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Experimental Investigations into Electro Discharge Machining of NiTi Shape Memory Alloys using Rotational Tool

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Electro discharge machining is one of the nontraditional machining procedures, which is used for machining the high strength and hardness materials. In this article, the impact of rotational tool and input parameters include; pulse current, pulse on time, voltage and pulse off time, on output parameters such as material removal rate, surface roughness and tool wear rate, in Nickel Titanium alloy with cupper electrode and de-ionized water dielectric has been investigated. Taguchi's design of experiment has been used for statistical analysis of the results. The obtained results indicate that regardless of rotational tool with the increase of pulse current, pulse on time and voltage, material removal rate increases as well. In addition, when the pulse off time increases, the material removal rate diminishes. When the rotational tool revolution is 200RPM, rotational EDM material removal rate decreases in comparison with the traditional EDM. The most important effect of the rotational EDM is on the surface roughness and tool wear. With the increase of pulse current, pulse on time and voltage, without any respect to the rotational tool, surface roughness increases. The surface roughness with rotational EDM is less than traditional EDM. In addition, with the rotational tool, the tool wear rate diminishes in comparison with the traditional EDM. The rotational EDM with 200RPM is led to less material removal rate and better surface roughness and tool wear.

Keywords: Electro discharge machining; Shape memory alloys; Smart materials; Material removal rate; Rotational EDM; Surface roughness; Nickel Titanium

1. INTRODUCTION

Considering the industry developments and improvement in production of new materials with better mechanical properties such as high hardness and strength, shape memory behavior, high corrosion resistance and etc., there are lots of problems with the traditional electro discharge machining (EDM) because of the direct contact of tools and work piece. These problems include; tool wear, high temperature, surface roughness and vibration. Nowadays, shape memory alloys are rapidly replaced with the traditional materials. Considering the increasing usage of mentioned alloys in various industries, specially military and aerospace industries, machining these alloys is highly important [1]. EDM is a non-conventional manufacturing process. In this process, the material is removed by erosive action of electric discharges occurring between a tool electrode and work piece based on the fact that no tool force is generated during machining. Both workpiece and tool electrode are submerged in a solution called dielectric as shown in figure 1. The mechanical characteristics of workpiece and electrode are not a concern because the electrical energy is converted into thermal energy causing melting of the material [2]. EDM process allows the machining of hard materials and more complex shapes which cannot be processed by other conventional methods. The EDM process is normally applied to mould and die making. Compared to conventional machining method, the material removal rate (MRR) of this machining remains rather low [3, 4]. EDM is a process of removing material in a closely controlled manner from an electrically conductive material immersed in a liquid dielectric by a series of randomly distributed discrete electrical sparks or discharges. Non-conducting materials cannot act directly on electrode to achieve EDM [5].

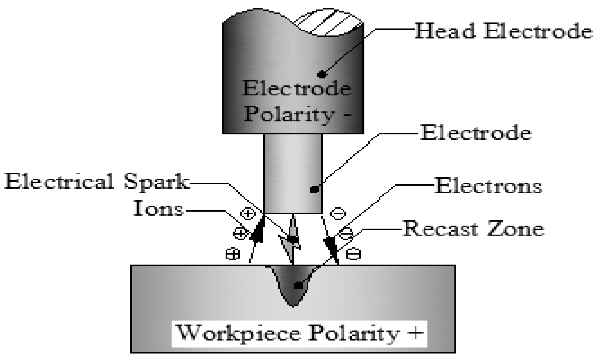


Figure 1. The schematic diagram of electro discharge machining [6]

