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Effect of Multi-wall Carbon Nanotubes with Different Volume Fractions on Surface Roughness in Electro Discharge Machining

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Abstract

In this study, effect of multi wall carbon nanotubes with different volume fraction on surface roughness in Electro Discharge Machining (EDM) has been investigated. Multi-wall carbon nanotubes are added to the dielectric used in the EDM process to improve its performance when machining the AISI D2 tool steel, by means of copper electrodes. Design of the experiment was chosen as full-factorial. Statistical analysis has been done to experimental data and then appropriate model was extracted. The experimental results show that with dispersing of carbon nanotubes in dielectric with volume fraction of 0.1%, surface roughness decreased about 1μm and approximately 15 percent. Also by mixing carbon nanotubes in dielectric with volume fraction of 0.2%, surface roughness decreased about 1.4 μm and approximately 20 percent. These indicate the good performance of using carbon nanotubes in dielectric.

Keywords: Electro Discharge Machining, Multi-wall Carbon Nanotubes, Surface Roughness, Volume Fraction

1. Introduction

In recent years, the research field of electro discharge machining has divided into four areas[1]:

- Development of electro discharge machining including hybrid machining, process applications and...
- Improvement of performance scale covering surface quality, material removal rate, electrode wear ratio and …
- Process observation and control including frequency, artificial intelligence, time and pulse domain and...
- Optimization of process variables which involves electrode design and manufacture, electrical and non-electrical parameters and …

In this regard, Mr. Yang and his colleagues in 2009 studied the influence of input parameters such as voltage, pulse on-time and off-time on surface quality and volumetric material removal rate in two stages of roughing and surface finishing by hybrid model (combination of a mathematical approach with neural network). They could optimize EDM machining conditions in order to achieve the desired surface quality and material removal rate[2].

In the same year, Mr. Sameh and his colleagues investigated the effect of EDM machining parameters on electrode wear ratio, volumetric material removal rate and surface quality by using response surface methodology. They developed a mathematical model based on which they could achieve appropriate level of electrode corrosion, volumetric removal rate and surface quality by varying parameters such as voltage, pulse on-time and peak current[3].

In 2011, Mr. Siddver and colleagues published a review of research conducted in the field of nanotechnology and studied its significant role in various industries[4].

In 2011 Mr. Nam and his colleagues published research upon which they examined volume fraction of nanofluid on micro-drilling. According to this research

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amount of 1% nanofluid in terms of tool wear was more effective than the amount of 2% volume fraction[5].

In 2012 Kalita et al. published a study according to which nanofluid was used for cooling during grinding. They took advantage of MoS_2 nanofluid in shear fluid, in this case much better conditions were provided compared to near dry and wet situations in terms of machining[6].

In this study, effect of various electro discharge machining parameters such as peak current and pulse on-time on surface roughness have been investigated by using normal kerosene and also its mixture with carbon nanotubes volume fractions of 0.1 and 0.2 on the electro discharge machining steel AISI D2.

2. Procedure

In this section, there will be a brief description of the equipment and material used to carry out the EDM experiments. Also, the design factors used in this work will be outlined.

2.1. Selected Materials

AISI D2 steel was selected as a tool material. It is an air hardening, high-carbon, high-chromium tool steel. It has high wear and abrasion resistant properties. AISI D2 steel's high chromium content gives it mild corrosion resisting properties in the hardened condition. Typical applications for AISI D2 Steel: Stamping or forming Dies, punches, Forming Rolls, Knives, slitters, shear blades tools and scrap choppers. A new set of instrument (electrode (tool) and workpieces) for each experiment has been used. Main properties are summarized in Table 1.

The used dielectric in this study is kerosene. Among nanoparticles, multi-wall carbon nanotubes were selected due to their high thermal conductivity and excellent heat transfer capability, thereby a large amount of heat will be removed from machining area. These particles containing volume fractions of 0.1% and 0.2% disperse in kerosene by ultrasonic bath. Table 2 shows the properties of these particles.

Table 1. Details of Workpiece and Tool

Electrode	Workpiece
Copper Dimension: cylindrical shape with a diameter of 10mm (8.9×8.9×25mm)	Cold Work Steel : DIN 1.2379 Composition—C: 1.53 %; Cr:12%;Mo: 0.85%; V: 0.85%; Mn: 0.4%; Si: 0.35%; rest iron Dimension: cylindrical shape with a diameter of 40mm (40mm×40mm×5 mm)

2.2. Equipment Used in the Experiment

The arithmetic surface roughness was measured on the machined surface by using the Diavite-compact model. The accuracy of this equipment was 0.001 microns.

