Scientific Journal of University of Benghazi

SJUOB (2024) 37 (2) Applied Sciences: 73 – 80

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http://journals.uob.edu.ly/sjuob

Evaluation of the Recycling Conditions Through Injection Molding Using Fuzzy Logic Approach

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Received: 27 / 08 / 2024; Accepted: 05 / 11 / 2024

ABSTRACT

Recycling plastic products is still essential and crucial in every country around the globe due to its positive benefits on the environment and the economy. There are several mixing procedures for recycling, and it is crucial to understand how these mixtures affect the quality of products by standards and specifications. Consequently, it is helpful to apply analysis and prediction techniques to find out scientifically. Artificial intelligence "AI" techniques are widely used in many manufacturing engineering fields such as recycling operations. This is because of the many advantages that artificial intelligence techniques offer, including the ability to reduce human errors, save time, provide digital support, and make objective decisions. This study intends to employ the fuzzy logic method as one of the "AI" techniques for predicting a significant property that customers frequently need based on their quality levels and standards. This study employed the injection molding process to forecast the values of a mechanical characteristic, specifically tensile strength, under specific operating conditions based on data from the authors' earlier work. This investigation was conducted using two distinct mixing plans. The first mixed all the raw materials, while the second mixed 50% of the raw materials with 50% of the recycled materials. The fuzzy logic results were acquired, and the mean absolute percentage error for the two plans was calculated. Additionally, the outcomes of the current study, which employed the fuzzy logic approach, were contrasted with those of the earlier study, which utilized the response surface methodology approach. Furthermore, the results showed that the response surface technique approach is more accurate than the fuzzy logic since it has the lowest mean absolute percentage error.

KEYWORDS: Injection molding, fuzzy, recycling, prediction.

1. INTRODUCTION

Due to the expanding amounts of plastics used in various products, plastic reprocessing is one of the manufacturing sectors with the greatest growth rate. This is due to its lightweight, low cost, and reprocessing ability. Thermoplastics constitute 85% of consumed plastics in the world [1]. For this reason, the reprocessing of thermoplastics and the usability of reprocessed materials are gaining significance due to environmental and economic reasons. The well-known commercial and public term for reprocessed plastic material is recycling. Recycling may be defined as any activity involving reclamation, recovery, or reuse of materials (e.g., waste, post-consumer materials, plastic disposal in landfill sites, etc.); in other words, any method of extracting value in the form of energy or material from waste generated at any time in the life cycle of a product [2].

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One of the most common recycling techniques is to blend virgin and recycled polymers to produce materials with satisfactory characteristics. This practice is widespread in an industry where plastic scraps are ground and reintroduced into the processing apparatus and the virgin material. The main problem related to this practice is choosing the right amount of recycled polymer to be blended with the virgin polymer to obtain materials that do not show significant variation from the virgin component [2].

The recycling of homogeneous polymers is a relatively easy challenge only when their structure is preserved, and no significant degradation occurs either during the lifetime or during the processing operations. Indeed, the degradation phenomena, causing a decrease in molecular weight, formation of branching, and other chemical groups, etc., give rise as a consequence of these structural and morphological changes to the remarkable worsening of all physical properties [2]. Scrap and rejects generated during processing can be largely reprocessed almost 100%. It is well known today that the complete reuse of waste from products such as runners, sprues, and short shots is possible

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without significant loss in quality [3]. Furthermore, recycled materials require sorting, filtering, cleaning, drying, and other processes (Fig.1), which can raise manufacturing costs [4].

Investigating the reprocessing ability of polymeric materials is a significant issue, particularly in the area of glass fiber-reinforced compounds, as the fiber during the reprocessing could influence different properties, such as mechanical and rheological properties as presented in previous studies [5]. Predicting the amount of recycled material to add to raw material is necessary for various reasons, including the environment and product quality.

Numerous studies have employed the fuzzy logic method, but some examined the impact of specific process parameters [6-7]. Other studies focused on predicting errors and failures in injection molding [8–10]. Additionally, some researchers examined the prediction of injection molding flow length [11]. Furthermore, the prediction of warpage and shrinkage in injection molding was examined [12–14]. Some researchers have extensively examined another crucial material property regarding tensile strength [15–17]. Additionally, the fuzzy logic approach and the response surface methodology method were compared in the context of the injection molding process [18–19].

