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Modelling of the Flexural Strength of Low Flow Polypropylene Talc/Colemanite Hybrid Composite Materials with Taguchi and ANFIS Methods

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Abstract: In this experimental study, Taguchi experiment design and Adaptive Neuro-Fuzzy Inference System (ANFIS) methods were used to optimize the flexural strength of polypropylene / talc / colemanite hybrid composite materials depending on their production parameters and hybrid filler ratios in different percentages by weight.

It is known, that in most sectors today, for example, in the automotive industry, weight reduction efforts are under way. However, there is currently no published scientific and / or experimental studies on the three point bending properties of polypropylene / talc / colemanite hybrid composite materials. On the other hand, it is also known that the three point bending properties of thermoplastic composites are influenced by injection molding parameters and that these characteristic features influenced by injection molding parameters can not be predicted and/or determined, for example from flow analysis and/or computer-aided design programs. In this context, in the first phase of the study, the predicted boundary conditions of the design parameters such as hybrid filler ratio and injection parameters such as nozzle temperature, injection speed and mold temperature were determined, which can influence the three-point bending properties and also increase and / or decrease the flexural strength. In the second phase of the study, three-point bending tests were performed on talc (TC) and colemanite (GC) filled polypropylene (LPPH) hybrid composite materials according to ISO 178, and the ANFIS method was used to model the flexural strengths of LPPH / TC / GC hybrid composite materials. The results obtained were compared with the ANOVA results obtained with the Taguchi experiment design method. It was found that the ANFIS method provided satisfactory results.

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Keywords: Polypropylene, colemanite, talc, composites, flexural properties, desing of experimental, Taguchi, ANFIS.

1.INTRODUCTION

Polypropylene (PP) based products are frequently used in almost every area of our daily life. Especially the automotive industry is becoming the primary usage area for this thermoplastic. It is known, that in the automotive industry, weight reduction efforts are under way. However, it is also known that the values of mechanical properties of PP material after production can decrease or increase depending on both time (Sahin and Yayla, 2005a) and test parameters (Sahin and Yayla, 2005b). The investigations have shown that there are a limited number of studies on the mechanical properties of PP/GC composite materials (Sahin, 2011). However, there is currently no published scientific and / or experimental studies on the three point bending properties of PP/TC/GC hybrid composite materials.

In the first phase of the study, the Taguchi experiment design was used to optimize the flexural strength of LPPH/TC/GC hybrid composite materials depending on both their production parameters and hybrid fillers ratio. In the second phase, the ANFIS method was used to model the flexural strength of the hybrid composite material due to the experimental results. The results obtained were compared with the ANOVA results obtained by Taguchi experiment design. Finally the obtained results from both methods are concluded.

2.EXPERIMENTAL

2.1. Materials

In this study, the PP raw material, which has a commercial name of PETOPLEN EH 102 (Petkim/Turkey), with a density of 905 kg /m^3 and 11 g/10 min (230°C/2.16 kg) melt flow rate (MFR) has been used. The other mechanical properties of LPPH from the manufacturer are given as 1450 MPa flexural modulus, 35 MPa tensile stress at yield (Petkim, UR.17-BF-U1732, October 2017). For the hybrid fillers, as the first mineral with a commercial name of Ground Colemanite (Eti Mine Works General Management) with a

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density of 2420 kg/m^3 and an average particle size of 14.0 μm (Etimaden, EYS FRM-ETİ-00 10 /20/5/2014-02) and as the second mineral with a commercial name of TALC CM2 (IMIFABI) with a density of 2800 kg/m^3 and an average particle size of 3.5 μm (imifabi, August 2008) were used.

2.2. Composite preparation

The composite raw materials were manufactured with physical modification method at different quantities of TC/GC with hybrid content of 10/5, 7.5/7.5 and 5/10 percentage of the weight ratio. For the LPPH/TC/GC composite raw materials production, a twin-screw extruder (Coperion Werner and Pleiderer ZSK 25 P8.2 E WLE) with screw-ratio (L/D) of 45 and screw length (L) of 1125 mm was used. The production of the composite raw materials has been performed with fixed parameters and under the conditions in which screw speed is 900 rpm, barrel zones temperatures from the feeding zone to the die zone is between 160°C to 230°C and nominal production capacity is 30 kg/h. Nevertheless each hybrid composite granules has been again dried in an oven at 50°C for 4 hours after the production.