Metal removal takes place as a result of the generation of extremely high temperatures generated by the high intensity discharges that melt and evaporate the two electrodes [7]. Shape memory alloys are a class of metallic alloys that display several unique characteristics, such as shape memory effects, Young’s modulus-temperature relations, and high damping characteristics. Unlike plastically deforming metals, the nonlinear deformation is metallurgically reversible. Large deformations can be recovered by either applying heat (shape memory effect) or by removing the stress causing the deformation (superelastic effect) [8]. There are two independent phases in shape memory alloys: martensite and austenite. The martensite phase has two stable structures: the twinned form and the deformed or de-twinned form. Martensite exhibits a rhombic geometry, and is more stable at low temperature and at high stresses. It also tends to be softer and more ductile. Austenite is highly symmetric and exhibits a body centered cubic geometry. It is more stable at high temperatures and low stresses, and tends to be harder and stronger. The most commonly used shape memory alloy is the binary NiTi alloy. This alloy has many valuable characteristics, including large recoverable strain capabilities, corrosion resistance, large hysteresis, stability, biocompatibility and exhibits excellent shape memory and super elastic functions [9, 10]. The main drawbacks to NiTi alloys are their high manufacturing cost and the fact that they are difficult to machining. Machining this kind of alloys with the traditional methods is very difficult and cost consuming because of their high strength and wear resistance. EDM is one of the significant solutions for these problems [11]. As the roughness and high resistance do not have any considerable effect on material removal efficiency in electro discharge machining, So many scientists use this method for machining different alloys. In 2001, Lee et al. investigated the impacts of input parameters of EDM process, such as electrode type, electrode polarity and open-circuit voltage, on tungsten carbide machining. They have concluded that the best performance of machining occurs when electrode and work piece are considered as cathode and anode respectively and the best electrode for tungsten machining is copper [12]. In 2008, Lin et al, by considering the electro discharge energy in EDM process, investigated the machining parameters and bending strength of tungsten carbide. It has been concluded that when the electro discharge energy increases, material removal rate, surface roughness and percentage of surface cracks significantly increase which are led to decrease the bending strength of work piece [13]. Yilmaz et al. in 2006, in order to simulate a model for relationship between input and output parameters of EDM process, prepared a fuzzy model for selecting machining parameters of AISI 4340. The optimum input parameters for mentioned work piece machining was obtained [14]. In this regard, researchers claimed that the tool vibration in electro discharge machining is an effective way in improving this process specification. In 1989, Kremer et al. demonstrated that the ultrasonic vibrations of the electrode significantly improve the material removal efficiency in steels machining [15]. Mrthy et al. in 1987 claimed that Integration of ultrasonic vibrations with copper electrode in electro discharge machining of steels is led to reduce the negative pulses considerably [16]. In addition, nickel and titanium alloys machining have been investigated as well. In 2009, Kibria et al. investigated the effects of different dielectric include; kerosene, deionized water and boron carbide (B_4C) powder suspended kerosene, on surface roughness and overcut between tool and work piece. In this research, tool and work piece was made from tungsten and titanium alloy respectively. They claimed that low intensity of electrical current is led to less overcut and when the electrical current increases, the overcut increases consequently and overcut as well as surface roughness prepared by deionized water are better than other dielectrics [17]. In 2004, Theisen and Schuemann explored the electro discharge machining with tungsten and copper electrode on nickel-titanium alloys. They claimed that current and voltage changes have some effects on cracks depth and surface roughness [18]. In 2007, Chen et al. investigated the impacts of machining on Ni Al Fe alloys. They concluded that material removal rate (MRR) has reverse relationship with alloy's melting temperature and thermal conductivity. They also investigated the effect of MRR on surface roughness and recast layer [19]. EDM of shape memory alloy like NiTi is investigated by Lin et al. this experiment is done on three types of shape memory alloys include; Ti49Ni49 -Ti50Ni50 - Cu10Ni40Ti50. By investigating the heat transfer coefficient of these alloys, it is cleared that the material removal rate has reverse relationship with multiplied by melting point and heat transfer coefficient of the material. In addition, by increasing the pulse time, material removal rate and tool corrosion increases as well and reach to their maximum values and then decreases. Due to differences in the crystalline and mechanical properties of the alloys, they have same EDM machining properties [20]. According to the investigations, there is not any special research on the effects of tool rotation on electro discharge machining parameters. So in this research, the impacts of tool rotation on electro discharge machining output parameters include; surface roughness, material removal rate and tool wear for NiTi shape memory alloy, are investigated.

2. EQUIPMENTS AND TEST METHODS:

In the current study, nickel titanium sample, with dimensions 50×60×20mm, is cut and grinded by wire EDM. The physical and mechanical properties of this alloy are shown in table 1. As nitinul have high hardness and wear resistance, machining with traditional procedures is time and cost consuming. In this experiment, copper electrode with dimensions 10×20mm is used. Copper electrode density is 8/93gr/cm$^{3.}$ The entire tests are done with Azarakhsh Tehran Ekram model machine 204H with iso frequency generator. Weight changes of electrode tool and work piece before and after machining are measured by AND digital scale model GR-300 with accuracy 0.0001. Surface roughness is measured by Mahr roughness tester model M300-RD18. In all tests, de-ionized water is used as dielectric due to have the minimum effect on NiTi smart alloy.

Table 1. Physical and mechanical Properties of NiTi [21]

Density	6.45 G/cc
Tensile strength, ultimate	754 - 960 Mpa
Tensile strength, yield	560 Mpa
Elongation at break	15.5 %
Modulus of elasticity	75.0 Gpa
Poisson's ratio	0.300
Shear modulus	28.8 Gpa
Specific heat capacity	0.320 J/g-°c
Thermal conductivity	10.0 W/m-k
Melting point	1240 - 1310 °C

Table 2. The machining parameters

Experiment variable	Descriptions
Generator mode	Iso pulse
Tool polarity	Negative (-)
Dielectric fluid	De-ionized water
Discharge current	10, 15, 20 (A)
Pulse off- time	30, 70, 200 (µs)
Pulse on-time	35, 50, 100 (µs)
Electrode revolution	200 RPM
Gap voltage	30, 50 (V)
Machining time	6 Min
Workpiece polarity	Positive (+)

For rotating tool, the motor with revolution 200RPM is used. Table 2 demonstrates the used input parameters. Input parameters include, pulse on time, pulse current, voltage, pulse off time, which their impacts on output parameters are investigated.

