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Optimization of Process Parameters of Wire Electric Discharge Machining Process for Machining AISI A2 Tool Steel

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Abstract

In this investigation, AISI A2 tool steel is considered as the workpiece material, which is typically used to manufacture blanking tools, punches die etc., due to its good toughness and wear resistance. In this work, the effect of controlling parameters of the Wire Electric Discharge Machining (WEDM) process is investigated. Molybdenum tool electrodes of 0.18mm diameter and de-ionized water dielectric medium are utilized. Peak current, on-time, off-time and voltage are considered as the controlling parameters. Surface roughness average and material erosion rate are considered as the response parameters. The type of design of experiments considered for this work is Taguchi's L_{27} orthogonal array. Analysis of variance indicates the percentage contribution of each machining parameter on response parameters. The optimum combination of machining parameters yields a minimum surface roughness of 2.87 µm and the highest material removal rate obtained in this work is 774 mm^3/hr.

Keywords: *AISI A2 Tool Steel, Design of Experiments, Material Removal Rate, Surface Roughness, Wire Electric Discharge Machining*

1.0 Introduction

Non-conventional machining processes play a major role in machining hard metals and alloys. Machining hard metals using a conventional machining process leads to instant work hardening of the work piece[1]. So, wire electric discharge machining is an appropriate non-traditional machining process, free from work hardening. In WEDM, the material is removed by localized melting of the tiny areas from the workpiece surface. The temperature-induced due to the voltage is responsible for material disintegration from workpiece[2]. In the WEDM process, the tool electrode and workpiece electrode are immersed in a dielectric liquid. The potential difference is created between tool and workpiece[3]. WEDM has a major application in machining metallic moulds, tools, etc., made of nickel alloys, titanium alloys, tool steels, hastalloy, nimonic, etc[4]. The Surface roughness ensures

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smooth operation in mechanical assemblies[5]. In any machine process, a higher material removal rate is the desired response, to improve the production efficiency[6]. Optimization is the process of obtaining the best result under the provided conditions. The concept of Design of Experiments (DoE) is one of the scientific approaches to optimization. A designed experiment is the method to carry out a concurrent evaluation of two or more factors for their effect on the resultant average. Also, it indicates the level of variation of a particular product or process nature. The design of the experiment is a chain of stages, which is to be followed in a certain sequence of the experiment to analyze process performance. The preparation phase, execution phase and investigation phase are the important stages of DoE[7]. Taguchi method is a type of statistical method developed by the statistician Taguchi, to improve the quality of the selected batch of products. Taguchi's orthogonal array is a type of design of experiments, which is an efficient technique in robust design. Taguchi's orthogonal arrays reduce the number of experiments, compared to the conventional approach of full factorial experiments. Analysis of Variance (ANOVA) is the most efficient arithmetical method for analysing the comparison of the central tendency of means. Signal to noise ratio is a log format of the expected result, which helps in statistics investigation and estimate of best results[8].

Regression analysis is a statistical method to work on the preparation of mathematical models that show relationships among variables. Statistical analysis like variance monitoring, prediction, simulation etc., can be carried out accurately using these mathematical models[9]. A regression model indicates that the Y is the function of X and β.

$Y = f(X, \beta)$

Where, Y - Reliant variable

X - Autonomous variable

β - Indefinite constraint

It can be linked with an independent variable using a linear function:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k \quad (1)$$

Much research was carried out based on actual physical experiments rather than statistical analysis. In those experiments, the effects of process parameters were identified efficiently. They reported that regression models were used to predict the machining parameters. With proper operating conditions such as low current and slower material removal rates, the surface roughness can be controlled. In this work, the optimization process is applied to minimise surface roughness on the workpiece and to achieve maximum material removal rate.

2.0 Experiment Process

2.1 Materials and Methods

In this work, AISI A2 tool steel is used as the workpiece material. Machining arrangement, raw material dimensions and workpiece dimensions are shown in Figure 1 (a), (b) and (c).

