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FUZZY ANALYTICAL HIERARCHY PROCESS APPLIED TO DETERMINE THE MATERIAL MACHINABILITY IN EDM PROCESS

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Abstract: *The purpose of this research paper is to apply the principle and technique of Fuzzy Analytical Hierarchy Process (FAHP) to obtain the weights of materials machinability in Electrical Discharge Machining (EDM) process, with the appropriate parameters concerning the process depending on their dielectric medium used in the process. FAHP is a powerful and flexible tool for multiple attribute decision making method to get priorities and take the best decision when different aspects of a decision need to be considered. It is known that EDM is a manufacturing process that is based on thermal erosion due to the plasma channel formed between the work piece and the work tool formed in the dielectric during the electrical discharge.*

Key words: *Electrical Discharge Machining (EDM), Fuzzy Analytical Hierarchy Process (FAHP), manufacturing process, materials machinability.*

1. INTRODUCTION

During the evolution of the new materials with special physical properties (high abrasion resistance, low density, mechanical resistance, etc.), the manufacturing processes have had to continuously reach properties of the cutting tools at least as good as the new materials. This evolution is driving the industry to a continuous competition. Some of these materials cannot be processed by cutting so the solutions to these problems are the nonconventional technologies as LASER (Light Amplification by Stimulated Emission of Radiation), Plasma – that is usually used for cutting but in some cases it is used for material deposition, Ultrasonic processing – uses for welding or in combination with classic milling or turning processes, ECM (Electro-Chemical Machining) – used for finishing surfaces, etc. Some of these technologies have become essential parts for other manufacturing technologies such as rapid prototyping that uses deposition with electron beam, laser or plasma for sintered surface cladding [1].

The EDM process is known since 1943, which could be considered a "young" machining process, discovered by the two Russian scientists B.R. Lazarenko and N.I. Lazarenko. They discovered that the electrical erosion process was more controllable if the two electrodes were immersed into dielectric fluid. This led them to develop an EDM machine that was used to process materials that were difficult to work. So appeared the first S-EDM based on a RC type circuit [1].

In 1960 is developed the first W-EDM machine (Wire Electrical Discharge Machine) used for making tools from hardened steel. [1]

As it was a very useful process it has developed continuously. EDM typically works with materials that are electrically conductive, although methods for machining insulating ceramics with EDM have also been processed [2, 3].

Due to its development, the process is continuously increasing its performances regarding the MRR (Material Removal Rate) and surface quality that can be quantified in surface roughness R_a and surface integrity concerning the high temperature in plasma channel and the fluid of dielectric flooding the heated surface create heat stress in the surface.

In the specialized literature we could not find study regarding the selection of material machinability in EDM process.

The study find in the literature are presented below. These study are refers at the selection of non-traditional machining using different multiple attribute decision making method.

Choudhury Tonmoy et. al. in [4] has realized a selection of NTM (Non Traditional Machining) process based on hybridized "technique for order preference by similarity to ideal solution" (TOPSIS) and an analytical hierarchy process (AHP) expert system in which an AHP matrix is referred. The relative closeness of the NTM alternatives is evaluated using TOPSIS which shows the best alternative machining process. Yurdakul and Cogun in [5] presented a multi-attribute selection procedure to help manufacturing personnel determine the suitable NTM process for a given machining application. N. D. Chakladar and S. Chakraborty in [6] have developed an expert-system based on a TOPSIS – AHP method in order to help selecting the most suitable NTM process from among a large number of available NTM process.

2. EXPERIMENTAL METHOD FOR ACHIEVING INDEPENDENT CRATER AND THE MEASUREMENT OF THE DIMENSIONS

The micro craters were realized with the help of an experimental RC - generator. The generator uses a DC transformer at 80/100V from AC 220 v / 50 Hz, bridge rectifier KBPC 1008, one bipolar switch Kn3(c) - 202 used for charging and discharging the capacitor, electric resistance of 1 Ω and one capacitor of 200 μF/100V. An electrode was used a copper wire with a diameter of 1 mm maintaining the same distance for every probe. On the flat surface of every material, were produced several independent eroding craters.

