Influence of Additive Alumina Nanopowder on Surface Roughness During WEDM Process

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Abstract. The present paper focuses on the wire electrical discharge machining (WEDM) of titanium alloys. It can be considered as an attempt to develop two dielectrics in the WEDM significantly affects the efficiency of machining. This paper explores surface ruggedness during the processing of titanium of various dielectric fluids, including demineralized water and dielectric alumina. The findings show that dielectric alumina as a dielectric produces decreased ruggedness on the surface. Also, surface ruggedness is better for demineralized water as the dielectric powder is mixed with non-conductive alumina powder. Many dielectric liquids show that surface ruggedness decreases. Alumina powder and ethylene glycol to dielectric water. A comparative surface roughness analysis for different dielectric fluids was also performed. Using surface roughness to analyze surface roughness is further studied. Conducting a further investigation to use the response surface method (RSM) on surface integrity in each type of the dielectric with the help of better. Hence, WEDM is performed on Ti-6242 to use the designer expert 10 to analysis ANOVA RSM titanium and varying dielectric fluids. From the findings, it is noted that combining non-conductive alumina powder and demineralized water has a significant impact, which decreased of WEDM machined surface of Ti-6242.

Keywords. Alumina nanopowder, Ti-6242, ANOVA, RSM.

1. Introduction
The materials engineering is from complex disciplines in the science of engineering branches, especially mechanical engineering, where the path of mechanical engineering study the characteristics of materials of various types, especially those that contain high hardness and excellent strength and resistance to the impact of weight and lightweight and excellent corrosion resistance. Moreover, the in-depth study of such materials requires careful attention. Examples of such materials are composites of alloy-ceramic, alloy-materials and/or hard-materials such as Tungsten-Carbide, titanium, etc., all are evolving to meet the daily life demands. One of the most important materials used in mechanical engineering is the titanium due to its highest-strength regarding the weighted ratio compared to all other metals. Due to the hardness of titanium compared to other materials, the feeding rate of the milling machine will have a thickness of about half the thickness of the feeding rate, which makes it difficult to operate the machine in the preparation of traditional machines compared to aluminum or steel. Another reason is that the tool that cut
them generates much more heat than aluminum or steel compared with titanium. This heat will also work on the heat treatment of titanium, making it more complicated than the carbide cutting tools, thus breaking the tool. We want to point out that in the solid-state, titanium hardness will be similar to stainless steel. All these reasons provide a platform for the current research to use titanium as a material that can be manufactured by the process of cutting the vacuum wire. Dielectric employed in WEDM plays a critical role, especially in micro-WEDM, which is employed in the machining of microparts. Electrode gap and feed rate during micro-EDM are minute, and properties of the into kerosene combined with aluminum, kerosene improves the depth of the substance removal. Using aluminum or SiC with kerosene effectively increases the distance between the electrode and the workpiece and disperses the released energy to improve surface ruggedness.

Previous studies suggest that the application of powder to kerosene is stronger than the application of SiC [1]. The application of surfactants, such as graphite, decreases dielectric fluid surface tension, which increases the material removal rate. Surface roughness and refractive layer thickness have been increased, and also the tools wear rate (TWR). Besides, the increased concentration contributes to an initial rise in the thickness of the recast layer, which is subsequently reduced [2]. Various wire electrodes, such as brass wire, zinc-coated wire, and diffused coated wire, are also used. The coated wire is received better surface finishing and minimum brazing width [3], [4]. The medium use of oxygen gas is synergistic to splashes with oxidation and better metal removal and processing rate performance [5].

Oxygen gas results in internal electric gap expulsion and has beneficial effects on process levels [6]. Air, in addition to oxygen, results in higher working levels than nitrogen due to the presence of O2 gas in the air. The presence of oxygen, however, often impairs surface quality and measurement accuracy. The gas generated by nitrogen (N2) gives a lower working speed compared to other gas media [7], [8]. There are often numerous desirable responses that contradict each other with changes in some parameters. Besides, to increase the surface finish, it is useful to add some nanopowders in the dielectric fluid (lower surface roughness) [9]. Added powder stabilizes the discharge flow and improves main factors such as surface finish, corrosion, and wear resistance (WR).

Adding kerosene powders may induce kerosene to suspend and reduce the deviation from the discharge effect. Besides, the addition of Pullover into dielectric fluid also has a significant impact on micro slit machining employing machined energy from micro electric discharges. The fact that this area has not received much attention is generally accepted, and further efforts that support WEDM without any profit [10]. A variety of dielectric fluids for WEDM processes have been investigated in this paper. The experimental studies show that the reaction characteristics, e.g., surface, are decreased following adding dielectric and alumina powder suspension (with a decrease in roughness). Aluminum nanopowder preparation was made of a dielectric. There has been a contrast between the two surface rugged liquids, which have yielded promising results for improved rugosity of titanium metal.

