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OPTIMIZATION OF KERF AND SURFACE ROUGHNESS OF AL 7 475-T7 351 ALLOY MACHINED WITH WEDM PROCESS USING THE GREY-BASED TAGUCHI METHOD

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In this study, the effects of cutting parameters on kerf and surface roughness were experimentally investigated in WEDM. Al 7 475-T7 351 alloy was selected as the work material to conduct experiments. The factors selected for the optimization are the pulse on time, table feed rate and the wire speed, each of the factors in three different levels. An optimal parameter combination of the WEDM process was obtained by applying the grey relational analysis (GRA). Also, the analysis of variance (ANOVA) was carried out for finding out the contribution and the effects of machining parameters on the multiple performance characteristics (MPC).

Key words: WEDM (Wire Electrical Discharging Machining), Al 7 475-T7 351, Grey relational analysis.

Optimiranje kvalitete reza i hrapavosti površine Al 7 476-T7 351 legure obrađene WEDM postupkom uz primjenu "gray-based / sivo temeljene" Taguči metode. U ovom radu se obrazlažu rezultati eksperimentalnog istraživanja utjecaja parametara rezanja na kvalitetu reza i hrapavosti površine Al 7 476-T7 351 legure. Izabrani su faktori za optimiranje: vremenski impulse, brzina dodavanja ploče i brzina žice. Svaki od odabranih parametara izabran je na tri različita nivoa. Optimalna kombinacija parametara rezanja je dobivena primjenom "grey-sive" relacijske analize (GRA). Također je provedena i analiza varijance (ANOVA) za pronalaženje pojedinačnih doprinosa i efekata pojedinih parametara obrade.

Ključne riječi: WEDM, Al 7 476-T7 351, "grey-siva" relacijska analiza

INTRODUCTION

Owing to low densities and good mechanical properties, 2xxx and 7xxx series aluminum alloys have been broadly used as structural materials in aeronautical industry. Among these alloys, 7 475 series alloys are successfully used thanks to superior fracture toughness [1]. Nevertheless, those materials are difficult to be machined by traditional cutting methods. Hence, non-traditional materials removal process including electrolytic grinding, supersonic machining and electrical discharging machining are applied [2]. Recently, WEDM has become an important non-traditional materials removal process, extensively used in the aerospace and automotive industry [3].

Many studies have been done interested in kerf and surface roughness in WEDM operations. The machinability of standard GGG40 nodular cast iron by WEDM using different parameters was investigated by Ozdemir and Ozek [4]. They used a regression model to estimate cutting rate and surface roughness using machining parameters. Gökler and Ozanözgü [5] experimentally investigated the effect of cutting and offset parameter combinations on the surface roughness. They concluded that the surface roughness of the process is closely dependent on machining parameters. Tosun et al. [6,7] optimized machining parameters on the cutting width, surface roughness and material removal rate in WEDM operations and they derived a mathematical model. Ramakrishnan and Karunamoorthy [8] developed artificial neural network model and MPC using multi response signal-to-noise ratio, to achieve better material removal rate and surface finish simultaneously.

Muthu Kumar et al. [9], Mahapatra and Patnaik [10] and Shah et al. [11] investigated experimentally the influence of the machining parameter on the kerf width, metal removal rate and the surface roughness of the machined workpiece surface using Taguchi method. Above mentioned and other experimental investigations have shown that the kerf and surface roughness of machined workpiece is strongly dependent on cutting parameters.

In this study, grey-based Taguchi method for minimizing both the kerf and the surface roughness were used. Experiments were performed under different cutting condition, such as pulse on time, table feed rate and wire speed. The kerf and surface roughness of the machined workpiece are measured and analyzed through Taguchi and GRA to determine the optimal parameters in WEDM process.