With the help of an Alicona Infinite Focus microscope baser on the focus variation were measured the dimensions of the crater and the quantity of the material that was removed and adhered on the surface of the surfaces.

Using the ANOVA analysis it has been developed a mathematical model of the surface roughness depending on the current I [A] and the impulse time t_i [μs], these two being the main parameters of the process.

3. FUZZY ANALYTICAL HIERARCHY PROCESS FOR DETERMINING THE MATERIAL MACHINABILITY IN EDM PROCESS

The Fuzzy Analytical Hierarchy Process (FAHP) is a decision tool developed by Saaty [7-9]. Here, the FAHP was adapted to solve one of the crucial problems of EDM process: the determination of the machinability concerning different types of material depending on several criteria and on the experimental results obtained from processing different types of materials in different conditions.

In order to solve this problem, a new approach is proposed for the FAHP algorithm adapted to determine the materials machinability of different materials by EDM process. Therefore it is required the following steps:

3.1 Construct de decision tree

The construction of the decision tree involves setting the objective, identifying the criteria and the alternatives that will be analyzed.

Structuring the decisional model is a very important step in this algorithm because it indicates the relationships established between the various elements that belong to a specific level with the elements belonging to an immediately lower level. These relations indicate that each element is interconnected with at least one element from the lower level immediately below. In figure 1 is presented a structure of the hierarchic tree.

3.2 Assigning fuzzy numbers

In this stage, each alternative is assigned a fuzzy number according to its importance.

Fuzzy number assignment is done according to the following judgment: the most important alternative will get fuzzy largest number ($\underline{17}$), while the least important alternative will get fuzzy lowest number ($\underline{1}$).

Fuzzy numbers with α cut, having the optimism grade β are defined as follows:

$$\underline{1}_{\alpha}^{\beta} = (1-\beta) + \beta \cdot (3 - 2 \cdot \alpha). \qquad (1)$$

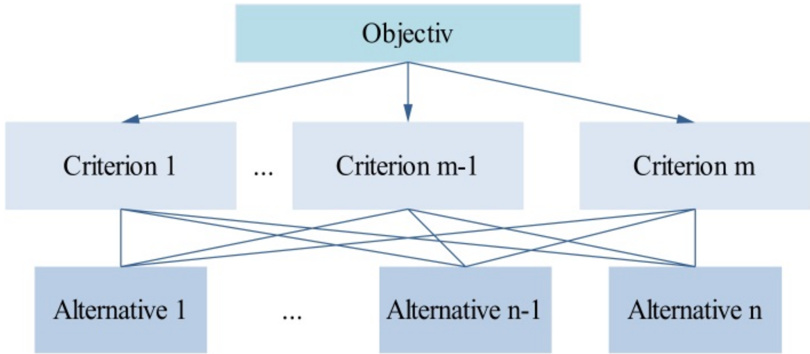


Fig. 1. The hierarchical structure of decision tree

$$\underline{(2k \tilde{+} 1)}_{\alpha}^{\beta} = (1-\beta) \cdot (2 \cdot k - 1 + 2 \cdot \alpha) + \beta \cdot (2 \cdot k + 3 - 2 \cdot \alpha). \qquad (2)$$

where: α, β □ [0,1] and k=0÷8 [10].

Graphical representation of fuzzy numbers with α cut can be seen in figure 2.

3.3 Construct the pair-wise fuzzy comparison matrix

The pair-wise fuzzy comparison matrix is made so that the criterion in row *i* (i=1,2,...,n) is ranked relative to each of the criteria represented by the *n* columns.

Construct the pair-wise fuzzy comparison matrix is achieved as follows [11]:

$$\underline{g}_{ij}^{\alpha,\beta} = \begin{cases} \max(\underline{g_i, g_j}), \text{if } i < j \\ (\underline{g}_i)^{-1}, \text{if } i > j \\ 1, \text{if } i = j \end{cases} . \qquad (3)$$

The result of the pair-wise comparison on *n* criteria can be summarized in a (*nxn*) evaluation matrix G.