2.3. Multipurpose Test Specimen Preparation

The multipurpose test specimens of TC/GC filled LPPH hybrid composite materials were injection moulded using an injection moulding machine (Engel victory 330/50 tech) with 35 mm of screw diameter (D). The multipurpose test specimens type -1A according to ISO3167 are directly injected moulded, on the dimensions of 216 mm x 10 mm x 4 mm in a two cavity type-A ISO tensile mould with T-runner according to ISO294-1.

2.4. Flexural Test Specimen Preparation

The single-edge-notch bending (SENB) test specimens according to ISO178 for three-point bending tests was prepared by cutting from the central portion of the type A multipurpose test specimen with the dimension of 80 mm x 10 mm x 4 mm with a circular saw. Afterwards a single type-A notch (V-shaped) with 45°-angle and depths of 2 mm was prepared on the wide edge of 10 mm in the middle of the long edge of the test specimens by milling machine with a special metal slitting cutters (following the requirements of ISO 2818).

3.TAGUCHI EXPERIMENT DESIGN METHOD

Taguchi method have been applied to production control and structural optimization by many researchers and successful results have been obtained (Chiang and Hsieh, 2009; Lim et.al. 2010; Poorjandaghi and Afshar, 2014). Despite the weaknesses aspects of the methods, powerful results are obtained in the number of real-life applications. Taguchi concepts have been transformed into engineering methods for the development of qualifications. This is called quality engineering in Japan and robust design in the West (Barker, 1994).

In order to design the experiments carried out in the process analysis and development studies in industrial applications, many methods have been developed to obtain the most information with the least cost and energy at the shortest time. Implementation of the test design method at the beginning of the product and process development cycle provides many benefits such as improved process output, reduction of variability around nominal or target value, reduction of total development time, reduction of total cost (Montgomery, 1997). The Taguchi method which was used especially for product development after 1980 is one of these works. It has been used as an effective tool for creating the best production conditions in many different production environments, particularly in order to achieve more effective results with fewer trials.

3.1. Application of Taguchi Method

Taguchi Experimental Design method has been utilized to optimize the bending properties of talc and colemanite-added polypropylene hybrid composite materials and to determine the optimum production parameter levels. First, the controllable parameters that are effective on the experimental results and the different levels for each parameter have been determined. After designation of the appropriate orthogonal array for the experimental study, production of test samples was carried out. Test specimens produced according to the specified plan were subjected to bending test and the obtained bending strength values were evaluated statistically.

3.2. Determining the Factors and Levels

In the study, controllable factors considered to be effective on the bending properties of talc and colemanite-added polypropylene hybrid composite materials were determined. In determining the factors, factors affecting the output in plastic composite material production processes are discussed and four different factors are chosen. All factors were examined in three separate experimental levels. Experimental study was carried out using L9 (3^4) orthogonal array and five experiments in a structure containing four control factors of these three levels. The determined factors and levels are given in Table 1.

Table 1. The control factors and their levels

Factors		Level 1	Level 2	Level 3
TC/GC hybrid fillers ratio (by wt.%)	A	10 / 5	7.5 / 7.5	5 / 10
Nozzle temperature	B	180°C	220°C	260°C
Injection speed	C	5 mm/s	15 mm/s	25 mm/s
Mold temperature	D	10°C	30°C	50°C

3.3. Selection of Suitable Orthogonal Array

While the appropriate orthogonal sequence is determined for the experiment, the factors are decided according to the number of levels and accordingly the total degrees of freedom. The orthogonal array with this total degree of freedom or greater number of trials is selected as the appropriate sequence. The degree of freedom for a factor equals one minus the number of levels of that factor. In this study, the orthogonal array L9 (3^4) was selected for the experiment, since the orthogonal array L9 can accommodate

three levels and eight degrees of freedom. Moreover experimental conditions which will be applied are shown in Table 2.

