature is thousands of degrees (°C).The spark generated by the electrode carried by dielectric medium lead to erode the material at selected area [4].

Selection of correct process parametric setting is very important for obtaining the better-quality responses like material removal rate (MRR), surface qualities in WEDM [5, 6]. The important machining parameters in WEDM are pulse on time, pulse off time, spark gap voltage, servo feed, peak current, wire tension [7] etc. MRR is considered to be important quality response for improving the productivity. Analyzing and optimizing process variables to maximize the MRR in WEDM is important area of research. Statistical based robust parameter design of Taguchi method is very useful for planning the experiments and for studying and controlling the input parameters of manufacturing processes / systems. Statistical analysis of variance is used to determine the significant process parameters on output responses. In the present work, Taguchi method and analysis of signal-to-noise ratio have been used to analyze and optimize the MRR in WEDM of D2 tool steel.

As already mentioned that the present work is focused to study and analyze the influences of process parameters on MRR of D2 tool steel in WEDM operation. The literature survey has been made to study the reported articles from literature related to analyze and optimization of WEDM process by using statistical tools. The details of literature survey are given as follows:

Suha [8] had been studied the effect of wire electrical discharge machining (WEDM) process parameters such a pulse on time (Ton), pulse off time (Toff) and peak current (Ip) on the machining characteristics such as material removal rate (MRR), kerf width, and surface roughness during WEDM of friction-stir-welded 5754 aluminum alloy. ANOVA result reveals that the interaction between Toff and Ip significantly affects the MRR. An increase in both Ton and IP increases the MRR, where as decreasing Toff leads to a decrease in MRR.

Tushar *et al.* [9] had been investigated the wire electric discharge machining using Taguchi's design approach to optimize the machining performances. The impact of the process parameters viz. Ton time, Toff time, Peak current and Wire types on response characteristics viz. MRR and surface roughness were studied. They found from the study that MRR was increasing with increase of Ton time. Since, the energy discharge per spark increases within crease in Ton time, hence higher time for each spark is given prompting to more removal rate. The optimized parameters for maximizing the material removal rate (MRR) is Ton time 125 µs, T off time 45 µs and peak current 180A.Manjaiah *et al*. [10] had been investigated the effect of process parameters on the response such as MRR and surface roughness of Ti50Ni40Cu10 SMA machined by WEDM using the Taguchi Technique. ANOVA had been used to investigate the contribution and effects of peak current, pulse-on time, pulse-off time and wire feed on surface roughness and MRR. They stated from the investigation that parameters namely peak current, pulse-on time and servo voltage were most significant for MRR. Kuldeep, *et al*. [11] had been made a experimental research work to study the effects of process parameters on MRR and surface roughness in WEDM of H-13 die tool steel. They mentioned from their investigation that MRR in WEDM is highly depends on the proper selection of input parameters. Singh *et al*. [12] had been utilized RSM for analyzing and optimizing the process parameters to predict the output responses: MRR, surface roughness and cutting rate. They stated from their work that process variables were the most significant for all the responses.

From the literature review, it is observed that the details of WEDM related to selection of optimum parameters and effects of input parameters on response quality parameters are not well known. More research works needs to made on various aspects of WEDM to enhance its performance. The present work is one step forward to add knowledge base of WEDM of different materials. Machining information of WEDM of D2 steel and more data related WEDM of different materials may helpful to industrial persons.

Materials and Methods

D_2 tool steel: Tool steel refers to a various carbon and alloy steels that are particularly suited to made into good tools. Their appropriateness originates from their high hardness, good resistance to abrasion and deformation, and their ability to hold a cutting edge at high temperatures. Tool steels are suited for use in the shaping of different materials.

