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Effects of the properties of workpiece, electrode and dielectric fluid in micro-EDM drilling process

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Abstract

In the last years, the miniaturization of the components took place in many industrial sectors such as automotive, aerospace, biomedical. Significant industrial efforts were made to support this new manufacturing trend in order to propose effective solutions. In this scenario, Electrical Discharge Machining (EDM) finds use for a variety of drilling applications in automotive, aerospace, biomedical sectors on different materials such as stainless steels, titanium alloys and others metals regardless of their mechanical properties. The material removal occurs thorough electrical discharges between the electrode tool and the workpiece in a dielectric fluid. Dielectric, electrode and workpiece are the main factors involved during the discharges. Aim of this paper is to analyse the effects of the physical and thermal properties of the dielectric fluid and material of electrode and workpiece on the process performance of micro-EDM drilling operation. Two traditional (water and mineral oil) and an unconventional (vegetable oil) dielectrics were tested on sheets of stainless steel and titanium alloy using both brass and tungsten carbide electrodes. The performance were evaluated considering the material removal rate, the tool wear ratio and the geometrical characteristics of the holes. The results were correlated to the properties of the dielectric, electrode and workpiece. The results can be useful to both improve the knowledge and allow the optimization of the process.

Keywords: micro-EDM; micro-drilling, dielectric, electrode, process performance.

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1. Introduction

In Electro Discharge Machining (EDM), material is removed by a sequence of electric sparks. Such sparks bridge the gap between the workpiece and an electrode that is initially filled with a dielectric fluid. The removal process is thermo-electric, since each spark supplies some amount of localized energy, causing melting and evaporation from both workpiece and electrode, alteration in the dielectric fluid and, subsequently, both ejection of melted material and flushing by dielectric fluid. EDM acts independently from the mechanical properties of the work material, such as strength, hardness etc. thus making this process very interesting for machining difficult-to-cut materials. Anyway, other properties (electrical, thermal etc.) of the work material can affect EDM output and should therefore be considered.

EDM can be used to manufacture small features (having characteristic size of about 1 mm or less), in this case the term "micro EDM" is often used. In Micro EDM, however, sparks are activated through smaller gaps and involve less amount of energy; discharge frequency is higher and consequently pulse on times are shorter than in traditional EDM. Because of these features, micro EDM equipment differs from macro EDM machines; it is worth mentioning the type of pulse generators, RC relaxation type generators rather than transistor type ones [1].

EDM efficiency is generally evaluated through several parameters, such as Material Removal Rate (MRR,) Tool Wear Ratio (TWR) and some indexes about geometrical accuracy in terms of Diameter Over Cut (DOC) and Taper Rate (TR). All efficiency parameters are a function of both process data (mainly Voltages and Currents, Pulse Time, Pulse Frequency and Polarity) and the properties of all involved materials, namely workpiece, electrode and dielectric. As regards the workpiece material, EDM is able to process materials of any

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hardness, considered difficult to cut using traditional machining, as long as the material can conduct electricity.

The material of the workpiece, in particular some physical and electrical properties, affect the process. Many authors have studied the effect of the workpiece material on the discharge process following different approaches. A physical approach was followed in [2] where the discharge process was divided into three phases, the breakdown, the discharge and the erosion phase. It was found that the type of particles suspended in the dielectric fluid, originated by the erosion of both the tool and the workpiece, affects the duration of the first phase. Moreover, the radius of the discharge channel is dependent on electrodes materials (workpiece and tool). In the erosion phase, two types of forces are responsible of the removal of material from the electrode surfaces: electric (magnetic and static) and mechanical forces.

In [3] the authors declare that the mechanism of material removal depends on the duration of the discharge (pulse on time). Only for long pulses (ton>100μs) the material is removed by melting while for very short pulses (ton < 5 μs) the electrostatic forces acting on the surface are responsible to the removal of metal. Ton has effects on the depth of the crater for long pulses. For short pulses, the depth is almost a constant varying the discharge duration.

Some researchers are not in agreement with these results and the micro-EDM process was considered only a thermal process regardless of the entity of the discharge duration. It can be noted that when EDM is used in micro-applications, the discharge is always very short.

The process was studied using the thermal model available in the literature [4-5] in order to create the temperature profile due to an individual pulse. The thermal model assumes that workpiece is isotropic having thermal properties independent of temperature. The workpiece properties involved in the model are the thermal conductivity, the density, the specific heat and the latent heat of fusion.