Table 2. Experimental conditions for L9 orthogonal array

Experiment number	Factors			
	Hybrid fillers ratio (by wt.%)	Nozzle temp. (^oC)	Injec. speed (mm/s)	Mold temp. (^oC)
1	5TC/10GC	260	15	10
2	7.5TC/7.5GC	220	25	10
3	10TC/5GC	180	5	10
4	5TC/10GC	180	25	30
5	5TC/10GC	220	5	50
6	10TC/5GC	260	25	50
7	7.5TC/7.5GC	180	15	50
8	10TC/5GC	220	15	30
9	7.5TC/7.5GC	260	5	30

3.5. Analysis of Flexural Strength Test Results

The results obtained from the Taguchi L9 design experiments were analyzed using the Minitab 17 packet program. The results obtained from the analysis are shown below. As can be seen from Table 3 and Table 4 the most effective parameter sequence is the Nozzle temperature, Hybrid filler ratio, Mold temperature and Injection speed.

Table 3. Response table for signal to noise ratios (larger is better)

Level	Hybrid fillers ratio	Nozzle temp.	Injec. speed	Mold temp.
1	**38.42**	**38.64**	**38.37**	38.16
2	38.40	38.27	38.18	38.26
3	38.00	37.91	38.27	**38.39**
Delta	0.42	0.73	0.20	0.23
Rank	**2**	**1**	**4**	**3**

Table 4. Response table for means

Level	Hybrid fillers ratio	Nozzle temp.	Injec. speed	Mold temp.
1	**83.44**	**85.56**	**83.00**	81.09
2	83.26	81.98	81.25	81.92
3	79.51	78.68	81.97	**83.20**
Delta	3.92	6.88	1.75	2.12
Rank	**2**	**1**	**4**	**3**

Table 5. Analysis of variance

Source	DF	Adj SS	Adj MS	F Value	P Value
Hybrid fillers ratio	2	235.80	117.90	72.67	0.000
Nozzle temp	2	568.14	284.07	175.08	0.000
Injec. speed	2	36.98	18.49	11.40	0.000
Mold temp.	2	54.56	27.28	16.81	0.000
Error	63	102.22	1.62	-	-
Total	71	997.71	-	-	-

Table 6. Model summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.27377	89.75%	88.45%	86.62%

Using variance analysis, the effects of parameters on response variable were investigated. The results of the analysis of variance are given in Table 5. When Table 5 is examined, it is seen that all parameters have a significant effect on the response variable. As shown in Table 6, the model was found to be 86.62% successful in predicting experimental data. The regression equation obtained as a result of the analyses is as shown below.

Flexural Strength = 86.867 + 0.0 A(10T/5K) - 0.176 A(7.5T/7.5K) - 3.924 A(5T/10K) + 0.0 B(180) - 3.579 B(220) - 6.879 B(260) + 0.0 C(5) - 1.746 C(15) - 1.032 C(25) + 0.0 D(10) + 0.833 D(30) + 2.116 D(50)

4.ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS) METHOD

In this study, Adaptive Neuro-Fuzzy Inference System (ANFIS) was used for modelling of the Flexural Strength of Low Flow Polypropylene Talc/Colemanite Hybrid Composite Materials. ANFIS model gives satisfy fitting to the experimental data according to Mean Squared Error (MSE) and linear regression (R^2) value. Matlab® program was used for all ANFIS coding.

ANFIS has a feed-forward neural network structure where each layer is a neuro-fuzzy system component which is developed by Roger Jang et al. (1997, 1993, and 1992). There are several studies in the literature that apply the ANFIS method alone or in combination with different methods for many problems such as optimization and modeling (Ponce et al. 2015; Maher et al. 2015; Sarhan, 2015, Al-Jarrah et al. 2015, Pashchenko et al. 2016). As in this study, there are also studies in which Taguchi and ANFIS methods are used together. (Huang and Yu, 2016; Sangaiah, 2015; Li et al. 2014; Arabasadi et al. 2013). In this study, the performances were measured by Mean Squared Error (MSE) as follows:

$$SE = \frac{1}{n}\sum_{i=1}^{n}(STR_{pred} - STR_{exp})^2 \quad (1)$$

where n is the number of sample, STR_{pred} and STR_{exp} are the values of predicted and experimental flexural strength (STR), respectively.

In the study, 51 of training and 21 of testing data are separated for representing all different sections of experimental data. The TC ratio, GC ratio, nozzle temperature, injection speed and mold temperature are the inputs and Bending Properties is output of ANFIS model.

