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THERMAL PROPERTIES OF THE WORKPIECE MATERIAL AND THE MACHINABILITY BY ELECTROEROSION

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ABSTRACT

The machinability is the technological property of the workpiece material to be machined in more convenient conditions for the manufacturer. In the case of the electroerosion, one of the machinability tests takes into consideration the quantity of the workpiece material removed by a single electrical discharge. Some thermal properties of the workpiece material can influence the machinability of the proof sample material by electroerosion: the specific heat, the melting temperature of the metallic material, the thermal conductivity etc. The paper presents some authors theoretical considerations concerning the influence of the thermal properties of the proof sample material on the quantity of material removed by a single electrical discharge.

KEYWORDS: electrical discharge machining, machinability, single electrical discharge, thermal properties, mathematical models

1. INTRODUCTION

The electrical discharge machining can be defined as that machining method which uses the erosion effect of the electrical discharges in pulse, occurring between the electrode - tool (that contributes to the macroscopic localization of the process), and the workpiece - electrode, if there is an equipment that provides the adequate conditions for the machining development [7]. Nowadays, the electrical discharge machining is applied to obtain generally complex surfaces in workpieces made of conductive materials and when the classical machining methods cannot be used or can be used in non-efficient conditions.

Even the mechanical properties of the workpiece material do not exert a direct influence on the parameters of technological interest valid in the case of the electrical discharge machining, the indexes sizes of machinability by electrical discharge machining could be affected by some chemical and physical properties of the workpiece material.

Machinability is the technological property of the workpiece material which ensures the development of the machining process in circumstances favourable for the producer [4]: at the high speed, but generating reduced tool wear, the minimal mechanical loading of the technological system, needing reduced energy consumption, facilitating the obtaining of the smaller surface roughness, of more convenient chips shapes etc.

A first remark concerning the machinability definition could refer to the fact that distinct criteria (the electrode tool wear, the material removal rate, the machining speed, the surface roughness etc.) can be used to appreciate the machinability of a certain material.

There are different methods applied to evaluate the materials machinability. Thus, one can mention that there are *direct methods*, which are based on the proper tests of machining and *indirect methods*, which do not use the proper machining process for the establishing the machinability indexes.

As one can notice, the result of the electrical discharge machining could be influenced by the thermal properties of the electrodes material; in fact, just the electrode tool material must be chosen so that its machinability by electrical discharge machining is minimum and electrode tool is minimal affected by an erosion phenomenon.

The thermal-physical properties of the electrode tools were taken into consideration by J. Marafona and J.A.G. Chousal [5], to elaborate a model able to explain the electrical sparks generation during the electrical discharge machining; they found a certain correspondence between these properties and some factors of technological interest (tool wear ratio, material removal rate, surface roughness).

Poroś and Zaborskia considered [6] that some thermal properties of the workpiece material (melting point, thermal conductivity, thermal expansions coefficient, heat capacity), together with other physical properties can influence the volumetric efficience of the wire electrical discharge machining of hard-to-machine materials.

An analytical model applied in the case of the micro-crater generated by a single electrical discharge was proposed by Yeo et al. [9]; they took into consideration the temperature distribution on the workpiece, to explain the ejection from the workpiece only a small quantity of molted material. The experimental researches confirmed the validity of their model.

2. THEORETICAL CONSIDERATIONS

The stages able to explain the material removal from workpiece during the electrical discharge machining (Fig.1) could be considered [8] as follows:

1. Getting an intense electric field between the most closed peaks of the workpiece and the electrode tool surfaces;

2. Ionization of the dielectric medium existing between the electrodes by the powerful electric field. A high electrical conductivity column appears between the most closely situated peaks of the electrodes surfaces;

3. Proper discharge initiation, when the current strength takes very high values (10^7 to 10^8 A/second). The high-intensity current produces a strong magnetic field and compresses the current beam. In this manner, the additional heating of the column occurs. The dielectric surrounding of the electrical conduction column is vaporized and decomposed;

4. Thermal effect of the plasma column produces an extremely high temperature in the small area of the peaks (in the discharge column, the temperature is significantly higher than 10,000 ° C); this temperature is high enough to melt a certain volume of the workpiece and tool materials and even to evaporate the small quantities of the workpiece and the tool materials.;

5. Developing of a mechanical effect of the electrical discharge; during this stage, one can notice the abrupt volume variation due to the melting and to the above described evaporation phenomena or due to the chemical reactions and micro-blasts produced in the dielectric fluid;

6. Removal of the eroded particles, chips and debris from the machining gap by the dielectric fluid flushing during this last stage.