Die-sinking EDM machine used in this experiment was Pishtazan manufactured by Iran. The photograph of die-sinking EDM set is shown in Figure 1.

2.3. Design of the Experiment

The main parameters affecting the electrical discharge machining process are spark current, pulse on-time, pulse off-time and spark voltage[3,8]. In this study, the design of experiment is carried out by full-factorial methodology through Minitab software and also effect of most important machining parameters, namely spark current (I) and pulse on-time (T_{on})[2,8] on surface roughness is evaluated. The immersion method was selected for dielectric and also the electrode and workpiece were considered negative

Table 2. Properties of used Carbon Multi-wall nanotube

Multi walled nanotubes (MWNTs)
Purity: ≥98 wt %(carbon nanotubes)
Outside diameter: 5-15 nm
Inside diameter: 3-5 nm
Length: 50μm (TEM)
SSA: 233 m2/g (BET)
Color: Black
Ash: ≤1.5wt %(TGA)
Manufacturing method: CVD

Figure 1. Die-sinking EDM set.

and positive respectively. In this experiment, the removal process is done on 0.2mm workpieces by the electrode.

Table 3 shows how to perform experiment and parameters calibration.

Then the same experimental conditions are repeated for multi-walled carbon nanotubes with volume fractions of 0.1 and 0.2 dispersed in dielectric, in this way one can observe the effect of multi-wall carbon nanoparticles on the surface roughness. A total 27 experiments are carried out and each one repeats at least two times and eventually 54 tests are done.

Finally, the effect of input machining parameters on output parameters is observed through dielectric with different volume fractions of carbon nanoparticles then it is compared with normal dielectric and eventually the optimal model is presented.

In the measurement stage, the sampling length (L_c = 0.8mm), measuring length (L_m = 3.2 mm) and traverse length (L_t = 4.8 mm) are taken, respectively. Surface roughness (R_a) that occurred on each part as a result of each EDM experiment was measured three times and its average value was calculated.

3. Result and Discussion

All of the 27 surface roughness measured as a result of the EDM based on parameters such as the discharge current, pulse on-time have been indicated in Table 4.

Table 3. Parameters Calibration

Dielectric	Kerosene
Current(I)	4,8,12 A
Pulse on-time(Ton)	35,75, 115 μs
Input voltage	50 V
Tool polarity	Negative

Table 4. EDM tests

No	I(A)	T_{on} (μs)	R_a(μm)	R_a(μm) volume fraction=0.1	R_a(μm) volume fraction=0.2
1	4	35	3.49	2.87	2.66
2	4	75	4.08	3.01	2.72
3	4	115	4.99	3.42	3.00
4	8	35	4.70	4.23	3.95
5	8	75	5.50	4.39	3.96
6	8	115	5.67	4.59	4.32
7	12	35	5.85	5.12	4.79
8	12	75	6.00	5.13	4.93
9	12	115	6.12	5.45	5.20

Statistical analysis was conducted through the software Minitab on the obtained results from conventional dielectric, dielectric with carbon nanoparticles volume fraction of 0.1% and also volume fraction of 0.2%. In case of R^2 (adj)>0.950 and R^2>0.950, the statistical analysis done on the data indicates that the regression model is correct[7].

3.1. Statistical Analysis Results of Conventional Dielectric

Table 5 shows the values of $R^2$and R^2 (adj) in regression models on surface roughness.

According to Table 5, it can be concluded that the second order regression model has less error compared to first order regression model and that is the first order regression model is not acceptable. Therefore, the second order regression is recommended for the conducted experiment. Equation obtained from the regression model is as follow:

$$R_a = 0.509 + 0.571 I + 0.0321\ T_{on} - 0.0126\ I^2 - 0.000035\ T_{on}^{\ 2} - 0.00192\ IT_{on} \qquad (1)$$

To test the above equation, it was considered that I=10A and T_{on}=75μs. The value of surface roughness obtained by the equation is 6.18μm and experimental value of surface roughness is 5.89μm and due to 4.9% error arising from equation the result is acceptable. Diagram of average roughness Ra has been plotted in terms of current and pulse on-time. Figure 2 represents the average roughness Ra of the conventional dielectric in terms of EDM machining parameters (peak current (A), pulse on-time (μs)).