The diagram of ANFIS model is shown in Fig. 1. Since the model has 5 inputs and each input has three Two-sided Gaussian membership function (gauss2mf), the model totally has 243 fuzzy rules ($3^{gauss2mf\ 5inputs} = 243$ rules). These 3 gauss2mf can be defined as “SMALL”, “MEDIUM” and “LARGE” by an analogy of earlier study of İnal (2008).

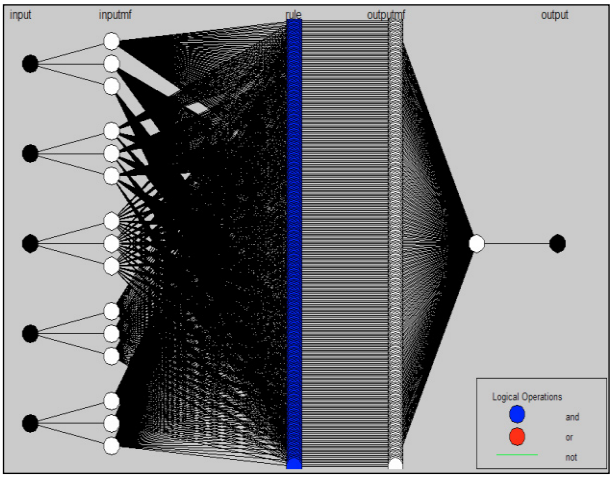

Fig. 1. The schematic diagram of ANFIS model.

The 243 fuzzy rules produced by ANFIS model for predicting the flexural strength (STR_{pred}) in terms of input parameters are represented as follows:

(1) IF (TC ratio is SMALL) AND (GC ratio is SMALL) AND (nozzle temperature is SMALL) AND (injection speed is SMALL) AND (mold temperature is SMALL) THEN (STRpred = o1 * TC ratio + p1 * GC ratio + q1* nozzle temperature + r1* injection speed + s1* mold Temperature + t1)

(2) IF (TC ratio is SMALL) AND (GC ratio is SMALL) AND (nozzle temperature is SMALL) AND (injection speed is SMALL) AND (mold temperature is MEDIUM) THEN (STRpred = o2 * TC ratio + p2 * GC ratio + q2* nozzle temperature + r2* injection speed + s2* mold Temperature + t2)

(3) IF (TC ratio is SMALL) AND (GC ratio is SMALL) AND (nozzle temperature is SMALL) AND (injection speed is SMALL) AND (mold temperature is LARGE) THEN (STRpred = o3 * TC ratio + p3 * GC ratio + q3* nozzle temperature + r3* injection speed + s3* mold Temperature + t3)

(241) IF (TC ratio is LARGE) AND (GC ratio is LARGE) AND (nozzle temperature is LARGE) AND (injection speed is LARGE) AND (mold temperature is SMALL) THEN (STRpred = o241 * TC ratio + p241 * GC ratio + q241* nozzle temperature + r241* injection speed + s241* mold Temperature + t241)

(242) IF (TC ratio is LARGE) AND (GC ratio is LARGE) AND (nozzle temperature is LARGE) AND (injection speed is LARGE) AND (mold temperature is MEDIUM) THEN (STRpred = o242 * TC ratio + p242 * GC ratio + q242* nozzle temperature + r242* injection speed + s242* mold Temperature + t242)

(243) IF (TC ratio is LARGE) AND (GC ratio is LARGE) AND (nozzle temperature is LARGE) AND (injection speed is LARGE) AND (mold temperature is LARGE) THEN (STRpred = o243 * TC ratio + p243 * GC ratio + q243* nozzle temperature + r243* injection speed + s243* mold Temperature + t243)

where oi, pi, qi, ri, si and ti are adaptive parameters of the ANFIS model i = [1..243].

The schema of two-sided gaussian membership function (gauss2mf) of the nozzle temperature input is given as an example in Fig. 2. The gauss2mf selected as membership function for supplying the lowest MSE. In application of ANFIS stages, first a FIS is supplied for training of the ANFIS model. ANFIS model is trained for 1000 epoch with MSE of 0.1156. In the training of ANFIS model, percent of MSE and R^2 are calculated as 0.0262% and 0.9484 respectively.

