Fuzzy inference system for modelling machining parameters in electrical discharge machining

S Rebai, A Belloufi, M Abdelkrim, I. Rezgui, I Baci and B Beladjal
Université Kasdi Merbah Ouargla, Faculté des Sciences Appliqués, Département de Génie Mécanique, Ouargla 30000, Algeria

E-mail: belloufi.ab@univ-ouargla.dz

Abstract. The monitoring of the machining process has become a preliminary step in the mechanical manufacturing processes, especially for the electrical discharge machining (EDM). However, the monitoring of the electrical discharge machining process remains an ill-defined problem and is generally based on heuristics that are difficult to model. Therefore, artificial intelligence especially the fuzzy logic technique can be applied to processes such as electrical discharge machining in which the experiences and knowledge of the experts play an important role. This study presents a method for the identification of electric discharge machining parameters using the fuzzy inference system. The fuzzy inference system was used to determine the values of material removal rate; surface roughness and radial shrinkage based on process parameter values (open circuit voltage, discharge current, Pulse, duty factor and rinse pressure). The purpose of this is to highlight the development of mathematical models using artificial intelligence (fuzzy logic technique) to correlate relationships of various parameters of the process for determine the influence of those parameters on the quality of the machined parts. The fuzzy model developed for the determination of material removal rate, surface roughness and radial shrinkage formed (fuzzy rules) and tested using experimental data. The mean deviation of the test data did not exceed 3% for the three objectives used, which corresponds to an accuracy of 97%. The results of the tests have shown that the proposed fuzzy model can be used successfully for the selection of the parameters of the electric discharge machining process. The elaborate model offers a more precise and easy selection of EDM parameters.

1. Introduction
Machining by chip removal was the subject of numerous studies since the beginning the twentieth century, which has allowed this process to remain one of the most used in industry mechanical, despite the arrival and development of competing processes such as EDM or, more recently, manufacturing processes by adding material. The machining techniques are constantly changing, in order to maintain their performance at the highest level and to be able to meet new industrial requirements in terms of quality and productivity, but also impact on the environment and health [1].

The needs of the technology for the manufacture and machining of hard materials and resistance, lead modern machining to replace traditional processes. The EDM is one of the largest and most useful processes modern machining. EDM is a machining technique without contact conductive materials electricity; it is particularly suitable for machining hard materials. The principle is career electrical discharges between a tool and a work piece; both are immersed in a dielectric [2]. The electrical discharge machining is a technique by conducting melting, vaporization and ejection of

matter. The energy is supplied by electrical discharges passing between two electrodes, the work piece and the tool. Creating a plasma channel between the tool and the work piece, through which a current strong electric leads to melting of the material at the ends of the work piece and the tool [3]. Investigations were carried out to study the effects of machining parameters such as discharge current, pulse duty cycle on the roughness of the surface using different techniques whose purpose is to optimize the parameters of the EDM process [4-6]. Therefore, the objective of this study is to provide a fuzzy model to establish functional relationships between the fuzzy system entries that are parameters EDM, namely open circuit voltage, discharge current, pulse, factor service, flushing pressure and the outlet which are the removal rate, surface roughness the area and the radial shrinkage.

2. Experimental procedure
The data below (table 1) represent the results obtained from the study of CP Mohanty [7]. This work is done in order to study the influence important parameters of the process (open circuit voltage, discharge current, pulse duty cycle and the flushing pressure) on the rate of removal of material, roughness of the surface and the radial shrinkage.

Table 1. Experimental data for the brass electrode [7].

| | Setting machine | | | | | Experimental results | | |
Tes t	Voltage (v)	Current (A)	Impulsion (µs)	Duty cycle (%)	Pressure rinsing (bar)	MRR mm^3/min	roughness of the surface µm	Radial shrinka ge mm
1	80	5	100	80	0.3	12,8	10,35	0,07
2	80	5	300	80	0.3	5,1	12,42	0,11
3	80	5	100	90	0.3	17,9	11,23	0,08
4	80	5	300	90	0.3	12,5	13,31	0,11
5	80	3	200	85	0.2	6,81	6,8	0,03
6	80	7	200	85	0.2	20,1	13,21	0,1
7	80	3	200	85	0.4	7,01	7,8	0,04
8	80	7	200	85	0.4	20,2	13,95	0,11
9	70	5	100	85	0.3	18,2	10,2	0,06
10	90	5	100	85	0.3	11,95	10,4	0,06
11	70	5	300	85	0.3	11,85	13	0,1
12	90	5	300	85	0.3	5,92	13,3	0,1

