2-бөлім **Раздел 2** **Section 2**

Механика **Механика** **Mechanics**

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MODELING OF MAGNETIC ABRASIVE FINISHING OF BRASS ALLOY BASED ON FUZZY LOGIC APPROACH

Magnetic abrasive finishing (MAF) is a non-classical finishing in which a super-finished surface is produced. This study aims to develop a fuzzy logic (FL) model for predicting the CuZn28 surface roughness produced by a new pole geometry MAF process. The experimental work was done before, and its data were recalled here to develop the FL model. Pole geometry, rotational speed, MAF time, and applied current were used with three levels that generated nine experimental runs based on the L9 Taguchi experimental scheme. Four membership functions were applied, and the developed FL model reached 87% prediction accuracy. The degree of change in each membership function reflects the significance rank of parameters, which were speed, current, time, and pole geometry.

Keywords: Fuzzy logic, magnetic abrasive finishing, CuZn28, surface roughness.

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Жез қорытпасын магнитті-абразивтік өңдеуді бұлыңғыр логика тәсілі негізінде модельдеу

Магнитті-абразивтік өңдеу (МАө) - аса жоғары сапалы беткі қабат алуға мүмкіндік беретін дәстүрлі емес өңдеу әдісі. Бұл зерттеудің мақсаты - жаңа полюс геометриясы қолданылған магнитті-абразивтік өңдеу процесі нәтижесінде алынған CuZn28 жез қорытпасының беткі кедір-бұдырлығын болжауға арналған бұлыңғыр логика (FL) моделін әзірлеу. Эксперименттік жұмыстар бұрын жүргізілген, ал олардың нәтижелері осы зерттеуде бұлыңғыр логика моделін құру үшін пайдаланылды. Полюс геометриясы, айналу жылдамдығы, МАө уақыты және берілетін ток күші үш деңгей бойынша таңдалып, Тагучидің L9 эксперименттік жоспары негізінде тоғыз тәжірибе жүргізілді. Төрт мүшелік функция қолданылып, әзірленген бұлыңғыр логика моделі болжам жасауда 87% дәлдікке қол жеткізді. Әрбір мүшелік функцияның өзгеру дәрежесі параметрлердің маңыздылық ретін көрсетті, олар: айналу жылдамдығы, ток күші, өңдеу уақыты және полюс геометриясы.
Түйін сөздер: Бұлыңғыр логика, магнитті-абразивтік өңдеу, CuZn28, беткі кедір-бұдырлық.

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Моделирование магнитно-абразивной обработки латунного сплава на основе подхода нечеткой логики

Магнитно-абразивная обработка (МАО) представляет собой нетрадиционный метод финишной обработки, позволяющий получать поверхность с высокой степенью чистоты. Целью данного исследования является разработка модели на основе нечеткой логики (Fuzzy Logic, FL) для прогнозирования шероховатости поверхности латунного сплава CuZn28, получаемой в процессе магнитно-абразивной обработки с использованием новой геометрии полюсов. Экспериментальные исследования были проведены ранее, а полученные данные использованы для разработки модели нечеткой логики. В качестве входных параметров использовались геометрия полюсов, скорость вращения, время магнитно-абразивной обработки и величина приложенного тока, каждый из которых рассматривался на трех уровнях. Для планирования эксперимента была использована схема Тагучи L9, включающая девять экспериментальных запусков. Было применено четыре функции принадлежности, а разработанная модель нечеткой логики обеспечила точность прогнозирования на уровне 87%. Степень изменения каждой функции принадлежности отражала ранг значимости параметров, которыми оказались скорость вращения, ток, время обработки и геометрия полюсов.
Ключевые слова: Нечеткая логика, магнитно-абразивная обработка, CuZn28, шероховатость поверхности.