Just during the existence of the plasma column specific to the electrical discharge, the workpiece and the electrode tool materials are heated up to the temperatures corresponding to the melting and vaporizing.

Thus, the volume of the material increases in a very short time and the conditions for a mechanical phenomenon are fulfilled; small quantities of the material affected by melting and vaporization are thrown out of the material, being partially removed by the work liquid circulation. Other part of the expulsed material could arrive on the electrodes surface, being affected by the solidifying phenomenon and adhering to the surfaces round of the cavity previously generated.

But not all the quantity of heat developed as result of the electrical discharge is used for melting and vaporizing; other quantity of the heat penetrates and spreads in the electrodes material; if the temperatures thus developed reaches the temperature corresponding to the structural changes, new metallographic structures can be found in the so-called heat affected zone (layer).

As one can see, the development of the material removal from the workpiece is in a strictly connexion with the thermal phenomena accompanying the electrical discharge.

Practically, the thermal phenomena have a decisive contribution to the material removal from the workpiece. This contribution was noticed by P. M. Palatnik, who proposed to use a certain indicator to evaluate [1] the materials machinability by electrical discharge:

$$\pi = C \rho \lambda \theta_m^2, \qquad (1)$$

where C [J/kg·°C] is the specific heat of the workpiece material, ρ [kg/m^3] – the workpiece material density, λ [kcal/grd·cm·s] – the coefficient of thermal conductivity, θ_m [°C] – the absolute melting temperature.

The greater the Palatnik's criterion size is, the more reduced the machinability by electrical discharge machining method is. The influence of the workpiece material thermal properties on the machinability by electrical discharge machining is emphasized by the presence of certain thermal properties in the mathematical model corresponding to the Palatnik's criterion.

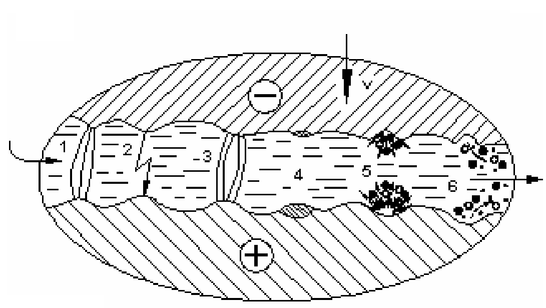
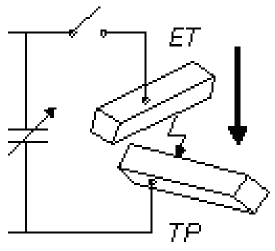
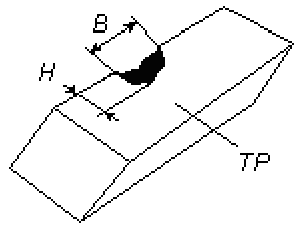


Fig. 1. Stages of the material removal as consequence of the electrical discharges



a



b

Fig.2. Electrical discharge produced between the electrode tool and test piece (*a*) and the gap generated by the electrical discharge (*b*)

Thus, it is known that the specific heat or the specific heat capacity characterizes the amount of heat required to change temperature of one kilogram of a substance by one degree. It is possible that a high size of the specific heat will generate a diminished machinability by electrical discharge machining.

The melting point of the conductive material used for the electrodes during the electrical discharge machining is the temperature range at which it changes state from solid to liquid.

