Experimental Investigation of the Effect of Deionized Water on Surface Roughness of Near Dry Electro Discharge Machining of AISI D2 Steel

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Abstract
The electro discharge machining (EDM), one of the methods used in the machining industry and a non-traditional manufacturing method, the electro erosion process does not depend on the hardness of material and offers a way to process materials of very complex geometry with very fine and high precision by using cheap electrode materials, which make it a preferred method.
In this study, effect of wet and near dry EDM has been investigated. Design of the experiment was chosen as full-factorial. Experimental data has been statistically analyzed and then appropriate model was extracted. The experimental results show that surface roughness decreases by increase of peak current and also pulse on-time; it should be mentioned that effect of peak current on surface roughness is greater than pulse on-time. Also by using near dry machining (NDM), surface roughness decreased about 1µm and approximately 15 percent. These indicate the good performance of NDM.

Keywords
Electro discharge machining, Deionized water, Surface roughness

1. Introduction

The fundamentals of electro discharge machining (EDM) can be traced as far back as 1770, when English chemist, Joseph Priestly, discovered the erosive effect of electrical discharges or sparks. However, it was only in 1943 at the Moscow University that Mr. and Mrs. Lazarenko exploited the destructive properties of electrical discharges for constructive applications [1].
The EDM method is one of the methods used in the machining industry and a non-traditional manufacturing method. The electro erosion process does not depend on the hardness of material and offers a way to process materials of very complex geometry with very fine and high precision by using cheap electrode materials, which makes it a preferred method [2].
The selection and delivery of the dielectric fluid are critical to the material removal rate, surface roughness, and environmental impacts of electro discharge machining. Dielectric fluid acts as an electrical insulation barrier in the gap between the workpiece and electrode. Deionized water and kerosene-based oil are two commonly used dielectric fluids in conventional wet EDM [3-5].
The near-dry EDM process is a process in which a mixture of gas and liquid is used as dielectric. Mostlya tube-shaped tool is used and the dielectric at high speed is sprayed through the hole in the

tool on the workpiece surface, and with establishing electrical current between the tool and workpiece, machining operations is conducted [6].

Near-dry EDM was reported by Tanimura et al. in 1989 for the first time [7]. Tao et al. [8] studied near dry EDM milling as a finishing process. They added an electrical resistance to EDM power generator to be able to reduce the surface roughness. They investigated the effects of dielectric fluid, tool materials and pulse energy on material removal rate (MRR) and surface roughness (SR).

Fujiki et al. [9] investigated the effects of dielectric fluid flow rate on MRR, tool wear ratio (TWR), and SR in near dry EDM milling process. They also developed a computational fluid dynamics (CFD) model to predict the dielectric fluid flow rate and compare with the information measured by experiments.

Fujiki et al. [10] established a new gap control strategy for five-axis near-dry EDM milling. This new strategy is capable of retracting the electrode in its axial direction. Their results showed that MRR is increased 30% by applying this strategy.

The near dry EDM experimental setup and procedures are presented first in this paper. The mixture of deionized water and air is experimented as the dielectric fluid for near dry EDM. The surface roughness envelopes in near dry EDM are compared with wet ED Mof AISI D2 steel.

2. Methods

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 and 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 are: 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 deionized water.

Table 1. Details of workpiece and tool

Electrode	Workpiece
Copper Dimension: cylindrical shape with a diameter of 15mm (15×30mm)	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 50mm (50mm×50mm×5 mm)

2.2 Used equipment 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. The photograph of this machine is shown in Figure1.

Figure1. The measuring surface roughness machine

Die-sinking EDM machine used in this experiment was Pishtazan manufactured by Iran. The photograph of die-sinking EDM set is shown in Figure.2.

Figure2. Die-sinking EDM set

The equipment utilized to control the MQL was RSK100 (manufactured by Royal Sanat Khavaran Co., Iran) in which oil supply pumps are used. In this system, the compressed air and deionized water flow can be adjusted separately and mixed in the nozzle to make micro-droplets of deionized water, fly to the gap zone by compressed air. The photograph of MQL set is shown in Figure 3.

Figure3. MQL set

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 [11, 12]. 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}) [12] on surface roughness are evaluated. The immersion method was selected for dielectric and also the electrode and workpiece were considered negative and positive respectively. In this experiment, the removal process is done on 0.5mm workpiece by the electrode. Table 2 shows how to perform experiment and parameters calibration.

Table2. Parameters calibration

Dielectric	Deionized water
Current(I)	4,8,12 A
Pulse on-time(Ton)	50,100, 150 μs
Input voltage	40 V
Tool polarity	Negative

The MQL needs to be supplied at high pressure and impinged at high speed through the nozzle at the cutting zone. Air pressure of MQL is 3 bar and distance of nozzle to tip tool is 50mm and the mount of lubricant in MQL is gotten 300 ml/h in this experiment.

