Study on the Wire Electrical Discharge Machining of AA 7075 Aluminum Alloy

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***Abstract*—In the present study, wire electrical discharge machining (wire EDM) behaviors of Aluminum alloy 7075-T6 were investigated and the influence of the wire tension, voltage and peak current on the surface quality were evaluated. Experiments were performed based on the Taguchi L_{27} full factorial experiment design and optimal cutting parameters for surface quality were determined. The mean effect plot and analysis of variance (ANOVA) were used to evaluate the cutting parameters on the machined surface. Experiment results showed that the most efficient parameter on surface roughness was the peak current value. It was observed that aluminum was affected by the electric arc during the wire EDM process and caused the crater formation on the machined surface of the aluminum alloy. The vertical crack connected with non-continuous horizontal crack parallel to the machined surface of the workpiece were seen on the machined surface.**

Keywords-AA7075 T6; Wire EDM; surface roughness; machinability

I. INTRODUCTION

Wire EDM machining is a non-contact electro thermal material removal process and has a very important role in modern manufacturing industry. This machining process is mostly used in aerospace industry, automotive industry and die making industry to machine hard and toughness materials having complex two or three dimensional shapes. In the wire EDM process, an electric spark is created between the wire electrode and a workpiece and produces very intense heat. This heat dissolves the material to produce the desired geometric shape. The spark always occurs in the dielectric deionized water and the water functions as a cooler and cleans the worn metal particles [1-8].

AA 7075 T6 alloy is one of the indispensable materials for aerospace, aviation and defense industry due to its high mechanical properties as well as lightness. Among the unconventional manufacturing methods, wire EDM is one of the most applied methods of the industry. Due to the large number of machining variables and the complicated machining mechanism in application of wire EDM, it is difficult to select the correct machining parameters [9]. On the other side, capacity of cutting whole materials that conduct electricity is the greatest superiority of wire erosion machine.

Mouralova et al.; have studied the effects of machining parameters for the required surface quality and high dimensional accuracy when machined with 99.5% pure aluminum with WEDM [10]. Palgarg and Sharma; have studied the effects of machining parameters of ZrSiO4p / 6063 Aluminum matrix composite on dimensional deflection [11]. Oberholzer et al. have determined the best machining parameters in order to produce dovetail joint by using AA 7075 T6 alloy and optimized the results by ANOVA [12]. Çaydaş and Hasçalık have investigated surface roughness and microstructure change of aluminum alloy depending on dielectric liquid circulation pressure, pulse time, voltage and wire feed rate parameters [13].

Fard et al. [3] studied the wire EDM properties of the Aluminum based SiC reinforced metal matrix composites and determined the cutting variables on the surface quality. They reported that the peak current and pulse-on-time was the most significant parameter. The brass wire as electrode material and using oxygen presented a higher machining velocity during the wire EDM process.

Sharma et al. [7] investigated the effect of wire EDM parameters on cutting performance in machining of Aluminum 6063 based ZrSiO4 reinforced composite materials. They stated that the cutting performance improved with increasing peak current and pulse-on-time values.

Motorcu et al. [14] investigated the wire EDM behavior of the aluminum based hybrid metal matrix composites. They reported that wire speed was the most effective machining variables during the tests. Shandilya et al. [15] reported that the cutting speed was affected from the spark gap voltage, pulse-off time and cutting feed during the wire EDM of aluminum 6061 based SiC reinforced metal matrix

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composites. Several researchers were studied the wire EDM properties of the aluminum based metal matrix composites and investigated the effect of the cutting parameters on surface roughness and machining performance [8, 16, 17, 18]. Lee et al. [19] studied the relationship between the surface crack creation and wire EDM cutting variables. They developed a crack prediction map indicating the effect of the wire EDM parameters. Kang et al. [20] reported that the carburization and sharp crack propagation was created after the heat treatment. On the other hand, the dielectric fluid prevented crack formation. Ekmekci [21] investigated the crack formation, heat treatment and white layer composition during the wire EDM process. Author found that the surface cracks were started at the surface in machining with hydrocarbon-based dielectric water under high pulse-on duration and low average current. The crack creation penetrating the workpiece material was observed in machining brittle materials using deionized water. Kumar et al. [22] machined the pure titanium workpiece material and studied the surface crack density and recast layer thickness during the wire EDM process. They observed that the peak current, pulse on time and pulse off time were the most significant cutting parameters on surface crack formation and recast layer thickness.

In this study, surface roughness properties of aluminum alloy 7075 specimens joined by friction stir welding (FSW) method was investigated during wire EDM. Surface defects and surface cracks on the machined surface of AA7075 were evaluated and the influence of cutting parameters on surface quality was determined. ANOVA was used to determine the optimal wire EDM parameters in machining of AA 7075.