The material removal rate (MRR) and tool wear rate (TWR) are calculated according to equations 1 and 2:

$$\mathrm{MRR} = \frac{M_{w1} - M_{w2}}{\rho_w . t} \times 10^3 \qquad (1)$$

$$\mathrm{TWR} = \frac{M_{T1} - M_{T2}}{\rho_T . t} \times 10^3 \qquad (2)$$

Where:

M_{w1}: Work piece weight before machining (gr)

M_{w1}: Work piece weight after machining (gr)

ρ: Work piece density (gr/cm^3)

t: Machining time (min)

MRR: Material removal rate (mm^3/min)

M_{w1}: Electrode weight before machining (gr)

M_{w1}: Electrode weight after machining (gr)

ρ_T: Tool density (gr/cm^3)

TWR: Tool wear rate (mm^3/min)

In this study, Taguchi's design of experiment method, as one of the strongest design and experiment analysis methods is used. Orthogonal array is utilized for optimizing the number of experiments and increase results to all of the considered levels. In this study, number of experiments and factors are 18 and 4 respectively.

3. RESULT AND DISCUSSION

3.1.Comparison the Material Removal Rate

The effect of rotational tool on NiTi alloy material removal rate is shown figures 1 to 4. The most significant parameter, which influences the material removal rate, is spark energy. According equation 3, spark energy is related to spark voltage, spark current and pulse on time. With enhancement of pulse current and spark current, spark energy increases as well which is led to increasing the work piece surface temperature, melting, evaporation and material removal rate.

$$W_{av} = I_{sp} \times V_{sp}(T_{on} - T_d) \qquad (3)$$

With the enhancement of pulse current, the ions attack to the work piece surface increases as well which is led to temperature increase of the area, material evaporation of the work piece surface and enhancement of the material removal rate. By increasing the pulse on time up to 100µs, the material removal rate increases. the more increase of pulse-on-time has provided the needed time for the plasma channel to become wider and for the positive ions to become more active as a result and their attacks to the negative pole increase so the possibility of melting and evaporating the work piece becomes less. According to the thermodynamic and heat transfer fundamentals, when the pulse on time increases very much, the heat and energy, which is transferred to the work piece surface, become less and the material removal rate loses its rises gradually. Figure 2 shows the effects of pulse current on the NiTi alloy material removal rate in the rotational tool and without rotational tool conditions.

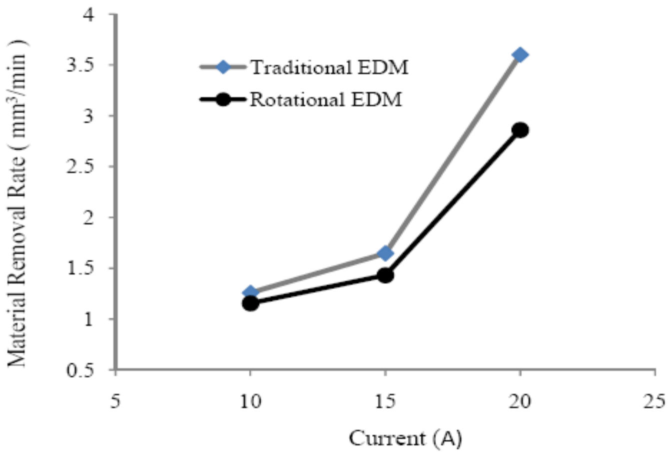


Figure 2. Comparison of MRR between traditional EDM and rotational EDM at various discharge currents for the NiTi60 alloy

According to the figure 2, by rotational tool 200RPM with 10A, 15A, 20A as pulse current, the material removal rate decreases in comparison with the traditional EDM. In the rotational EDM, breakdown resistance of the dielectric decreases, so for preserving the stability of electro discharge, gap distance between two electrodes must be increased. The wider electro discharge channel reduces the electrical power density in the area which is let to diminish the impulsive forces on the work piece surface. As a result, smaller voids are created on the machining surface and the material removal rate decreases consequently. As demonstrated by figure 2, when the pulse current is 10A, the material removal rate is the least. Figure 3 illustrates the impacts of the pulse on time on the material removal rate in the rotational and traditional spark. Without any respect to the rotational tool, by increasing the pulse on time up to 100µs, the material removal enhances. Investigations present that the enhancement of pulse on time up to a specified amount, plasma channel becomes wider and as the time goes on, energy density decreases, in addition material removal rate diminishes consequently. According to figure 3, in NiTi machining, when the pulse on time is up to 100µs, material removal rate of the rotational spark is less than traditional spark. Figures 4 and 5 show the effect of pulse off time and voltage on the material removal rate of the rotational and traditional spark. With the increase of voltage, the number of ions, which hit the work piece, increases and material removal rate, rises as well. When the pulse off time increases, material removal rate of NiTi alloy decreases. Material is not removed in the pulse off time between two pulses and this time is provided for flushing and removing plasma channel, which is led to cooling the machining area. As demonstrated in the figure 4 and 5, with the increase of pulse off time up to 200µs and voltage up to 250V, the material removal rate of rotational spark is less than traditional spark.