Every element g_{ij} (i,j=1,2,...,n) denotes the comparative importance of criteria is respecting the criteria *j*. To a criterion that is compared to itself is always assigned the value 1 so the main diagonal entries of the pair-wise comparison matrix are all 1.

$$G = \begin{bmatrix} 1 & \underline{g}_{12} & \cdots & \underline{g}_{1n} \\ \underline{g}_{21} & 1 & \cdots & \underline{g}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \underline{g}_{n1} & \underline{g}_{n2} & \cdots & 1 \end{bmatrix} . \qquad (4)$$

where: $\underline{g}_{ij} \neq 0$ and $\underline{g}_{ji} = 1/\underline{g}_{ij}$ [12,13]

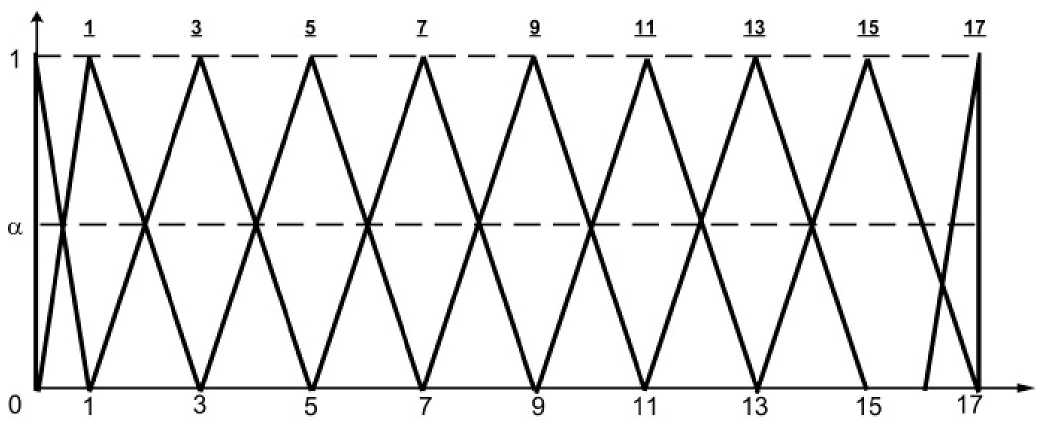


Fig. 2. Fuzzy numbers with α cut

3.4 Data processing

At this stage, first normalized matrix (N) is constructed by dividing each number in the fuzzy comparison matrix column to the amount of its column.

Next step is to determine the relative weight (W) depending on the alternative chosen criteria by adding the normalized matrix lines.

Then we must calculate the level of consistency (C):

$$C = N \cdot W . \tag{5}$$

where: N is the normalized matrix and W is the relative weight matrix, and:

$$C = \begin{bmatrix} c_1 \\ c_2 \\ \cdots \\ c_n \end{bmatrix} . \tag{6}$$

Then it's calculated:

- consistency value [14]:

$$CV_i = n \cdot \frac{c_i}{w_i} . \tag{7}$$

- maximum eigenvalue [15-17]:

$$\lambda_{max} = \frac{\sum_{i=1}^{i=n} CV_i}{n} . \tag{8}$$

- consistency index [15-17]:

$$CI = \frac{(\lambda_{max} - n)}{n-1} . \tag{9}$$

- random index [15-17]:

$$RI = \frac{1.987(n-2)}{n} . \tag{10}$$

- consistency ratio [18]:

$$CR = \frac{CI}{RI} . \tag{11}$$

If CR<0.1 then the results are accepted and these results can be analyzed and interpreted. If CR>0.1 then the procedure must be repeated [].

3.5 Interpretation of results

At this stage, the relative weights of the alternatives, previous obtained, are analyzed according to all of the criteria.

4. CASE STUDY

The main objective of this study is to determine the machinability of different materials that are usually processed by EDM.

Here, the FAHP was adapted to solve one of the crucial problems of EDM process: determining machinability of different material types concerning the dielectric medium, where the process takes place, the crater volume formed by a single discharge, the amount of material removed from the work piece and the amount of material adhered on the surface during the process.