3. Fuzzy logic
Fuzzy logic is an extension of Boolean logic created by Lotfi Zadeh in 1965 [8]. Based on the mathematical theory of fuzzy sets, which is a generalization of classical set theory. By introducing the concept of a degree in verification of condition, thus allowing a condition of being in a state other than true or false, fuzzy logic provides a very significant flexibility reasoning the use, which makes it possible to take account of inaccuracies and uncertainties. Therefore, the theory of fuzzy logic applied to different manufacturing processes where tests and expert knowledge play an essential role [9-10].

3.1. Principle of fuzzy logic
The principle of fuzzy control approaching the human gait in the direction the processed variables are not logical variables (as defined by the binary logic example) but linguistic variables, relatives of human language daily. Of over these linguistic variables are processed using rules that refer to some knowledge of the behaviour of the system. A series of fundamental concepts developed in fuzzy logic. These concepts used to justify and demonstrate some basic principles. In what follows, will retain only the elements essential for understanding the principle of control by fuzzy logic.

3.2. Fuzzy system

We chose a fuzzy inference system Madman guy with five variables the input (open circuit voltage, discharge current, pulse duty cycle and flushing pressure) and three variables to the output (the rate of removal of material, roughness the surface and the radial narrowing).
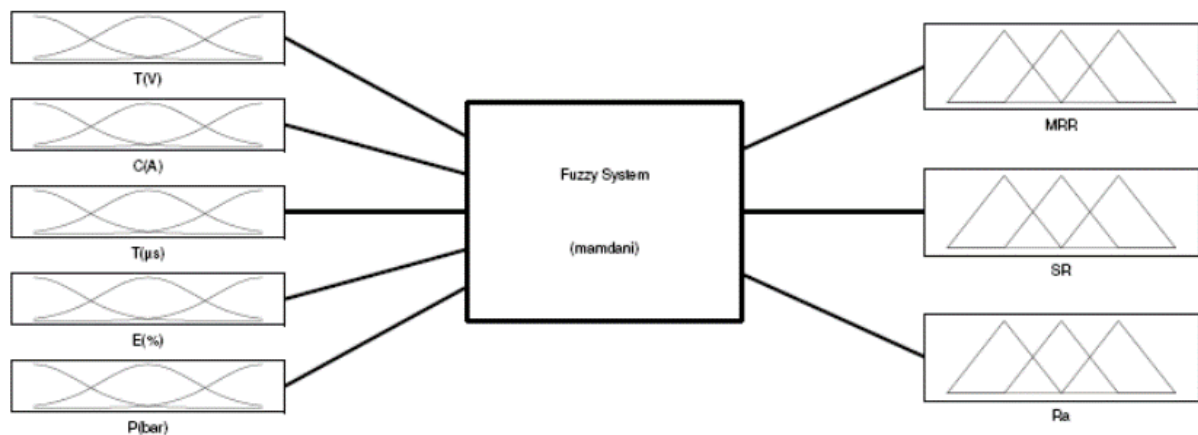

Figure 1. Inputs and outputs of the fuzzy system.