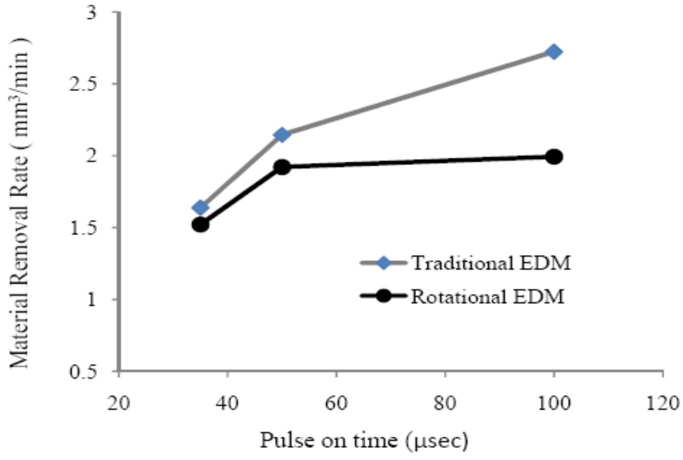


Figure 3. Comparison of MRR between traditional EDM and rotational EDM at various pulse on time for the NiTi60 alloy

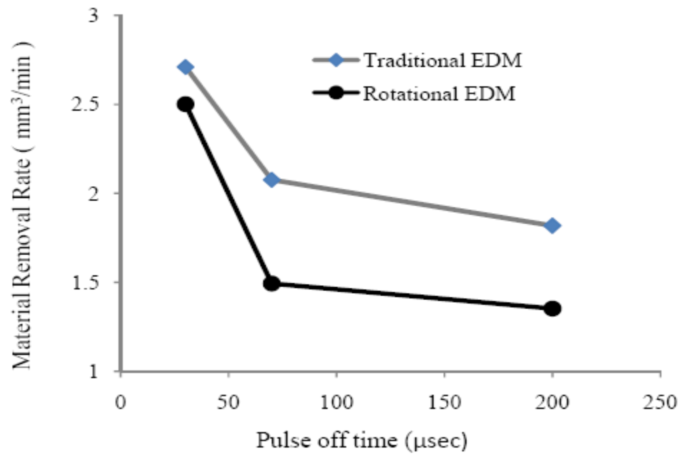


Figure 4. Comparison of MRR between traditional EDM and rotational EDM at various pulse off time for the NiTi60 alloy

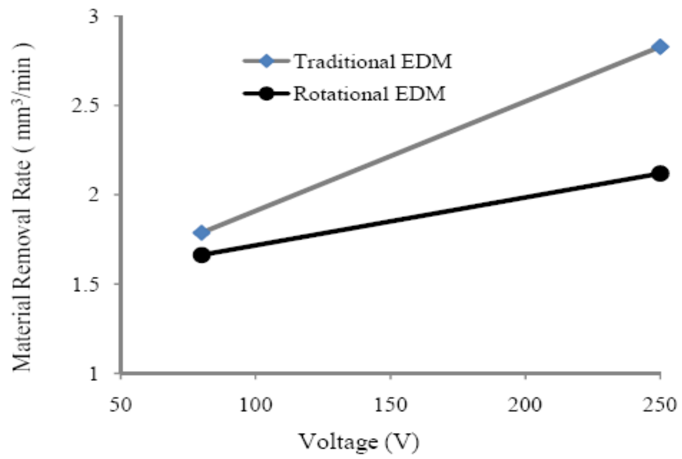


Figure 5. Comparison of MRR between traditional EDM and rotational EDM at various gap voltage for the NiTi60 alloy

3.2. Comparison of Surface Roughness and Topography

The quality of EDM surfaces is assessed by surface integrity. The significant parameters of the surface include; surface topography, surface roughness, surface cracks, hardness distribution and metallurgical changes in and under the surface [22, 23]. There are some surface and subsurface defects due to the rapid melting of the workpiece surface during the discharge process and then rapidly cooling of the workpiece surface during the washing by dielectric fluid. These surface and subsurface defects include cracks, surface voids, pits and holes, residual stresses, phase transformations and heat affected zone. Mentioned defects are led to reducing hardness, wear resistance and corrosion resistance of the work piece surface. The rotational spark machining is used to keep the machined surface properties and decrease the surface and subsurface defects. Figures 6,7,8 and 9 show the impacts of the rotational tool on NiTi60 alloy surface roughness. Figure 6 demonstrates the effects of rotational tool and pulse on time on NiTi alloy surface roughness. According to the mentioned figure, rotational spark is resulted in less surface roughness in comparison with the traditional spark.