This study uses the fuzzy logic approach to predict the mechanical qualities of injection-molded parts in terms of tensile strength utilizing recycled material. The data for this study came from previous research [20] that employed response surface methods to predict outcomes. This study's second goal is to compare this study's findings with previous research findings.



Fig. 1. Plastic recycling overview.

2. PLAN OF THE STUDY

Based on the previous study [20], the reprocessing operations started by introducing 10 Kg of raw material. The first plan products were granulated (including runners and sprues). The second plan was performed by blending 50% of regrind material from plan I with 50% of raw material as shown in Fig.2 [20].

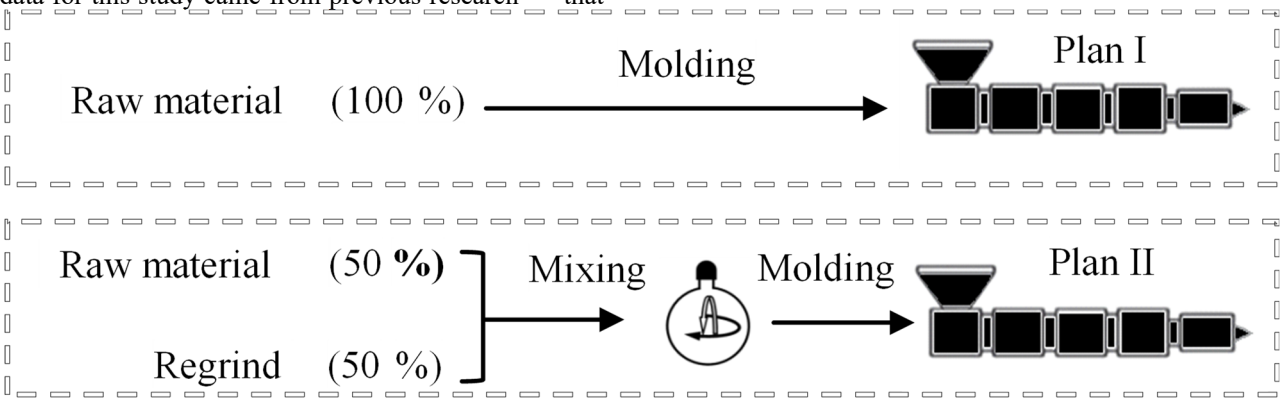


Fig. 2. Processes Scenario [20].

3. MATERIAL AND METHOD

3.1 Materials Selection

Based on the original work [20], the material used in this study was long glass fiber (GF) reinforced polypropylene (PP-20 wt.%) homopolymer; grade Polyform FPP 21 GFM HI supplied from A. Schulman Inc.

3.2 Machine's Facilities, and Conditions

The injection molding machine used in this study was a 100-ton clamp force FANUC Robocat S-2000i-100A all-electric drive with a screw diameter of 32 mm, and L/D of 22:1. The injected test part was an ASTM D638 tensile bar specimen with a gauge length of 90 mm, width of 10 mm and thickness of 4mm. Based on

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the original work [20], The molding conditions settings (factors) used were: melt temperatures (°C), screw speed (rpm), holding pressure (bar), holding time (sec), and injection rate (mm/sec). The property objected to in this study (response) is a tensile strength at yield. Table1 shows the levels considered for each reactor [20].

Table 1. The Levels of Factors [20].

Factor	Units	Low level	High level
Melting temperature (A)	ºC	230	270
Screw rotational speed (B)	Rpm	50	300
Holding pressure (C)	MPa	50	250
Holding time (D)	Sec	15	35
Injection rate (E)	$mm.sec^{-1}$	50	300

3.3 Fuzzy Logic Modeling

Fuzzy logic is a multi-reasoning logical concept where the evaluation is based on true/false, yes/no, high/low, etc. In fuzzy-logic modeling, reasoning is defined in terms of human linguistics, which is the common reasoning for the decision-making of situational problems. The linguistic variables are defined as extremely small, very small, small, medium, less high, high, very high, extremely high, and very extremely high, etc. In fuzzy logic, the Mamdani modeling system mainly consists of data definition, fuzzification, implication, aggregation, and defuzzification. The data definition defined all the input and output data to be considered for the selected model. The fuzzification and implication of the users developed the membership functions in terms of human linguistic variables to generate the fuzzy rules. The if-then rule describes the fuzzy rules in the Mamdani model. Next, the aggregation process mixes up all output rules and the defuzzification process converts the aggregation output to a single predicted value. In the current study, the triangular membership functions used for the input process parameters are melting temperature (°C), screw rotational speed (rpm), holding pressure (MPa), Holding time (sec), the injection rate ($mm.sec^{-1}$) to predict tensile strength. The membership function for each input variable was divided into three levels (low, medium, and high), and the output variable was divided into six levels (extremely low, very low, low, medium, high, and very high). The fuzzy logic controller was Median type and contained a rule base. This base comprises groups of rules; each output was defined by forty-six rules.

