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Optimization of WEDM Parameters for Machining of AZ31B Mg Alloy Using Taguchi Method

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Abstract :- This work involves optimization of machining parameters of wire cut Electrical Discharge Machining (WEDM) used for maching of AZ31B magnesium (Mg) alloy with molybednum wire to attain the lowest surface roughness from the process. Mg alloys such as AZ31B are light-weight materials with high potential for industrial applications and used in the manufacture of airframes, aircraft engines, helicopter components, automotive parts and light trucks. L9 orthagonal array with three input parameters such as Voltage (V), Pulse on time (μ s) and pulse off time (μ s) at three levels are used to conduct the experiments. Taguchi method is utilized to study the effect of these parameters on the surface roughness (SR). From the investigation it was found that pulse on time exert the major influnce on surface roughness while Voltage and pulse off-time have lesser influnces on the process to reduce the surface roughness.

Keywords: WEDM, Molybednum Wire, Mg alloy, Surface Roughness, Taguchi Technique and optimization.

1. Introduction

Light alloys are getting great attention in mechanical industries such as automobile, aerospace and ship building constructions. Due to more industrial needs, Mg alloys are widely used because it is a light-weight metallic structural material with high specific strength and stiffness, good heat conductivity, good machinability and cast ability [1, 2]. Among the Mg alloys, AZ31B wrought Mg alloy has gained significant attention because of its lightness, good stiffness, heat conductivity, excellent weldability/machinability and higher corrosion/oxidation resistance [3]. WEDM is one of the unconventional machining processes, used to erode material from the workpiece to fabricate parts with intricate shape and profiles. In this process, the material is removed from the workpiece by a series of discrete spark discharges between a work and tool electrode immersed in a liquid dielectric medium. The spark developed by discharge of electricity melts and vaporizes minute amount of the work material. The removed material is ejected and flushed away by the dielectric [4]. After analysing the effects of the three input parameters used for the WEDM process that include pulse on time, pulse current and servo feed rate on the performance characteristics, namely; material removal rate (MRR), kerfwidth and surface roughness during machining of AZ91 Mg alloy, optimisation is carried out. From the experimental outcome the WEDM of Mg alloy it was observed that the material removal rate and the kerfwidth are higher than hard materials. It was noted during the processing of Mg alloys that at high cutting rate, the surface roughness is appropriate and also the surface topography and microstructural changes are studied using atomic force microscope, scanning electron microscope and EDX analysis [5]. The machining parameters of WEDM on Mg metal matrix composite reinforced with Reduced Graphene Oxide(r- GO) are optimised to reach maximum MRR with a lowest surface roughness (Ra) value. The optimal combination was found for a maximum MRR (18.38mm3/min) and minimum Ra (3.29 µm by using grey relation analysis [6]. To provoke the effect of machining operations over kerf and cutting speed in wire cut electrical discharge to machining Mg AZ91 the alloy material was analysed by MOORA method. The optimized results for kerf width (KW) and cutting speed (CS) were obtained with Taguchi L27 design matrix [7]. The turning work on AZ91Mg alloy with cemented carbide tools was carried out with an objective to minimize cutting zone temperature. Based on experimental outcome the regression model is developed by RSM technique. The model showed that cutting speed is the significant factor affecting cutting zone temperature. Apart from regression equation ANOVA was also carried out. It is found

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that parameter combination of cutting speed at 40m/min, feed at 0.2mm/rev and depth of cut at 0.50mm for minimum cutting zone temperature using RSM [8]. The wire-cut EDM process using Cemented Tungsten Carbide tool has been investigated for obtaining better fine surface finish and faster material removal and the machining conditions influencing the process to optimise the parameters using Grey-Taguchi method. The pulse on time is found to be the dominant parameter for both, surface roughness and MRR. For the multiple performance characteristics the Grey-Taguchi method is recommended [9, 10].

In this study, using Taquchi technique, the process parameters of WEDM are optimised. ANOVA is also carried out to find the influence of each input parameter on the machining process. As the experimental design is taguchi based, the statistical analysis software, MINITAB 19 is used to perform ANOVA analysis.

2. Experimental method

2.1. Work material

In this work, AZ31B Mg alloy is used as test material and Table 1 provides the chemical properties of the base plate. The as-received Mg alloy optical and SEM microstructures are presented in Fig.1. The work material used in the experimental machining tests is a rectangular plate with a length, breadth and thickness of 10cm x 10cm x 12mm respectively.