3.3. Linguistic variables

All the variables used in our study are divided into categories called linguistic variables. Each linguistic variable corresponds to numerical data interval. The linguistic variables for the input variables are selected as shown in figure 2.
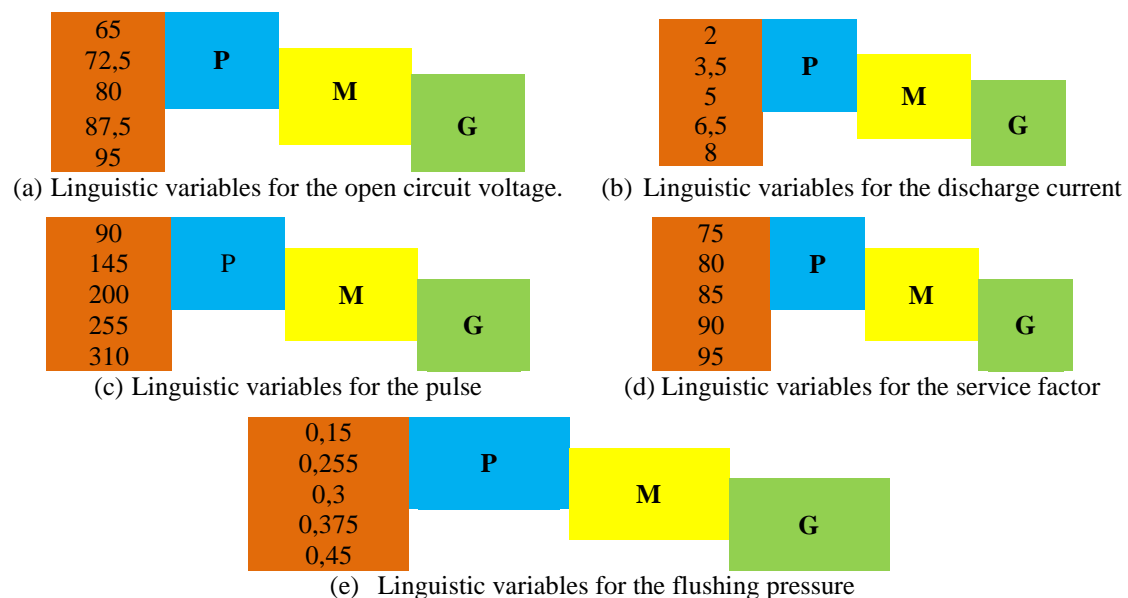

(a) Linguistic variables for the open circuit voltage.   (b) Linguistic variables for the discharge current

(c) Linguistic variables for the pulse   (d) Linguistic variables for the service factor

(e) Linguistic variables for the flushing pressure

Figure 2. Linguistic variables for the input variables.

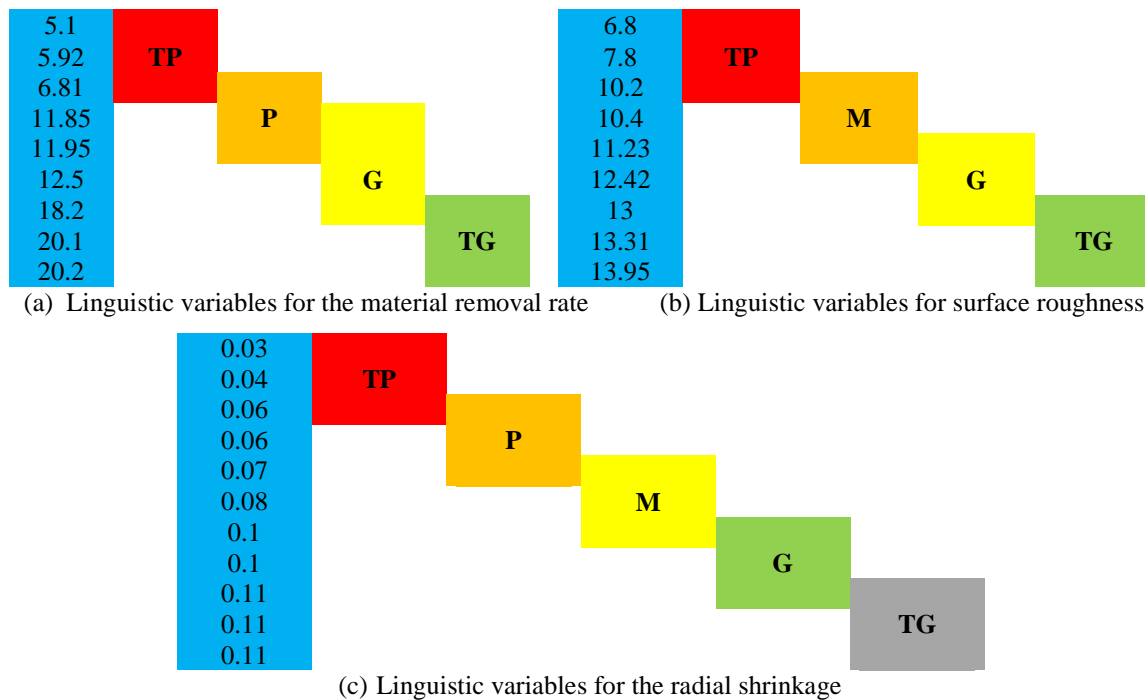The linguistic variables for the output variables are selected as shown in figure 3.