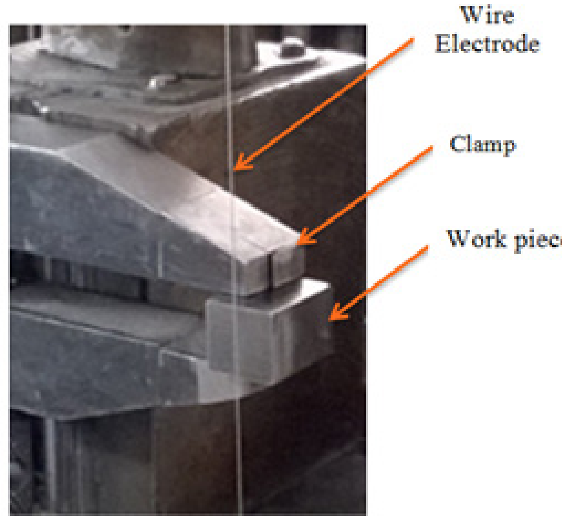

Figure 1a. Machining arrangement.

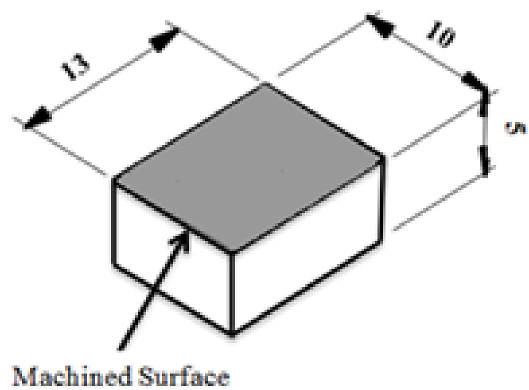

Figure 1b. Raw material.

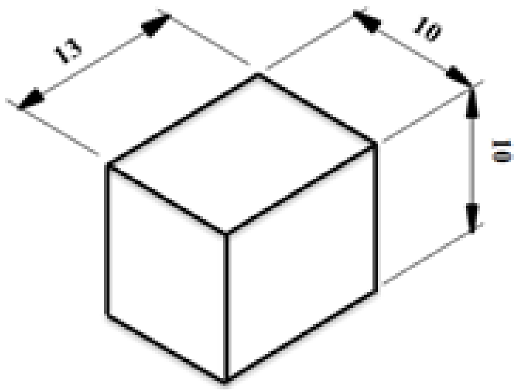

Figure 1c. Workpiece dimensions.

The chemical composition of AISI A2 tool steel is reported in Table 1. The wire electrode material selected for this work is molybdenum[10]. CNC WEDM (Concord DK-7732) is used for machining workpieces. De-ionized water is utilized as a dielectric medium. Peak current, pulse on-time, pulse off-time and voltage are considered machining variables, and their ranges are mentioned in Table 2.

Response factors considered are surface roughness, R_a (μm) and material removal rate (mm^3/hr). Machining time and weight of the specimen are noted and MRR is calculated[11,12].

3.0 Results and Discussion

The workpieces are machined based on the experiments planned as per Table 3.

The minimum R_a 3.09 μm and maximum MRR 774 mm^3/hr are obtained as the response of the machining trials based on the design of experiments. Higher MRR is obtained at a higher value of peak current because the discharge energy is increased by increasing this input factor. Minimum surface roughness is obtained at lower levels of voltage because of the formation of smaller craters with low depth.

3.2 Analysis of Variance (ANOVA)

The influence of machining variables on response is identified by analysis of variance[13]. The variance of the data considered for this work is a 95% confidence level. The machining variables of P-values less than or equal to the alpha value of 0.05 are considered. The result data from ANOVA is tabulated in Table 4.

