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RESEARCH ARTICLE

Process parameter optimization of T4 Heat treated Magnesium alloy AZ91C for Wire Electrical Discharge Machining by Taguchi Methodology

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Abstract

An experimental study was designed for optimizing the process of multiple quality characteristics response for Wire Electrical Discharge Machining (WEDM) of magnesium alloy AZ91C for intricate shape cutting after giving the tempering heat treatment. Multiple quality characteristics response involved cutting speed, surface roughness, Material Removal Rate (MRR) and percentage of dimension deviation (% DD). Taguchi L9 orthogonal array was used to design the experiments and Anova test confirmed the experimentation. The optimum parameter confirmed with the experimental value for the optimum response characteristics. The result of the study shows that machining AZ91C Mg alloy for maximum material removal rate, servo voltage is a significant factor having a contribution of 49.84%. Similarly, for minimum percentage dimension deviation pulse off time (78.47%) was the significant factor.

Keywords: Magnesium alloy AZ91C, material removal rate, dimension deviation, Taguchi methodology.

Introduction

Magnesium alloy is the low specific weight material with excellent machining ability and good cycle potential. They are not used frequently because of the high cost of the parent material, coupled with partial absence of recycling possibility. Magnesium was discovered in 1774 and named after the ancient city Magnesia. Magnesium is found to be the 6th most abundant element constituting 2% of the total mass of the earth crust. It stands to the second main group in the periodic table of element and is therefore not found in the elemental group. Besides traditional machining such as turning, milling, grinding there are many advanced non-traditional machine process such as laser beam machining, abrasive jet machining and electric discharge machining. It is the process which produces burr free machining, moreover excellent machine capability and also the machine cost is very less. Electrical discharge machining involves the use of an electrode by which electrical spark energy is converted into thermal energy. By using this thermal energy the metal is removed from the metal surface and hence machining is done (Kalpakjain and Steven, 2000). Mohammadi *et al.* (2008) investigated the effect of various process parameters for turning WEDM such as current, pulse off time, servo voltage, wire tension, wire speed along with rotational speed of wire on surface roughness and roundness. Cemented steel was chosen as work piece material and Taguchi standard orthogonal array was chosen for the design of experiments. ANOVA test was made for determining level of contribution of machining parameters on surface roughness and roundness. Experimentation result shows that factors affecting the surface roughness were current, wire speed, voltage, wire tension, pulse off time, servo and rotational speed of wire. The variation of the surface roughness and roundness was modeled with regression analysis method. Chan and Lin (2009) proposed a novel combined process that integrates electrical discharge machining (WEDM) and ultrasonic machining (USM) to investigate the machining performance and surface modification on Al-Zn-Mg alloy. TiC particles were added into the dielectric to identify the influence of the combined process on the material removal rate (MRR), the relative electrode wear ratio (REWR), the surface roughness and the expansion of the machined hole.

Electron probe micro-analyzer (EPMA) was used to quantitatively determine elemental distributions of titanium and carbon on the cross-section. Micro-hardness and wear resistance tests were conducted to evaluate the modifications on the machined surface caused by the combined process. The experimental results revealed that the combined process was associated with improved machining performance. The combination of EDM with USM yielded an alloyed layer that improved the hardness and wear resistance of the machined surface. Lin and Wang (2010) optimized quality characteristics of WEDM via Taguchi method based grey analysis for Mg alloy AZ31B. The input variable such as wire feed rate, pulse on time, no load voltage, pulse off time, servo voltage and wire tension was selected.

Material removal rate and surface roughness was response variable of the WEDM machining. L18 array was selected for DOE. The author concludes that pulse on time, servo voltage and pulse off time is very significant in MRR, pulse on time and servo voltage is very much significant in SR. Puri *et al*. (2010) proposed the statistical and regression analysis of kerf width using design of experiment. Experiment was planned as per Taguchi L32 mixed orthogonal array. SS 304L was selected as a work piece material to conduct experiment. ANOVA test was used to certain the percentage contribution of each variable affecting the kerf width. Author developed a mathematical model to predict the error which was less than 4%. Shabgard *et al*. (2011) reported the influence of input parameters on the characteristics of the edm process using AISI H13 tool steel as work piece. It is stated by the author that increase in pulse on time leads to an increase in MRR, SR, white layer thickness, heat effected zone and tool wear rate decreases. Increase in pulse current leads to sharp increase in the material removal rate and surface roughness.