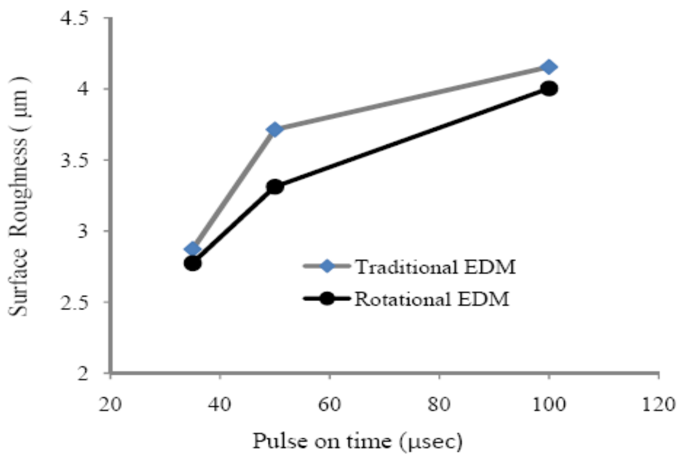


Figure 6. Comparison of surface roughness between traditional EDM and rotational EDM at various pulse on time for the NiTi60 alloy

Spark energy enhances by increasing the pulse on time, as a result, the voids become deeper, and the surface roughness increases consequently. When the pulse on time is 40µs, the surface roughness is the least. When rotational tool speed and pulse on time are less, plasma channel destroys rapidly, voids depth is less and surface roughness decreases as well. the effects of pulse current and rotational tool on surface roughness are shown in figure 7.

According to the above figure, with the increase of pulse current up to 15A, surface roughness decreases and then by increasing the current more, surface roughness increases. In the various pulse currents, the roughness in rotational spark is less than traditional spark. Spark energy enhances by increasing the pulse current, which is led to melt and evaporate more materials from the work piece then dimensions and depth of craters of electro discharge on the workpiece surface increase. Due to the mentioned reasons, surface roughness increases in traditional spark method. In the rotational spark, depth of craters of electro discharge is uniform and the surface roughness is less because of the electrical arc continual movement.

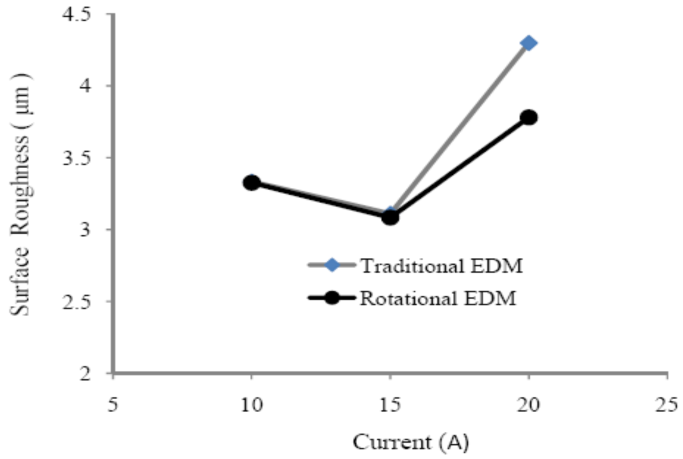


Figure 7. Comparison of surface roughness between traditional EDM and rotational EDM at various discharge currents for the NiTi60 alloy

By increasing the pulse current and pulse on time in rotational and traditional spark, electro discharge energy and impulsive forces increase so; more molten materials are going out. After the eruption of molten material within the craters, due to dielectric fluid flow during the cooling step, the remaining molten materials around the craters froze and are let to creating rough and uneven surface. Less current and pulse on time are led to less craters depth so, the surface roughness is less consequently. The impact of pulse off time on surface roughness is shown in figure 8. By increasing the pulse off time up to 70µs, the surface roughness decreases and then by enhancing the pulse off time up to 200µs, there is not a drastic change in surface roughness. Figure 9 demonstrates the effects of voltage on NiTi alloy surface roughness in rotational and traditional spark. By increasing the voltage up to 250V, surface roughness increases consequently.

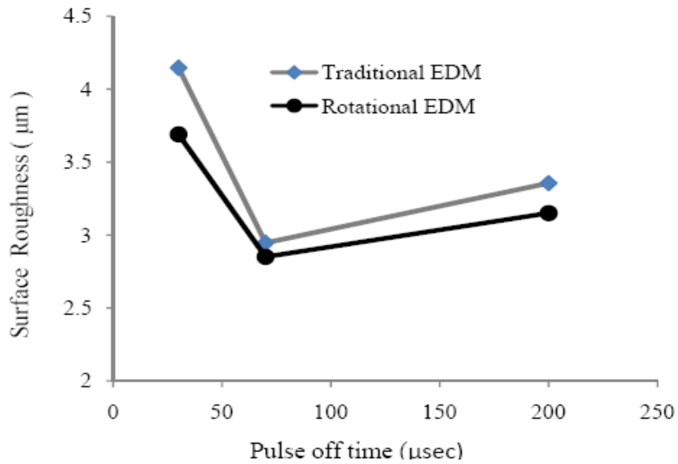


Figure 8. Comparison of surface roughness between traditional EDM and rotational EDM at various pulse off time for the NiTi60 alloy