1 Introduction

The excellent dimensional accuracy and surface integrity, besides the improved mechanical properties of products, are largely needed by the progressing industry. Presently, the classical finishing operations are substituted by non-traditional finishing processes. They included a set of processes like on such as magnetic abrasive finishing (MAF). It is applied in the industrial sector after commercialization for finishing purposes. From the historical point of view, it was initially proposed as a machining process in 1930 and later registered in the United States as a patent by Harry P. Coats in 1938. Though it was not subjected to further development until 1960 [1-2]. Artificial intelligence (AI) is a new technology and science that has developed based on the studied theories, applications, and mechanisms for simulating the human brain through computerized robots. There are many techniques used in artificial intelligence [3-6]. Fuzzy logic is one type of artificial intelligence method that was used for the first time in 1965 by Lotfi A. Zadeh. It was adopted by many researchers and applied in several fields, including machining technology as a successful tool in estimating the surface roughness and material removal, as well as identifying the significance degree of the independent variables [7].

For instance, T.C. Kanisha et al [8] constructed a fuzzy logic system to estimate the improvement in surface roughness of 316 stainless steel finished by the MAF process. Three levels and four parameters were applied, while ANOVA analysis and Signal-to-noise ratio were adopted to find the significant parameter and improvement percentage. The fuzzy model findings showed good agreement with experimental results, with a deviation of no more than 7.16%.

R. Kumar Singh in 2018 [9] utilized the experimental results of MAF finishing of ceramics, composites, and super alloys to build up a fuzzy logic model to boost the surface roughness and estimate the surface temperature. The experiments were conducted using three parameters and levels, which are: working gap $1-2$ mm, abrasive weight $20-30$ gm, current $3-6$ Amp, and the magnet speed $100-300$ rpm. The obtained prediction accuracy was 90% based on the model result, which gives good matching with experimental findings.

Prabhu and Uma [10] evaluated the performance of two AI models: fuzzy logic and neural network models to predict the output response of the MAF process, as well as to investigate the relationship between the finishing process parameters and determine the effectiveness of each parameter through adopting Taguchi design of experiments. The utilized parameters with two levels were: Cutting speed (n)rpm (2000 2500), Feed mm/min (1.9, 2.5), and gap mm (0.1 0.2). The developed fuzzy logic model revealed its ability to predict surface roughness with a minimum error of 9.23%.

Also, it was stated by F. Djavanroodi that artificial neural networks (ANN) have proven their ability for predicting surface roughness during MAF process during MAF process [11]. ANN was combined with a genetic algorithm (GA) by Ahmed et al [12] to predict the surface roughness of stainless steel finished by a magnetic abrasive finish. The findings showed that the ANN-GA model provides a surface improvement of 0.256 μm. Neural networks were also combined with the moth optimization method by Singh et al. [13] to estimate the MAF response of AA 6061 alloy. The hybrid model was effective in predicting surface roughness. Amer Mosa [14] demonstrated the optimization of magnetic abrasive finishing by using an adaptive fuzzy inference system. The average error between the real and predicted achieved surface finish did not exceed 2%. The generated temperature of the mild steel surface was predicted by fuzzy logic applied by Rajneesh and validated successfully [15].

Although magnetic abrasive finishing is used for finishing different materials, it is still subject to investigation and enhancement of its performance. Therefore, the target of the current study is to develop a fuzzy logic model for surface roughness prediction of CuZn28 alloy during.

2 Materials and procedures

In the current study, a real experimental work that was done by Mahmoud et al [16] is adopted to develop a fuzzy logic model for predicting surface roughness that is produced during MAF of CuZn28 alloy. The description of the experimental setup and discussion of the achieved findings in terms of the effect of the controllable parameters and their optimized method are all found in the same reference [16]. Briefly, the surface of CuZn28 alloy with $100 \times 50 \times 3$ mm^3 dimensions was finished by the MAF process by utilizing a modified vertical milling machine.

Table 1 shows four MAF parameters, namely: speed, working gap, MAF time, and different angles pyramid pole. Each parameter was set on three levels (Low, Medium, and High) as the Table shows. Due to its robustness, Taguchi's experimental design [17] was applied using an L9 orthogonal array. The change in surface roughness ($\Delta Ra(\mu m)$) during MAF of CuZn28 alloy was measured and recorded as shown in Table 2. The $\Delta Ra(\mu m)$ refers to the (Ra before MAF-Ra after MAF), and the average calculated value was 0.352 μm. Tool steel blocks were machined into pyramidic shape pole geometry with 35°, 50°, and 65° different angles as revealed in Figures 1 and 2. An SRT-6210 style roughness tester with a 0.8 mm cutoff measured the change in surface roughness before and after MAFs.