A part of the discharge energy is absorbed by the dielectric fluid, another part is evacuated by radiation and the rest is absorbed by both electrode and workpiece by conduction. Many factors affect these energy partition, such as discharge parameters, dielectric types and electrode material [6]. The thermal properties of the materials play a key-role [7]. Among these, literature is in agreements as regard the thermal conductivity of the workpiece material that influences the energy received due to a single spark. The quantity of absorbed heat is directly proportional to this property. Increasing the heat absorption of the workpiece, the efficiency of the machining improves and the tool wear is reduced [8].

An erosion resistant index was proposed in [9] that is calculated as:

$$ER = c \cdot k \cdot T^2 \qquad (1)$$

where c is the specific heat, k is the thermal conductivity and T is the melting point of the workpiece material. This index indicates how well a material can be removed by the EDM, for low value the material is machined obtaining good MRR while for high value the erosion occurs in more difficult way.

As regards the removal process, the evaporated material is removed completely from the machining zone, while only a fraction of molten material is removed. This fraction depends on the dimension of the crater, the radius of the discharge channel, the dielectric flushing conditions and the thermal properties of material [10, 11]. Electrical conductivity of the workpiece also affects the machining performance [12], since the density of energy is related to it.

A different approach was followed in [13] where the authors identified the main factor affected the micro-EDM process such as material microstructure, processing parameters and thermal conduction. The material microstructure (grain and its boundary, defects, impurity) affects the thermal and electrical characteristics of material. Others works found that the grain size influences the cutting speed [14]. Moreover, grain and grain boundary show in general different properties in terms of thermal conductivity and melting point. In front of this consideration, micro-EDM performance on polycrystalline material are influenced by the volume fraction of the grain boundary [6]. Another element involved into the discharge process is the electrode. A good electrode material has to be highly electrically conductive and wear resistant [15].

Most of literature studied the influence of process parameters on the electrode wear [16, 17]. The effects of electrode material on the process performance are also studied. Many works make a comparison between two electrode materials and through experimental researches define the best electrode to optimize some particular aspects such as MRR, TWR or roughness surface of the workpiece [18, 19].

The thermal conductivity of the electrode material has effects on the heat dissipation rate into the electrode. Increasing the thermal conductivity of the electrode, the heat dissipated into the electrode increases and consequently the discharge energy density is lower creating lower depth craters on the surface of the workpiece. The thermal conductivity affects also the proper maintenance of the electrode shape: for materials having a low thermal conductivity, the electrode tip is more damaged by melting and vaporization causing a low dimensional accuracy of the machining.

The over cited erosion resistance index can be applied to electrode material too. In this case, a high value of index preserves the electrode minimizing its level of wear [20]. Thermal conductivity and the melting point affect the erosion resistance index, yet in [21] the authors suggest that thermal conductivity is more important than the melting point on the tool wear. High thermal conductivity acts in positive manner for both the tool wear and the roughness surface but the MRR is penalized.

Anyway, the process is complex and many variables are involved during the process: the performance are affected not only by the single characteristics but also by the combination of settings of the technological parameters [22].

The electrode material affects also the surface cracks that are related to the white layer thickness [15].

Dielectric fluid has been acknowledged to be important since the earliest application of EDM [24], it actually affects the process performance. The action of dielectric fluids is still matter of investigation. Generally, macro and micro EDM make use of several fluids, such as water (deionized water or less frequently tap water or other kind of water solutions [25]), organic oils (Kerosene, vegetable oils) or gases (dry or near-dry EDM). Powder mixed dielectrics (PMEDM) can be used too and are well documented in literature [26].

According to most researchers, dielectric fluid performs four functions: insulation, ionization, debris removal (flushing) and spark cooling [27]; anyway, the balance between different effects occurring during either ionization (material removed by spark itself) or flushing (molten material "washed out" by the dielectric fluid) has been questioned [28]. When selecting a dielectric fluid, health and sustainability issues should be also considered. Sparks produce toxic fumes, vapours and aerosols that can result negative for occupational health and environmental aspects [29]. As a general trend, water is reported to achieve faster removal than organic fluids. In many case studies, the effect of water as dielectric on MRR is large. This effect has been reported by several authors [30, 31] for micro EDM and by [32] for macro EDM. However, some researchers observed a different behavior, at least for macro EDM [27]. The influence of dielectric on other performance indexes like TWR and surface roughness is discussed in [33]. Using water the electrode wear is low [31] but the machining accuracy is poorer than that with hydrocarbon oils.