The density of the workpiece material can be defined as its mass per unit volume. Generally, one can not establish a direct correspondence between the density and the machinability of a certain electroconductive material by electrical discharge machining. In accordance with the Palatnik's criterion, the increasing of the density should have to characterize a diminished machinability.

The thermal conductivity is the property of the material that emphasizes its capacity to conduct heat. Properly, the thermal conductivity can be defined as the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area, due to a unit temperature gradient under steady state conditions.

If the thermal conductivity of the workpiece material is high, this could mean that the heat generated by the electrical discharge could be faster dissipated and, thus, the material removal from the workpiece could be smaller. In accordance with the mathematical model corresponding to the Palatnik's criterion, the increasing of the thermal conductivity generates the diminishing of the machinability by electrical discharge machining.

Sometimes, the coefficient of thermal conductivity is used to characterize the material thermal conductivity; this coefficient of thermal conductivity can be defined as the quantity of heat that passes through a unit cube of the substance in a given unit of time, when the difference in temperature of the two faces is 1 K.

The melting point or melting temperature of a solid is the temperature at which the material changes state from solid to liquid. At the melting point, the solid and liquid phases are in equilibrium.

The Palatnik's criterion shows that the machinability of a certain material by electrical machining decreases in accordance with the square of the size of the melting temperature; this could mean that the melting temperature is the main factor able to influence the machinability by electrical discharge.

But not only the thermal properties included in the mathematical model of the Palatnik's criterion could exert on the machinability by electrical discharge; other such properties could be the latent heat of melting or the latent heat of vaporization.

Generally*, the latent heat* is the amount of energy released or absorbed by a material during the change of state (for example, changing from solid to liquid, or from liquid to gas), or the phase transition. If the material has a great size of the latent heat, this means that it needs a greater quantity of heat to be melted or to be vaporized and, thus, it could be characterized by a diminished machinability by electrical discharge machining.

3. EXPERIMENTAL RESULTS

In the laboratory of non-conventional technologies of the Technical University of Iaşi, the study of the electroconductive materials machinability by electrical discharge machining was made by using the scheme presented in figure 1, *a*. As criterion for the machinability evaluation, the quantity of the material removed by a single electrical discharge was used.

As one can see in Fig. 2, *a*, the electrical discharge was generated between the electrode tool *ET* and the test piece *TP*. The both electrodes had a parallelipipedic shape and they were placed so that one of their longitudinal edges to be placed in the same vertical plan; in this manner, by decreasing the distance between the electrodes, it is expected that the electrical discharge appears in the closest zones of the electrodes. As consequence of the electrical discharge, a gap is generated on the test piece (Fig. 2, *b*); the depth *H* and the width *B* of the gap were relatively easy measured by means of an optical microscope.

Different energies of the electrical discharges were used, by the modifying the voltage applied to the electrodes and the capacities of the capacitors included in the relaxation circuit (specific to the electrical discharge machining). Because the initial experiments shown that the after the electrical discharge, a certain voltage remain on the capacitors, one established to take into consideration the difference between the initial voltage applied to the electrodes and the final voltage remained on the electrodes after the electrical discharge.

An experimental factorial plan with two variables (the capacity C and the potential drop U) at two levels was elaborated, to diminish the number of the experiments. Thus, the voltages were U_{max}=80 V and U_{min}=40 V, while the capacities were C_{max}=10200 μF and C_{min}=1000 μF.

The test pieces were made of five different materials: steel containing 0.15 % carbon, high speed steel, sintered carbide type ISO - P35, aluminium and brass. These materials were selected so that they are characterized by different thermal properties and aiming to establish if there are certain correlations between the thermal properties of the test pieces materials and the above mentioned indexes of machinability by electrical discharge machining.