Table 1. MAF Parameters and Levels

No.	Parameters	Symbol	Level (1)	Level (2)	Level (3)
1	Rotational Speed (rpm)	A	110	520	930
2	time (min.)	B	5	10	15
3	Current (Amp.)	C	1	1.5	2
4	The angle of the pole degree (°)	D	35	50	65

Table 2. L9 Orthogonal Array (Coded and Real Factors)

No.	A (r.p.m)	B (min)	C (Amp.)	D (°)	ΔRa (μm)
1	110	5	1	35	0.114
2	110	10	1.5	50	0.062
3	110	15	2	65	0.024
4	520	5	1.5	65	0.049
5	520	10	2	35	0.152
6	520	15	1	50	0.242
7	930	5	2	50	0.097
8	930	10	1	65	0.226
9	930	15	1.5	35	0.246

3 Development of fuzzy logic model

The detailed steps and validation of the developed model of fuzzy logic that was used to predict the surface roughness of a brass alloy (CuZn28) will be introduced in this part of the research paper. Fuzzy logic is considered one of the most significant Artificial Intelligence methods and turns out to be broadly utilized in different fields of science and engineering [18]. It enables to utilization of scientific rationale in a way and sense so near human reasoning

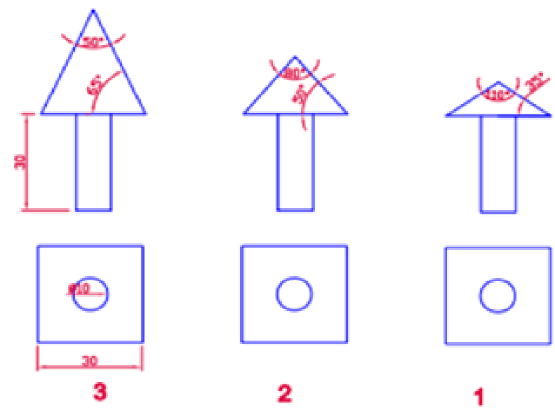

Figure 1: Pyramid Pole with Different Angles Schematic Shape, [16]

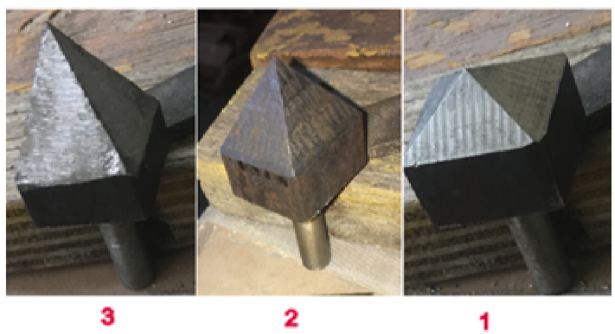

Figure 2: Pyramid Pole with Different Angles Real Shape [16]

and judgment. In another expression, fuzzy logic will mollify the transition between crisp scopes of information [19,20].

The model developed in this research is based on a correlation between surface roughness, which represents the output of the process, and independent factors, which represent the inputs to the process, which are rotation speed, working gap, finishing time, and pole angle. Fuzzy logic consists of three core phases, namely: Fuzzification, Fuzzy Inference, and Defuzzification. Figure 3 shows the system that was created based on the input and output parameters that were discussed earlier to illustrate the details of the proposed fuzzy inference.

