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CONSIDERATIONS AND APPRECIATIONS ON THE MODELING OF THE TECHNOLOGICAL PROCESS OF WIRE EROSION PROCESSING

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Abstract: The aim of the hereby paper is the modeling of physical and technological phenomena present in the EDM (Electrical Discharge Machining), for the technological purpose of optimizing the technological parameters for forecasting the form of the imprint generated in the process. The materialization of this objective led to the technological development of an instrument consisting of two parts completing each other. In the first part, the aim is to optimize the approximation of the thermal energy flow produced by the EDM device, by means of a cubic spline regression function cancelled at the end of the radius, which uses the regression points found mostly on the Gaussian bell. The second part, different from the first one, but also leading to optimizations of the EDM processes, consists of the application of the triangular cut of fuzzy numbers logics and FAHP method (Fuzzy Analytic Hierarchy Process) on certain essential characteristics of the EDM. They are applied for designing mathematical models allowing interventions within the important processes for the optimization of the results obtained during the materials processing where wire erosion is used. This "fuzzy" mathematical model, which is an innovation in this field, provides beneficial effects, using both the qualities of the essential features of the EDM processes, as well as the experimental measurements obtained using the wire erosion processing machine
Key words: EDM, modeling, thermal flow optimization, spline function, fuzzy numbers, FAHP algorithm.

1. INTRODUCTION

Processing, in the most general case, is a "local or global transformation by which dimensions, form, constitution or aspect of a material are changed, to obtain certain end products". An end product is considered to be one of the three elements: part, subset, set. Processing encloses physical transformation processes in which the form and dimensions are changed, but also complex processes of chemical or other type, by which the constitution and aspect are changed, referring to all the possibilities of changing it by methods designated of coverage, while the constitution refers to the change of the chemical composition, structure and property of the material, using methods of chemical and thermal-chemical treatment.

The transformation of the primary energy (electrical) in effect energy (thermal) is accomplished at the level of the electrode shades and leads to the formation of an erosion crater (sampling) on the surface of the semi-fabricated product to be processed, and respectively, an erosion crater (wearing) on the active surface of the electrode.

Material sampling represents, technically, a means of separation of particles of sub-millimetric dimensions from the base material of the semi-fabricated product, through non-mechanical phenomena.

Modeling is "schematizing, modeling, simulation, close-related notions, used to refer to various steps of the general recognition procedure, an attempt to propose a schematic and simplified representation of the physical, technical or industrial reality, for the purpose of progressing in perfecting the actual technological actions".

At the same time, the objectives of modeling can be synthesized as follows: knowledge, forecasting, optimization, adjustment and dynamic control of the evolution of phenomena present within the technological process. At the level of modeling functions, they can be expressed as follows: “modeling, as representation of reality, modeling as action lever, modeling as analogy, modeling as experimental act, modeling as attribute of artificial intelligence”.

At the level of the methodology used for approaching the technological process modeling, we partially worked on the one developed in the paper of Prof. Vasile Soporan (V. Soporan, C. Vamoș, C. Pavai – Modelarea numerică a solidificării *[Numerical Modeling of Solidification]*, Dacia Publishing House, 2003, Cluj-Napoca), synthesized below:

- Description of the phenomena occurred in the analyzed process;
- Establishing the importance and priority of phenomena in the general context analyzed;
- Establishing the mathematical equations governing the evolution of the phenomena;
- Imposing geometrical, physical, initial and limit conditions, to obtain a unique solution of the system of mathematical equations;
- Discretization of the governing equations;
- Establishing the numerical algorithm;
- Verification of the obtained solutions, by establishing some test experiments.

The complexity of the entire process should be emphasized, as it includes essential physical phenomena: “melting or vaporization of certain elementary material volumes; rupture of material from the surface layers of the semi-finished material; corrosion”.

2. THE PHENOMENOLOGICAL DESCRIPTION OF THE TECHNOLOGICAL PROCESS OF WIRE EROSION PROCESSING

Regarding the phenomenological description of the technological process of wire erosion processing, the diagram presenting the participating domains is taken into consideration, namely figure 1.