Next it will use the following notations: V_1 – crater volume [μm^3], V_2 – removed material [μm^3], V^3 – adhered material on the work piece surface [μm^3], MM – medium machinability, M – eroded material, M_1 – ceramic material, M_2 – steel, M_3 – CBN 10229, M_4 – CBN 10660, M_5 – PKD 30221, M_6 – PKD 30662, M_7 – PKD 40664, M_8 – PKD 50664, D_M – dielectric medium, D_A – air considered as dielectric fluid and D_O – oil considered as dielectric fluid.

Using the Alicona Microscope based on focus variation; it was possible to measure the values of V_1, V_2 and V_3 by using the integration functions for volume analysis. In figure 3 is presented the removed material from the micro crater measurement. Figure 4 presents the studied hierarchic tree.

Table 1 shows the results of measurements to determine the machinability of the materials in various dielectric media on the test stand.

As it is shown in table 1, the value of the quantity of the material that is removed from the surface of the material depends a lot on the material. In the specific literature, the only condition that a material must perform is the electrical conductivity. As a qualitative condition it is enough.

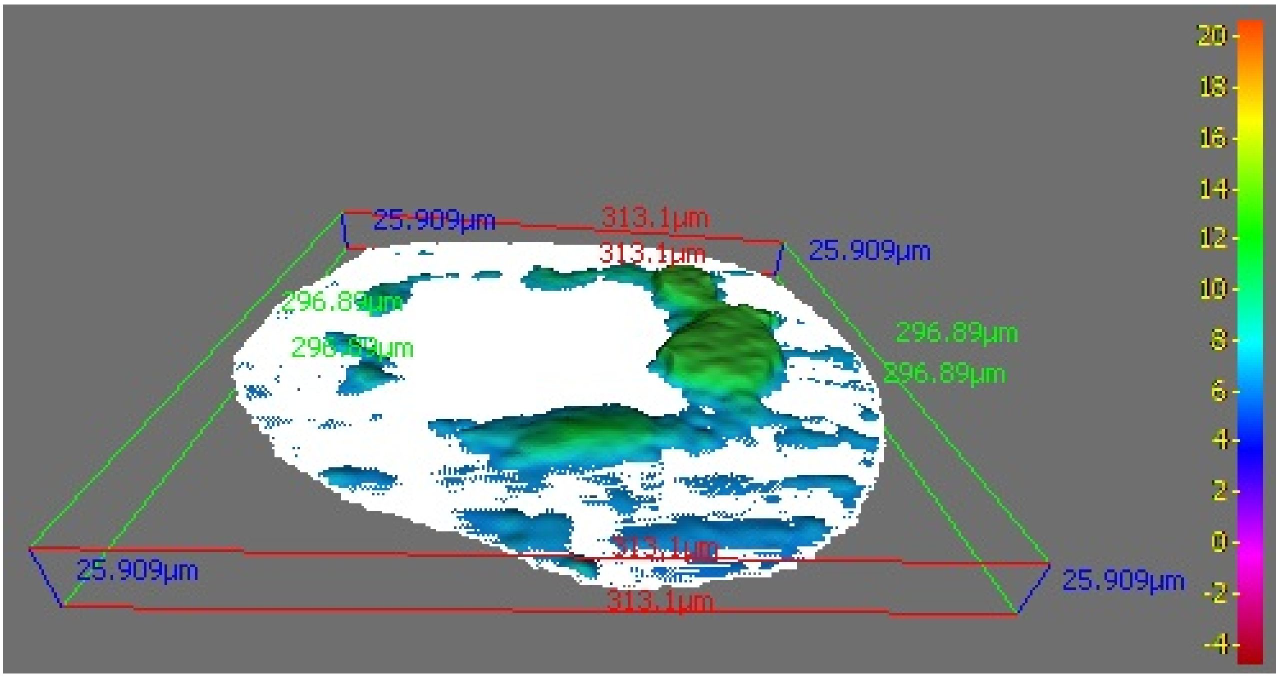


Fig. 3. Removed material from the micro crater measurement

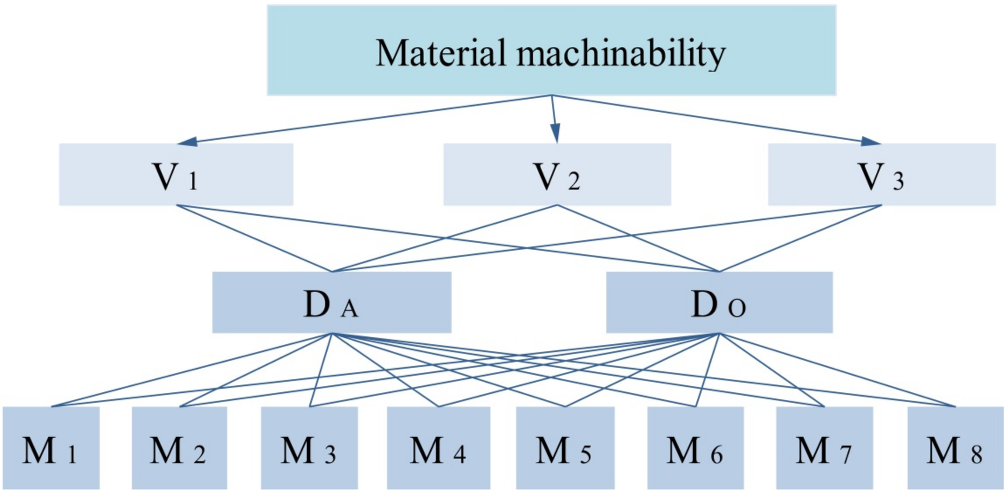


Fig. 4. The proposed hierarchical model

By this study, using the same amount of energy and the same dielectric medium, the quantitative appreciation is realized on different materials with different properties.

The assignment of the fuzzy number for each studied alternative can be seen in table 2. The values of these number were selected partial but after a detailed study concerning the properties of all materials and dielectric properties.