According to Figure 2, by increasing parameters of current and on-time, the surface roughness increases so the surface quality decreases. Furthermore, the effect of spark current on surface roughness is greater than pulse on-time.

3.2. Statistical Analysis of Dielectric with 0.1% Carbon Nanotubes on Surface Roughness

Table 6 shows the values of R^2 and R^2 (adj) in regression models on surface roughness.

Table 5. The values of Regression Models

Regression models	Regression degree1	Regression degree2
R^2	0.918	0.988
R^2 (adj)	0.891	0.968

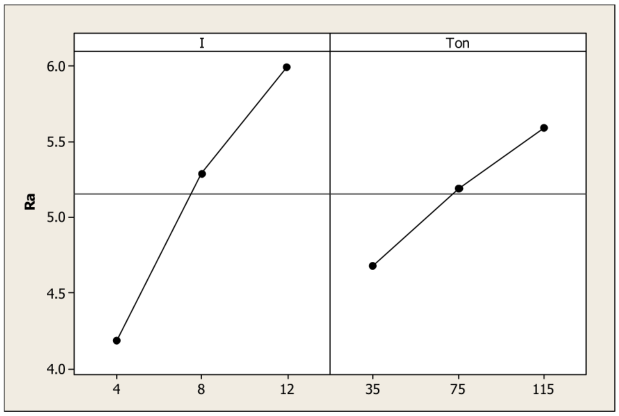

Figure 2. The average R_a of the Conventional Dielectric in terms of EDM Machining Parameters.

Table 6. The values of Regression Models

Regression models	Regression degree1	Regression degree2
R^2	0.979	0.999
R^2 (adj)	0.972	0.997

According to Table 6, it can be concluded that the second order regression model has less error compared to first order regression model. Thus, the second order regression is recommended for the conducted experiment. The equation obtained from the regression model is as follow:

$$R_a = 1.02 + 0.529\ I - 0.00177\ T_{on} - 0.0148\ I^2 + 0.000065\ T_{on}{}^2 - 0.000344\ ITon \quad (2)$$

To test the above equation, it was considered that I=10A and T_{on}=75µs. The value of surface roughness obtained by the equation is 4.80µm and experimental value of surface roughness is 4.96µm and due to 3.3% error arising from equation the result is acceptable.

Diagram of average roughness R_a has been plotted in terms of different current and pulse on-time. Figure 3 indicates the average roughness R_a of the dielectric with 0.1% volume fraction in terms of EDM machining parameters (current (A), pulse on-time (µs)).

According to Figure 3, by increasing parameters of current and on-time, the surface roughness increases so the surface quality decreases. Furthermore, the effect of peak current on surface roughness is greater than pulse on-time.

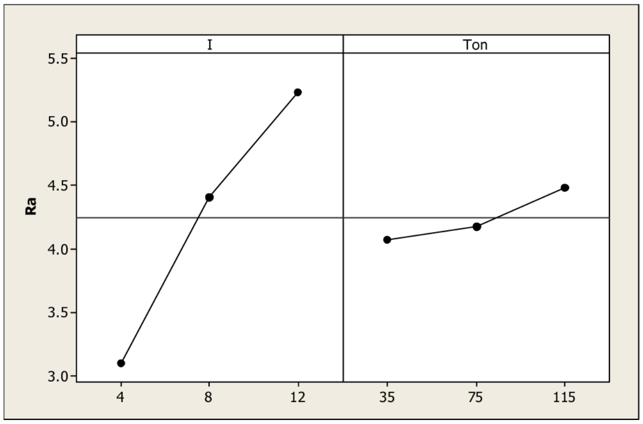

Figure 3. The average R_a of the Dielectric with 0.1% volume fraction in terms of EDM Machining parameters.

3.3. Statistical Analysis of Dielectric with 0.2% Carbon Nanotubes on Surface Roughness

Table 7 shows the values of R^2 and R^2 (adj) of the regression models on surface roughness.

Considering Table 7, it can be indicated that the second order regression model has less error in comparison with first order regression model. Thus, the second order regression is recommended for the conducted experiment. The equation extracted from the regression model is as follow:

$$R_a = 1.17 + 0.458I - 0.00715T_{on} - 0.0121I^2 + 0.000073T_{on}{}^2 + 0.000109IT_{on} \quad (3)$$

To check the above equation, it was considered that I=10A and T_{on}=75µs. The value of surface roughness obtained by the equation is 4.47µm and experimental value of surface roughness is 4.40µm and relation indicates about 1.5% error which is acceptable.