By mathematical processing of the experimental results (by means of specialized software [2] based on the method of the smallest squares), the following empirical relations were determined [7]:

$$B = 0.0163C^{0.290}D^{0.546}, \quad (2)$$

$$H = 0.00418C^{0.385}D^{0.540}, \quad (3)$$

for the steel containing 0.15 % carbon,

$$B = 0.0148C^{0.340}D^{0.464}, \quad (4)$$

$$H = 0.00502C^{0.404}D^{0.427}, \quad (5)$$

for the high speed steel,

$$B = 0.00368C^{0.405}D^{0.560}, \quad (6)$$

$$H = 0.00211C^{0.382}D^{0.449}, \quad (7)$$

for the test piece made of sintered carbide type ISO - P35:

$$B = 0.0293C^{0.293}D^{0.402} \quad (8)$$

$$H = 0.00377C^{0.379}D^{0.673}, \quad (9)$$

for the test piece made of aluminium, and

$$B = 0.0263C^{0.283}D^{0.439} \quad (10)$$

$$H = 0.0147C^{0.311}D^{0.375}, \quad (11)$$

for the test piece made of brass.

The analysis of this relation proved the reduced size of the machinability of the sintered carbide, in comparison with the sizes of the machinability corresponding to the other materials; graphical representations can be elaborated to emphasize the influence exerted by the capacity C and the voltage U on the dimensions B and H of the gap generated by the single electrical discharges in the test pieces made of different materials.

4. POSSIBLECORRELATIONS BETWEEN THE THERMAL PROPERTIES AND THE MACHINABILITY BY ELECTRICAL DISCHARGE MACHINING

Table 1. Thermal properties of some electroconductive materials

No.	Thermal property	Steel containing 0.15 % C	High speed steel	Sintered carbide type P35	Aluminium	Brass
1.	Specific heat, c, J/(kg·K)	420	420	960	900	385
2.	Density, ρ, kg/m^3	7850	7850	12000	2699	8730
3.	Coefficient of thermal conductivity, λ, W/(m·K)	54	55	29.3	250	100
4.	Melting temperature, θ_m, K	1755 K	1783	3143	933	1213
5.	Index of machinability evaluated by means of the material removal rate [3]	1.0	1.0	0.5	4	1.6
6.	B, mm	1.129	1.035	0.597	1.149	1.120
7.	H, mm	0.544	0.469	0.185	0.812	0.584
8.	Palatnik's index, π	$5.48 \cdot 10^{14}$	$5.76 \cdot 10^{14}$	$33 \cdot 10^{14}$	$5.28 \cdot 10^{14}$	$4.94 \cdot 10^{14}$