In this diagram, we used the notations having the following meanings: *D1* – electrode domain, *D2* – the domain of the part which is to be processed, *D3* – dielectric domain, *S13* – border between the electrode and the dielectric, *S23* – border between the part and the dielectric, *S1ma* – border between the electrode and the environment, *S2ma* – border between the part and the environment, *S3ma* – border between the dielectric and the environment, *D1l* – electrode domain transformed in liquid phase (melted), *D1s* – electrode domain in solid phase, *D1ls* – electrode domain between the solidus temperature phase and the liquidus temperature (paste area between liquidus and solidus), *D2l* – domain of the part to be processed, which is transformed in liquid phase (melted); *D2s* – domain of the part to be processed in the solid phase; *D2ls* – domain of the part found between liquidus temperature and solidus temperature (paste area between liquidus and solidus).

In the technological process, the following physical phenomena occur:

- Thermal phenomena, among the participating domains defined above, through the borders and at strictly within the domains;
- Electrical phenomena among the defined domains;
- Mechanical phenomena;
- Hydraulic phenomena;
- Mass transportation phenomena.

In the process, we consider that the thermal phenomena present at the contact between electrode and cast part, through the dielectric of participation and the environment of their evolution, are very important.

The insight and modeling of the thermal phenomena is materialized, within the modeling, through the knowledge of the thermal field on the part and electrode. The values of the punctual temperatures and their distribution in time provide information on the melted material and its dislocation potential. This data provide information on the cavity that is to be created in the mass of the part’s material, therefore, considering the objective of the modeling activity, that of determining the cavity formed, we consider that the modeling preliminary discussion must linger in the area of thermal processes modeling in the participating domains (electrode, part and dielectric).

In the stages of the wire erosion technological process, the presence of the physical phenomena is described in Table 1.

Tabel 1

Table 1. Physical phenomena present in the stages of the wire erosion technological process

Crt. No.	The stage of the technological process	Physical phenomena occurred
1.	Electric arc ignition and consolidation	Electrical phenomena generating thermal energy
2.	Transformation of the electrical energy in thermal energy	Source of thermal energy at the domains' interface
3.	Transfer of the thermal energy in the domain of the part	Conductive process in the mass of the part's material
4.	Transfer of the thermal energy in the electrode domain	Conductive process in the mass of the electrode's material
5.	Accumulation of thermal energy in the mass of the part to be processed	Melting the mass of the part, proportionally with the stored heat and the occurrence of the liquid phase
6.	Material dislocation on the outline delimited by the liquid phase and the obtained crater	Hydrodynamic processes in the dielectric and the liquid phase of the fusion
7.	Continuation of the process in another layer	Resumption of phenomena or their simultaneous evolution

Considering the presentation of the modeling approach, the paper shall develop the finding of the optimal form of the crater, by relating to the solution given by summing up the experimental data. The variants to be analyzed are presented in Table 2.

Table 2

Table 2.Variants of analyses for the form of the crater obtained throught EDM

Approximation of the open border	Approximation of the energy flow function
Sphere type border	Gauss
	Spline
Spherical dome-type border	Gauss
	Spline
Rotation semi-ellipsoid-type border	Gauss
	Spline

At the same time, considering the complexity of the phenomena present in the process of wire erosion processing, the paper proposes the use of fuzzy numbers for the accomplishment of the FAHP algorithm regarding the optimization of the phenomena occurring in the wire erosion.