5. RESULTS

In table 3 and 4 are presented the obtained results after applying the FAHP method adapted for determining the material machinability in EDM process.

Figure 5 and 6 present the weights for the machinability of the studied materials in dielectric medium air and oil. Figure 7 represents the weights of medium machinability in dielectric environment: air and oil.

Table 1

Measured values of the volumes used for determining the material machinability.

M	D_M	V_1 [μm^3]	V_2 [μm^3]	V_3 [μm^3]
M_1	D_A	33895	16994	16901
M_1	D_O	26244	25664	580
M_2	D_A	122475	27082	95393
M_2	D_O	87751	15083	72668
M_3	D_A	15153	15245	92
M_3	D_O	11015	9510	1505
M_4	D_A	4582	7603	3021
M_4	D_O	7001	7837	836
M_5	D_A	638	3100	2462
M_5	D_O	552	24101	23549
M_6	D_A	277	6263	5986
M_6	D_O	233	2532	2299
M_7	D_A	885	1870	985
M_7	D_O	1656	13521	11865
M_8	D_A	1191	1903	712
M_8	D_O	239	31173	30934

Table 2

Assigning fuzzy numbers for studied alternatives.

M	D_M	V_1	V_2	V_3
M_1	D_A	15	13	13
M_1	D_O	14	15	3
M_2	D_A	17	16	17
M_2	D_O	16	11	16
M_3	D_A	13	12	2
M_3	D_O	12	9	7
M_4	D_A	10	7	10
M_4	D_O	11	8	5
M_5	D_A	6	5	9
M_5	D_O	5	14	14
M_6	D_A	4	6	11
M_6	D_O	2	4	8
M_7	D_A	7	2	6
M_7	D_O	9	10	12
M_8	D_A	8	3	4
M_8	D_O	3	17	15

The best results in case of manufacturing in dielectric medium air are obtained for steel and ceramic material. The M_3 material is also closing up to the performances of M_1 by far, the other material are hardly processed by EDM. This is the reason why we can tell that as for the material, the most indicated materials that should be machined by EDM are M_1 and M_2. The other materials present a poor machinability by EDM.

The highest score of 45.81% for V_2 criteria was assigned for material M_2 in case of air used as dielectric medium.