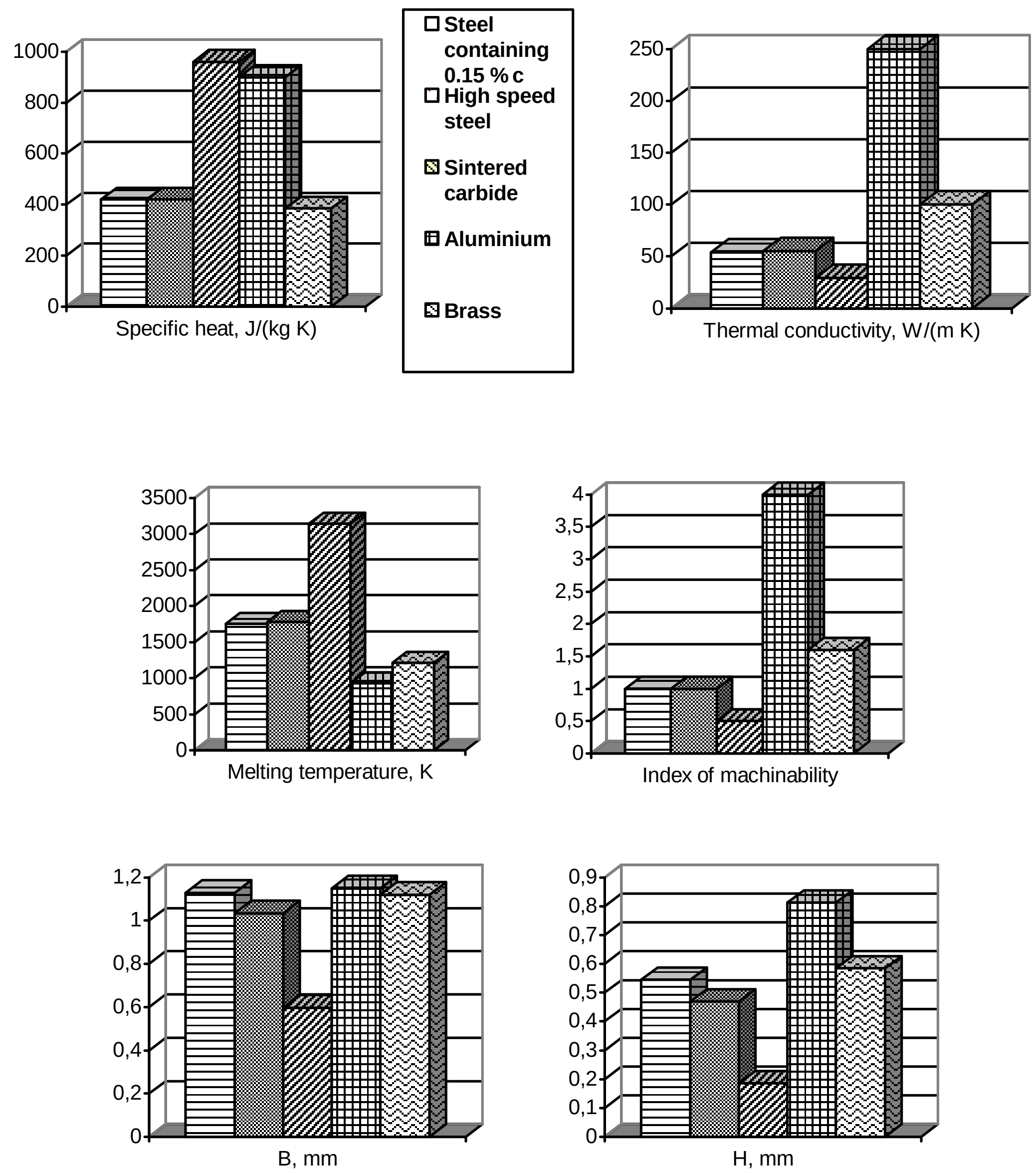


Fig. 3. Graphical representations corresponding to different thermal properties and indexes for the evaluation of the machinability by electrical discharge machining

To search the eventual correlations between the thermal properties of the test pieces materials and the sizes of the machinability indexes, the table 1 was elaborated.

In the lines 1, 2, 3 and 4 of this table, the sizes of different thermal properties were included; in the line 5, the sizes of a machinability index found in the specialty literature [3] was inscribed, while the line 6 and 7 contain the sizes of the parameters *B* and *H*. Finally, in the line no. 8 the sizes of the Palatnik's criterion (sizes calculated by the using of the values corresponding to the thermal properties of the test pieces materials) were specified.

As general remark, one can notice that for some materials included in the table 1, different sizes of the indexes characterizing the thermal properties are indicated in the specialty literature. For example, in the case of high speed steel, the specific heat had sizes included in the interval 420-456 J/(kg·K). Other difficulty is generated by the fact that some of the sizes characterising the thermal properties of the test pieces materials are depending on the measurement temperature. In the considerations presented in this paper, only the sizes of the thermal properties at 20 º C (293 K) were taken into consideration.

As one ca see by examining the information included in the table 1, the highest machinability by electrical discharge machining corresponds to the steel containing 0.15 % carbon, while the most reduced machinability by the same machining method was proved by the sintered carbide type ISO -P35.

To clearly emphasize the correlations existing between the thermal properties of the electroconductive materials and the machinability by electrical discharge machining, the graphical representation included in Fig. 3 were elaborated; the sizes corresponding to the steel containing 0.15 % C were represented by rectangles containing horizontal lines, to the high speed steel – by rectangles containing points, to the sintered carbides – by rectangles containing inclined lines, to the aluminium – by rectangles containing crossed vertical and horizontal lines, and to the brass – by rectangles containing waved lines.