As previously explained, Fig. 3 represents the software's screen capture which illustrates the inputs and outputs of the study for model building. The inputs (also known as parameters or factors) that are indicated by the letters A, B, C, D, and E, as shown in Fig. 3. They are the melting temperature, the screw rotational speed, the holding pressure, the holding time, and the injection rate. However, the output (also known as the response) is the tensile strength in the Mamdani model.

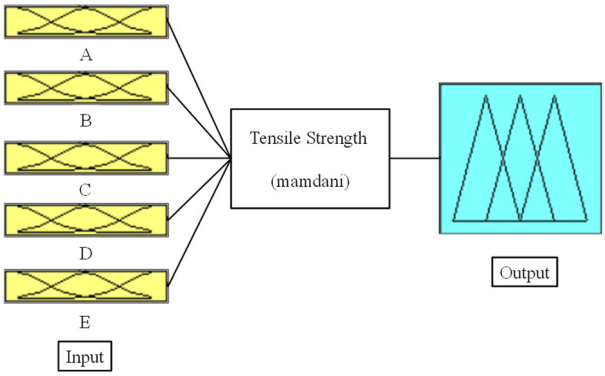


Fig. 3. Input-Output Parameters of the Fuzzy Logic Control Model.

4. RESULTS AND DISCUSSION

The scenario in plan I is to use 100% raw material (0% recycled material). The criteria of comparison between the actual values (original work-RSM) and the predicted values (fuzzy logic) is the mean absolute percentage of error (MAPE). Table 2 shows the actual and predicted values for Plan I.

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Table 2. The actual and predicted values for plan I.

Run no.	Parameters					Tensile strength (MPa)		MAPE
	Melt Temperature (°C)	Screw speed (RPM)	Holding pressure (MPa)	Holding time (sec)	Injection rate (mm/sec)	Actual	Predicted	
1	230	50	150	25	175	38.7	38.8	0.23
2	270	50	150	25	175	38.2	38.8	1.65
3	230	300	150	25	175	39.1	39.8	1.71
4	270	300	150	25	175	40.2	40.6	1.11
5	250	175	50	15	175	37.4	37.8	0.94
6	250	175	250	15	175	38.8	38.8	0.12
7	250	175	50	35	175	37.2	37.8	1.62
8	250	175	250	35	175	39.4	39.8	0.96
9	250	50	150	25	50	37.4	37.8	0.94
10	250	300	150	25	50	38.3	38.8	1.18
11	250	50	150	25	300	38.6	38.8	0.54
12	250	300	150	25	300	39.5	39.8	0.70
13	230	175	50	25	175	35.7	36	0.84
14	270	175	50	25	175	39.6	39.8	0.45
15	230	175	250	25	175	40.9	40.6	0.71
16	270	175	250	25	175	38.0	38.8	2.00
17	250	175	150	15	50	37.9	37.8	0.23
18	250	175	150	35	50	37.6	37.8	0.52
19	250	175	150	15	300	39.0	39.8	1.94
20	250	175	150	35	300	38.8	38.8	0.08
21	250	50	50	25	175	37.2	37.8	1.71
22	250	300	50	25	175	38.2	38.8	1.57
23	250	50	250	25	175	38.8	38.8	0.02
24	250	300	250	25	175	39.1	39.8	1.71
25	230	175	150	15	175	39.0	38.8	0.41
26	270	175	150	15	175	38.9	38.8	0.15
27	230	175	150	35	175	39.2	38.3	2.25
28	270	175	150	35	175	39.6	39.8	0.58
29	250	175	50	25	50	36.6	36.7	0.16
30	250	175	250	25	50	37.7	37.8	0.26
31	250	175	50	25	300	38.2	38.8	1.70
32	250	175	250	25	300	40.0	40.6	1.46
33	230	175	150	25	50	38.3	38.8	1.37
34	270	175	150	25	50	37.9	37.8	0.39
35	230	175	150	25	300	39.5	39.8	0.69
36	270	175	150	25	300	39.4	38.3	2.85
37	250	50	150	15	175	38.6	39.8	3.22
38	250	300	150	15	175	39.2	39.8	1.48
39	250	50	150	35	175	39.1	38.8	0.88
40	250	300	150	35	175	38.5	38.8	0.74
41	250	175	150	25	175	38.8	39.3	1.24
42	250	175	150	25	175	39.1	39.3	0.64
43	250	175	150	25	175	38.6	39.3	1.72
44	250	175	150	25	175	39.4	39.3	0.20
45	250	175	150	25	175	39.0	39.3	0.68
46	250	175	150	25	175	39.2	39.3	0.15