(a) Linguistic variables for the material removal rate   (b) Linguistic variables for surface roughness

(c) Linguistic variables for the radial shrinkage

Figure 3. Linguistic variables for the output variables.

3.4. Membership functions
Based on the choice of the linguistic variables for the input parameters and output performed in the figure 4 associated membership functions.

3.5. Fuzzy rules
49 fuzzy rules divided by three electrodes were prepared according to the conditions Experimental. By joining process maximum-minimum composition, fuzzy these rules produced a fuzzy output. Each rule takes the following form:
Si is (Linguistic variable) **and** I is (Linguistic variable) **and** t is (variable linguistic) **and** is (linguistic variable) **and** P is (linguistic variable) **So** MMR is (Linguistic variable) **and** SR is (linguistic variable) **and** RO is (linguistic variable) All the developed fuzzy rules are summarized in the tables below.

4. Study of the Precision and error of the fuzzy system
Errors were calculated by measuring the difference between the measured value and the value predicted.

The errors can be calculated using the equation 1. The percentage of errors individual was obtained by dividing the absolute difference of the prediction by the value of measured.

To validate our results for the percentage of error was calculated and precision Model of fuzzy logic has been determined. The experimental conditions, the experimental results and the predicted values fuzzy model are shown in Table 3

The mean percentage error for the prediction of fuzzy model was 2.92 %, 2.87% and 4.47% for the three objectives. The error level indicates that the results of the removal rate of matter predicted by the Model of fuzzy logic were very close to the actual experimental values. Table 3 also shows that the accuracy of the fuzzy model was 97.08 %, 97.13% and 95.53% for the three objectives. Percentages of precision shows that the proposed model can be used successfully to predict the: rate of removal of material, Surface roughness and Radial shrinkage with the brass electrodes. The low level of error indicates that the results predicted by the logic model Fuzzy were very close to actual experimental results.
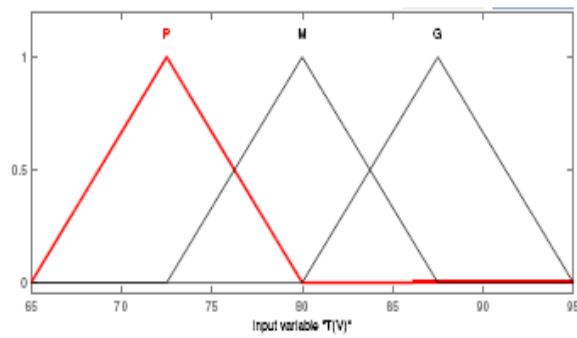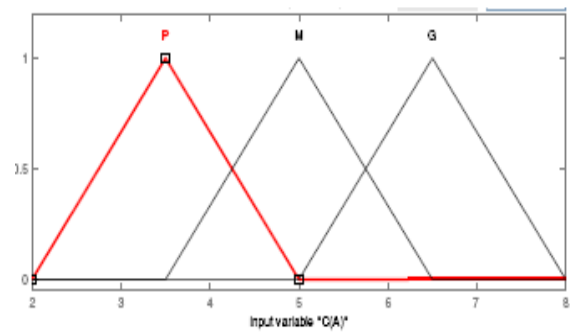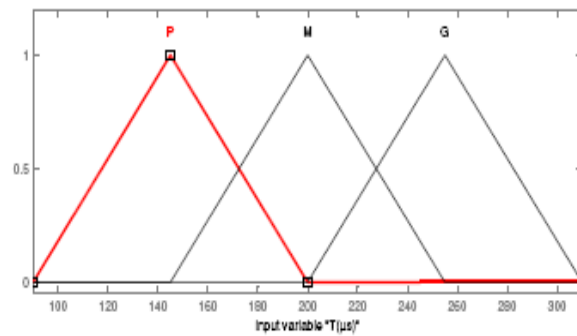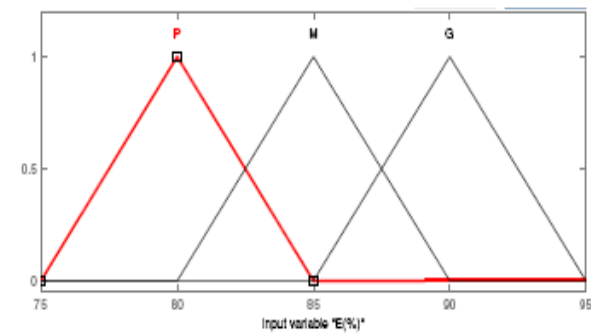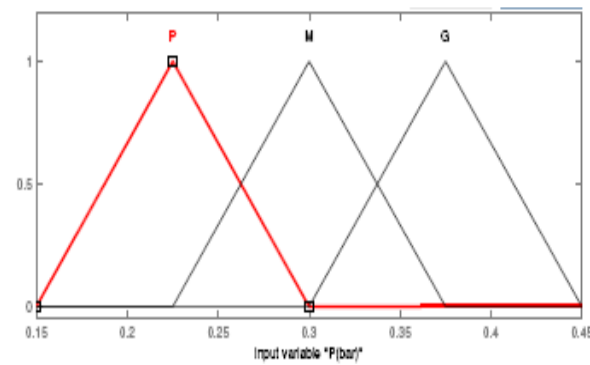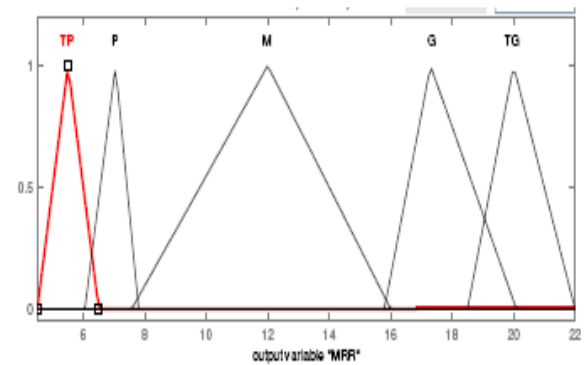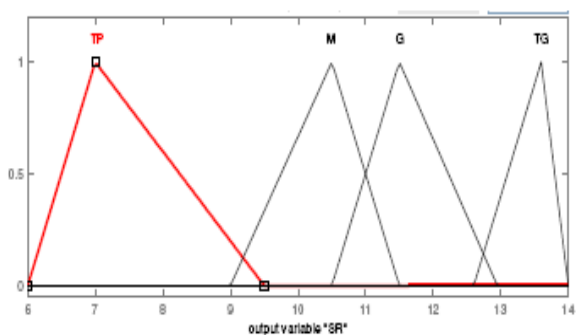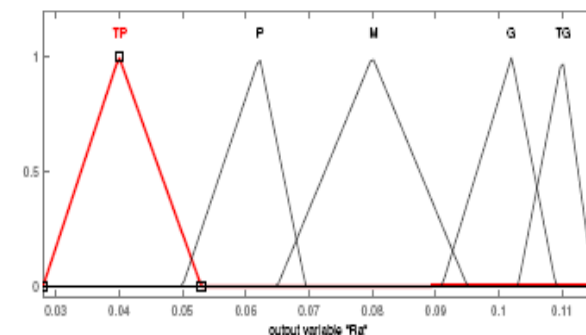
(a)   Membership functions for T(V)

(b)   Membership functions for C(A)

(c)   Membership functions for T(µs)

(d)   Membership functions for E (%)

(e)   Membership functions for P(bar)

(f)   Membership functions for MMR

(g)   Membership functions for SR

(h)   Membership functions for Ra

Figure 4. Membership functions for machining parameters with brass electrode.

Table 2. Fuzzy rules (machining with brass electrode).