Table 3

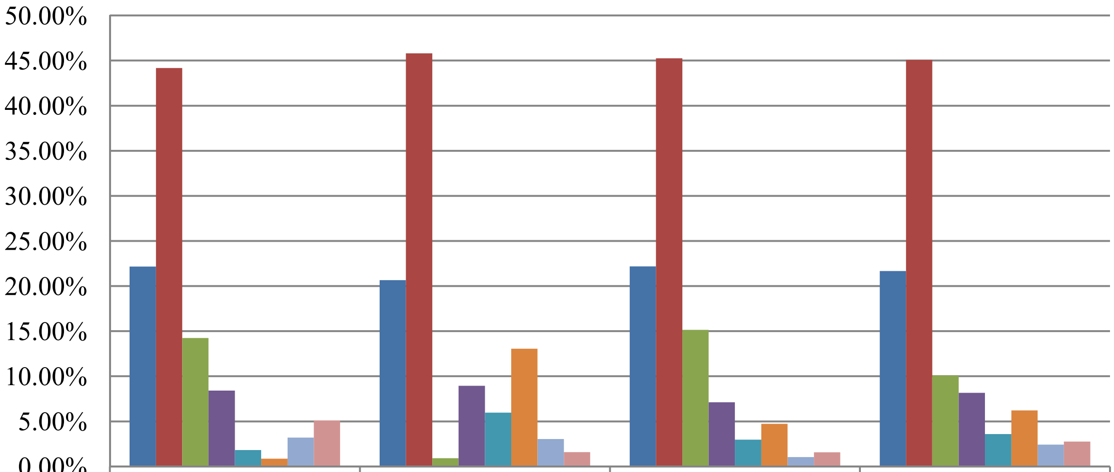
Results obtained for dielectric environment air.

	W	C	CV	λ	CI	RI	CR
V_1 - D_A							
M_1	0.2217	0.1482	5.3496	7.8027	-0.0282	1.4903	-0.0189<0.1
M_2	0.4417	0.6512	11.7947				
M_3	0.1425	0.0701	3.9357				
M_4	0.0841	0.0391	3.7200				
M_5	0.0183	0.0208	9.1228				
M_6	0.0087	0.0201	18.4645				
M_7	0.0321	0.0229	5.7113				
M_8	0.0510	0.0276	4.3226				
V_2 - D_A							
M_1	0.2066	0.1377	5.3345	7.9884	-0.0017	1.4903	-0.0011<0.1
M_2	0.4581	0.6552	11.4425				
M_3	0.0092	0.0209	18.1737				
M_4	0.0895	0.0425	3.7955				
M_5	0.0597	0.0294	3.9449				
M_6	0.1306	0.0693	4.2467				
M_7	0.0304	0.0234	6.1454				
M_8	0.0159	0.0215	10.8244				
V_3 - D_A							
M_1	0.2217	0.1507	5.4360	8.0088	0.0013	1.4903	0.0008<0.1
M_2	0.4526	0.6481	11.4562				
M_3	0.1514	0.0687	3.6288				
M_4	0.0712	0.0362	4.0635				
M_5	0.0298	0.0241	6.4870				
M_6	0.0472	0.0280	4.7520				
M_7	0.0104	0.0218	16.8687				
M_8	0.0157	0.0223	11.3783				

Table 4

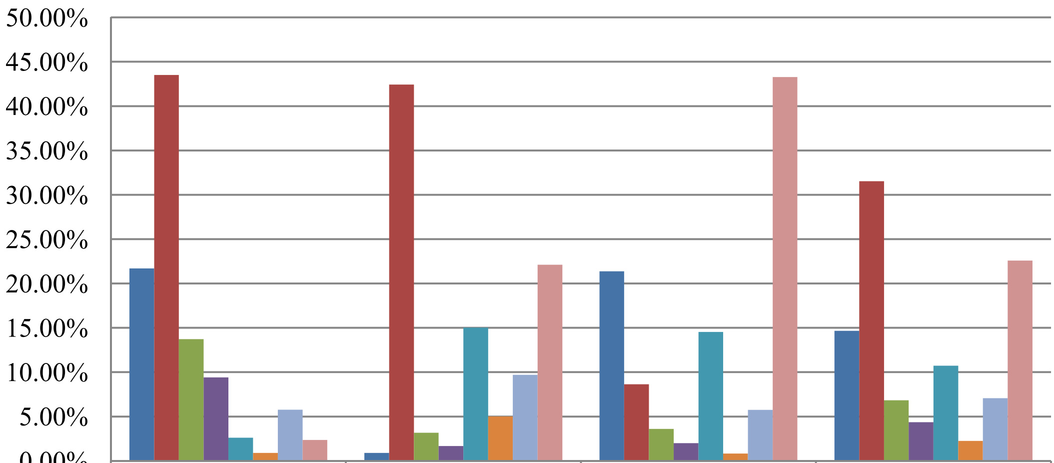
Results obtained for dielectric environment oil.