2. Experiments and methods

The current experiment is a pilot study where MRR and SR are being studied to evaluate the performance of the SR with input configurations feed rate wire, wire tension, pulse on time, pulse stop time, and current-voltage for peak and voltage range. Four-axis El pulse 15 Electra has been tested on the EDM system. Figure (1) illustrates the experimental setup used with the EDM CNC machine. The electrode wire was used in copper plated with 0.25 mm diameter, and the deionized water was sterilized as the insulating fluid around the wire and lateral cleaning technique. The previous measurements are also described in Table (1).
Figure 1. Four-axis El pulse 15 electra WEDM

Table 1. The parameters and their range.

| Number | Parameter                  | Specific details | Specific details |
|--------|---------------------------|------------------|------------------|
| 1      | ON-TIME PULSE             | TON              | 120-130 (μs)     |
| 2      | OFF-TIME PULSE            | TOFF             | 50-60 (μs)       |
| 3      | PEAK-CURRENT              | IP               | 10-12A           |
| 4      | SPARK-GAP-SET-VOLTAGE     | SGSV             | 20-50V           |
| 5      | RATE OF WIRE-FEED         | RWF              | 2-5 m/min        |
| 6      | TENSION OF WIRE           | TW               | 2-5 μm           |

3. Numerical computations analysis
Table (2) shows the measured-values for SR responses, respectively, corresponding to BBD-design-matrix. Also, the effects of process-parameters on SR had been analyzed by the response-surface and contour-plots.

Table 2. Design matrix and output responses.

| Run | A: pon (μs) | B: poff (μs) | C: IP (A) | D: SPV | E: wf | F:wt | SR without Nano (μm) | SR with Nano (μm) |
|-----|-------------|--------------|-----------|--------|-------|------|----------------------|------------------|
| 1   | 125         | 60           | 11        | 35     | 1     | 1    | 2.44                 | 2.01             |
| 2   | 125         | 55           | 10        | 50     | 3     | 1    | 2.96                 | 2.87             |
| 3   | 125         | 55           | 12        | 20     | 3     | 5    | 3.17                 | 2.67             |
| 4   | 125         | 50           | 12        | 35     | 1     | 3    | 3.13                 | 2.81             |
| 5   | 130         | 55           | 12        | 35     | 3     | 5    | 3.17                 | 2.87             |
| 6   | 120         | 55           | 10        | 35     | 3     | 5    | 2.76                 | 2.58             |
| 7   | 125         | 55           | 10        | 20     | 3     | 5    | 2.67                 | 1.51             |
| 8   | 130         | 55           | 11        | 20     | 5     | 3    | 2.03                 | 1.76             |
| 9   | 130         | 55           | 11        | 20     | 1     | 3    | 2.04                 | 1.44             |
| 10  | 125         | 50           | 11        | 35     | 1     | 1    | 2.96                 | 2.61             |
| 11  | 125         | 50           | 12        | 35     | 5     | 3    | 2.83                 | 2.53             |
| 12  | 125         | 55           | 11        | 35     | 3     | 3    | 2.45                 | 2.15             |
| 13  | 125         | 55           | 10        | 50     | 3     | 5    | 2.72                 | 2.52             |
| 14  | 125         | 55           | 11        | 35     | 3     | 3    | 2.66                 | 2.35             |
| 15  | 120         | 55           | 11        | 20     | 1     | 3    | 2.04                 | 1.44             |
| 16  | 130         | 60           | 11        | 50     | 3     | 3    | 2.34                 | 2.05             |
| 17  |             |              |           |        |       |      | 2.96                 | 2.71             |
| 18  |             |              |           |        |       |      | 2.18                 | 1.88             |
| 19  |             |              |           |        |       |      | 2.96                 | 2.76             |
| 20  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 21  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 22  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 23  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 24  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 25  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 26  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 27  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 28  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 29  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 30  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 31  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 32  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 33  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 34  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 35  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 36  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 37  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 38  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 39  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 40  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 41  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 42  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 43  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 44  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 45  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 46  |             |              |           |        |       |      | 2.91                 | 2.71             |
| 47  | 125         | 60           | 10        | 35     | 1     | 3    | 2.31                 | 2.11             |
| 48  | 125         | 55           | 12        | 20     | 3     | 1    | 2.96                 | 2.71             |
| 49  | 120         | 55           | 11        | 50     | 1     | 3    | 2.18                 | 1.88             |
| 50  | 130         | 55           | 12        | 35     | 3     | 1    | 2.96                 | 2.76             |
| 51  | 125         | 50           | 10        | 35     | 5     | 3    | 2.91                 | 2.71             |
| 52  | 125         | 55           | 11        | 35     | 3     | 3    | 2.66                 | 2.38             |
| 53  | 120         | 50           | 11        | 20     | 3     | 3    | 2.89                 | 2.31             |
| 54  | 125         | 60           | 11        | 35     | 5     | 5    | 2.74                 | 2.44             |
3.1. Surface roughness analysis of the model tools without nanopowder

