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FEM SIMULATION OF THE THERMAL TRANSFER DURING THE ELECTRICAL DISCHARGE MACHINING

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Abstract: *The paper presents the simulation of the thermal transfer from the plasma channel during the electric discharge. The simulation is trying to approximate the isotherm surface that corresponds to the melting temperature of the work piece material. The results are compared with the measured craters obtained experimentally and measured with an electronic microscope.*

Key words: *EDM, thermal transfer, thermal simulation, FEM, crater.*

1. INTRODUCTION

Electrical discharge machining (EDM) is a manufacturing process by which a tool cuts the required shape into the work piece within a dielectric fluid. Short time discharges are generated in a liquid dielectric gap, which separates tool and work piece. The material is removed with the erosive effect of the electrical discharges between tool and work piece. The electrical discharge in the EDM process is a highly complex phenomenon but scientific knowledge of this phenomenon is incomplete both at macroscopic as well as at the microscopic level. In the past 50 years, research has been done to develop and improve different models of material removal from both tool and work piece. [1]

EDM is becoming more frequently used for the machining of complex micro-parts that traditional processes are unable to create. During the process, the work piece is immersed in a dielectric fluid and a voltage is applied between a tool electrode and work piece. When the tool electrode is brought close to the work piece, sparks will arc across the inter electrode gap (μm), melting and vaporizing microscopic bits of the work piece. The molten work piece particles harden and are washed away by the continuously flushing dielectric fluid. The area and the movement of the tool determine the shape of the cavity created in the work piece. [2]

In this study, a process simulation for the EDM machining on high alloyed metal will be presented. Material removal will be analyzed using an Abaqus-based thermo-numerical model for a single spark discharge process. The estimated crater dimensions will be compared with experimentally obtained single-spark data using scanning electronic microscopy (SEM) and optical evaluation methods.

During the simulation process, the hydrodynamic process and the removal of the material were not taken into considerations in order to simplify the numerical model.

2. SIMULATION OF THE EDM PROCESS

For the FEM simulation of the thermal transfer phenomena it was used ABAQUS program. The numerical tests were performed for the experimental cases.

The thermal field study of the work piece that is by machined by EDM can be studied if a cylinder is cut out and it should be large enough so that the crater does not influence the boundary of the cylinder. In this case, the process can be described using cylindrical coordinates and the domain can be simplified to a rectangle.

2.1 Discretization of the thermal transfer model with finite elements

- Definition of the geometric domain of analysis. Because of the axial symmetry of the thermal transfer process, the model was defined in a cylindrical coordinates system. (r=0,5mm –radial coordinate and z=0,5mm – axial coordinate).
- Defining the physical properties of the material (HSS alloy). In this field were defined the physical properties of the material: conductivity k=43 $\left[\frac{kg \cdot m}{K \cdot s^3}\right]$, material density ρ= 7860 $\left[\frac{kg}{m^3}\right]$, specific heat c_p= 370 $\left[\frac{m^2}{K \cdot s^2}\right]$,
- Defining the speps of the thermal process simulation. The FEM corresponds to a single stage, the thermal transfer associated to a single electrical discharge. This step is a transient process with the duration t_d – impulse time.
- Defining the thermal loading applied to the FEM model. On the model it was introduced only one load, a thermal flux equal in the intensity with Q = $\frac{4{,}56 \cdot f_c \cdot U \cdot I}{\omega^2 \cdot \pi}$ [W/m^2], where U= 25 [V], I=current intensity [A], ω=$4{,}673 \cdot I^{0{,}43} \cdot t_d^{0{,}44} \cdot 10^{-6}$ [μm] – Gaussian radius of the thermal flux, f_c=0,5 [-] thermal flux distribution. The flux was applied on a small section of the analysis domain.
- Initial conditions of the simulated process. The ambient temperature is fixed at 293,15 K.
- Meshing analysis domain. For the mesh there were used triangular elements (DCAZ3), designed for thermal transfer processes analysis with axial symmetry. The mesh density was set so that the dimension of the elements that are situated near the heat flux to be much smaller as shown in figure 1.

2.2 FEM simulation

The main objective of the simulation was to determine the characteristic dimensions of the crater obtained after a single electrical discharge.

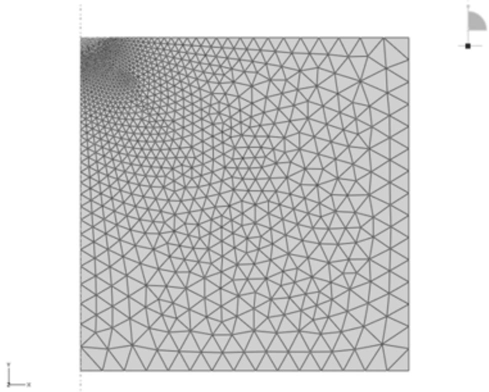


Fig. 1. Triangle elements mesh of the analysis domain[4]

These dimensions have been determined from the thermal distribution diagram. On the diagram it was individualized the level curve corresponding to the melting temperature of the steel (1810 K in this case).

The approximated form of the crater was a spherical cap for which there were measured the depth h and the radial extension R. With this values were calculated the volumes of the craters as shown in table 1.

Numerical simulation has showed an increase of the crater dimensions (axial and radial) direct with the discharge time and current. These results are qualitatively consistent with the experimental observations. However in terms of quantity, there are some differences as highlighted in figure 4.