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Figure 4 illustrates the high dependability of the model by comparing the actual and predicted values of fuzzy logic for plan I. This can be confirmed by calculating the percentage of error which is 1.02%. Here, it can be said that the percentage of error is accepted because it falls within the acceptable range of engineering error where the maximum acceptance limit does not exceed 10%. Therefore, this indicates the validity of this model using the fuzzy logic method for plan I. Physically, the results of plan I, which uses 100% of the raw material, can be interpreted as this material being considered a virgin material, it has not been used or recycled before. This means that it has not been exposed before to mechanical or thermal stresses resulting from the injection molding machine during its manufacture or the effect of the shear force resulting from the grinding machine. More precisely, this may mean that the material used in this work is a composite material containing a percentage of glass fibers. The primary function of these fibers is to enhance and strengthen the mechanical properties represented in this work by tensile strength. The material did not have a critical reduction in the lengths of its fibers, so there was no significant variation in the tensile strength values. Thus, this could justify the behavior of the data shown in Fig. 4.

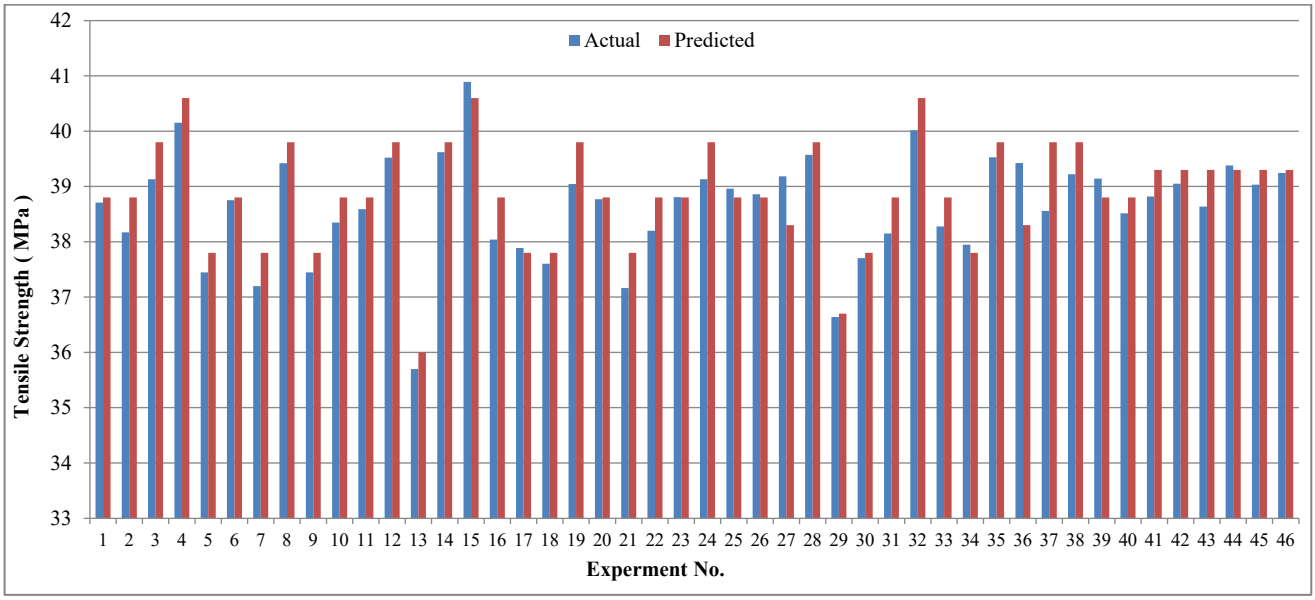


Fig. 4. Actual Vs. Predicted Values for Plan I.