A total 18 experiments are carried out and each one repeats at least two times and eventually 36 tests are done. Finally, the effect of input machining parameters on output parameters is observed through dielectric with NDM, then it is compared with wet machining 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 18 surface roughnesses measured as a result of the EDM based on parameters such as the discharge current and pulse on-time have been indicated below, in Table 3.

Table3. EDM tests

No	I(A)	T_{on} (μs)	R_a(μm) Wet Machining	R_a(μm)NDM
1	4	50	3.49	2.87
2	4	100	4.08	3.01
3	4	150	4.99	3.42
4	8	50	4.70	4.23
5	8	100	5.50	4.39
6	8	150	5.67	4.59
7	12	50	5.85	5.12
8	12	100	6.00	5.13
9	12	150	6.12	5.45

3.1 Statistical analysis results of wet EDM and NDM

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 [1].Table 4 shows the values of $R^2$and R^2 (adj) in regression models on surface roughness for wet EDM.

Table4. The values of regression models

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

According to Table 4, it can be concluded that the second order regression model has less error compared to the first order regression model and Thus, 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:

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

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 R_a has been plotted in terms of current and pulse on-time. Figure 4 represents the average roughness R_a of the conventional dielectric in terms of EDM machining parameters (peak current (A), pulse on-time (μs)).

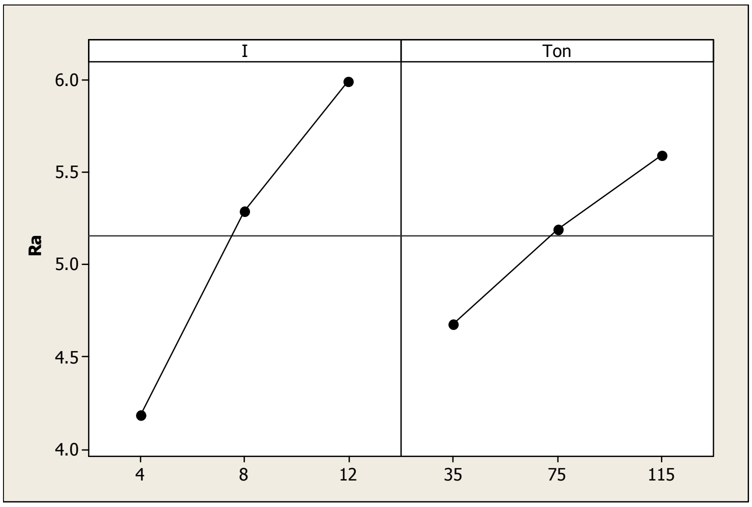

Figure4. The average R_a of the wet EDM

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

Table5. 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 5, it can be concluded that the second order regression model has less error compared to the 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:

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

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 5 indicates the average roughness R_a of NDM.

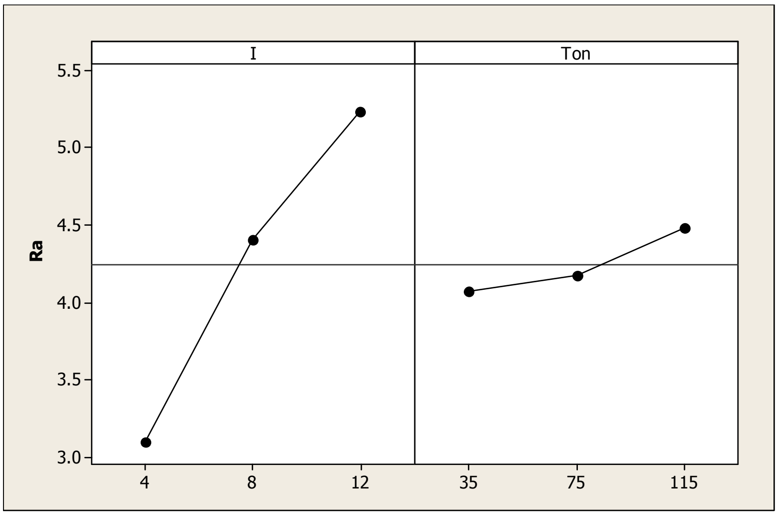

Figure5. The average R_a of the NDM

According to Figure 5, 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.

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. NDM and wet EDM with deionized water have been done while machining the AISI D2 tool steel, by means of copper electrodes. A full-factorial experiment was designed and statistical analysis was applied to experimental data and then appropriate model was extracted and the following results were obtained:

1. 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 will be removed.
2. In different cases, surface roughness decreases by increase of peak current and also pulse on-time and it should be mentioned that effect of peak current on surface roughness is greater than pulse on-time.
3. By applyingNDM, the surface roughness would be about 1μm and decrease by 15%, showing good performance of NDM.

5. References

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