These differences between simulation and measurements made in the laboratory can be explained by the idealizing assumptions of the fininte element model:

- Applying a uniform heat flow distribution over a boundary area;
- Hypothesis of the constancy of the material parameters though the temperature investigations;
- Neglecting the boundary changes in discretized domain due to the vaporization of the material forming craters.

After running the simulation in ABAQUS program, 13 representations of the isotherm of the studied material were determined. Each isotherm representations were chosen as having a temperature of 1810 K. The isotherm was considered as defining the crater shape obtained from a single discharge as in figure 2.

Table 1

Values of the crater dimensions

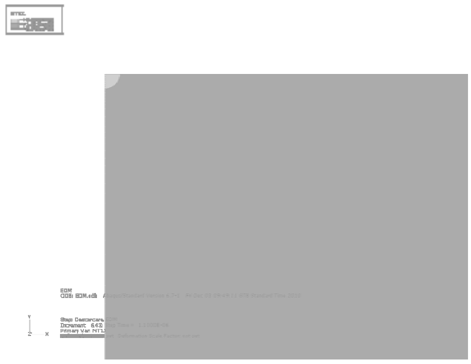
I-[A]	U-[V]	t_d-[s]	R-[um]	h-[um]	V-[um^3]
1,2	25	0,0000011	5,052163	5,2	281,930
1,2	25	0,0000015	5,508653	5,2	320,7084
1,2	25	0,0000178	11,21168	10,7	2749,76
1,8	25	0,0000237	17,21484	16,5	10019,694
2,4	25	0,0000274	17,95939	16,5	10656,5033
3,2	25	0,0000316	17,319393	16,5	10109,11
4,4	25	0,0000422	21,54875	20,1	18846,56
6,2	25	0,0000866	28,8015	25,4	41215,4
8	25	0,0001155	37,66566	33,2	92106,72
10	25	0,000154	45,51230	39,4	157908,48
13	25	0,0001778	53,99507	46,7	263291,03
17	25	0,0001778	64,224242	52,8	408347,17
21	25	0,0002	69,362297	59,8	555307,75

Here were represented the smallest and the largest crater obtained from the weakest and the most intense processing parameters.
In figure 2 it can be observed the evolution of the crater dimension regarding the values of the discharge energy.

3. MEASUREMENT OF THE EDM CRATER

Infinite Focus is based on Focus-Variation. The optical technology delivers a measurement density of more than 100 mil measurement points which enables form and roughness measurement of even large measurement areas and volumes. As an area based technology, Focus-Variation is already included in the most recent EN ISO standard 25178. With each measurement, users automatically receive data for evaluating the measurement uncertainty. [4]

With the infinite focus microscope were measured the dimensions of the EDM machined craters. Because of the reflections problem due to the molten material and because of the oxide from the surface, the functions of the software weren't accurate enough to measure the volume. So it was necessary to measure the dimensions of the crater with the function profile analysis as in figure 3.



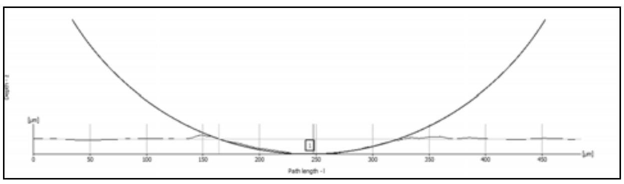
a)

b)

Fig. 2 . Representation of the isotherms in the considered work piece [4]

The measurements were made for 13 series of craters so that the simulation could be compared quantitatively.

s)



b)

Fig. 3. Function Profile Analysis of the software Alicona IFM, a) Selecting the section through the crater, b) actual topography of the crater

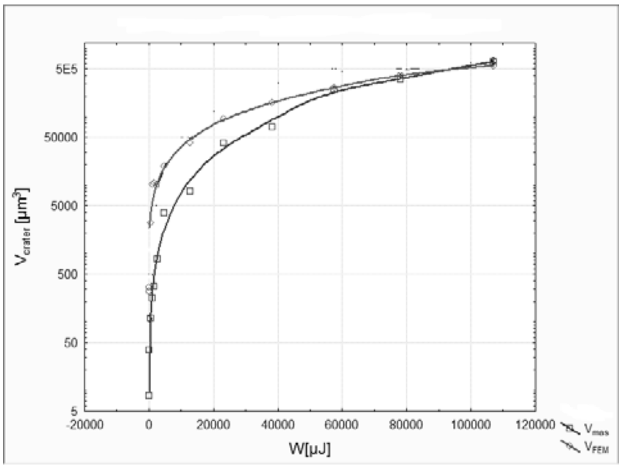


Fig. 4. Volume variation concerning the discharge energy of the spark

4. CONCLUSION

The numerical model is qualitatively approximating the shape of the crater but quantitatively there is place for a further improvements. The shape of the crater is generating the surface quality and by improving or controlling the crater form the surface of the EDM or micro-EDM worked pieces can be improved.

5. REFERENCES

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Simularea cu elemente finite a procesului de eroziune termica in timpul prelucrarii prin eroziune electrica

Lucrarea prezintă simularea de transfer termic de la canal de plasmă la piesa in timpul unei descarcari electrice la prelucrarea prin eroziune electrica. Simularea încearcă să aproximative suprafata izoterma care corespunde la temperatura de topire a materialului piesei de prelucrat. Rezultatele vor fi comparate cu cratere măsurat experimental, dimensiunile fiind masurate in urma masurarii craterelor cu un microscop electronic.

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