The scenario in plan II is to use 50% raw material and 50% recycled material. Table 3 shows the actual and predicted values for plan II.

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Table 3. The actual and predicted values for Plan II.

Run no.	Parameters					Tensile strength		MAPE
	Melt Temperature (°C)	Screw speed (RPM)	Holding pressure (MPa)	Holding time (sec)	Injection rate (mm/sec)	Actual	Predicted	
1	230	25	250	175	42	42.02	175	0.05
2	270	35	150	175	41	41.82	175	1.96
3	250	35	150	175	42	42.95	300	2.21
4	250	15	150	175	42	42.56	300	1.32
5	230	25	150	175	39.9	40.98	50	2.64
6	250	15	250	175	42	42.18	175	0.43
7	230	25	150	50	42	42.15	175	0.36
8	250	25	250	175	42.8	43.9	300	2.51
9	250	15	150	300	41	41.7	175	1.68
10	250	35	150	300	41	41.78	175	1.87
11	250	25	150	175	41.5	41.89	175	0.93
12	270	25	150	50	41	41.71	175	1.70
13	230	25	50	175	38.8	39.67	175	2.19
14	250	35	250	175	41	41.82	175	1.96
15	270	25	250	175	42	40.08	175	4.79
16	230	25	150	300	41	41.8	175	1.91
17	270	25	150	175	42	42.48	175	1.13
18	250	25	150	175	41	41.47	300	1.13
19	250	25	150	50	42	42.43	175	1.01
20	250	25	250	300	41	41.98	300	2.33
21	250	35	50	175	38.8	39.18	175	0.97
22	250	25	150	175	41	41.42	175	1.01
23	250	25	50	175	41	41.5	300	1.20
24	250	15	50	175	39.9	40.4	175	1.24
25	270	25	150	300	41	41.46	175	1.11
26	270	25	150	175	38.8	39.59	50	2.00
27	250	25	250	50	41	41.73	175	1.75
28	250	25	50	50	38.8	39.61	175	2.04
29	230	15	150	175	41	41.61	175	1.47
30	250	25	250	175	38.8	40.88	50	5.09
31	230	25	150	175	42	42.33	300	0.78
32	250	25	150	175	41	41.79	175	1.89
33	250	25	50	300	39.9	40.4	175	1.24
34	250	35	150	175	38.8	39.8	50	2.51
35	230	35	150	175	41	41.98	175	2.33
36	270	25	50	175	39.9	40.43	175	1.31
37	250	25	150	50	38.8	39.7	50	2.27
38	250	15	150	50	39.9	40.91	175	2.47
39	250	25	150	175	41	41.28	175	0.68
40	250	25	150	175	42	42.38	175	0.90
41	250	25	150	300	39.9	40.68	50	1.92
42	270	15	150	175	41	41.23	175	0.56
43	250	35	150	50	41	41.83	175	1.98
44	250	15	150	175	39.9	40.11	50	0.52
45	250	25	150	300	42	42.62	300	1.45
46	250	25	50	175	38.1	37.75	50	0.93

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Figure 5 illustrates the high dependability of the model by comparing the actual and predicted values of fuzzy logic for plan II. This could be confirmed by calculating the error (%) of 3.02% which falls in the accepted range of the engineering error. In this plan, the error (%) is higher than its value for plan I of 1.02%. This could be justified as the material used in this plan is 50% raw material mixed with 50% recycled material. In other words, the material employed in this study is not only recycled but also a composite material that contains glass fibers. This means that it has already been subjected to mechanical stresses produced by the injection machine or granulating machine. This indicates that these repeated stresses may have caused the glass fibers to shorten, which possibly caused an increase in the variation of the tensile strength values and slightly increased the error (%). This may justify the behavior of the data as seen in Fig. 5. By comparing the error (%) between Plan I (100% of the raw material) and Plan II (a mixture of 50% raw material with 50% recycled material), it was found that the error (%) in Plan II is 3.02% higher than its counterpart in Plan I of 1.02%, as mentioned previously. Even though the material was subjected to previous stresses since the material used is recycled, the variation in the tensile strength values in Plan II is still acceptable. This can be explained by the fact that the settings of the injection molding machine as shown in Table 1 (specifically the screw rotational speed and the injection rate, which possibly cause the glass fibers to break and reduce their lengths) were chosen experimentally to reduce their negative effect on the tensile strength values [20].