The roughness of the surface and its processing is one of the most important criteria for the process. In this process, the state of the surface to be formed is determined, and this process is the most important of these steps. It should be mentioned that the working materials should be graded at low material removal levels if the surface roughness of the working material is the most relevant and definitive factor. The variance-analysis is given in Table (3); during the preparation of the form, in-significant-terms are eliminated by default. Values of “Prob> F” below 0.05 indicate that the formation conditions are important at a 91% confidence level. In addition to this normal piece of residue, the remaining residues, as opposed to the forecast, were also drawn, as shown in Figures (2) to (4). On the other hand, most residue falls in a straight line, leading to errors that are distributed in normal behavior. The results also prove that the regression-model is well-fitted with observed values. The results and charts showed that the expected and observed values that the analysis can find them sufficient to determine a real-functional relation among them input-parameters and surface-roughness. The model can be recognized their importance from F which is 21.98, and the p-value, which is < 0.05; this means that there is a 0.01% chance only because F is a higher value, which may occur due to noise. In SR-case, there are five factors namely; A, B, C, E, and F contribute nearly 87% of the total variation in the response data. After the surface-equation represents the specific relation among surface-roughness and process-coefficients.

The surface-equation responsible for determining the relation between surface-roughness and process-factors is obtained.

\[
\text{SURFACE ROUGHNESS} = +2.47 - 0.14 \times A - 0.13 \times B + 0.18 \times C + 0.055 \times D + 0.036 \times E - 0.047 \times F + 0.13 \times AC + 0.086 \times AF + 0.095 \times BC + 0.20 \times BF + 0.056 \times CF + 0.085 \times EF - 0.084 \times A^2 + 0.18 \times B^2 + 0.31 \times C^2 - 0.23 \times E^2 + 0.16 \times F^2
\]

(1)
Figure 2. Normal probability plot for residuals of surface-roughness.

Figure 3. Actual against predicted surface roughness.
3.2. Surface roughness analysis of the model tools with nanopowder

The contour plots and the 3-D response surface have been developed according to the model for method parameters effect on SR. Through the study, changes in the addition of nanopowder to dielectric indicate a change in the rate of surface roughness, and the obtained values are shown in Table (4). The capacity of the model was achieved using ANOVA and tested at a 93% level of confidence, the results in Table (4).

In addition to this normal piece of residue, the remaining residues were also drawn, as shown in Figures (5) to (7). Most residue falls in a straight-line. The results also prove that the regression model is well-fitted with the observed values. The results and charts showed that the expected and observed values that the analysis is sufficient to determine a real functional relation among input-parameters and surface-roughness. The model can be recognized its importance from F value, which is 27.26, and the p-value. This means that there is a 0.01% chance only because F is a high value that may occur due to noise. In SR-case, there are five factors, namely, B, C, D, E, and F, which contribute nearly 83% of the total variation in the response data. The obtained surface equation represents the specific relation between surface-roughness and process-coefficients. The surface equation responsible for determining the relation between surface-roughness and process-factors is obtained.

A comparison of SR machined with different dielectric fluids is shown in Table 4. The data show that the surface finish within the selected WEDM parameters is better with the dielectrics. This is because of increased thermal stability, continuous machining, and shorter dielectric breakdown time lag [6]. Also, when machining is done under Al2O3 dielectric, the surface roughness is small compared to standard dielectric machining. This was due to the reason discussion previously, the surface roughness of the dielectrics Al2O3 is decreased. Titanium is stable at high temperatures and is vulnerable to oxidation by chromium. These results in a significant amount of reaction heat and get sensitized at temperatures above 600 °C. It was found that a reduction in the surface was provided when adding nanoparticles. This means that the dielectrics have a significant role to play in enhancing the surface roughness.

\[
\text{SURFACE ROUGHNESS = } +2.22-0.12* A -0.097* B+0.13* C +0.11* D +0.099* E-0.12* F-0.15* AB+0.19* AC+0.093* AF+0.16* BD+0.18* BF-0.37* CD-0.12* CE+0.063* CF+0.14* B2+0.30* C2-0.27* D2-0.18* E2+0.10* F2 \\
\]

(2)
Table 4. ANOVA for response surface of the reduced-quadratic-model.