Test	Setting machine					Experimental results		
	Voltage (v)	Current (A)	Impulsion (µs)	Duty cycle (%)	Pressure rinsing (bar)	MRR (mm³/min)	Surface roughness (µm)	Radial shrinkage (mm)
1	M	M	P	P	M	M	M	M
2	M	M	G	P	M	TP	G	TG
3	M	M	P	G	M	G	G	M
4	M	M	G	G	M	M	TG	TG
5	M	P	M	M	P	P	TP	TP
6	M	G	M	M	P	TG	TG	G
7	M	P	M	M	G	P	TP	TP
8	M	G	M	M	G	TG	TG	TG
9	P	M	P	M	M	G	M	P
10	G	M	P	M	M	M	M	P
11	P	M	G	M	M	M	TG	G
12	G	M	G	M	M	TP	TG	G

$$e_i = \left(\left|T_{\exp} - T_{\mathrm{Pr}}\right|/T_{\exp}\right) \times 100 \qquad (1)$$

$$A = \frac{1}{N}\sum_{i=1}^{N}\left(1 - \left|P_{\exp} - P_{sim}\right|/P_{\exp}\right) \times 100 \qquad (2)$$

Table 3. The results of the fuzzy system (machining with brass electrode).

Test	MRR (mm³/min)				Surface roughness (µm)				Radial shrinkage (mm)			
	EXP	SUM	Err.	Pré.	EXP	SUM	Err.	Pré.	EXP	SUM	Err.	Pré.
1	12.80	11.8	7.81	92.19	10.35	10.3	0.48	99.52	0.07	0.08	14.29	85.71
2	5.10	5.50	7.84	92.16	12.42	11.7	5.80	94.2	0.11	0.109	0.91	99.09
3	17.90	17.9	0.00	100	11.23	11.7	4.19	95.81	0.08	0.08	0.00	100
4	12.50	11.8	5.6	94.4	13.31	13.3	0.08	99.92	0.11	0.109	0.91	99.09
5	6.81	6.96	2.2	97.8	6.8	7.54	10.89	89.11	0.03	0.0404	34.67	65.33
6	20.10	20.2	0.5	99.5	13.21	13.4	1.44	98.56	0.10	0.101	1.00	99.00
7	7.010	6.96	0.71	99.29	7.8	7.54	3.33	96.67	0.04	0.0404	1.00	99.00
8	20.20	20.2	0.00	100	13.95	13.4	3.94	96.06	0.11	0.109	0.91	99.09
9	18.20	17.9	1.65	98.35	10.2	10.3	0.98	99.02	0.06	0.06	0.00	100
10	11.95	11.8	1.26	98.74	10.4	10.3	0.96	99.04	0.06	0.06	0.00	100
11	11.85	11.8	0.42	99.58	13	13.3	2.31	97.69	0.10	0.10	0.00	100
12	5.92	5.50	7.09	92.91	13.3	13.3	0.00	100	0.10	0.10	0.00	100
Average Accuracy			97.08				97.13					95.53
Average Error		2.92				2.87					4.47	

(a)   Rate of removal of material MRR   (b)   Surface roughness
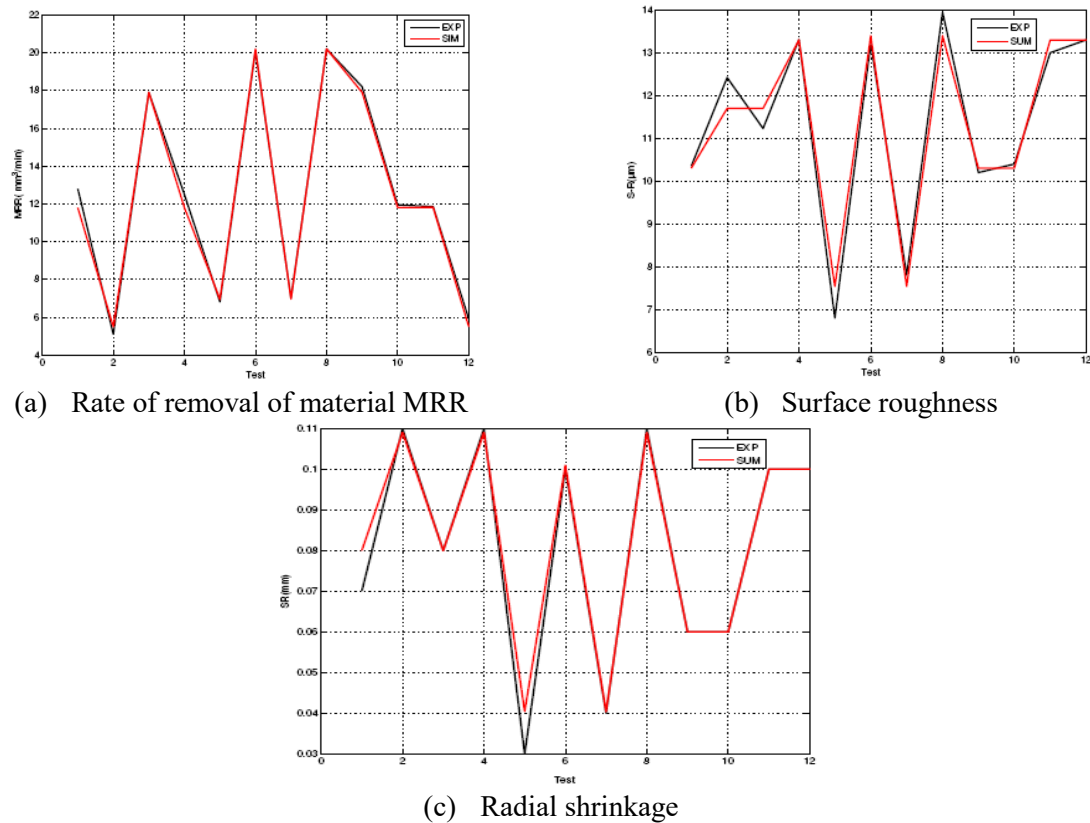