	W	C	CV	λ	CI	RI	CR
V_1 – D_O							
M_1	0.2169	0.1501	5.5355	7.7827	-0.0310	1.4903	-0.0208<0.1
M_2	0.4352	0.6375	11.7197				
M_3	0.1373	0.0735	4.2828				
M_4	0.0942	0.0437	3.7077				
M_5	0.0261	0.0232	7.1283				
M_6	0.0090	0.0207	18.3879				
M_7	0.0577	0.0293	4.0629				
M_8	0.0236	0.0220	7.4370				
V_2 – D_O							
M_1	0.0089	0.0201	18.1079	7.9169	-0.0119	1.4903	-0.0080<0.1
M_2	0.4243	0.6331	11.9376				
M_3	0.0317	0.0228	5.7414				
M_4	0.0167	0.0208	9.9681				
M_5	0.1503	0.0767	4.0853				
M_6	0.0501	0.0272	4.3450				
M_7	0.0969	0.0419	3.4554				
M_8	0.2211	0.1574	5.6948				
V_3 – D_O							
M_1	0.2138	0.1504	5.6273	7.7227	-0.0396	1.4903	-0.0266<0.1
M_2	0.0863	0.0415	3.8489				
M_3	0.0360	0.0231	5.1313				
M_4	0.0200	0.0205	8.2020				
M_5	0.1453	0.0749	4.1224				
M_6	0.0083	0.0196	18.9538				
M_7	0.0575	0.0291	4.0472				
M_8	0.4328	0.6409	11.8484				



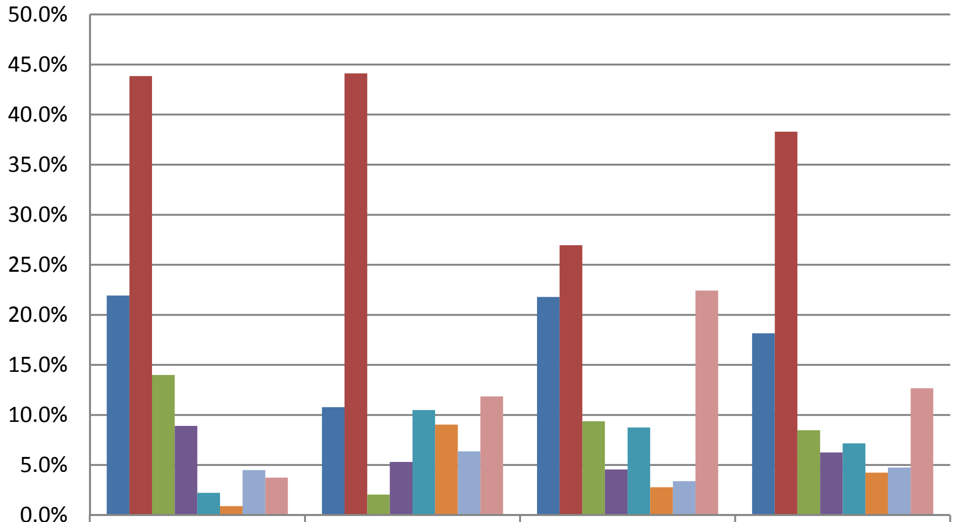
	V1	V2	V3	MM
M1	22.17%	20.66%	22.17%	21.67%
M2	44.17%	45.81%	45.26%	45.08%
M3	14.25%	0.92%	15.14%	10.10%
M4	8.41%	8.95%	7.12%	8.16%
M5	1.83%	5.97%	2.98%	3.59%
M6	0.87%	13.06%	4.72%	6.22%
M7	3.21%	3.04%	1.04%	2.43%
M8	5.10%	1.59%	1.57%	2.75%