II. EXPERIMENTAL PROCEDURES

AA7075 sheets were joined by Friction stir welding method and then mechanical test specimens were cut using wire EDM machine. The welded aluminum specimens were cut on the Mitsubishi MV1200 series CNC wire EDM (Fig.1). A brass wire of diameter 0.30 mm and pure water ionized as dielectric fluid were used during the experiments. Chemical composition of the AA7075-T6 specimens used in the tests was given in Table I.

TABLE I. CHEMICAL COMPOSITION OF THE AA7075-T6 (%WT.)

Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al	Other
0.07	0.12	1.39	0.059	2.45	0.18	0.0039	5.63	0.026	Bal.	<=0.15

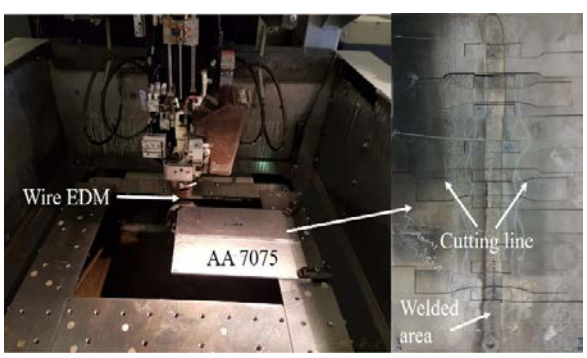

Figure 1. Overview of the experimental set-up for WEDM machining

The mechanical tests specimens were prepared according to standard and surface roughness was measured using Mitutoyo surftest SJ210 measurement device as shown in Fig. 2. The measurements were carried out at three areas perpendicular to cutting direction and their average was taken. Macro investigations of cutting surfaces were performed with Leica M205C stereo microscope. Leica DMI 500M optical microscope was used to examine the machined surface defects. Experimental results were evaluated by Minitab 18 statistical software. Wire tension, voltage and peak current was chosen as the cutting variables and 27 full factorial experiments were performed. Wire EDM machining parameters and levels were presented in Table II.

TABLE II. WIRE EDM CUTTING VARIABLES

Cutting parameters	Level 1	Level 2	Level 3
Wire tension, Wt (gram)	8	10	12
Peak current,amp (A)	8	10	13
Voltage, volt (V)	35	55	70

III. EXPERIMENTAL RESULTS AND DISCUSSION

This study was conducted to investigate surface texture of the wire EDM properties of the aluminum specimens. Surface measurement of the specimens on the machined surface was given in Fig. 2. The lowest and highest surface roughness values were obtained as 4.336 µm and 6.434 µm, respectively.

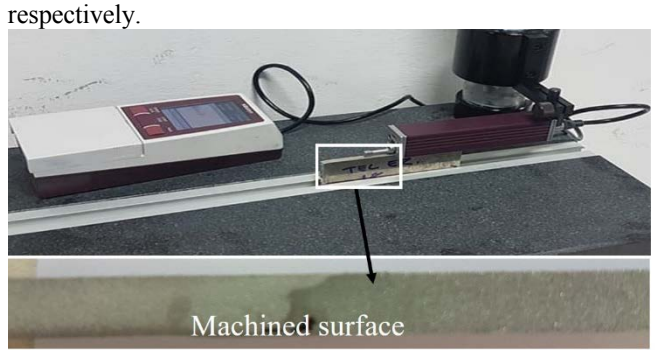

Figure 2. Surface measurement on the machined specimen

The influence of the wire tension, peak current, and spark gap voltage on surface quality was depicted in Fig. 3. The surface quality was worsened with increasing peak current value depending on the increasing cutting feed during the wire EDM process. Surface quality of the machined aluminum specimens was not significantly affected from the wire tension and spark gap voltage parameter. However, it was observed that the increasing wire tension values had positive effect on the surface quality. The mean effect of machining parameters on surface roughness is presented in Fig. 4. The surface quality was decreased with increasing peak current value as can be seen in Figs 3 and 4. The wire tension and gap voltage were not exhibited the significant effect on the surface roughness. The best surface roughness values were obtained with the highest wire tension, lowest peak current and spark gap voltage values used in the experiments. Wire tension variable is a gram-equivalent load with which the progressively fedwire is kept under tension so

that the wire remains smooth between the wire guides. Hence, surface roughness was improved with the increasing wire tension value. Generally, roughly surface roughness values were measured at all machining parameters and surface roughness values were obtained in between 4.336 µm and 6.434 µm. This can be attributed to increasing built – up edge (BUE) formation and surface defects due to melting and solidifying aluminum material. The increasing wire tension value reduces the vibrations and deviations during the machining [23, 24]. The increase in peak current affects the roughness negatively because it increases the pulse discharge energy leads to higher cutting speed [1]. In addition, machined surfaces can deteriorate because cutting at high feed rate with increasing peak current value results in breakdown and retraction of the wire [25]. It was observed that the machined surface quality was decreased due to the increasing crater sizes depending on the spark gap voltage value [13]. Wire EDM test parameters and the measured surface roughness values were presented in Table III.