The effect of dielectric fluids on EDM performance may be related to both physical and chemical phenomena. Among physical properties, viscosity seems to be the most important parameter. It affects both the ionization phase, by restricting the plasma channel, and debris flushing. Restriction of the spark is favoured by high viscosity [24], whereas debris flushing takes advantage from low viscosity [28, 33]. Also in literature, the overall effect of viscosity is still debated. Another dielectric property affected the process is the dielectric electrical conductivity: the metal removal rate is higher as the dielectric electrical conductivity increases [34] thanks to a higher heat flux to the workpiece. A higher electrical conductivity leads to longer sparks, so increasing the gap (improving MRR despite geometrical accuracy) [35]. It is worth mentioning that the properties of dielectric fluid (especially conductivity) are affected by debris formation; a limited amount of debris may be beneficial, whereas higher concentrations may affect process stability causing frequent short circuits and consequently reducing the MRR.

The dielectric strength of a fluid is related to its electrical conductivity. In general, dielectric strength is affected by molecular polarity (resulting in higher permittivity) and low ion concentration (decreasing electrical conductivity). The resistivity of deionized water is much smaller than hydrocarbon oils permitting an easier and earlier breakdown. Consequently, the removal process is faster [31].

The temperature of the sparks depends on the dielectric type and it was demonstrated to be higher for water than hydrocarbon oils [36]. The high temperature during the process can modify the mechanical properties of the workpiece due to metallurgical alterations. The extension of the alterations depends also on the thermal conductivity of dielectric that influence the cooling rate of the workpiece [32, 37].

Chemical properties of the dielectric are important too. Due to the high temperature reached by the spark, chemical reactions involving the dielectric take place and affect the surfaces of both electrode and workpiece, causing changes in the dielectric itself. Consequently, MRR, TWR and geometric accuracy are generally affected.

Reaction heat of the dielectric is quoted by [37] among the main parameters involving EDM performance. Presence of reaction products is often referred to as an important aspect; water based dielectric fluids generally lead to oxidised products, whereas organic fluids may cause carbon deposition [28]. Carbon deposition on the electrode is deemed to be positive, since it protects it against wear [32]. Different physical properties of oxides rather than carbides (especially their melting point, for Titanium) may account for faster removal rates when using water compared with kerosene.

As seen, the effects of the workpiece material, the electrode material and the dielectric on the EDM process has been widely studied in the literature. However, in general, the studies taken into account only a factor per time and potential interactions between them are not reported.

Aim of this work is to investigate in micro-EDM drilling process the combined effects of the three factors (dielectric, electrode and workpiece) and to verify if interactions among them exist. Two traditional (water and mineral oil) and an unconventional (vegetable oil) dielectrics were tested on sheets of stainless steel and titanium alloy using both brass and tungsten carbide electrodes. The performance were evaluated considering the material removal rate, the tool wear ratio and the geometrical characteristics of the holes. ANOVA technique was used to confirm the significance of workpiece, electrode and type of dielectric on the process performance and the presence of interactions among them. This approach allowed the evaluation of multiplicative coefficients describing the effects of the above-mentioned factors. Finally, the results were correlated to the properties of the dielectric, electrode and workpiece.

Nomenclature

MRR	Material Removal Rate
TWR	Tool Wear Ratio
DOC	Diameter Over Cut
TR	Taper Rate
T_w	Melting temperature of workpiece
ρ_w	Electrical resistivity of workpiece
K_w	Thermal conductivity of workpiece
T_{el}	Melting temperature of electrode
ρ_{el}	Electrical resistivity of electrode
k_{el}	Thermal conductivity of electrode
I	Peak current
V	Voltage
D	Dielectric
E	Electrode
W	Workpiece
ER	Erosion Resistance
TC	Tungsten Carbide
B	Brass
c_W	Coefficient of the workpiece material
c_E	Coefficient of the electrode material
c_D	Coefficient of the dielectric fluid

2. Experimental plan

The experimental campaign was conducted on AISI316L and Ti6Al4V grade 5 sheets having a thickness of 0.5mm as workpiece. Two types of electrode, commonly used in industrial field, were used, brass and tungsten carbide both tubular, having an external diameter of 0.3 mm and the internal one of 0.12 mm. As regards the dielectric fluid, kerosene, demineralized water and vegetable oil were tested.