Fig. 5. Weights obtained for the machinability of the materials in dielectric medium air



	V1	V2	V3	MM
M1	21.69%	0.89%	21.38%	14.65%
M2	43.52%	42.43%	8.63%	31.53%
M3	13.73%	3.17%	3.60%	6.84%
M4	9.42%	1.67%	2.00%	4.36%
M5	2.61%	15.03%	14.53%	10.72%
M6	0.90%	5.01%	0.83%	2.25%
M7	5.77%	9.69%	5.75%	7.07%
M8	2.36%	22.11%	43.28%	22.58%

Fig. 6. Weights obtained for the machinability of the materials in dielectric medium oil



	V1	V2	V3	MM
M1	21.9%	10.8%	21.8%	18.2%
M2	43.8%	44.1%	26.9%	38.3%
M3	14.0%	2.0%	9.4%	8.5%
M4	8.9%	5.3%	4.6%	6.3%
M5	2.2%	10.5%	8.8%	7.2%
M6	0.9%	9.0%	2.8%	4.2%
M7	4.5%	6.4%	3.4%	4.8%
M8	3.7%	11.8%	22.4%	12.7%

Fig. 7. Medium weights obtained for the machinability of the materials

In case of machining in dielectric medium oil, the situation remains almost the same as in case of dielectric air.

The highest score of 43.52% for V_1 criteria was assigned for material M_2 in case of oil used as dielectric medium.

The most significant result concerning the machinability of the studied materials is shown in figure 7, where can be easily observed that the M_2 that represents steel presents the highest machinability by EDM process.

6. CONCLUSIONS

In this research, the alternatives were studied only from the quantitative point of view and not from as a qualitative appreciation. Due to this study, it has been realized a ranking of the materials from the point of view of the machinability by EDM process.

In terms of quantitative appreciation, the alternatives have been analyzed concerning the dielectric medium (air or oil) that has been used for processing the materials, the volume of material that has been removed from the surface, crater volume and the material volume that has been accede on the surface after one discharge.

In this study it has been studied only the crater formed after one single discharge depending on the materials and dielectric medium and not the surface quality obtained after EDM process, this constituting another further research.

To reduce the risk of choosing an inappropriate material to be processed by EDM or to evaluate the capacity of the process concerning the material that has to be processed, it has been adapted the principles and the techniques of the FAHP method to study the machinability of the materials by EDM process.

Taking into consideration in this study other criteria like: surface quality – roughness, surface integrity – concerning the micro cracks, microstructure of the material etc. the study can be continued taking into considerations other criteria of appreciation.

A chemical and metallurgical study can be realized on the influence of the temperature on the micro layer, some of the material changing their structure at high temperature.

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APLICAREA PROCESULUI DE ANALIZĂ IERARHICĂ FUZZY PENTRU DETERMINAREA PRELUCRABILITĂȚII MATERIALELOR ÎN PROCESELE EDM

Rezumat: *Scopul acestei cercetări a fost aplicarea principiilor și a tehnicilor Procesului de Analiză Ierarhică Fuzzy (FAHP) pentru a obține ponderea prelucrabilității materialelor în procesele de prelucrare prin descărcare electrică (EDM), cu parametrii corespunzători procesului în funcție de mediul dielectric utilizat.FAHP este un instrument puternic și flexibil pentru metodele de luare a deciziilor cu atribute multiple, care permite prioritizarea și luarea celei mai bune decizii posibile atunci când trebuie luate în considerare diferite aspecte decizionale Este bine cunoscut faptul că EDM este un proces de fabricație care se bazează pe eroziunea termică datorita canaluluui de plasma format intre elecrodul scula si electrodul piesa in dielectricul aflat in interstitiul dintre cele doua.*

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