Muthuraman and Ramakrishnan (2012) investigated multi-parametric optimization of WC-Co composite using desirability approach. The 0.25 mm copper coated brass wire was used as an electrode material and L32 orthogonal array was used to conduct the experiment. Author suggested for using the desirability function analysis to improve the response characteristics such as MRR, SR. Huang *et al*. (2013) suggested the optimization of cutting condition of YG15 on rough and finish cutting in WEDM based on statistical analysis. The result presented by the author optimized the input parameter of MRR and SR for rough and finish process respectively and confirm the ability and efficiency of the model. Considering the above facts, an experimental study was designed for optimizing the process of multiple quality characteristics response for Wire Electrical Discharge Machining (WEDM) of magnesium alloy AZ91C for intricate shape cutting after giving the tempering heat treatment.

Materials and methods

Experimental design using Taguchi approach: All experiments were designed by Taguchi approach. MINI Tab 15 Software was used for the designing experiments. Figure 1 shows the Taguchi methodology followed for conducting the experiment.

Work piece material: The magnesium alloy grade of AZ91C rectangular piece of 700 mm X 500 mm X 50 mm of size has been used as a work piece material for the present experiment. Magnesium alloy is the low specific weight material with excellent machining ability and good cycle potential. They are not used frequently because of the high cost of the parent material, coupled with partial absence of recycling possibility.

Fig. 1. Taguchi methodology for experimental design.

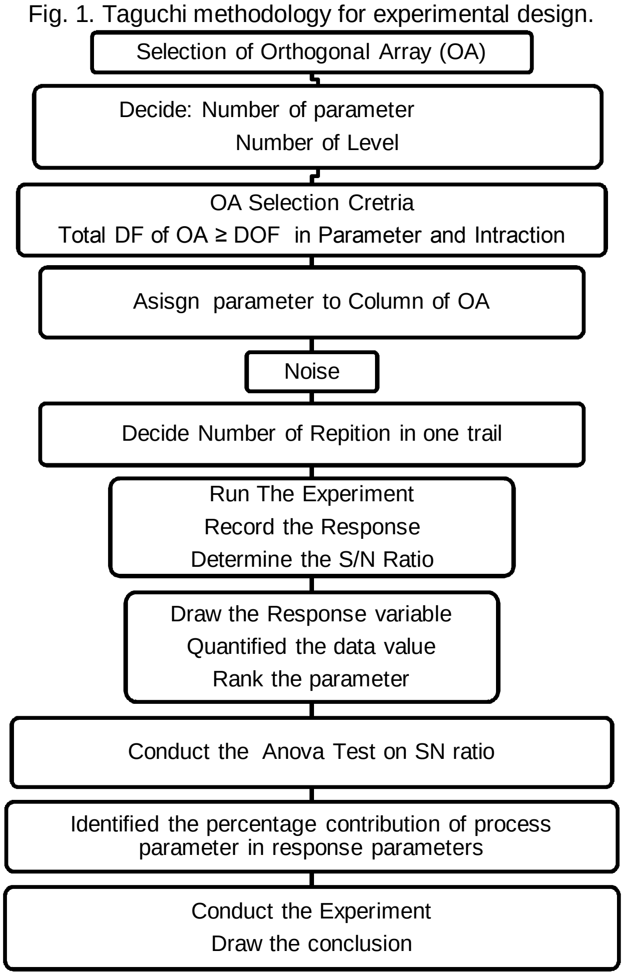

Table 2. Chemical composition of the material accordance with ASTM E35-88 (1993).

Mg alloy AZ91C	Percentage of ingredients by weight					
	Al	Zn	Si	Cu	Ni	Mn	Mg
	8.92	0.53	0.23	0.06	0.009	0.28	Rem

The chemical composition of the material is obtained by chemical test (Wet) in accordance with ASTM E35-88(1993) (Table 1). The AZ91C Mg alloy rectangular piece of 70 mm X 60 mm X 6 mm is mounted on the ELECKTRA WEDM (ELPLUS 15) machine for cutting specimen of 20 mm X 10 mm X 5 mm of size. The MRR was calculated by the following expression.

$$\text{MRR} = \frac{\text{Weight before machining} - \text{Weight after machining}}{\text{Density} \times \text{Time taken in machining}}$$

In the present experiment, the percentage of dimension deviation was estimated for the length only using the given equation. Vernier caliber of least count of 0.02 mm was used for the measurement.

$$\%\,DD = \frac{\text{Actual dimensions} - \text{Measured dimensions}}{\text{Actual dimensions}} \times 100$$

Table 3. Range of parameters.