Tables 1 and 2 reports the physical characteristics of the workpiece materials and the electrode materials respectively. Table 3 compares the physical-electrical characteristics of the three fluid dielectrics.

Table 1 Physical properties of workpiece materials.

Physical Property	AISI 304	Ti6Al4V
Density [g/cm^3]	7.95	4.43
Melting temperature (T_w) [°C]	1455	1650
Electrical resistivity (ρ_w) [Ωcm]	$7.2 \cdot 10^{-5}$	$1.78 \cdot 10^{-4}$
Thermal conductivity (k_w) [W/mK]	16.2	6.7
Specific heat [J/(g°C)]	0.502	0.5263

Source: www.matweb.com

Table 2 Physical properties of electrode materials [23].

Physical Property	Brass C26800	Tungsten carbide WC94Co6
Density [g/cm^3]	8.47	14.8
Melting temperature (T_{el}) [°C]	905-930	2867
Electrical Resistivity (ρ_{el}) [Ωcm]	$6.63 \cdot 10^{-6}$	$20 \cdot 10^{-6}$
Thermal conductivity (k_{el}) [W/mK]	121	70
Specific heat [J/(g°C)]	0.38	0.3

Table 3 Properties of the dielectrics.

	Kerosene	Water	Vegetable oil
Dynamic viscosity [g/m·s]	1.64	0.92-1	48.4
Density [g/dm3]	781	1000	915-925
Dielectric rigidity [kV/mm]	14-22	65-70	62-65
Thermal conductivity [W/m·K]	0.14–0.149	0.606–0.62	0.14-0.16
Specific heat [J/g·K]	2.1–2.16	4.19	1.67
Dielectric constant	1.8	80.4	2.86

The micro holes were executed with Sarix SX-200 machine. With the objective of starting the tests with an appropriate set of parameters, some preliminary tests were carried out. In this case, the objective was not to widely analyze the effect of parameters or to obtain the optimum parameters but to select an adequate set of parameters with which it was possible to machine efficiently. Table 4 shows the adopted electrical parameters. For all the tested combinations the polarity was negative, width (time in which the transistor remains active) 3 µs, frequency 150 kHz, gain (parameter that controls the gain of the reaction block) 20, gap (value proportional to the distance between the electrode and the workpiece during the erosion) 30. Overall 120 micro holes were executed, each experimental condition was tested ten times. The erosion time was recorded by the system automatically. At the end of each hole, the electrode wear was measured through an electrode touch in a fixed point of the sheet. Then, the electrode tip was cut using the wire unit to guarantee the same start condition of the electrode for all the holes. A coordinate measuring machine, Zeiss O-Inspect 543, was used to measure the top and bottom diameter of the holes.

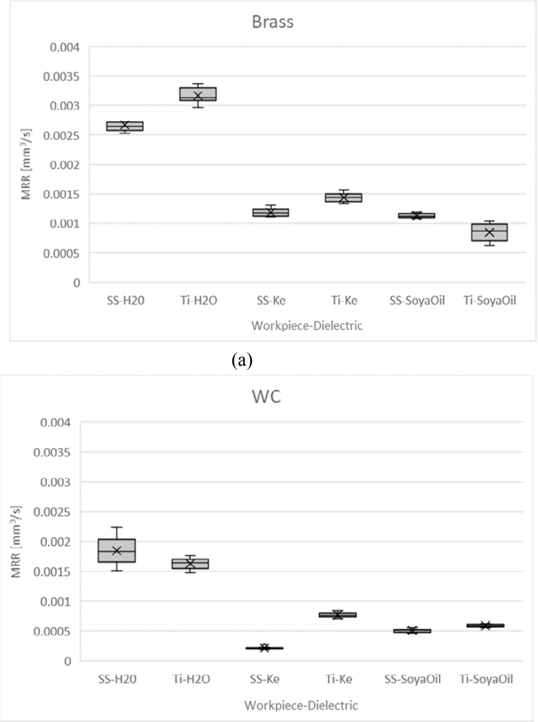
Table 4 Electrical process parameters used for each dielectric, electrode and workpiece combination.