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GREY ANALYSIS

In GRA the first step is to perform data pre-processing. In particular, to avoids the problem of different scales, units and targets. Experimental results are normalized in the range between zero and one. Then, the second step is to calculate the grey relational coefficient from the normalized experimental results to express the relationship between the best and the actual experimental results [12]. Kerf and surface roughness which are lower-the-better performance characteristic are pre-processed as follows:

$$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \qquad (1)$$

where: $x_i^*(k)$ is the value after grey relational generation, $x_i^0(k)$ the original value, $\min x_i^0(k)$ the smallest value of $x_i^0(k)$ and $\max x_i^0(k)$ the largest value of $x_i^0(k)$. The higher preprocessed value shows better performance and best preprocessed result should be equal to one. The grey relational coefficient [$\xi_i(k)$] can be expressed as follows:

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i}(k) + \zeta\Delta_{\max}} \qquad (2)$$

Where ζ is the distinguishing coefficient ($\in$[0–1]), $\Delta_{0i}(k)$, the difference in absolute value between $x_0^*(k)$ and $x_i^*(k)$, $x_0^*(k)$ the ideal or reference sequence, $\Delta_{\min}$ the smallest value of Δ_{0i} and $\Delta_{\max}$ the largest value of Δ_{0i}. Grey relational grade is computed by averaging the grey relational coefficients corresponding to each performance characteristics. The experimental result of the kerf and surface roughness are evaluated by using this grey relational grade. The optimum level of the process parameters is the level with the highest grey relational grade. The grey relational grade can be calculated as:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \qquad (3)$$

where γ_i is the grey relational grade and n is the number of performance characteristics.

EXPERIMENTAL WORK

In this study, Al 7 475-T7 351 was chosen as the work materials because of its extensive use in the aerospace industry. The mechanical properties and chemical compositions of Al alloy were presented in Table 1. The machining experiments were performed on five-axes CNC WEDM. In the experiment, coated brass wire (CuZn 37) of 0,25 mm diameter was used as electrode and the ion water is used as the dielectric liquid. During all experiments, tension of the wire of 800 g, upper nozzle set 25 mm, cutting length of 20 mm and workpiece thickness of 12,7 mm were kept constant. The experiments were carried out according to Taguchi's L_{27} orthogonal array design matrix. The experiments are designed at three levels as shown in Table 2. Machine table feed rate is controlled step by step. By raising step position from 4 to 6 the table feed rate (mm/min) is reduce, in other words it is changed inversely proportional.

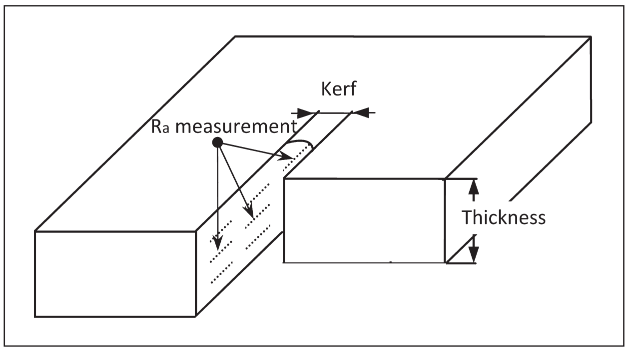

Figure 1 Measurement of kerf and surface roughness

In this study, kerf and surface roughness were selected as the quality characteristics for optimizing machining parameters. The kerf (K) and surface roughness (R_a, the arithmetic average) of an each machined workpiece was measured by means of an optical microscope and surface roughness tester (Mahr Perthometer) using a meter cut off 1,750 mm respectively. Kerf and surface roughness measurements are shown in Figure 1.

Table 2 **Control factors and their levels used for experiment**

#	Factors	Unit	Level		
			1	2	3
1	Pulse on time (A)	μs	0,2	0,4	0,6
2	Table feed rate (B)	step	4	5	6
3	Wire speed (C)	m/min	1	2	3

RESULTS AND DISCUSSION

The optimum parameters settings and the most influential factor of the kerf and surface roughness are determined by both the grey relational grade and the analysis of variance.

In the present study, the measured data (K and R_a), grey relational coefficients, grey relational coefficients after weighed, grey relational grade and rank evaluated for each group are shown in Table 3. Typically, smaller the better quality characteristic for both the kerf and the surface roughness should be taken for obtaining optimal machining performance.