Process parameters	Symbol	Units	Range (machine units)
Pulse on time	T_{on}	µs	106-112
Pulse off time	T_{off}	µs	48-30
Servo voltage	S_V	volts	35-60
Wire feed rate	W_F	m/min	2-12
Wire tension	W_T	Kg-f	420-1140

Table 4. Factors and levels.

Symbol	Factors	Level			Units
		1	2	3	
A	Pulse on time	106	109	111	µs
B	Pulse off time	48	39	30	µs
C	Servo voltage	35	50	60	v
D	Wire feed	2	8	12	m/min
Fixed setting	Water pressure	1 STEP			
	Wire tension	8 STEP			

Table 5. L9 orthogonal array.

Exp. No.	T_{on} (A)	T_{off} (B)	S_V (C)	W_f (D)
1	106	48	35	2
2	106	39	50	8
3	106	30	60	12
4	109	48	50	12
5	109	39	60	2
6	109	30	35	8
7	111	48	60	8
8	111	39	35	12
9	111	30	50	2

Selection of parameters range based on pilot experiment: The pilot experiment was carried out for different input parameters i.e. pulse on time, pulse off time, servo voltage, wire feed rate and wire tension and their effect was observed for response variables i.e. material removal rate and dimensional deviations. Based on the pilot experiment and literature review range of all parameters, three leve ls of each input parameters were selected for Taguchi experimental design (Table 3 and 4). The experiment was executed according to their levels and interaction in Table 5.

Results and discussion

Figure 2 and 3 shows the effect of four input parameters on the MRR and %DD by using the MINITAB 15. After analyzing the graphs the effect of the four factors can be predicted. It was noted that factors A3, B1, C1 and D1 (Table 6) gave maximum MRR (Fig. 2). It is concluded that factor A1, B1, C2, D1 gives minimum value of dimension deviation (Fig. 3). Response Table 7 show that factor C is very much significant for the maximum MRR. Factor B is very much significant which affects the DD (Table 8). The percentage contribution of each factor has yet to be estimated.

Fig. 2. Main effects plot for SN ratio of material removal rate.

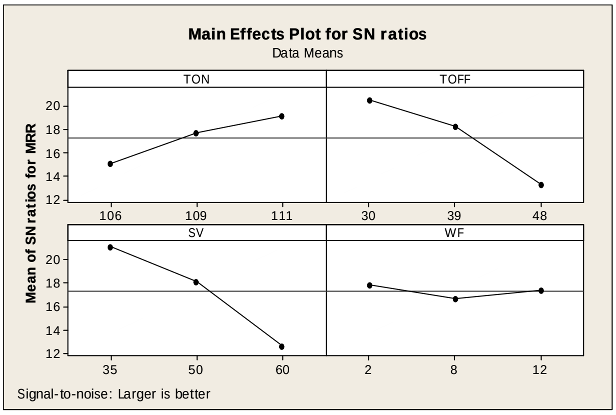

Fig. 3. Main effects plot for SN ratio of % DD.

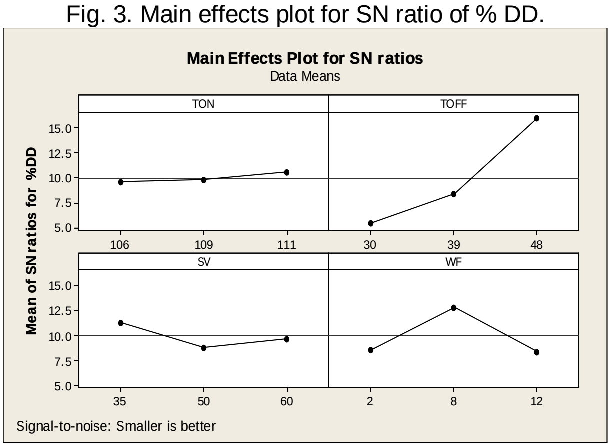

Table 6. DD and SN ratio for experimental design.