Dielectric	Electrode	Workpiece	I [index]	V [V]
Kerosene	Brass	SS	70	100
Kerosene	WC	SS	70	100
H_2O	Brass	SS	70	100
H_2O	WC	SS	70	100
SoyaOil	Brass	SS	90	110
SoyaOil	WC	SS	90	110
Kerosene	Brass	Ti6Al4V	70	100
Kerosene	WC	Ti6Al4V	70	100
H_2O	Brass	Ti6Al4V	70	100
H_2O	WC	Ti6Al4V	70	100
SoyaOil	Brass	Ti6Al4V	70	100
SoyaOil	WC	Ti6Al4V	90	110

The performance were evaluated considering MRR and TWR while, as geometrical characteristics, DOC and TR were taken into account. The following section shows the obtained results.

3. Results and discussion

Figure 1 shows the MRR obtained in all the tested conditions using brass (a) and tungsten carbide (b) electrode. In general, brass electrode makes the machining faster. Water confirms to be the most performing dielectric for both electrodes, followed by kerosene and by Soya Oil. Except for some specific cases, the deviation standard is almost limited. Titanium is more machinable than stainless steel except for some cases for which the performance are almost the same.

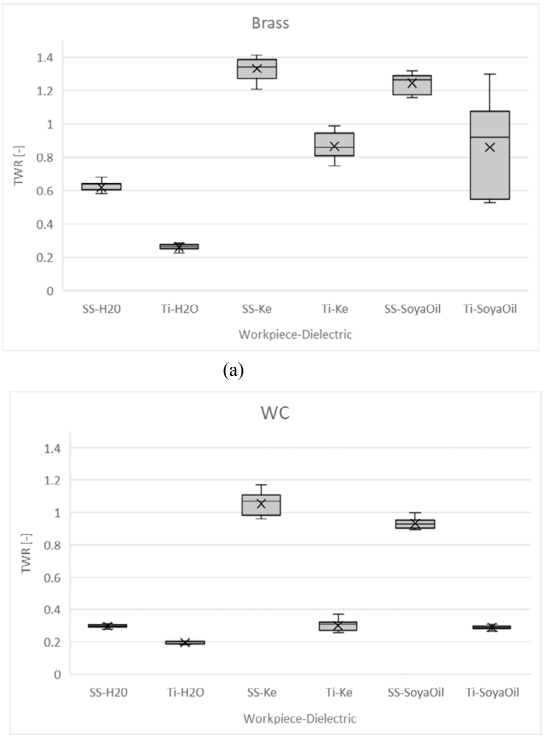


(a)

(b)

Fig 1 MRR for different workpiece / dielectric combinations using Brass (a) and WC (b) electrode.

TWR for all the tested conditions is reported in Figure 2. As already demonstrated, brass electrode obtains a faster machining at the expense of its wear. Water is the best dielectric from the point of view of the electrode consumption while, within the limit of this experimentation, the use of kerosene reveals to be the worst choice. As concern the workpiece material, when titanium is drilled the TWR is always lower than stainless steel.



(b)

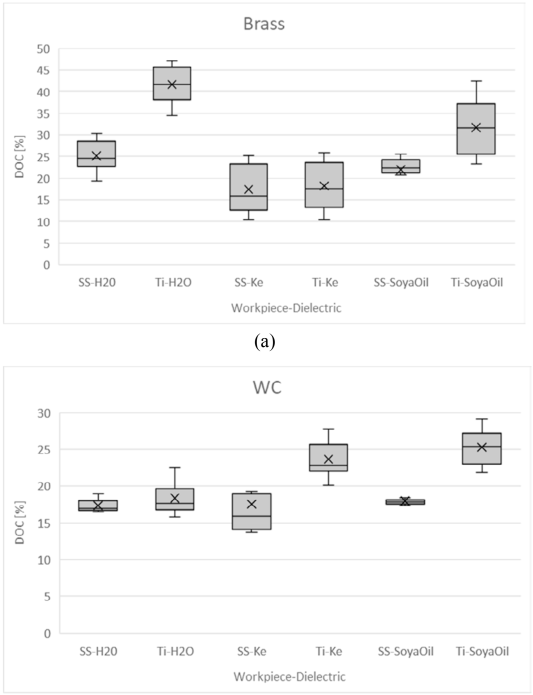
Fig 2 TWR for different workpiece / dielectric combinations using Brass (a) and WC (b) electrode.