Grey relational grade can be calculated by using equation (1-3). Always the highest grey relational grade is preferred. WEDM parameter setting of experiment number 7 has the highest grey relational grade clearly

Table 1 **Mechanical and chemical properties of Al 7 475-T7 351 aluminum alloy**

Materials	Tensile properties			Chemical compositions								
	R_m /MPa	R_e /MPa	Elongation /%	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
Al 7 475-T7 351	490	414	9	Base	0,20	1,5	0,12	2,0	0,06	0,10	0,06	5,3

Table 3 **The measured data, the evaluated grey relational co-efficients, grades and rank**

Group no	Measured data		Grey relational coefficients		Grey relational coefficients after weighed		Grey relational grade		
	Kerf	R_a	Kerf	R_a	Kerf	R_a	Grade	S/N	Rank
1	0,29	2,816	0,90909	0,72414	0,84615	0,64444	0,74530	-2,55431	4
2	0,31	2,922	0,72727	0,58355	0,64706	0,54559	0,59632	-4,49114	7
3	0,32	2,943	0,63636	0,55570	0,57895	0,52949	0,55422	-5,12667	8
4	0,29	2,753	0,90909	0,80769	0,84615	0,72222	0,78419	-2,11290	3
5	0,30	2,843	0,81818	0,68833	0,73333	0,61601	0,67467	-3,41882	6
6	0,31	2,922	0,72727	0,58355	0,64706	0,54559	0,59632	-4,49114	7
7	0,28	2,608	1,00000	1,00000	1,00000	1,00000	1,00000	0,00000	1
8	0,28	2,683	1,00000	0,90053	1,00000	0,83407	0,91704	-0,75252	2
9	0,29	2,822	0,90909	0,71618	0,84615	0,63790	0,74203	-2,59274	5
10	0,34	3,105	0,45455	0,34085	0,47826	0,43135	0,45481	-6,84378	14
11	0,32	3,089	0,63636	0,36207	0,57895	0,43939	0,50917	-5,86343	9
12	0,35	3,098	0,36364	0,35013	0,44000	0,43483	0,43742	-7,18242	16
13	0,34	3,074	0,45455	0,38196	0,47826	0,44721	0,46274	-6,69382	11
14	0,35	3,122	0,36364	0,31830	0,44000	0,42312	0,43156	-7,29938	17
15	0,37	3,031	0,18182	0,43899	0,37931	0,47125	0,42528	-7,42711	20
16	0,33	3,003	0,54545	0,47613	0,52381	0,48834	0,50608	-5,91613	10
17	0,35	3,029	0,36364	0,44164	0,44000	0,47243	0,45622	-6,81689	13
18	0,36	3,020	0,27273	0,45358	0,40741	0,47782	0,44261	-7,07997	15
19	0,38	3,174	0,09091	0,24934	0,35484	0,39979	0,37731	-8,46626	23
20	0,39	3,254	0,00000	0,14324	0,33333	0,36852	0,35093	-9,09584	25
21	0,39	3,362	0,00000	0,00000	0,33333	0,33333	0,33333	-9,54251	26
22	0,35	3,008	0,36364	0,46950	0,44000	0,48520	0,46260	-6,69645	12
23	0,36	3,064	0,27273	0,39523	0,40741	0,45258	0,42999	-7,33103	18
24	0,37	3,284	0,18182	0,10345	0,37931	0,35802	0,36867	-8,66748	24
25	0,35	3,131	0,36364	0,30637	0,44000	0,41889	0,42944	-7,34235	19
26	0,36	3,214	0,27273	0,19629	0,40741	0,38352	0,39546	-8,05839	21
27	0,37	3,155	0,18182	0,27454	0,37931	0,40801	0,39366	-8,09779	22

shown in Table 3 and Figure 2. Thus, the seventh experiment gives the best MPC simultaneously among the 27 experiments. The machining parameters in experiment number 7 are: (A) Pulse on time 0,2 μs; (B) table feed rate 6 step and (C) wire speed 1 m/min.

The response graph for the overall grey relational grade is presented graphically in Figure 3. It shows that, the larger the grey relational grade, the better is the MPC. The optimized parameters are $A_1B_3C_1$. The kerf and surface roughness diminishes with increasing table feed rate (as step), decreasing the pulse on time and wire speed (Figure 3).

The standard commercial statistical software package Minitab 15,0 was used in the analysis of results. Table 4 shows the result of ANOVA analysis and indicates that pulse on time, table feed rate and wire speed are significant (at the 95 % confidence level) parameters which influence the kerf and surface roughness. Furthermore, pulse on time has the most significant impact on the MPC due to its highest percentage contribution among the process parameters. From Table 4, it can be seen that the pulse on time (74,505 %), table feed rate (6,307 %) and wire speed (6,054 %) have statistical and physical significance on the kerf and surface roughness.