Taguchi method

Taguchi's optimization technique is an efficient tool for design the experiments and analyze the manufacturing process and to enhance the system performance. The idea of orthogonal array of experiments in Taguchi technique is useful to determine the factors which most affect product quality with reduces number of experiments, thus production time and resources. It uses statistical method of signal-to-noise (S/N) ratio to measure performance of process parameters. S/N ratio in Taguchi method uses three different objective functions: larger-the-better, smaller- the-better and nominal-the better to analyze the response variable(s). The equation for larger the better criterion is shown in Eq.1.

$$\text{Larger-the-Better: S/N ratio} = -10\log_{10}\left(1/n\sum\nolimits^{n}_{i=1} 1/y_i^2\right) \quad (1)$$

Experimental process

The material used for this study is tool steel of D2 material. The experimental runs have been conducted using L16 orthogonal array of Taguchi methods with four factors four levels each. The selected input variables and their levels have been given in Table 1. L16 orthogonal array designs for performing experiments are shown in Table 2. Experimental runs have been carried out on WEDM setup when machining of D2 tool steel and MRR is measured shown in Table 2.

Table 1: Levels and process parameters

Process Parameters	Units	Levels			
		Level1	Level 2	Level3	Level 4
Voltage gap (A)	Volts	17	18	19	20
Wire feed (B)	mm/min	3	4	5	6
Pulse on-time (C)	µs	116	118	120	122
Pulse off-time (D)	µs	60	57	54	51

Results and analysis

The experimental data of MRR given in the Table 2 has been used to analyze and optimize the processing conditions in WEDM to maximize the MRR of D2 tool steel material with the use of statistical analysis of signal-to-noise and Taguchi method.

Table 2: L16 orthogonal array of Taguchi method and output response (MRR)

S. No.	Input parametric settings				Output response
	Voltage gap (A)	Wire feed (B)	Pulse on time (C)	Pulse off-time (D)	MRR
1	17	3	116	60	5.35
2	17	4	118	57	7.51
3	17	5	120	54	8.43
4	17	6	122	51	10.86
5	18	3	118	54	7.05
6	18	4	116	51	7.46
7	18	5	122	60	7.41
8	18	6	120	57	7.53
9	19	3	120	51	8.41
10	19	4	122	54	7.85
11	19	5	116	57	7.65
12	19	6	118	60	4.62
13	20	3	122	57	7.36
14	20	4	120	60	6.85
15	20	5	118	51	9.87
16	20	6	116	54	7.07

Factor effects on MRR

Analysis of signal-to-noise (AS/N) ratio is a statistical tool which useful to analyse the effects of input parameters on performance characteristics of any manufacturing process. In the present work, analysis of signal-to-noise ratio has been performed on experimental data of MRR as shown in Table 2. S/N ratio is conducted at 95% confidence level and 5% significant level. Significant input parameters can be identified by using P value in the S/N table; if value of P isles than 0.05 then the corresponding factor would be treated as significant on the corresponding response. If P value of factors is more than 0.05 then corresponding variable is treated as insignificant. The result of S/N for MRR is shown in Table 3. The correlation coefficient values of R-square and adv R-square values are 98.8% and 94.2% respectively. The values R-square and adv R-square indicating good correlation between the input and output variable(s).

S/N ratio able (Table 3) of MRR depicts that input parameter wire feed (B) has significant effect on MRR, because the value of P for wire feed isles than 0.05. The direct effects of voltage gap (A), pulse-on time (c) and pulse-off time (D) also have consider able effect on MRR as its P values are equal to 0.05. From the ANOVA results, it is stated that response MRR of D2 steel is significantly influenced by process parameters in WEDM operation.