Figure 3 shows the DOC obtained for the experimental tested. In this case too, the choice of the electrode has a significant effect on the geometrical characteristics. The precision of the machining is penalized using brass electrode. Moreover, it can be noted that the process is less stable showing a higher standard deviation. In general, titanium that reaches a faster machining (see Figure 1), shows on the other side a higher overcut penalizing the machining precision.

No general effects of the dielectric type can be found.

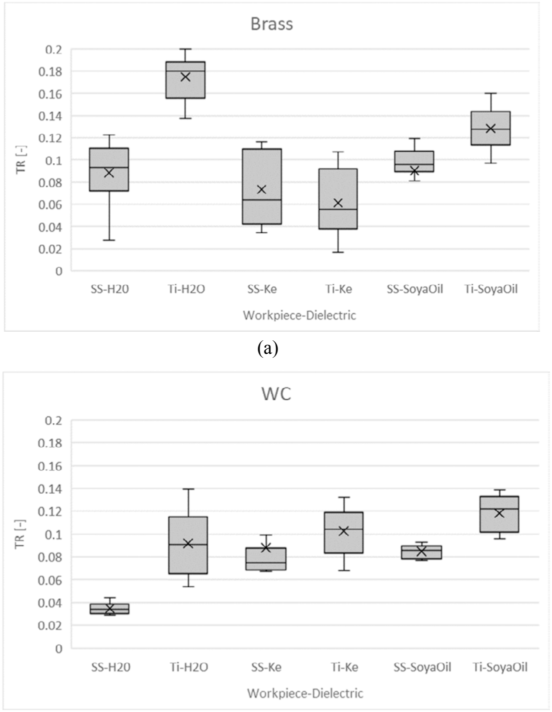
The comments related to overcut can be applied to the taper rate of the micro holes (Figure 4).

The obtained results were analysed using ANOVA method to verify statistically the effects of workpiece, electrode and type of dielectric. For all the adopted performance index, p-values are always lower than 0.05 confirming their significance. Figure 5 reports the interaction plots that show negligible interactions between the parameters (Dielectric, D / Electrode, E / Workpiece, W) supporting the assumption of the first order model. Only the geometrical characteristics show some degree of interaction that was not included into the model



(b)

Fig 3 DOC for different workpiece / dielectric combinations using Brass (a) and WC (b) electrode.



(b)

Fig 4 TR for different workpiece / dielectric combinations using Brass (a) and WC (b) electrode.