In this study, a verification experiment was carried out by utilizing the experimental condition of the three factors as: Pulse-on time 0,2 μs, table feed rate 6 step and wire speed 1 m/min ($A_1B_3C_1$) for the minimum kerf and surface roughness obtained through grey relation process. Table 5 shows the comparisons of predicted

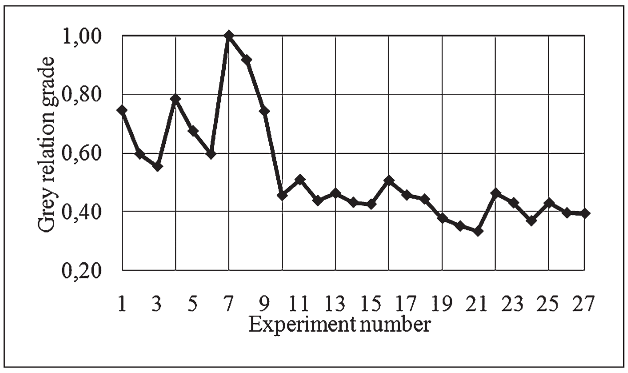

Figure 2 Variation of grey relational grade with experiment number

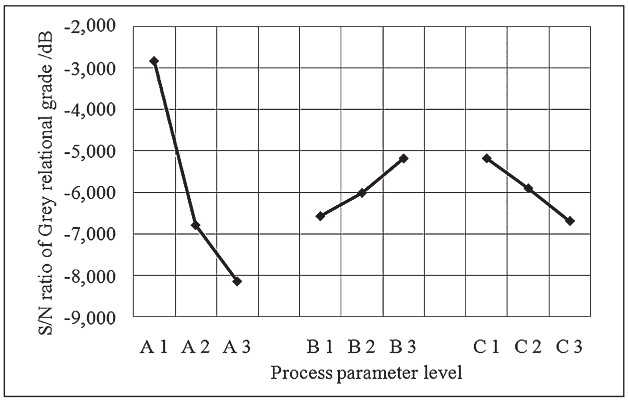

Figure 3 Effect of WEDM parameter levels on the K and R_a

Table 4 **Results of ANOVA**

S	Df	SS	V	F	%
A	2	0,5898	0,2949	56,73	74,505
B	2	0,0499	0,0249	4,80	6,307
C	2	0,0479	0,0239	4,61	6,054
Error	20	0,1039	0,0052	-	13,133
Total	26	0,7916	-	-	100

S: Symbol, Df: Degree of freedom, SS: Sum of squares, V: Variance, F: F ratio, %: Percent.

Table 5 **Results of the verified experiment for K and R_a**

	Initial parameters	Optimal WEDM parameters	
		Prediction	Experimental
Setting level	$A_2B_2C_2$	$A_1B_3C_1$	$A_1B_3C_1$
Kerf (mm)	0,35	-	0,28
Surface roughness (μm)	3,122	-	2,620
Grey relational grade	0,43156	1,0017	0,98458

Improvement of the grey reletional grade= 0,55302

and actual machining performance for MPC using their optimal WEDM parameters. The value of kerf and surface roughness at this optimum level has been found as 0,28 and 2,620, respectively, after conformation run (Table 5). As shown from table, kerf decrease from 0,35 mm to 0,28 mm; and surface roughness improve from 3,122 μm to 2,620 μm. It obviously demonstrates that the kerf and surface roughness are greatly improved through this approach.

CONCLUSIONS

In order to minimize both the kerf and the surface roughness of Al 7 475-T7 351, effect of various cutting parameters have been investigated in WEDM grey-based Taguchi method. The following conclusions can be drawn from the investigation:

The increase of the pulse on time, wire speed and decrease of table feed rate increase both the kerf and the surface roughness.

Through the grey-Taguchi method, the decrease in the kerf and surface roughness of Al 7 475-T7 351 from the initial machining setting ($A_2B_2C_2$) to the optimized condition ($A_1B_3C_1$) is 0,07 mm and 0,502 μm, respectively. The optimum condition of parameters setting is as pulse on time 0,2 μs, table feed rate 6 step and wire speed 1 m/min for minimizing both the kerf and the surface roughness.

The results of ANOVA (at a 95 % confidence level) for the machining indicated that the pulse on time, table feed rate and wire speed have influence on the both the kerf and the surface roughness by 74,505 %, 6,307 % and 6,054 % respectively.

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Note: The responsible translator for the English language is the lecturer from Technical Education Faculty, Simav-Kutahya, Turkey