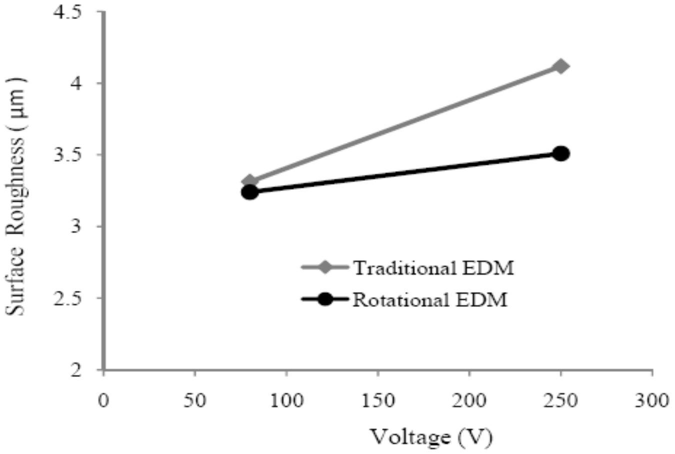
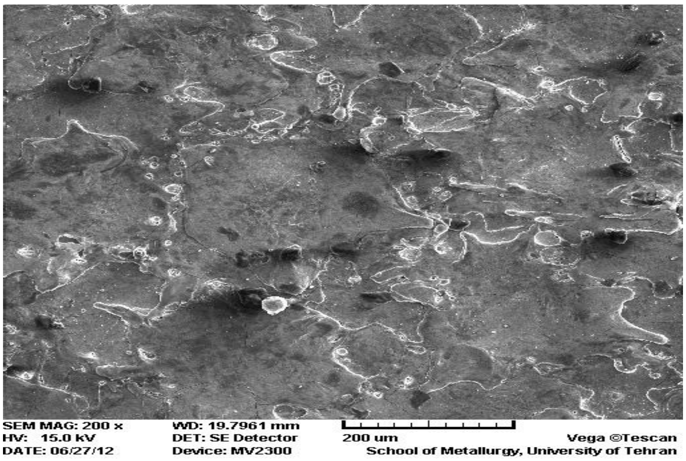
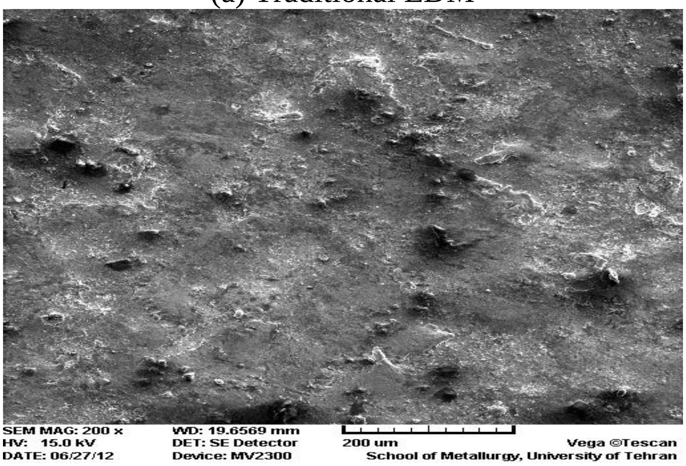


Figure 9. Comparison of surface roughness between traditional EDM and rotational EDM at various gap voltage for the NiTi60 alloy

Figure 10 demonstrates the impact of rotational tool on surface topography with scale 200X. According to the figure 10, the roughness of the rotational spark is less than traditional spark. The continual movement of electrical arc in rotational spark is resulted in decreasing the voids depth, craters and micro cracks in workpiece surface in comparison with the traditional spark. Regarding to the figure 10, rotational spark is led to less surface defects than traditional spark.



(a) Traditional EDM



(b) Rotational EDM

Figure 10. SEM micrograph of the EDM surface: (a) traditional EDM and (b) rotational EDM

3.3. Comparison of Tool Wear

The tool electrode has to have high electrical conductivity and low wear rates. The best materials for tool electrodes must have high melting point and less electrical resistance [24, 25]. After rotational and traditional spark experiments, by measuring the tool electrode mass difference before and after the test and utilizing equation 2, the copper tool wear rate (TWR) is obtained. Figures 11, 12, 13 and 14 show the effects of EDM input parameters on tool electrode wear rate. Figure 11 demonstrates the impact of pulse current on tool wear rate in traditional spark and rotational spark. Because of decreasing the dielectric break down resistance by tool electrode rotation, gap between tool and workpiece increases and plasma channel becomes broader and wider and as a result, electro discharge thermal energy distributes in broader area so electrical power density and material removal decrease and tool wear rate reduces consequently.