Exp. No.	A(T_{on})	B(T_{off})	C(S_V)	D(W_F)	MRR	SN ratio	% DD	SN ratio
1	106	48	35	2	5.85	15.3431	0.166667	15.563
2	106	39	50	8	6.45	16.1912	0.323333	9.807
3	106	30	60	12	4.83	13.6789	0.683333	3.3073
4	109	48	50	12	5.34	14.5508	0.22	13.1515
5	109	39	60	2	5.32	14.5182	0.463333	6.6821
6	109	30	35	8	15.89	24.0225	0.333333	9.5424
7	111	48	60	8	3.11	9.8552	0.11	19.1721
8	111	39	35	12	15.65	23.8903	0.366667	8.7146
9	111	30	50	2	15.37	23.7335	0.66	3.6091

Table 7. Response of MRR for signal to noise ratios (Higher is better).

Level	T_{on}	T_{off}	S_v	W_f
1	7.536	11.820	13.355	9.582
2	9.267	10.243	10.193	8.425
3	10.786	5.526	4.041	9.582
Delta	3.250	6.294	9.314	1.157
Rank	3	2	1	4

Table 8. Response of DD for signal to noise ratios (Smaller is better).

Level	T_{on}	T_{off}	S_v	W_f
1	9.559	5.486	11.273	8.618
2	9.792	8.401	8.856	12.841
3	10.499	15.962	9.721	8.391
Delta	0.939	10.476	2.417	4.449
Rank	4	1	3	2

Table 9. Analysis of variance of material removal rate.

Factor	DF	SS	Variance	F value	Percentage contribution
T_{on} (A)	2	25.752	12.8758*	0.92	11.76%
T_{off} (B)	2	81.948	40.9739	2.94	37.43%
S_v (C)	2	109.114	54.5572	3.91	49.84%
W_f (D)	2	2.091	1.0453*	0.07	0.95%
Residual error	0	-	-	-	-
Total	8	218.904	-	-	100%
Pooled error	4	27.843	13.9211	-	-

Table 10. Analysis of variance of % dimension deviation.

Factor	DF	SS	Variance	F value	Percentage contribution
T_{on} (A)	2	1.436	0.7181*	0.1378	0.64%
T_{off} (B)	2	175.411	87.7055	16.83	78.47%
S_v (C)	2	9.003	4.5015*	0.86	4.02%
W_f (D)	2	37.677	18.8386	3.61	16.85%
Residual error	0	-	-	-	-
Total	8	223.527	-	-	100%
Pooled error	4	10.439	5.2196	-	-

Table 11. Result of the experiment confirmation for CS and SR.

Response	Level	Prediction	Experimental
MRR(mm^3/min)	A3,B1,C1,D1	15.89	14.55
DD (%)	A1,B1,C2,D1	0.11	0.15

In previous section the optimum level of the four input factors are determined which give high efficiency for MRR and DD, though the percentage contribution of each factor in the machining process is not identified. The ANOVA table predicts the percentage contribution of each factor in response characteristics. The large value of variance ratio denoted by F in Table 9 and 10 mean that the effect of corresponding factor is large as compared to other factors. The contribution of servo voltage and pulse off time in MRR is 49.84% and 37.43% respectively. The contribution of pulse off time and wire feed in DD is 78.47% and 16.85% respectively. However, the final step is to predict and verify the improvement of the observed value through the use of optimum combination level of machining parameters.

MINITAB 15 is used to estimate the value of MRR and DD by using optimum parameter is shown in Table 11. This value is compared with the actual value obtained by the experiment using optimum input parameter factors.

Conclusion

In this study, an effort is made to obtain the effect of the input parameters such as pulse on time, pulse off time, and wire feed and servo voltage in WEDM process. These factors play a significant role on the response characteristics of the machine such as MRR and % DD. In the design of experiment, Taguchi method was used to evaluate the optimum input parameters combination for the maximum MRR and minimum % DD. The confirmation of experiment reveals the ranking contribution of each input parameters and ANOVA test predict the percentage contribution of each parameters.

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