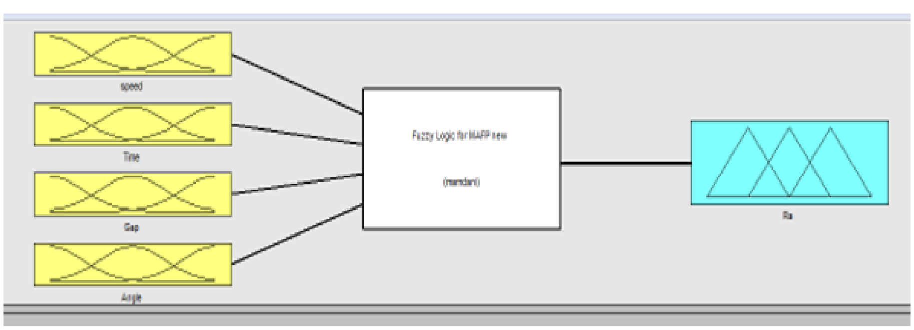

Figure 3: View of Fuzzy Inference System

3.1 Fuzzification

In Table 3, it can be noticed that the 5th column represents the three membership functions (MF) along with three levels (1/Small, 2/Medium & 3/Big) for each input parameter. Form the other hand, the membership function of the output response (ΔRa) was selected according to the range of (ΔRa) from a minimum of 0.024 μm to a maximum (0.246 μm). Table 3 illustrates the fuzzy linguistic variables for the parameters of the selected process.

Table 3. The fuzzy linguistic variables

No.	Parameters	Unit	Sym.	Name of Membership	Type of MF	Range
1	Speed	rpm	A	A1 A2 A3	Gauss	110-930
2	Finishing time	min.	B	B1 B2 B3	Gauss	5-15
3	Working Gap	mm	C	C1 C2 C3	Gauss	1-2
4	Angle of pole	Degree	D	D1 D2 D3	Gauss	35-65
5	Change in surface roughness	mm	ΔRa	Ra1 Ra2 Ra3 Ra4	Triangle	[-0.013-0.063] [0.063-0.135] [0.135-0.209] [0.209-0.283]

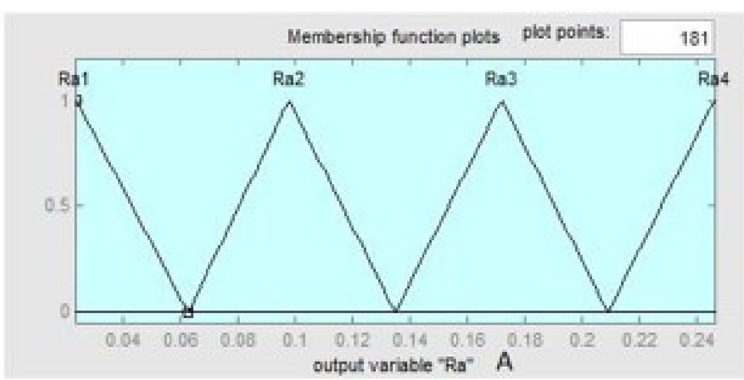

Figure 4: Membership functions for ΔRa.

Three membership functions (MFs) were introduced to encompass all input and output parameters of the proposed improved fuzzy model. The membership function MF will determine the representation of each point in the input space with a membership value ranging between zero and one. In order to achieve smoothness in the selected membership functions for each of the input parameters, the membership function in Gaussian-shaped membership function was applied to represent the fuzzy sets in this work. On the other hand, the triangular shape membership was used in the case of groups where the fuzzy output variables have progressively increasing or decreasing characteristics [20]. Figure 4 shows the membership functions corresponding to the output (ΔRa) s according to the experimental range of the parameter. Figure 5 (A, B, C, and D) shows the created membership functions for the fuzzy input variables, where the input parameters have been divided.

3.2 Fuzzy Inference Rules

Figure 6 illustrates the constructed set, which consists of nine rules, based on experimental results from the perspective of the knowledge derived from them. Experimental results were simulated based on Mamdani fuzzy logic by using MATLAB R2013a software as follows:

1 IF(Speed:A1)and(Time:B1)and(Gap:C1)and(Angle:D1)then(Ra2)

2 IF(Speed:A1)and(Time:B2) and(Gap:C3)and(Angle:D2)then(Ra1)

3 IF(Speed:A1)and(Time:B3)and(Gap:C3)and(Angle:D3) then(Ra1)

4 IF(Speed: A2) and (Time:B1) and (Gap:C2)and(Angle:D3)then(Ra1)

5 IF (Speed:A2) and(Time:B2)and(Gap:C3)and(Angle: D1)then(Ra3)

6 IF (Speed:A2)and(Time:B3)and(Gap:C1) and (Angle:D2)then(Ra4)

7 IF (Speed:A3)and(Time:B1)and(Gap:C3)and(Angle:D2)then(Ra2)

8 IF (Speed:A3)and(Time:B2)and(Gap:C1)and(Angle:D3)then(Ra4)

9 IF (Speed:A3) and (Time:B3)and(Gap:C2)and(Angle:D1)then(Ra5)

3.3 Defuzzification

In order to obtain results with high accuracy, the method of the centroids of area defuzzification (COA) was applied for this reason among all the available methods. As the main purpose of using this theory is the process of defuzzification, i.e., converting the fuzzy quantity into an accurate value usable in calculations [20].