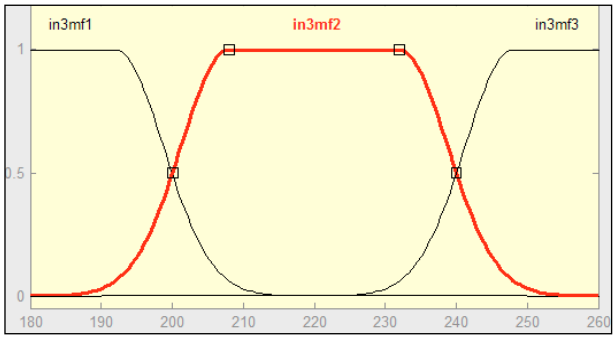

Fig. 2. The schema of two-sided Gaussian membership function.

The regression schema of training and testing stages which is represented by "postreg" Matlab® function is given in Fig. 3 and Fig.4, respectively. In the beginning of the training, the output of the ANFIS model is initially zero for all inputs. Then it converges to final state for presenting the best combinations of the inputs. It is concluded that the ANFIS can be suitable model for the flexural strengths analysis of the flexural strength.

After training, the test data is applied to the ANFIS model for obtaining the generalization capability. In the testing stage of the ANFIS, percent of MSE and R^2 are calculated as 0.0773% and 0.9446, respectively. The regression schema is shown in Fig. 4 for the test data.

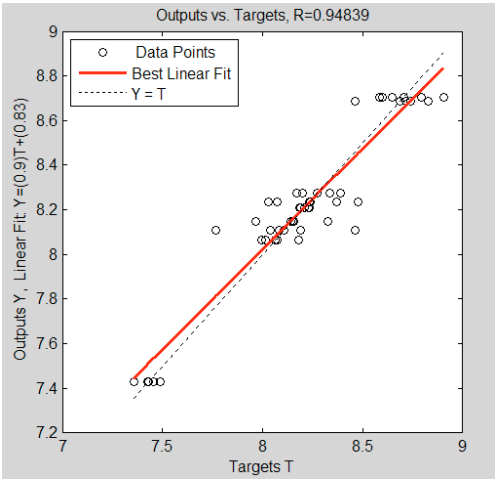

Fig. 3. The regression schema of training stage.

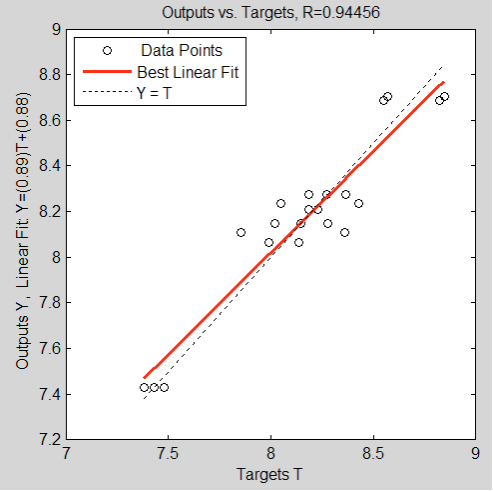

Fig. 4. The regression schema of testing stage.

5.CONCLUSIONS

In this study, Taguchi experimental design and Adaptive Neuro-Fuzzy Inference System (ANFIS) methods were used to optimize the flexural strength of polypropylene (PP)/talc (TC)/colemanite (GC) hybrid composite materials depending on both their production parameters and hybrid fill ratios. The Taguchi method is used to determine the effective parameters and the impact levels on the flexural strength value of the polypropylene talc / colemanite hybrid composite material. According to analysis of flexural strength of test results show that the most effective parameter sequence is the Nozzle Temperature, Hybrid Rate, Mold Temperature and Injection Speed. Furthermore, as a result of the variance analysis performed, it was found that all the experimental parameters had significant effects on the response variable. According to the results of variance analysis, the model predicts 86.62% of experimental data. Moreover, ANFIS method model the flexural strength for both training and testing results according to percent of MSE with R^2 parameters as 0.0262% with 0.9484 and 0.0773% with 0.9446, respectively. The mean of R^2 values of both training and testing stages are used for making a fairly comparison with Taguchi method. So it is calculated as 0.9465 while Taguchi method has 0.8662. It can be said that the model of ANFIS gives satisfactory results for modeling the experimental data.

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