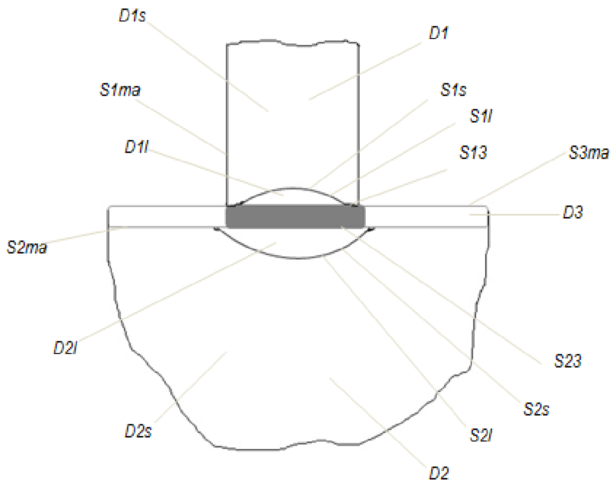

Figure 1. The diagram of the domains participating in the EDM process

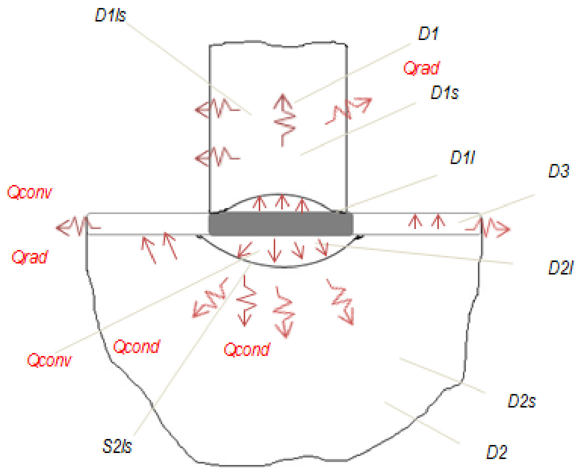

Figure 2. Detail of the analyzed system in the course of processing by electro

D1 – electrode domain,
D2 – the domain of the part which is to be processed,
D3 – dielectric domain

3. EXPERIMENTAL DATA REQUIRED FOR THE OPTIMIZATION

From the experimental point of view, the purpose of the research is to create experimental applications to obtain better results of the wire erosion processing of materials. Regarding the first part, the proposed theory has led us to obtaining the form and dimension of the crater. This result is based on the numerical model proposed in the discontinuous Stefan problem. If the numerical model is modified, the form and dimensions of the crater will certainly change. Measurements made with a high power micrometer indicated that the crater created with this model is closer to the real crater obtained in the above-mentioned laboratory.

The experimental measurements were performed in the Laboratory of Unconventional Technologies and Innovative Production within the department of Machines Construction Technology of the Technical University of Cluj-Napoca, which owns a wire erosion machine with massive electrode and numerical control that can automatically change the electrode during the complex processing of rough metals.

The measurement of the craters' dimensions, as well as the analysis and characterization of the surface were performed using the JSM-5600 LV (JEOL) scanning electron microscope with EDS spectrometer (Oxford Instruments), microscope belonging to the Department of Science and Technology of Materials, Laboratory of Electronic Microscopy of the Technical University of Cluj-Napoca. This is a high-performance microscope and can be used in many domains, as its operating mode is high vacuum and low vacuum, a resolution up to 3.5 nm, zoom up to 300000x and the possibility to detect elements from Boron to Uranium with a resolution of 133 eV.

Table 3 shows the data measured following the experiments performed. The parameters recorded by the wire erosion machine were:

- Current intensity *I [A]* taking the following values: *I = {1.2, 1.8, 2.4, 3.2, 4.4, 6.2, 8, 10};*
- Working tension *U [V]* with an approximate average value *U = 25 [V];*
- Positive polarization between the two poles;

For these data, the size of the crater's semi-axis, noted in table 3, resulted at each final execution time of an impulse.

Table 3

Tabel 3. Tabel of experimental data

Crt. No.	**Measured final time** t_f [μs]	**Crater semi-axis** $a(t_f)$ [μm]	**Current intensity** *I [A]*
1.	17.8	6.62	1.2
2.	23.7	8.06	1.8
3.	27.4	9.21	2.4
4.	31.6	12.15	3.2
5.	42.2	20.35	4.4
6.	86.6	25.55	6.2
7.	115.5	44.61	8
8.	154.0	55.48	10

Table 3 is the table of experimental data, measured in relation to an impulse's final execution time and the corresponding crater's semi-axis.