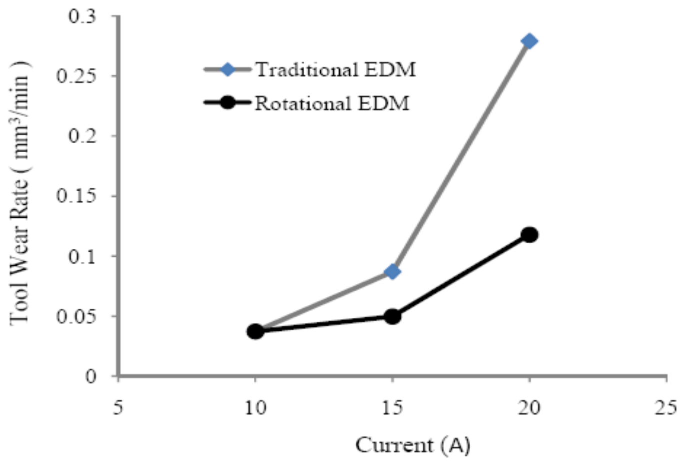


Figure 11. Comparison of TWR between traditional EDM and rotational EDM at various discharge currents for the NiTi60 alloy

On the other hand, tool rotation is led to transfer more heat to outside of the gap between tool and workpiece, which is resulted in reducing the electro discharge power on the tool electrode surface and tool wear rate.

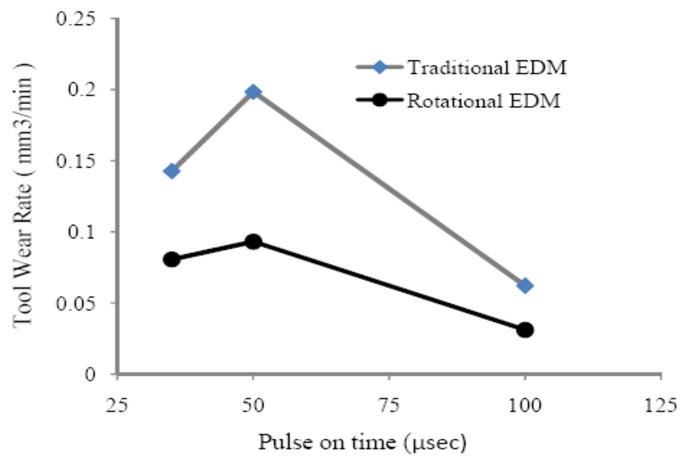


Figure 12. Comparison of TWR between traditional EDM and rotational EDM at various pulse on time for the NiTi60 alloy

The effects of pulse on time on tool wear rate in traditional and rotational spark for NiTi alloy are demonstrated in figure12.

Tool wear rate in various pulse on time in rotational spark in less than traditional spark. Regardless of tool rotation, by increasing of pulse on time up to 50µs, the tool wear rate increases, but when the pulse on time enhances up to 100µs, tool wear rate decreases consequently. Figure 13 illustrates impacts of the pulse off time on tool wear rate. By increasing the pulse off time up to 200µs, tool wear rate in rotational spark is less than traditional spark. Effects of voltage on tool wear in traditional and rotational spark are shown in figure 14. Tool wear rate in rotational spark in various voltages is less than traditional spark. By increasing voltage up to 200V, regardless of tool electrode rotation, tool wear rate increases.

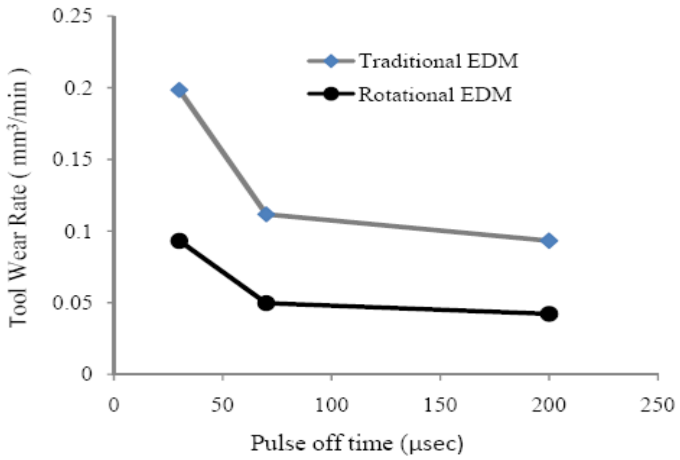


Figure 13. Comparison of TWR between traditional EDM and rotational EDM at various pulse off time for the NiTi60 alloy

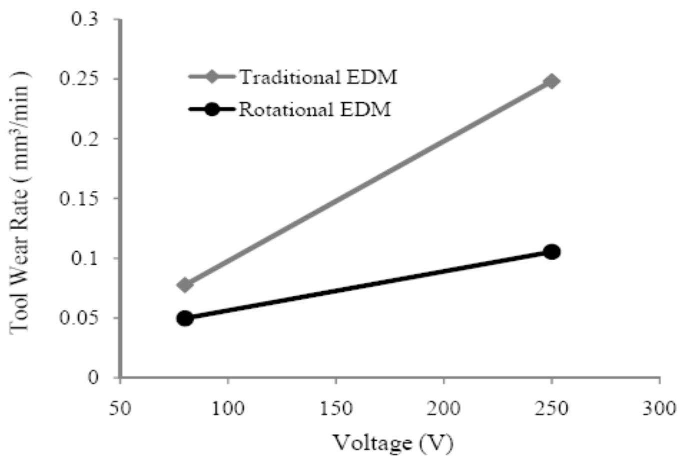


Figure 14. Comparison of TWR between traditional EDM and rotational EDM at various gap voltage for the NiTi60 alloy