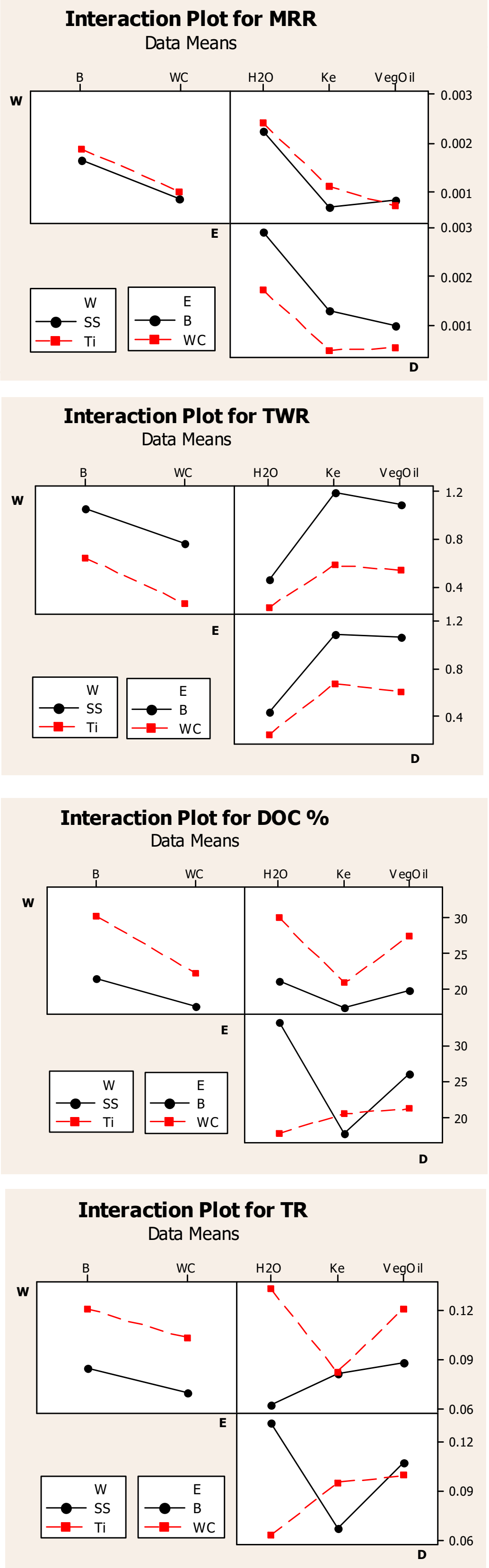


Fig 5 Interaction plots for MRR, TWR, DOC and TR.

A multiplicative model was chosen to represent the effects of the experimental conditions on the process performance. All the variables were transformed using a logarithmic function. It is worth noting that the adopted transformation does not change the statistical distribution of residuals and therefore does not affect the homoscedasticity assumption.

For example, the MRR model is stated as follows:

$$\ln(MRR) = K + \alpha D + \beta E + \gamma W \tag{2}$$

Through the exponential properties, the model becomes:

$$MRR = e^{K} \cdot e^{\alpha D} \cdot e^{\beta E} \cdot e^{\gamma W} \tag{3}$$

The multiplicative model allows a separate analysis of each factor (D/E/W). As an example, the effect of workpiece material can be evaluated as:

$$MRR_{SS} = e^{K} \cdot e^{\alpha D} \cdot e^{\beta E} \cdot e^{\gamma W_{SS}} \tag{4}$$

$$MRR_{Ti} = e^{K} \cdot e^{\alpha D} \cdot e^{\beta E} \cdot e^{\gamma W_{Ti}} \tag{5}$$

Thus

$$MRR_{ss}/MRR_{Ti} = e^{\gamma(W_{SS}-W_{Ti})} = c_W \tag{6}$$

where c_W describes the effect of the change of workpiece material on MRR. A similar approach can be used for the others response variables (namely TWR, DOC and TR).

3.1 Effects of the workpiece material

Table 5 reports the obtained coefficients of the model of the performance indexes (response variables) considering only the effects of the workpiece material.

Table 5. Model coefficients of the workpiece material.

$X_{SS}= c_W \cdot X_{Ti}$	c_W	
MRR	0.79	$(ER_{SS}/ER_{Ti})^{-1/2}=0.75$
TWR	2.16	$(ER_{SS}/ER_{Ti})=1.79$
DOC	0.77	$(ER_{SS}/ER_{Ti})^{-1/2}=0.75$
TR	0.69	$(ER_{SS}/ER_{Ti})^{-1/2}=0.75$

The comparison between stainless steel and titanium alloy shows a reduction of more of 20% of the MRR. This result is justified considering some properties of the workpiece material, in particular the melting temperature, the specific heat and the thermal conductivity. As these properties increase, the material becomes less machinable according to the erosion resistance index proposed in the literature [9], penalizing therefore the machining rate. It can be noted that the ratio of the square roots of the erosion resistance indexes assumes a value comparable to the coefficient c_W reported in the table 5. In general, performance indexes can be estimated as a function of few physical properties. A mathematical expression of such functions, together with the corresponding numerical value, are shown in the third column of table 5.

The workpiece material affects the TWR basing on the same considerations. The lower machinability of the stainless steel than titanium alloy (expressed by the erosion resistance index) penalizes the machining rate. As the machining rate decreases, the electrode works more time increasing its wear according to [38].

The workpiece material influences the geometrical characteristics too. Stainless steel as workpiece obtains lower overcut and lower taper rate than titanium alloy. This behavior can be justified by the erosion resistance of the material. An increase of the erosion resistance, the machining becomes more accurate, reducing both the diameter overcut and the taper rate. Also in this case, the coefficient c_w obtained for DOC and TR is similar to that one obtained for MRR, thus showing the same dependency on the square root of erosion resistance index.

3.2 Effects of the electrode material

The coefficients of the model of the performance indexes for the electrode material effects are reported in Table 6.

Table 6. Model coefficients of the electrode material.