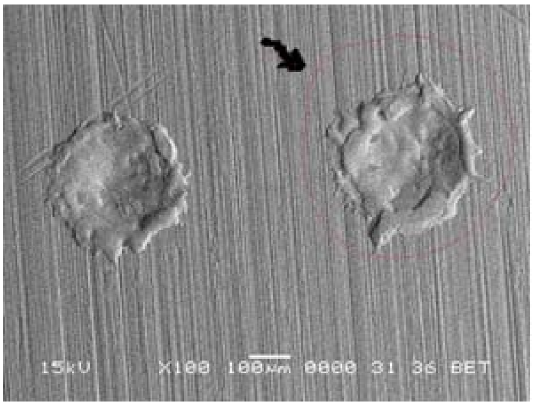

Figura 3. The image produced by scanning electron microscopy of a real crater

Using these numerical data from table 3 and the formulas required to apply the FAHP algorithm, we obtain the optimized numerical data in relation to the execution time t_f and the semi-axis $a(t_f)$ of the crater, shaped as a rotation half-ellipsoid.

Table 4

Tabel 4. Final results regarding the optimization of the execution time and rotation semiellipsoid using FAHP

$t_{f,o}$	$t_{f,m}$	$t_{f,p}$	$a(t_{f,o})$	$a(t_{f,m})$	$a(t_{f,p})$
128.328	127.507	128.371	45.653	45.289	45.667

7. CONCLUSION

The purpose of creating the fuzzy mathematics was the numerical processing of linguistic information. It is important to note that the information characterized by “crisp” numbers is not excluded by the fuzzy theory. If we use *A* to note the set of “characteristics”, the set that we consider abstract and that we call “the universe of the fuzzy elements” then the assignment of each element to a fuzzy number, namely the fuzzyfication of the universe means to define a function: $A \rightarrow [0,1], A \cdot \mu$. The use and interpretation of the linguistic information, using this new mathematical theory is accomplished through the FAHP (Fuzzy Analytic Hierarchy Process) algorithm. Any approximation is a result, but this does not mean that it is the best result. The linguistic information could not be quantified outside the fuzzy theory. Therefore, we can assert that an approach to the fuzzy theory with the “crisp” theories leads to high quality results which can be developed in the future. As an example, we can refer to the crater’s radiuses and the final execution time of an EDM impulse.

8. ACKNOWLEDGEMENT

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CONSIDERAŢII ŞI APRECIERI ASUPRA MODELĂRII PROCESULUI TEHNOLOGIC DE PRELUCRARE PRIN ELECTROEROZIUNE

Rezumat. În lucrarea de faţă se urmăreşte modelarea fenomenelor fizice şi tehnologice prezente in cadrul EDM (Electrical Discharge Machining), cu scopul tehnologic de optimizare a parametrilor tehnologici în vederea previzionării formei amprentei generate în cadrul procesului. Materializarea acestui obiectiv a impus dezvoltarea tehnologică a unui instrument constituit din două părţi care se completează reciproc. Faptul că nu am luat în considerare toate fenomenele în cadrul procesului de modelare, structurează desfăşurarea acesteia în două etape: - prima, în care s-a aproximat funcţia fluxului de energie şi frontiera liberă; - a doua, includerea în procesul de aproximare a funcţiei fuzzy prin procesul de fuzzyficare a influenţei asupra procesului. Utilizarea şi interpretarea informaţiilor lingvistice, folosind această nouă teorie matematică se realizează prin algoritmul FAHP (Fuzzy Analytic Hierarchy Process). Orice aproximare este un rezultat, aceasta nu înseamnă că este cel mai bun rezultat. Înformaţiile ligvistice nu s-au putut cuantifica înafara teoriei fuzzy. În consecinţă, putem afirma că o abordare a teoriei fuzzy cu teoriile "crisp" conduce la rezultate superioare care pot fi dezvoltate pe viitor. Ca exemplu ne putem referi la razele craterului şi a timpului final de execuţie a unui impuls EDM.

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