Figure 1. Microstructure of as received Mg alloy 1a) Optical Image 1b) SEM image

The machining was performed in WEDM, under different conditions of machining parameters using Concord DK-7732VC WEDM with a input capacity of 3 Phase, 415 Volts, 50 Hz and machine load of 1.5 KVA and the experimental setup is represented in Fig. 2. It is a 4-axis controlled CNC machine and the guide moves in X-Y plane. The deionised water is used as a dielectric fluid with the maximum tank capacity of 55 litres and a molybdenum wire of 0.2mm diameter is fed through the work piece for machining. The pictorial representation of machined out samples were presented in Figure 3.

Table 1. Cher	nical composition	of work material	(AZ31 Mg alloy) in wt%	%
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Element	Al	Zn	Mn	Si	Cu	Fe	Mg
%	3.42	1.15	0.38	0.025	0.025	0.0041	Bal

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The three levels of inputs values are specified for three process parameters in Table 2. The parameter values as recommended by the machine tool manufacturer were used in the experiments. Taguchi's L9 orthogonal array (OA) design was used to conduct the experiments to obtain smoothest surface by optimising EDM parameters and examining its effectiveness through confirmation test. After machining, the surface was measured using Surftest 211, Minutolo surface roughness tester for three times repeatedly to take the average.



Figure 2. WEDM of Mg alloy

Parameter	Units	Level				
		1	2	3		
Voltage	Volts	15	25	35		
Pulse on time	μs	10	20	30		
Pulse off time	μs	12	22	32		

Table 2. Selected parameters with their levels

3. Result and Discussion

From the experimental observations, the lower Ra and Higher Ra values measured and also the average Ra values calculated are shown in Table 3. ANOVA was carried out for the obtained results.

Experiment	Voltage V	Pulse on time (µs)	Pulse off time (µs)	Lower Ra (µm)	Higher Ra (µm)	Average Ra (µm)
1	15	10	12	3.76	3.88	3.820
2	15	20	22	5.22	5.74	5.480
3	15	30	32	7.18	7.65	7.390
4	25	20	32	6.35	6.90	6.625

Table 3. L9 OA with Average Ra

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5	25	30	12	8.50	9.10	8.800
6	25	10	22	4.22	4.65	4.435
7	35	30	22	9.21	9.60	9.405
8	35	10	32	3.81	4.22	4.015
9	35	20	12	5.50	5.80	5.600



Figure 3. Specimens machined using different parameter combinations

Table 4 shows the response of means. From the responses, it could be seen that the most important parameter is pulse on-time, followed by Voltage. Among the three parameters, Pulse off time is less significant compared to others. Main effects plot of mean SR is presented in Fig. 4

Level	Voltage V	Pulse on time (µs)	Pulse off time (µs)
1	5.563	4.090	6.073
2	6.620	5.902	6.440
3	6.340	8.532	6.010
Delta	1.057	4.442	0.430
Rank	2	1	3

Table 4. Response Table for Means



Figure 4. Main Effects plot of SR

From the Table 5 the optimum parameter combination for minimum SR is obtained which includes voltage at 15V, Pulse on time at 10 μ s and Pulse off time at 12 μ s. The Fig 5 shows the main effects plot for average surface roughness Ra. It reveals that Surface roughness increases as Pulse on time increases and pulse off time does not impact much on the surface roughness. The influence of each machining parameter is calculated and the difference in the S/N ratio is taken as the indicator to rank the dominance of the machining parameter on the performance parameter i.e surface roughness. In current work, smaller the better type S/N ratio is used to obtain optimal parameter combination for Ra and it is expressed in equation -1.

$$\frac{S}{N} = -10\log \frac{1}{n} \left(\sum_{i=1}^{n} y_i^2 \right)$$
.....Eqn. (1)

Level	Voltage V	Pulse on time (µs)	Pulse off time (µs)
1	-14.60	-12.22	-15.16
2	-16.08	-15.39	-15.73
3	-15.50	-18.58	-15.29
Delta	1.49	6.36	0.56
Rank	2	1	3

 Table 5. Response Table for SN Ratios

 oltage V
 Pulse on time (us)



Figure 5. Main Effects Plot for SN ratios

According to the analysis of variance of S/N ratio, the Pulse on time is dominant parameter on response parameter and the results are presented in the Table 6. From the Table-6 it is seen that Pulse on time (μ s) is the control factor that has the major contribution of 92.611% and is followed by Voltage (5.145%) whereas the contribution of Pulse off time is very small.