4 Results and Discussions

In this work, a model was developed to predict the surface roughness of a selected sample based on fuzzy logic theory. This was achieved by completing all the necessary steps to reach this goal using the results obtained from experimental work. Table 4 presents the most important results obtained according to the prediction approach of the developed fuzzy logic model, and the comparison with the experimental results, in addition to clarifying the absolute error values for each case under different working conditions.

Figure 7 shows the trend of surface roughness (ΔRa) against the interactive effect of each two independent parameters. It can be seen that the yellow corner of each graph included in

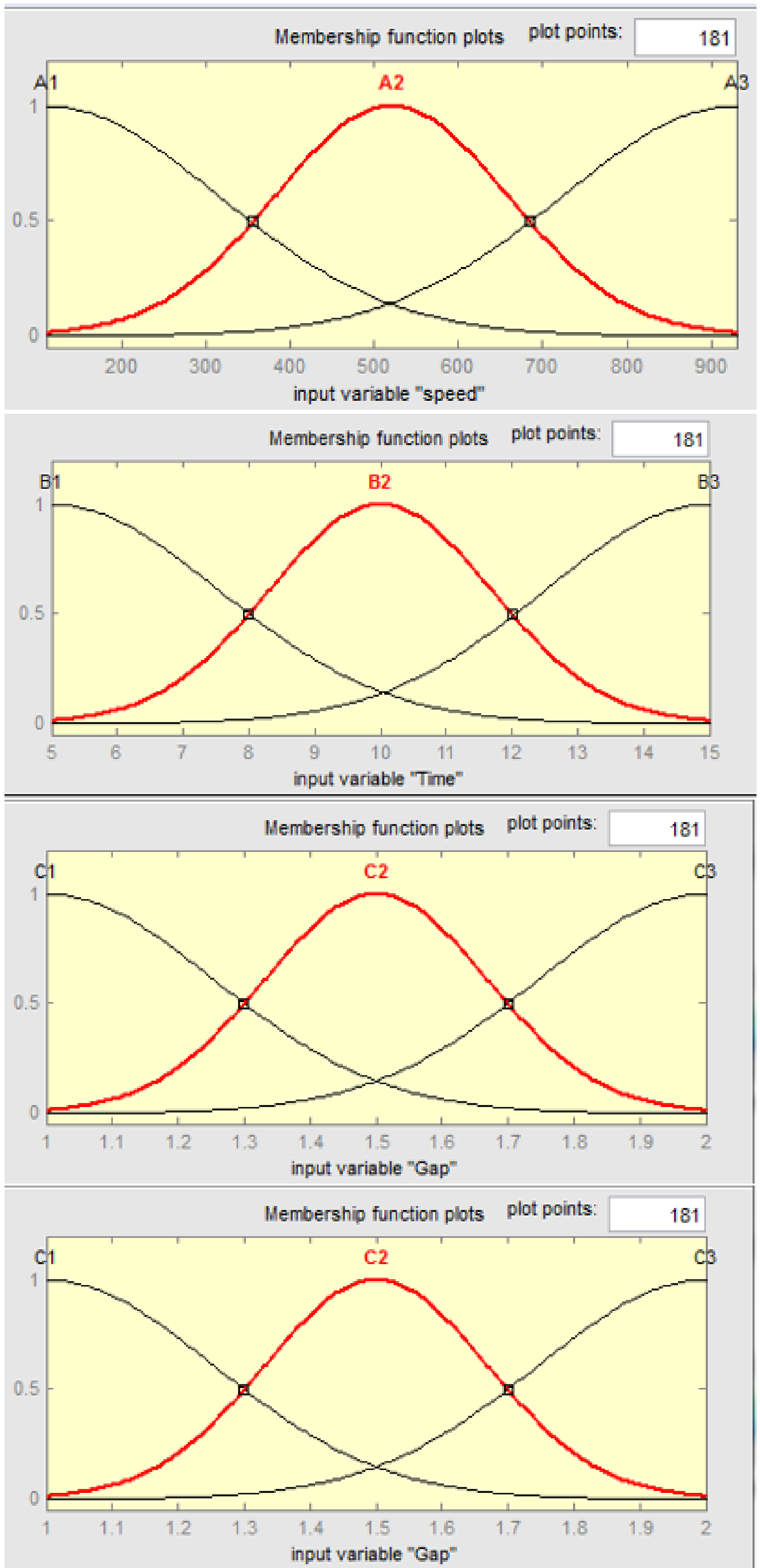

Figure 5: Memberships Function plots for input parameters (A, B, C, D).

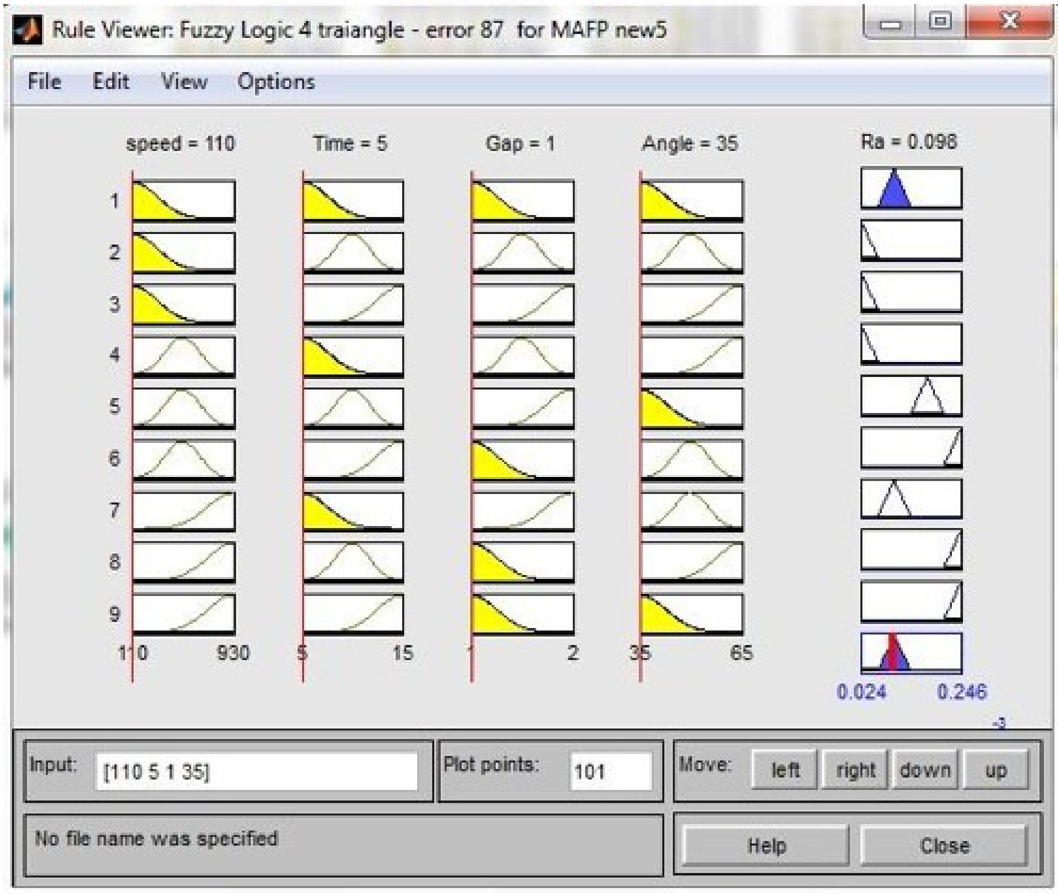

Figure 6: Fuzzy Inference Rules.

Figure 7 refers to the levels of each two input parameters that maintain a highly improved surface roughness (ΔRa).