$X_B = c_E \cdot X_{TC}$	c_E	
MRR	2.15	$[\rho_{TC}/\rho_B]^{1/2}=1.74$
TWR	1.82	$(ER_{TC}/ER_B)^{1/2}=2.11$
DOC	1.23	ρ, ER
TR	1.18	ρ, ER

Brass and tungsten carbide electrodes offer different performance. Brass obtains a better MRR than tungsten carbide electrode. This behavior can be explained taking into account the electrical resistivity of the electrode material [18]; as this property decreases, the machining occurs in faster way because each spark delivers a higher amount of energy. The square root of the ratio of electrical resistivity of the two electrodes is reported in table 6 since it gives a fair empirical estimation of the coefficient c_E. Using a similar procedure as in section 3.1, some mathematical models were proposed and they are shown in the third column of table 6.

As concern the TWR, the erosion resistance index of the tool material explains the experimental data. Also in this case, taking the square root of the ratio between the erosion resistance of the two materials gives a value that is closed to the experimental one.

As concern the geometrical characteristics, micro holes obtained using brass electrode result to have higher overcut and higher taper rate around of 20% than tungsten carbide electrode. Two considerations can explain this effect: the electrical properties and the erosion resistance of the electrode material. Brass has high electrical conductivity permitting to achieve a higher energetic density that improve the machining but makes the process less accurate. Moreover, due to the lower erosion resistance index of brass, the local temperature on the tip rises faster causing a damage of electrode shape. As a result, tungsten carbide electrode permits to obtain superior accuracy of the machining thanks to its ability to maintain the electrode shape longer. It should be noted that machining time affects the accuracy of the machining (less time for wear phenomena on both the electrode and the hole side), yet, this consideration is less relevant than the previous ones.

Anyway, no function was suggested for this case, because of the number of involved variables.

3.3 Effects of the dielectric fluid

The coefficients of the model of the performance indexes for the dielectric fluid effects are reported in Table 7.

Table 7. Model coefficients of the dielectric fluid.

	c_D $(X_{H2O}= c_D X_{Ke})$	c_D $(X_{H2O}= c_D X_{VO})$	c_D $(X_{Ke}= c_D X_{VO})$
MRR	3.08	3.01	0.98
TWR	0.40	0.43	1.08
DOC	1.30	1.03	0.80
TR	1.10	0.77	0.70

There is a significate difference between water and organic dielectrics in terms of both MRR and TWR. Using water the machining speed occurs three time faster and the TWR is reduced of about 60%. As regards the dimensional aspects, the precision of holes obtained using water is lower than that obtained with kerosene.

The behavior of kerosene and vegetable oil is almost the same for both MRR and TWR while kerosene shows better accuracy in terms of geometrical characteristics.

Some remarks can be made considering the physical and chemical properties of dielectric fluid. According to the literature, the main physical properties are the viscosity and breakdown voltage, although it is difficult to devise any empirical model able to fit the experimental data. In fact, experimental results of table 7 (especially of oil and kerosene) do not show large differences, whereas physical properties display very large variation.

As regards TWR, it is mainly dependent on machining time and therefore it is strictly linked to MRR. It can be noted that water shows a lower TWR (about 40%) than organic fluids. In general, kerosene leads to best accuracy, oil is intermediate and water performs worst.

The lower overall accuracy of water may occur because its contamination by the debris, produced during the EDM process, affects its electrical properties by a higher degree than the other dielectrics.

Conclusion

In this paper, the effects of the workpiece, electrode material and dielectric fluid in micro-EDM drilling process were investigated and a check for potential interactions was performed. Two traditional (water and mineral oil) and an unconventional (vegetable oil) dielectrics were tested on sheets of stainless steel and titanium alloy using both brass and tungsten carbide electrodes. The performance were evaluated considering the material removal rate, the tool wear ratio and the geometrical characteristics of the holes.

A regression model was built and ANOVA technique was used to confirm the significance of D/E/W on the process performance and the absence of significant interactions among them. This approach allowed the evaluation of multiplicative coefficients describing the effects of each one of the above-mentioned factors. The resulting coefficients were compared with some simple functions of physical properties of D/E/W, to assist the formulation of an empirical predictive model.

The effects of workpiece and electrode material could be fairly approximated by a simple function of the erosion resistance index and electrical resistivity. The effect of dielectric appears to be more complex and worth further investigation.

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