The Percentage Contribution (PCR) of machining parameters is tabulated. The star (*) represents the higher influencing process parameter. Voltage has a high PCR of 39% followed by T_{on}, I_p and T_{off} with PCR of 33%, 24% and 4% respectively for surface roughness. The most

Table 1. Chemical composition of AISI A2 tool steel

Element	C	Mn	S	Si	Cr	V	Mo
%	0.9	0.6	0.03	0.2	5.1	0.1	1.1

Table 2. Input variables and their levels

Input variables	Peak Current	On-Time	Off-Time	Voltage
Symbol	I_P	T_{on}	T_{off}	V
Units	A	μs	μs	volt
Level 1	3	10	8	80
Level 2	5	20	10	90
Level 3	7	30	12	100

Table 3. Taguchi's L_{27} orthogonal array with responses

Exp. No.	I_p	T_{on}	T_{off}	V	R_a	MRR
Unit	**A**	**µs**	**µs**	**volt**	**µm**	**mm^3/hr**
1	3	10	8	80	3.09	482
2	3	10	10	90	3.31	547
3	3	10	12	100	3.74	603
4	3	20	8	90	3.71	614
5	3	20	10	100	4.02	667
6	3	20	12	80	3.21	529
7	3	30	8	100	4.37	732
8	3	30	10	80	3.63	595
9	3	30	12	90	4.06	657
10	5	10	8	80	3.25	523
11	5	10	10	90	3.30	541
12	5	10	12	100	3.72	613
13	5	20	8	90	3.82	634
14	5	20	10	100	4.23	706
15	5	20	12	80	3.29	521
16	5	30	8	100	4.51	762
17	5	30	10	80	3.72	611
18	5	30	12	90	4.01	662
19	7	10	8	80	3.22	523
20	7	10	10	90	3.41	557
21	7	10	12	100	3.69	584
22	7	20	8	90	3.87	634
23	7	20	10	100	4.35	729
24	7	20	12	80	3.32	533
25	7	30	8	100	4.57	774
26	7	30	10	80	3.91	642
27	7	30	12	90	4.01	663

Table 4. ANOVA results

Parameter	R_a		MRR	
	P	PCR	P	PCR
I_P	0.212	24	0.234	**45***
T_{on}	0.145	33	0.543	10
T_{off}	0.640	4	0.610	7
V	0.132	**39***	0.271	38
Error	-	0	-	0
Total	-	100	-	100

influential factors for MRR are peak current and voltage with the PCR of 45% and 38%, respectively.

3.2 Inference From Main Effects Plot

Main effects plots indicate the effect of input parameters at various levels on the output parameters as shown in Figure 2 (a) and (b).

During the machining process, the material from the workpiece is removed in the form of globules or chips. The sizes of the globules indicate the surface roughness. So, from Figure 2(a), it is observed that when the peak current is low, the energy delivered is low and fewer chips are removed from the workpiece, which results in lower surface roughness. During lower on-time, the spark dwell time is less and hence it induces lower surface roughness, whereas an increase in off-time decreases the frequency of the sparks. In the case of a lower voltage supply, the discharge energy is less hence producing lower surface roughness.

From Figure 2(b), it is noted that when the peak current is increasing, larger craters are removed from the workpiece, which results in a higher material removal rate. As on-time increases, the spark duration is long and hence more material is disintegrated from the workpiece. An increase in off-time decreases the frequency of the sparks and hence reduces the frequency of the material disintegration process[14].

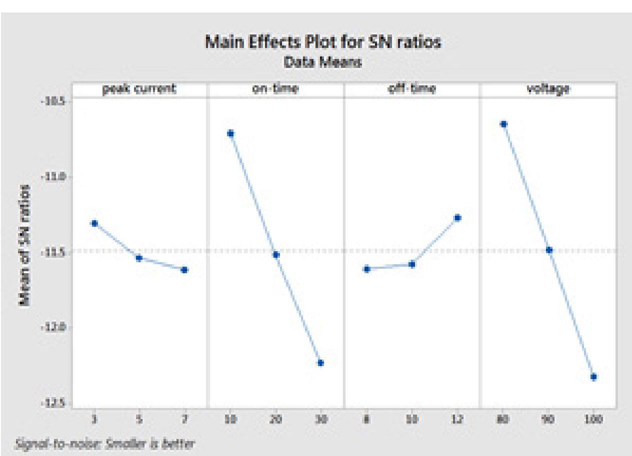

Figure 2a. Main effect plot of average roughness.