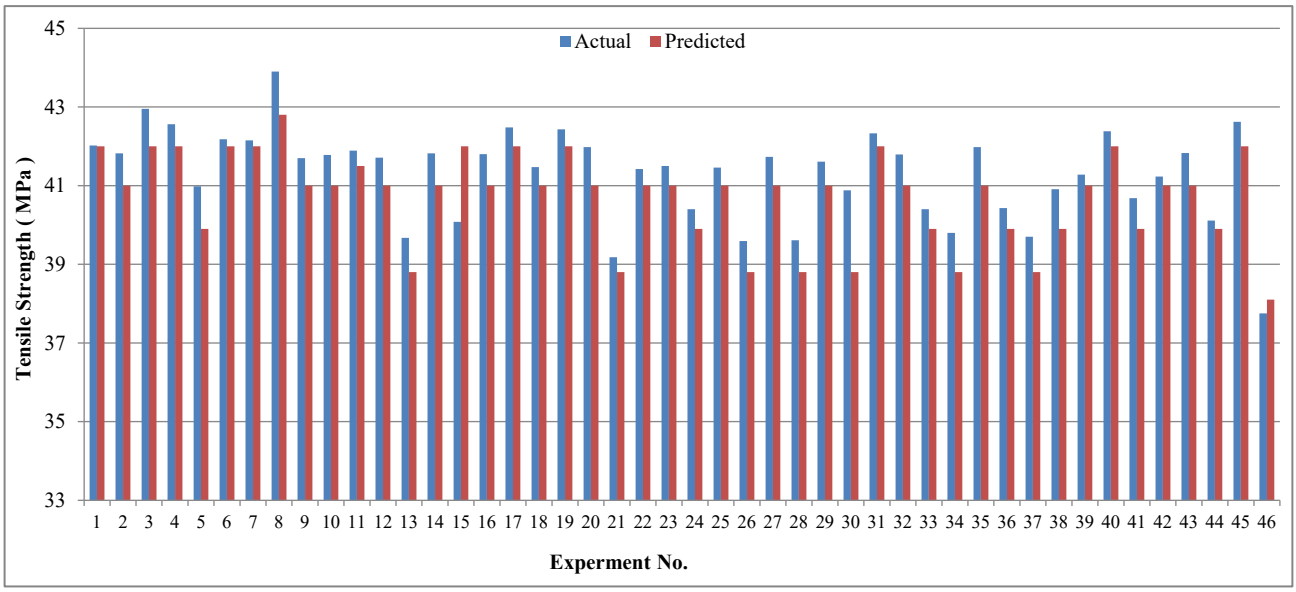


Fig. 5. Actual Vs. Predicted Values for Plan II.

Based on the result obtained from the original work [20], it has been found that the mean absolute percentage of error by using RSM is 0.52%, and 0.74% for plan I and plan II respectively. Using Fuzzy Logic, these values were found to be 1.02% for Plan I and 3.05% for Plan II. However, when comparing the two methods, it was found that the mean absolute percentage of error increased twice in the first plan (from 0.52% to 1.02%). When applying Fuzzy Logic as opposed to RSM, this proportion similarly rises in the second plan at a pace of four times (from 0.74% to 3.05%). This indicates that the RSM is more accurate because it has the lowest MAPE of the two plans.

5. CONCLUSIONS

This study used a Fuzzy Logic technique to predict the mechanical qualities of injection-molded parts in terms of tensile strength utilizing recycled material. The data for this study obtained previous research [20], which employed Response Surface Method "RSM" to predict outcomes. The second goal of this work is to make a possible comparison between the findings of this study and the previous research.

The following points can be concluded:

- At plan I (100% raw material) the mean absolute percentage error for RSM and fuzzy logic were found 0.52%, and 1.02%, respectively.
- At plan II (50% raw material + 50% regrind) the MAPE for RSM and Fuzzy logic, were found to be 0.74%, and 3.05%, respectively.
- RSM is more accurate because it has the lowest MAPE of the two plans.

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