TABLE III. WIRE EDM PARAMETERS AND SURFACE MEASUREMENT RESULTS

Wire tension, Wt, (g)	Voltage, volt (V)	Peak current, amp (A)	Surface roughness, Ra (µm)
8	35	8	4.65
8	35	10	5.52
8	35	13	5.85
8	55	8	4.75
8	55	10	5.25
8	55	13	6.01
8	70	8	4.58
8	70	10	5.67
8	70	13	6.43
10	35	8	4.78
10	35	10	5.10
10	35	13	5.84
10	55	8	4.71
10	55	10	5.46
10	55	13	5.92
10	70	8	4.57
10	70	10	5.25
10	70	13	6.29
12	35	8	4.67
12	35	10	5.38
12	35	13	5.91
12	55	8	4.58
12	55	10	5.29
12	55	13	6.26
12	70	8	4.34
12	70	10	5.14
12	70	13	6.02

Wire EDM is a non-contact thermal machining process using electric sparks producing intense heat with high temperatures to cut the workpiece leaving kerfs. The electric sparks are take places in the dielectric of deionized fluid between the wire and workpiece. The dielectric fluid behaves as a coolant and decontaminates the materials particles from the machining zone. Hence, the higher temperatures can be controlled and localized in the dielectric fluid. However, it was observed that crater formation on the machined surface due to the higher temperatures during the cutting process of aluminum alloy. The reason for the higher surface roughness values in wire EDM process of aluminum may be due to the melted and rapidly solidified aluminum caused to the surface defects on the machined surface.

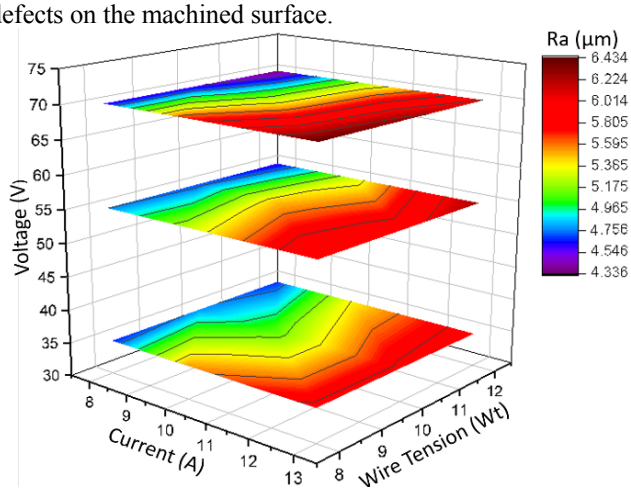

Figure 3. The effect of machining parameters on surface roughness

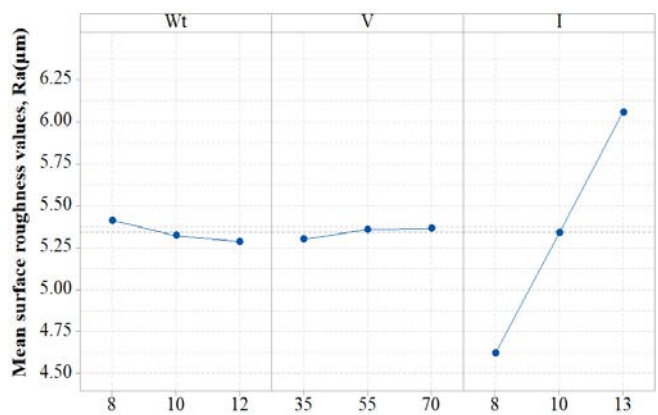

Figure 4. The effect of wire EDM parameters on surface roughness

Surface defects and cracks can be seen on the on the cutting line of the specimen different from the main structure in Fig. 5. In the cracked region, it was seen a layer that is exposed to very high temperatures and rapidly cooled and solidified from the melt state. This layer is untempered martensite and leads to a brittle surface layer formation called "white layer", which is very sensitive to rapid heating and cooling processes and thermal stress cracks [26]. As can be seen from the Fig. 5 (c), firstly a vertical crack was occurred and then flowed the dielectric fluid from the penetrated this vertical crack. Hence, a horizontal crack parallel to machined surface was created depending on the vertical crack. Wire EDM is a very sophisticate process due to the quick heating, cooling and random electrical sparks [21]. Stronger electric sparks are generated with increasing peak current values leading to the molten aluminum. The dielectric fluid could not remove continuously the molten aluminum from the machined surface, and then it is welded to the base material as a built up edge formation. These melting and cooling particles on the machined surface led to

surface damage in the form of surface crack depending on the peak current. Increasing peak current was increased the electrical discharge energy during the process and reduced the machined surface quality. Therefore, the peak current has remarkable influence on the surface roughness as shown in Fig. 4. Therefore, the vertical crack and later on horizontal crack formation may be attributed to the higher thermal and tensile stress due to the increasing pulse energy during the wire EDM process.