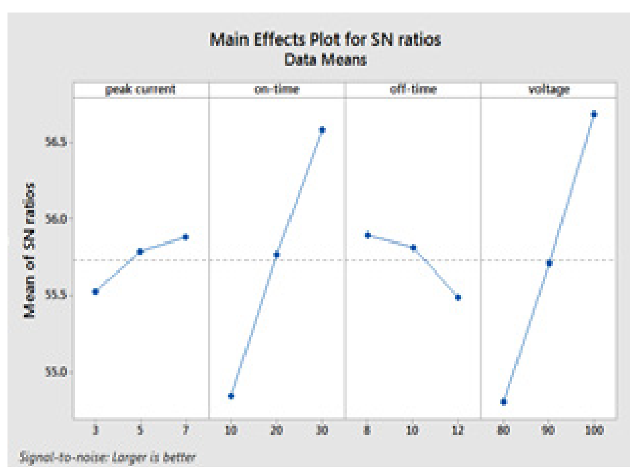

Figure 2b. Main effect plot of material removal rate.

3.3 Optimization of Machining Parameters

The S/N ratio is the response parameter to the corresponding machining parameter, which helps in the data investigation and identification of an optimum set of machining parameters.

S/N ratio outcomes are tabulated in Tables 5(a) and (b). The types of S/N ratio considered for this work are (i) larger the better and (ii) smaller the better, which is presented in Equations (3.1) and (3.2), respectively.

Where,

$$\eta_{ij} = -10 \log_{10}\{ \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \} \quad (3.1)$$

$$\eta_{ij} = -10 \log_{10}\{ \frac{1}{n} \sum_{i=1}^{n} y_i^2 \} \quad (3.2)$$

Y_{ij} - average response value

n - number of repetitions

In Table 5(a) and (b), machining parameters which influence more on output parameters are ranked higher. Optimum combinations of machining parameters to achieve lower surface roughness average and upper erosion rate are identified from main effects plots. Confirmation runs for each output parameter are carried out with the optimum combination of machining parameters and yield improved results.

The results of confirmation runs are presented in Table 6(a) and (b), indicating the process improvement obtained in the case of surface roughness (4.93%). The optimum combination of machine parameters resulting highest material removal rate is already available in DOE,

Table 5 (a). Response table of S/N ratio - Surface roughness (smaller the better)

Factor	Level 1	Level 2	Level 3	Delta	Rank
I_p	55.525	55.787	**55.887**	0.359	4
T_{on}	54.853	55.765	**56.578**	1.725	2
T_{off}	**55.899**	55.813	55.485	0.407	3
V	54.811	55.711	**56.677**	1.863	1

Table 5 (b). Response table of S/N ratio - Material removal rate (larger the better)

Factor	Level 1	Level 2	Level 3	Delta	Rank
I_p	55.525	55.787	**55.887**	0.359	4
T_{on}	54.853	55.765	**56.578**	1.725	2
T_{off}	**55.899**	55.813	55.485	0.407	3
V	54.811	55.711	**56.677**	1.863	1

Table 6(a). Response table (Data from design of experiments)

Output response	Parametric levels	Best Response values
Surface roughness	A1B1C1D1	3.04 μm
Material removal rate	A3B3C1D3	$774 mm^3/hr$

Table 6(b). Response table (Data from confirmatory runs)

Output response	Optimum Parametric levels	Predicted Response values	Actual Response values
Surface roughness	A1B1C3D1	2.91 µm	2.87 µm

Table 6(c). Improvement from DOE

Output response	(%)
Surface roughness	4.9

so the confirmatory run for improved material removal rate is not required[15,16].

4.0 Conclusion

From this work, the effects of WEDM parameters on response parameters and optimum machining parameters to obtain the best response parameters for machining AISI A2 tool steel using molybdenum wire are identified. The conclusions are: The effect of voltage is most influential with surface roughness at the percentage contribution of 39%. The minimum surface roughness average achieved by the optimum machining parameters I_P (3 A), T_{on} (10 µs), T_{off} (12 µs) and V (80 volt) is 2.87 µm. The effect of peak current is most influential with material erosion rate. The percentage contribution of peak current on material erosion rate is 44%. The highest material erosion rate obtained with optimum machining parameters I_P (7A), T_{on} (30 µs), T_{off} (8 µs) and V (100 volt) is 774 mm^3/hr.

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6.0 References

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