Table 3: Analysis of signal-to-noise ratio for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	0.8314	0.8314	0.2771	1.00	0.500
B	3	68.035	68.035	22.678	81.83	0.002
C	3	0.8314	0.8314	0.2771	1.00	0.500
D	3	0.8314	0.8314	0.2771	1.00	0.500
Residual Error	3	0.8314	0.8314	0.2771		
Total	15	71.361	R-Sq = 98.8%; R-Sq(adj) = 94.2%			

The main effect plots for MRR has made by using MINITAB 16.2 software and given in Fig. 1. Main effect plots are very useful to determine the factor effects on responses. Highest influential parameter on response can be identified from main effect plots. If difference between the levels of minimum and maximum factor is more, the effect of corresponding variable is highest compare to other parameters. Form the Fig. 1, it is found that wire feed (B) is most influential factor, next is pulse on time (C), voltage gap (A) and followed by pulse off time (D). Optimum parametric setting for maximizing the MRR can be identified from the main effect plots as given in Fig. 1 at highest value of S/N ratio of corresponding level of each factor. The optimal parametric condition for maximizing the MRR is found from the Fig. 1 is: voltage gap (A) = 18 volts, wirefeed (B) = 6 mm/min, pulse-on time (C) = 118 μs and pulse-off time (D) = 54 μs.

Confirmatory test

A confirmatory test has been performed to validate the optimized parametric condition. The results of confirmatory test have good agreement with the initial experimental runs as given in Table 2 and validate the predicted parametric condition by Taguchi methodology.

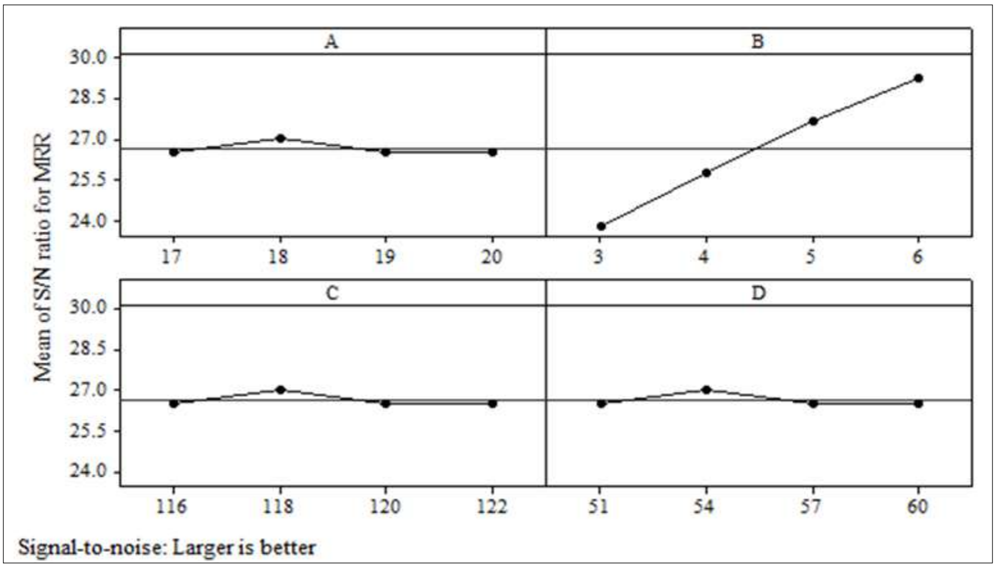

Fig 1: Main effect plots for MRR

Conclusions

The followings are the conclusions drawn from the present study:

1. The experiments are performed on WEDM of D2 tool steel.
2. Analysis of signal-to-noise ratio is conducted on experimental data of MRR to identify the influential process variables.
3. From the S/N table, It is found that wire feed (B) have significant effect on MRR of D2 steel and voltage gap (A), pulse on time (C) and pulse off time (D) also have considerable influence on MRR.
4. The main effect plots are made to illustrate the effects of input parameters on MRR.

5. Main effect plots reveals that parameter wire feed is most significant for MRR compared to other parameters.
6. Optimal WEDM parametric setting is obtained by Taguchi method for maximizing MRR is: voltage gap (A) = 18 volts, wire feed (B)= 6 mm /min, pulse-on time(C) = 118 µs and pulse-off time (D) = 54 µs
7. From the present work, it is stated that Taguchi method is very useful to maximize the MRR in WEDM of D2 tool steel.

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