Source	DF	Seq SS	Adj SS	Adj MS	F	Р	% of contribution
Voltage V	2	3.3695	3.3695	1.6848	3.56	0.219	5.145
Pulse on time (µs)	2	60.6547	60.6547	30.3273	64.01	0.015	92.611

Table 6. Analysis of Variance for S/N ratios of SR

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Pulse off time (µs)	2	0.5223	0.5223	0.2611	0.55	0.645	0.797
Residual Error	2	0.9476	0.9476	0.4738			1.447
Total	8	65.4941					100
S=0.688	83		R-Se	q=98.55%		R-Sq(ad	lj)= 94.21%

Regression Analysis

The Table 7 gives the regression coefficients for Ra

Average Ra (μ m) = 0.83 + 0.0388 Voltage V + 0.2221 Pulse on time (μ s) - 0.0032 Pulse off time (μ s)

Coefficients

Term	Coef	SE Coef	T-Value	P-Value
Constant	0.83	1.16	0.72	0.505
Voltage (V)	0.0388	0.0292	1.33	0.240
Pulse on time (µs)	0.2221	0.0292	7.61	0.001
Pulse off time (µs)	-0.0032	0.0292	-0.11	0.918

Table	7. F	Regression	coefficient	of sur	face	Roug	hness	(Ra))
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From the Fig 6, it was found that the normal probability plot of the residuals follows a straight line and all the points are distributed evenly.

In Residual versus fitted value graph shows the random pattern of the residuals on both sides of zero. Histogram shows the pattern of distribution of residuals for the average surface roughness Ra.

Residual versus observation order shows all residuals in the order that the data were collected. Residual is higher for the observation order seven and for majority of the observation orders, the residual values are situated above and also near to the zero line.



Figure 6. Residual plots for Average Ra from regression analysis

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Figure 7 shows the graph for experimental and predicted values of Average surface roughness (Ra) plotted together. It is clear that the predicted values are in good agreement with the experiment values.



Figure 7. Comparison of actual and predicted values

The main objective of conducting the experiments for machining AZ31 through WEDM is to achieve minimum surface roughness and find the optimal level of control parameters. The RSM optimisation technique is used to determine the optimal machining parameters with an objective of minimizing the surface roughness (Ra). The predicted results of the RSM optimization for the surface roughness are shown in the Table-8 and Figure-8. The results reveal that surface roughness (Ra) mainly depends on Pulse on time (μ s). The optimized cutting parameters are found to be cutting speed of 15 V, Pulse on time of 10 μ s and Pulse off time of 32 μ s. The optimised surface roughness predicted is Ra = 3.5306 μ m.



Figure 8. Parameters optimization for Surface Roughness

The verification test is carried out with optimal process parameter settings to confirm the optimal values. Table 9 shows the comparison of experimentally obtained Surface Roughness value with Taguchi predicted value. It was obtained with 95.41% similarity to the predicted value.

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nse	Goal	Optimum condition		ĩ	et	ŗ	ted lt	ility	
Respo		Voltage (V)	Pulse on time (µs)	Pulse off time (µs)	Lowe	Targ	Uppe	Predic Resu	Desirat
Surface Roughne ss (Ra)	Minimu m	15	10	32	3.82	3.82	9.41	3.53	1

Table 8. Predicted results of the RSM optimization for the surface roughness

Table 9 Conformation test values

Optimum	Process para	meters	Experimental	Predicted Surface		
Voltage (V)	Pulse on time (μs)Pulse of time (μs)		Surface Roughness Ra (μm)	(μm)		
15	10	32	3.702	3.5306		

4. Conclusions

The conclusions drawn from the WEDM machining of AZ31B Mg alloy for achieving minimum surface roughness are as follows:

- (a) The Pulse on time (μ s) is the main dominant factor that influences Ra the most followed by voltage whose contribution is comparatively very less.
- (b) The optimum EDM parameters have been obtained for machining AZ31B Mg alloy. Predicted Ra is in highly agreed with experimental responses.
- (c) From RSM optimization, the set of input values obtained for machining AZ31B Mg alloy with minimum surface roughness are: Voltage at 15 V, Pulse on time at 10μ s and Pulse off time at 32μ s.
- (d) The conformation test result proved a similarity of 95.4% between the developed regression model and the experimental value which shows the effectiveness of the analysis model employed.

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