The results obtained in Table 4 show that the maximum error between the developed prediction model of fuzzy logic and the experimental results of measuring surface roughness was 12.8%. In other words, the accuracy of the developed prediction model was 87%, which is considered an acceptable and good level of accuracy, especially since the relationship between the outputs and inputs is not linear; that is, the correlation is more complex than in processes where the correlation is linear. It can be seen in Figure 8, the optimal matching between the actual and predicted surface roughness under different working conditions.

By applying the fuzzy logic to the parameters, it was concluded that the optimization parameter speed was 930 rpm, time 10 min, gap 1 mm, and the angle of the pole was 35, which resulted in ?Ra achieved 0.234 μm. The results showed that it was necessary to conduct a test to confirm the validity of the findings, due to the absence of those values within the proposed experimental matrix. Actually, a confirmation test was carried out based on the optimized MAF conditions, and the mirror surface was obtained as depicted in Figure 9. The measured ΔRa for the confirmation test is 0.275 μm, and the predicted FL based on the optimized setting is 0.234 μm and both values are larger than the corresponding maximum values in Table 4.

Table 4. Predicted fuzzy and Experimental ΔRa with an average % error

No	Predicted FL ΔRa	Experimental ΔRa	% Error
1	0.098	0.1140	14.03508772
2	0.0626	0.0618	1.376518219
3	0.0368	0.024	5.333333333
4	0.0435	0.0490	11.2244898
5	0.168	0.1520	10.52631579
6	0.229	0.2480	5.404475043
7	0.0998	0.0970	2.886597938
8	0.212	0.2260	6.194690265
9	0.219	0.2458	10.88504578
Average			12.87406154

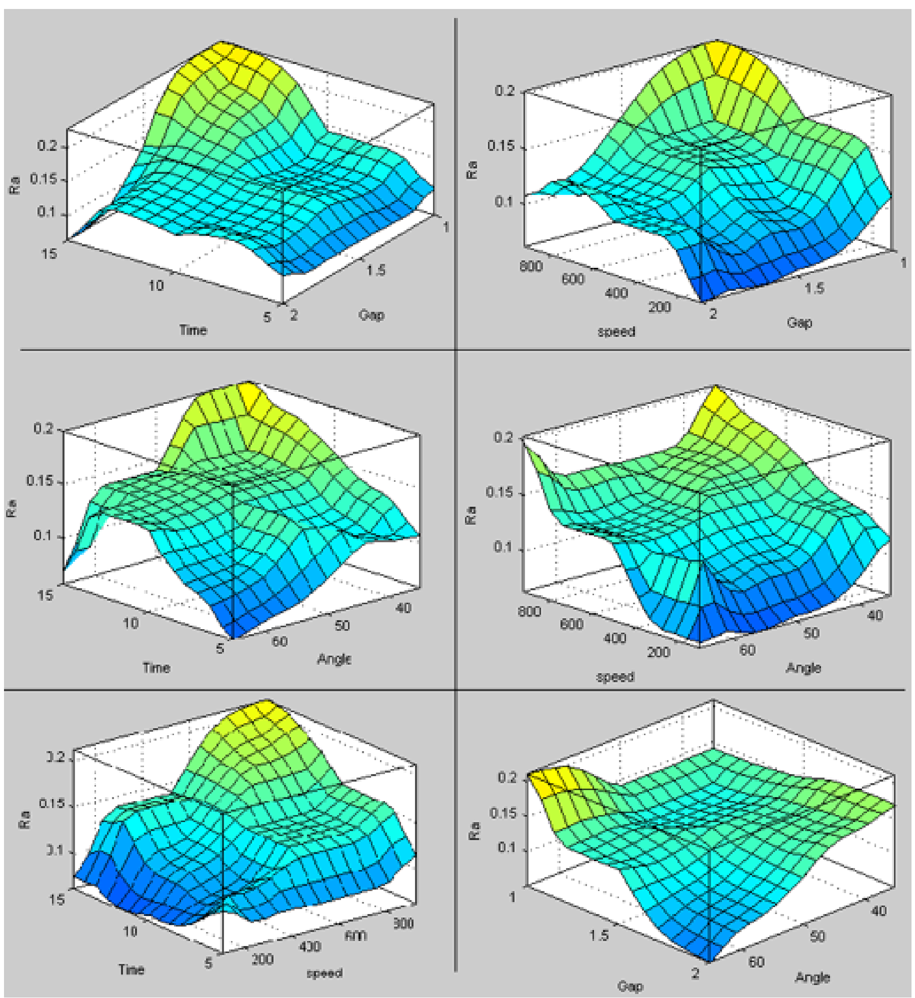

Figure 7: The relationship between input parameters and surface roughness (ΔRa).