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F |
|--------|----------------|----|-------------|---------|-----------------|
| Model  | 7.73           | 19 | 0.41        | 27.60   | < 0.0001 significant |
| A-pom  | 0.35           | 1  | 0.35        | 23.60   | < 0.0001         |
| B-poff | 0.23           | 1  | 0.23        | 15.34   | 0.004           |
| C-ip   | 0.43           | 1  | 0.43        | 29.11   | < 0.0001         |
| D-spv  | 0.29           | 1  | 0.29        | 19.99   | < 0.0001         |
| E-wf   | 0.24           | 1  | 0.24        | 16.00   | 0.0003           |
| F-wt   | 0.32           | 1  | 0.32        | 21.83   | < 0.0001         |
| AB     | 0.18           | 1  | 0.18        | 12.21   | 0.0013           |
| AC     | 0.28           | 1  | 0.28        | 19.07   | 0.0001           |
| AF     | 0.068          | 1  | 0.068       | 4.64    | 0.0384           |
| BD     | 0.20           | 1  | 0.20        | 13.89   | 0.0007           |
| BF     | 0.26           | 1  | 0.26        | 17.82   | 0.0002           |
| CD     | 1.09           | 1  | 1.09        | 73.76   | < 0.0001         |
| CE     | 0.11           | 1  | 0.11        | 7.17    | 0.0113           |
| CF     | 0.064          | 1  | 0.064       | 4.32    | 0.0452           |
| B²     | 0.20           | 1  | 0.20        | 13.72   | 0.0008           |
| C²     | 0.92           | 1  | 0.92        | 62.51   | < 0.0001         |
| D²     | 0.80           | 1  | 0.80        | 54.05   | < 0.0001         |
| E²     | 0.36           | 1  | 0.36        | 24.35   | < 0.0001         |
| F²     | 0.11           | 1  | 0.11        | 7.49    | 0.0098           |
| Residual | 0.50          | 34 | 0.015       |         |                 |
| Lack of Fit | 0.38      | 29 | 0.013       | 0.53    | 0.8711 not significant |
| Pure Error | 0.12     | 5  | 0.025       |         |                 |
| Cor Total | 8.24      | 53 |             |         |                 |

Std. Dev. 0.12 R-Squared 0.9391
Mean 2.25 Adj R-Squared 0.9051
C.V. % 5.39 Pred R-Squared 0.8617
PRESS 1.14 Adeq Precision 22.009

Figure 5. Normal probability plot for residuals of surface-roughness.
3.3. Comparison of surface roughness between the dielectric and nanopowder dielectric on titanium

From our point of view, and after conducting experiments, it was found that the nanopowder dielectric gives an improvement in the surface roughness of the titanium metal in machining. This proves the validity of the study, as presented in Table (5), which is showing the comparison between the two different dielectrics on the titanium alloy and the rate of improvement in roughness. Figure (8) shows the proportions and the roughness effect on titanium alloys, where a ratio was given when using a normal dielectric, it was estimated to be 0.885. As for using a nanopowder dielectric, a ratio was given to be 0.816.
Table 5. A comparison of surface roughness between the dielectric.

| Response | Dielectrically water without nanopowder | Dielectrically with Nanopowder |
|----------|----------------------------------------|--------------------------------|
| Surface Roughness | the SR increased with increasing of IP | the SR decreased with increasing of IP |
|            | in overall, an increased ton will increase SR | in overall, a decreased ton will increase SR |
|            | the lowest SR is 1.41(μs) (IP=10A pon=125(μs) al2O3=0 g/l) | the lowest SR is 1.39(μs) (IP=11A pon=130(μs) al2O3=2 g/l) |

Figure 8. Composite desirability for all responses.

4. Conclusion
The results showed that the used diverse dielectrics, such as deionized water and alumina, have a significant impact on micro-WEDM performance, such as surface efficiency. The dielectric rate with alumina (AL2O3) nanopowder decreases the surface roughness from (0.885) to (0.816) in the desirability. This is considered a good improvement in roughness. Thanks to the increased thermal stability, surface roughness is decreased with dielectric alumina. The roughness of the surface decreases when machining is done with dielectrics applied with alumina. Owing to electrolytic action, surface finishes are comparatively stronger with dielectric water mixture rather than dielectric suspensions.

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