Graph of average roughness, R_a has been plotted in terms of different values current and pulse on-time. Figure 4 indicates the average roughness R_a of the

Table 7. The values of Regression Models

Regression models	Regression degree1	Regression degree2
R^2	0.980	0.998
R^2 (adj)	0.970	0.998

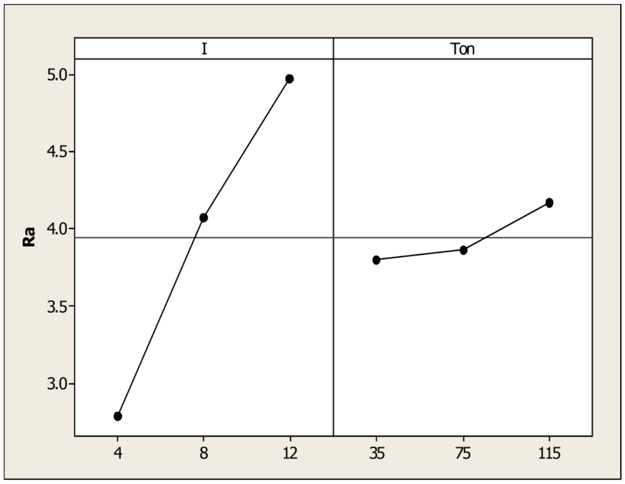

Figure 4. The average R_a of the Dielectric with 0.2% Carbon nanotubes in terms of EDM Machining parameters.

dielectric with 0.2% volume fraction in terms of EDM machining parameters (current (A), pulse on-time (µs)).

According to Figure 4, by increasing parameters of current and on-time, the surface roughness increases so the surface quality decreases. Furthermore, the effect of spark current on surface roughness is greater than pulse on-time.

3.4. Comparison of Surface Roughness in case of using Conventional Dielectric, Dielectrics with Carbon Nanotubes Volume Fractions as High as 0.1% and 0.2%

Effect of certain types of dielectrics on surface roughness according to different performed experiments has been shown in Figure 5. As can be seen in the following figure, the resulting effect of adding carbon nanotubes to dielectric on surface roughness is greater than just increasing the volume fraction.

Considering Diagram 5, and using point to point calculations through 0.1% nano dielectric, the surface roughness is about 1µm and decreases by 15% and also by using 0.2% nano dielectric, the surface roughness is around 1.4µm and decreases by 20%, indicating good performance of carbon nanotubes application in a dielectric.

4. Conclusion

In this study, the effect of various parameters of electro discharge machining (such as peak current and pulse on-time) on surface roughness has been investigated. Multi-wall carbon nanotubes are added to the dielectric used in the EDM process to improve its performance when machining the AISI D2 tool steel, by means of copper electrodes. Suitable regression models with low percentage error were achieved. By using these models one can calculates surface roughness.In this way the traditional methods of trial and error can be removed. By application of 0.1% nano dielectric, the surface roughness would be about 1µm and decreases by 15%; also by using 0.2% nano dielectric, the surface roughness is around 1.4µm and decreases by 20%, showing good performance of carbon nanotubes application in a dielectric.

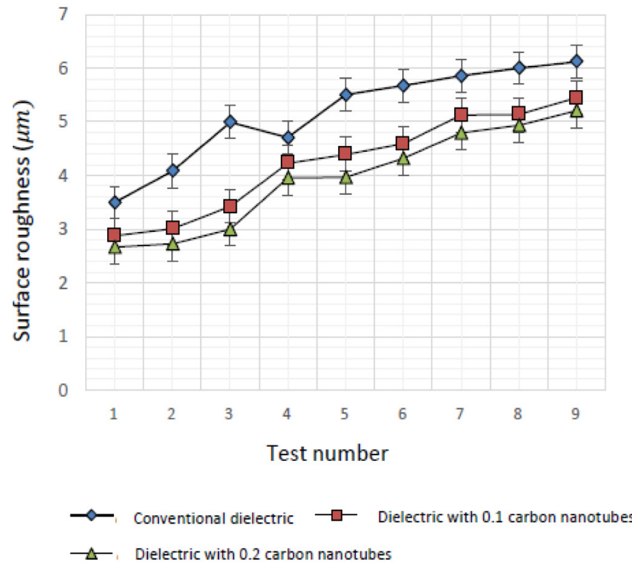

Figure 5. Diagram of surface roughness for different dielectrics.

5. Acknowledgement

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