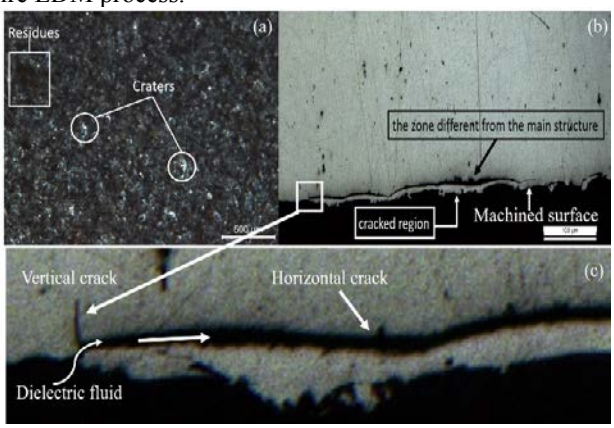

Figure 5. Machined surface texture of the specimen (a) and cutting line (b), higher magnification of the vertical and horizontal cracks (c)

The influence of wire EDM parameters on surface roughness were evaluated using mean effect plot and analysis of variance (ANOVA) results (Table IV). The wire tension and spark gap voltage parameters were not indicated a meaningful effect on the surface roughness according to the *P* and *F* values at the 95% confidence level.

TABLE IV. RESULTS OF ANOVA FOR WIRE EDM

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Ratio
Wt	1	0.071	0.071	2.00	0.170	1%
V	1	0.020	0.020	0.57	0.458	0%
I	1	9.155	9.155	258.34	0.000	91%
Error	23	0.815	0.035			8%
Total	26	10.062				

From the ANOVA results and mean effect plot, it can be seen that the most significant cutting parameter for surface quality, with a percentage influential ratio of 91% was the peak current value. At the base of the full factorial experimental results, regression analysis was used to develop a prediction model for surface roughness during wire EDM of AA 7075. The predictive surface roughness equation obtained from a linear regression model is given below and R^2 value was calculated as 91.9% for surface roughness.

$$\mathrm{Ra}\ (\mu\mathrm{m}) = 2.626 - 0.0314 * \mathrm{Wt} + 0.0019 * \mathrm{V} + 0.283 * \mathrm{I}$$
$$\mathrm{R-sq} = 91.90\%$$

Confirmation experiments were performed at random intermediate machining parameters to verify the surface measurement results and regression model. The measured surface roughness values obtained from the verification tests and predicted surface roughness values calculated by regression model were given in Table V. It was seen that a good agreement between the confirmation test results and predicted values and prediction performance of the regression model was computed as 96.4%

TABLE V. RESULTS OF ANOVA FOR WIRE EDM

Wire tension, Wt, (g)	Voltage, volt (V)	Peak current, amp (A)	Measured, Ra (µm)	Predicted, Ra (µm)
8	60	12	5.66	5.88
10	40	10	5.10	5.21
10	60	12	5.64	5.82
12	40	10	4.98	5.15
12	60	12	5.46	5.75

IV. CONCLUSIONS

In this study, AA 7075 sheets were cut in wire EDM and the effect of cutting parameters on surface roughness. The effect of wire EDM parameters on machined surface during the wire EDM process was studied. The reason of crack formation and surface defects were also investigated based on the cutting variables using the optical image. The experimental results can be summarized as follow:

- Surface roughness was not affected significantly from the wire tension and spark gap voltage values. However, the surface quality was improved with increasing wire tension values.
- It was observed that the peak current value was the most significant wire EDM parameter on the surface roughness and the best surface quality was obtained at lower peak current values.
- The electric sparks were caused to reduced surface quality due to the soft structure of the aluminum at higher peak current values. Crater formation, melted and solidified aluminum residues were observed on the machined surface.
- A non-continuous crack formation parallel to the machined surface was observed on the cutting line of the workpiece depending on the high cutting temperature and rapid cooling.
- Generally, higher surface roughness values were measured at all cutting experiments due to the surface defects on the machined surface of aluminum alloy.

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