(c)   Radial shrinkage

Figure 5. Comparison of experimental and predicted values.

5. Conclusions

The objective of our work was to predict the influence of parameters of electrical discharge machining: circuit voltage open, discharge current, pulse duty cycle and the flushing pressure on the rate material removal, surface roughness and the radial shrinkage. The study that we conducted allowed us to conclude that:

- The parametric study of the proposed fuzzy model indicates that the current discharge, the open circuit voltage and the pulse display an effect significant on performance measures.
- With our fuzzy model we can convert multiple inputs into a single output equivalent
- The results obtained using our fuzzy model has been proven by a comparison study with experimental   results. The predicted values are consistent with the actual hardness with a percentage does not exceed 5% and are associated with the experimental values.
- The proposed approach can be used to improve the quality and quality control of the electrical discharge machining process
- Our fuzzy model can be useful for automation of machining processes EDM.

6. References
[1]   Vaibhav K A 2015 Electrical Discharge Machining of Cu-Al$_2$O$_3$, Metal Matrix Composites, *Master thesis*
[2]   Lin J L and Lin C L 2005 The use of Grey-fuzzy Logic for the Optimization of the Manufacturing Process *Journal of Materials Processing Technology* **160** 9–14
[3]   Lin J L, Wang K S, Yan B H and Tarng Y S 2000 Optimization of the Electrical Discharge Machining Process Based on the Taguchi Method with Fuzzy Logics *Journal of Materials Processing Technology* **102** 48–55

[4]   Ftzeng Y 2007 Multi-Objective Optimization of High-Speed Electrical Discharge Machining Process Using a Taguchi Fuzzy-Based Approach *Journal of Materials Processing Technology* **28** 1159–68

[5]   Chung F and Yuang S 2001 Improvement of Machining Accuracy by Fuzzy Logic at Corner Parts for Wire-EDM *Fuzzy Sets and Systems* **122** 499–511

[6]   Wang P J 2001 Predictions on Surface Finish in Electrical Discharge Machining Based Upon Neural Network Models *International Journal of Machine Tools and Manufacture* **41** 1385–403

[7]   Mohanty C P 2015 Studies on some aspects of multi-objective optimization: A case study of electrical discharge machining process *Phd thesis* Rourkela university India

[8]   Zadeh L 1965 A Fuzzy sets *Information and Control* **8**(3) 338-353

[9]   Rezgui I, Mihi A, Belloufi A, Abdelkrim M and Brabie G 2017 Fuzzy Logic Approach for Predicting the Effect of Manufacturing Parameters of $Ni-Al_2O_3$ Composite Coatings by Electrodeposition, *International Journal of Modern Manufacturing Technologies* **9**(2) 65-72

[10]   Shabgard M R, Badamchizadeh M A, Ranjbary G and Amini K 2013 Fuzzy Approach to Select Machining Parameters in Electrical Discharge Machining (EDM) and Ultrasonic-assisted EDM Processes *Journal of Manufacturing Systems* **32** 32-39