By knowing certain thermal properties of the materials used to prepare the test pieces, one can establish the correspondence between the sizes of the gap made by a single electrical discharge and the thermal properties; practically, the sizes of the thermal properties could be considered as input variables, while the size B and H can be considered as output factors. The power function could be taken into consideration because it offers a direct image concerning the influence exerted by the input factors on the output sizes. By using the specialized software [2], the following empirical relations were established:

$$B = 1.56 \cdot 10^{15} c^{0.452} \rho^{-0.433} \lambda^{-1.94} \theta_m^{-3.45} \quad (12)$$

$$H = 2.56 \cdot 10^{25} c^{0.944} \rho^{-0.774} \lambda^{-3.232} \theta_m^{-6.020} \quad (13)$$

The relations (10) and (11) show that the biggest influence on the dimensions B and H of the gap generated by the single electrical discharge in specified test conditions is exerted by the melting temperature θ_m (the exponents of the input variable θ_m having the biggest absolute size).

As expected, the increase of the melting temperature determines the decreasing of the machinability by electrical discharge machining (the size of the exponent attached to the melting temperature θ_m has a negative value). On the second place, from the point of view of machinability by electrical discharge machining, the thermal conductivity λ can be considered; essentially, the increasing of the thermal conductivity leads to the faster evacuation of the heat from the work zone and, thus, to the diminishing of the machinability.

5. CONCLUSIONS

The machinability by electrical discharge machining of the electroconductive materials is an important technological property, exerting, for example, a significant influence on the material removal rate. Different thermal properties (specific heat, thermal conductivity, melting temperature etc.) can be taken into consideration when the machinability by electrical discharge machining must be analyzed. Some experimental results concerning the evaluation of the machinability of different materials by electrical discharge machining (results obtained by measuring the dimensions of the gap generated by a single electrical discharge) were used to emphasize the possible correlations between the thermal properties and the above mentioned machinability index. The experimental results proved the reduced machinability of the sintered carbides and the better machinability of the carbon steel, in accordance with the remarks derived from the analysis of the thermal properties of the studied materials.

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REFERENCES

[1] **Ablesimov, N.E., Verkhoturov, A.D., Pyachin, S.A.,** *On the energy criterion for the erosion resistance of metals*, Powder metallurgy and metal ceramics, 37, 1-2, 1998, pag. 94- 98;

[2] **Crețu, G**., *Bazele cercetării experimentale. Îndrumar de laborator.* Universitatea Tehnică "Gheorghe Asachi" Iasi, 1992, pag.19-26;

[3] **Gavrilaş, I., Stan, N., Gârleanu, I.,** *Prelucrări electrice în construcţia de maşini,* Editura Tehnică, Bucureşti, 1968;

[4] **Grămescu, T., Slătineanu, L., Braha, V., Sârbu, I.**, *Prelucrabilitatea materialelor,* Editura Tehnica Info, Chişinău, 2000;

[5] **Marafona, J., Chousal J. A. G**., *A finite element model of EDM based on the Joule effect*, International Journal of Machine Tools & Manufacture, 46, 6, 2006, pag. 595-602;

[6] **Poroś, D., Zaborskia, S**., *Semi-empirical model of efficiency of wire electrical discharge machining of hard-to-machine materials*, Journal of Materials Processing Technology, 209, 3, 2009, pag. 1247-1253;

[7] **Slatineanu, L., Coteata, M., Dodun, O., Anton, D.A.,** *Method for the evaluation of the materials machinability by electrical discharge machining,* International Journal of Machining and Machinability, 5, 2-3, 2009, pag. 290-307;

[8] **Slătineanu, L.**, *Tehnologii neconvenţionale în construcţia de maşini*, Editura Tehnica Info, Chişinău, 2000;

[9] **Yeo, S.H., Kurnia, W., Tan, P.C.,** *Electro-thermal modelling of anode and cathode in micro-EDM,* Journal of Physics D: Applied Physics, 40, 2007, pag. 2513-2521.