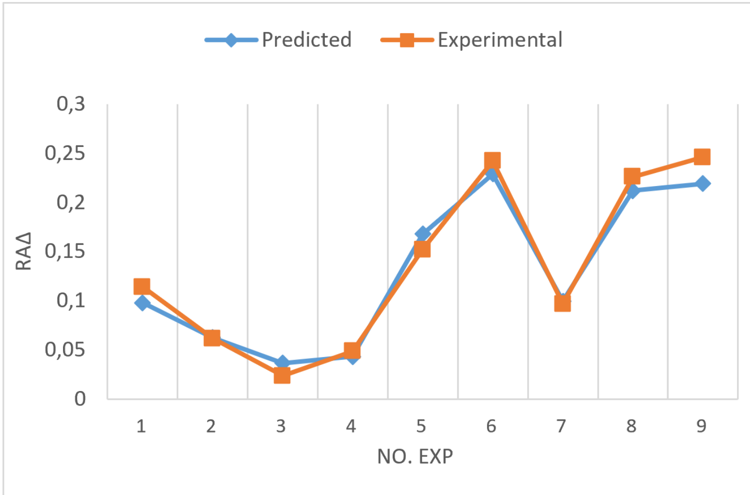

Figure 8: Predicted fuzzy and experimental surface roughness (ΔRa).

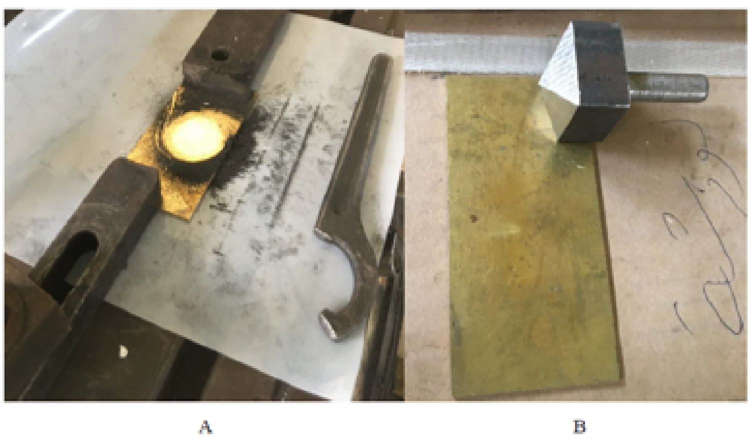

Figure 9: The surface finish of CuZn28 Brass alloy for the confirmation test: (a) After MAF, (b) Before MAF.

5 Conclusions and Remarks

In this research, a new polar geometry was applied to determine the nature of the surface roughness of a brass alloy (CuZn28) under the influence of magnetic abrasive finishing. Based on the results obtained in this research, it can be summarized the most important conclusions reached are as follows:

1 The results demonstrated that the following factors significantly impacted surface roughness improvement: rotational speed, working gap, finishing time, and pole angle. However, each factor had a different degree of influence. Rotational speed had the greatest impact, followed by working gap, finishing time, and pole angle, which had the least impact.

2 The model developed in this research provides a highly significant equation for predicting surface roughness under different operating conditions with an accuracy of

up to 87%, based on the developed fuzzy logic.

3 The most optimum working conditions were when the rotational speed of 930 rpm, the working gap of 1 mm, the finishing time of 15 min, and the pole angle of 35 °, led to the highest surface improvement (ΔRa). This gets ΔRa achieved 0.234 μm, where the ranking of parameters is based on their significance in terms of increasing surface improvement (ΔRa).

4 A real confirmation test was conducted to validate the optimized setting, where the maximum achieved ΔRa was 0.275 μm, and the corresponding maximum predicted value was 0.234 μm.

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