4. CONCLUSION

In this article, effects of rotational tool and EDM input parameters include; pulse on time, pulse current, pulse off time and voltage, on output parameters such as material removal rate, surface roughness and tool wear rate are investigated for NiTi alloy with utilizing copper tool and deionized water as dielectric. Tool electrode revolution is considered as 200RPM. The output parameters of rotational and traditional spark are compared. Results of this research demonstrate that regardless of rotational tool, the most significant and effective parameters in material removal rate are pulse current and pulse on time. When the pulse current and pulse on time increase, the spark energy enhances and as a result, material removal rate increases as well. Material removal rate for NiTi alloy in rotational spark is less than traditional spark. The main reasons of reducing the material removal rate in rotational spark are decreasing the dielectric resistance due to tool rotation, and increasing the machining gap as well as enhancing the plasma channel diameter. According to the results of investigating the surface roughness in rotational and traditional spark, it has been cleared that by increasing the pulse current and pulse on time, surface roughness increases consequently. Electro discharge craters of rotational spark are fewer due to electrical arc continual movement and the surface roughness in rotational spark is less than traditional spark. Regardless of tool rotation, by increasing the pulse current and voltage, tool wear rate increases. Tool electrode rotation is led to transform more heat to outside from the gap between tool electrode and workpiece, which is resulted in decreasing the electro discharge capacity on the tool electrode surface so the material removal rate in rotational spark is less than traditional spark. Therefore tool rotation with 200RPM is led to decreasing the material removal rate and improvement of surface roughness and tool wear rate.

References

1. R. Wasilewski, J. Perkin, *Shape Memory Effects in Alloys,* Plenum Press, New York. (1975) 245.
2. S. Daneshmand, E. Farahmand Kahrizi, M. Mortazavi Ghahi, *Australian Journal of Basic and Applied Sciences*. 6 (2012) 218.
3. S. Saedodin, M. Torabi, H. Eskandar, *Journal of Advanced Design and Manufacturing Technology*. 3 (2010) 17.
4. S. Daneshmand, E. Farahmand Kahrizi, E. Abedi, M. Mir Abdolhosseini, *Journal of Electrochemical Science*. 8 (2013) 3095.
5. B. Bhattacharyya, B.N. Doloi, S.K. Sorkhel, *Journal of Materials Processing*. 95 (1999) 145.
6. P. Janmanee, K. Jamkamon, A. Muttamara, *European Journal of Scientific Research*. 76 (2012) 133.
7. H. El-Hoffy, *Advanced Machining Processes: Nontraditional and Hybrid Machining Processes*. (2005) 115.
8. E. Abedi, S. Daneshmand, R. Hessami, *Life Science Journal*. 10 (2013) 944.
9. K. Gall, H.J. Maier, *Acta Material*. 50 (2002) 4643.
10. S. Miyazaki, M. Kohl, *Recent Development in TiNi-based Shape Memory Alloys*. Proceedings of SPIE, (1998) 3324.
11. P.G. Lindqist, C.M. Wayman, T.W. Duering, K.N. Melton, D. Stockel, C.M. Wayman, *Engineering Aspects Of Shape Memory Alloys*. (1990) 58.
12. S.H. Lee, X.P. Li, *Journal Material Process Technology*. 115 (2001) 344.
13. Y.C. Lin, L. Hwang, C.H. Cheng, P. Su, *Journal of Materials Processing Technology*. 206 (2008) 491.
14. O. Yilmaz, O. Eyercioglu, N. Gindy, *Journal of Materials Processing Technology*. 172 (2006) 363.
15. D. Kremer, J.L. Lebrun, B. Hosari, *Annals of the CIRP*. 38 (1989) 199.
16. V.S.R. Murthy, P.k. PhiliP, *Journal of Machine Tools Manufacturing*. 27 (1987) 469.

17. G. Kibria, B. R. Sarkar, B. B. Pradhan, B. Bhattacharyya, *Journal of Advanced Manufacturing Technology*. 46 (2010) 555.
18. A. Schuermann, *Materials Science and Engineering A*, 378 (2004) 200.
19. S.L. Chen, S.F. Hsieh, H.C. Lin, M.H. Lin, J.S. Huang, *Materials Science and Engineering A*. 445-446 (2007) 486.
20. H.C. Lin, K.M. Lin, Y.C. Chen, *Journal Material Processes Technology*. 105 (2000) 327.
21. http://www.Matweb.com.
22. A. Modgil, *Effects of High Speed Machining on Surface Topography of Titanium Alloy*, M.S Thesis, University of Florida. (2003).
23. A. A. Lotfi, S. Daneshmand, and S. Adib Nazari, *Journal of Advanced Design and Manufacturing Technology*. 2 (2009) 51.
24. A. Hasclik, U. Caydas, *Journal of Applied Surface Science*. 253 (2007) 9007.
25. A. A. LotfiNeyestanak, S. Daneshmand, *Advances in Materials Science and Engineering*. (2013) 6.