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Optimization of the Young's Modulus of Low Flow Polypropylene Talc/Colemanite Hybrid Composite Materials with Artificial Neural Networks

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Abstract: In this experimental study, Taguchi experiment design and Artificial Neural Networks (ANN) methods were used to optimize the Young's modulus of polypropylene / talc / colemanite hybrid composite materials depending on their production parameters and hybrid filler ratios in different percentages by weight. Low flow polypropylene homopolymer (LPPH) is a thermoplastic widely used in the automotive industry as a buffer and fender material (raw material) because of its high impact resistance.

It is known, that in the automotive industry, weight reduction efforts are under way. However, there is currently no published scientific and / or experimental studies on the Tensile properties of polypropylene / talc / colemanite hybrid composite materials. On the other hand, it is also known that the Tensile 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 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 tensile properties and also increase and / or decrease the Young's modulus. In the second phase of the study, tensile tests were performed on talc (TC) and colemanite (GC) filled polypropylene (LPPH) hybrid composite materials according to ISO 527-1, and the ANN method was used to model the Young's modulus 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 ANN method provided satisfactory results.

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*Keywords: P*olypropylene, colemanite, talc, composite materials, Young's modulus, experimental design, Taguchi, ANN.

1. INTRODUCTION

The semi-crystalline thermoplastics and the applications that filled with various micro particles of these have been subjected to numerous studies. Many researches accomplished to understand the deformation characteristics of these thermoplastic materials (Zhou and Mallick, 2002). It is a common opinion that, in composites with micro particles, particle size, adhesion between surfaces (Wulin et al., 2000) and surface characteristics influence the performance of filled system substaintially. Besides, it is known that particle shape, particle distribution and filler amount rate have a significant influence on system performance (Wah et al., 2000). Wollastonite (Hadal et al., 2004), Kaolin (Leong et al., 2004), Talc (Premalal et al., 2002), and Calcium Carbonate (Zuiderduin et al, 2003) substances are ones which are used conventionally.

On the other hand, boron is a rare element of the world and is gaining in importance from day to day. In recent years, the requirements for boron minerals has also increased due to technological developments and increased use of nanotechnology in the industry. Many sectors carry out various researches to benefit from this mineral. Colemanite is one of the commercially valuable boron minerals that is preferred in many products due to its light weight, abrasion resistance, energy efficiency and heat resistance.

However, there is currently no published scientific and / or experimental studies on the Tensile properties of PP/TC/GC hybrid composite materials.

In this context, in the first phase of the study, the Taguchi experiment design was used to optimize the Young's modulus of LPPH/TC/GC hybrid composite materials depending on both their production parameters and hybrid fillers ratio. In the second phase, the artificial neural network (ANN) method was used to model the Young's modulus of the hybrid composite material due to the

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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 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.

3. TAGUCHI EXPERIMENTAL DESIGN METHOD

The Taguchi method is an experimental design method that chooses the most appropriate combination of the levels of controllable factors and minimizes the variability resulting from uncontrollable factors in the product and process variables. While this method is effective in improving the quality of the products, it also provides better results in terms of quality improvement with much less experimentation (Loncher, 1990).

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 highest level of 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 TC/GC-filled LPPH 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 control factors/levels and the experimental conditions for Taguchi L9 orthogonal array is given in Table 1 and Table 2, respectively.

As shown in Table 3 and Table 4, the most effective factor on Young's Modulus response value is Hybrid Ratio. The other most effective factors are Injection Pressure, Mold Temperature and Nozzle Temperature respectively. Analysis of Variance and finally Taguchi Model Summary are represented in Table 5 and 6, respectively. The plots of

main effects for Signal to Noise (S/N) Ratios are shown in Fig.1.

Table 1. The control factors and levels

Factors	Level 1	Level 2	Level 3
Hybrid fillers ratio (by wt.%)	10TC/5GC	7.5TC/7.5GC	5TC/10GC
Nozzle temp.	180°C	220°C	260°C
Injec. speed	5 mm/s	15 mm/s	25 mm/s
Mold temp.	10°C	30°C	50°C

Table 2. The experimental conditions for L9 orthogonal array

Experiment Number	Factors			
	Hybrid fillers ratio (by wt.%)	Nozzle temp. (°C)	Injection speed (mm/s)	Mold temp. (°C)
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

Table 3. Response table for means of Young's modulus

Level	Hybrid fillers ratio	Nozzle temp.	Injection pressure	Mold temp.
1	**2428**	1884	1745	1964
2	1801	1983	**2161**	**2006**
3	1701	**2062**	2024	1960
Delta	727	178	417	46
Rank	1	3	2	4

Table 4. Response table for signal to noise ratios (Young's Modulus/Larger is better)

Level	Hybrid fillers ratio	Nozzle temp.	Injection pressure	Mold temp.
1	**67.61**	65.42	64.70	65.76
2	65.03	65.57	**66.54**	**65.80**
3	64.48	**66.12**	65.88	65.56
Delta	3.13	0.70	1.84	0.23
Rank	1	3	2	4

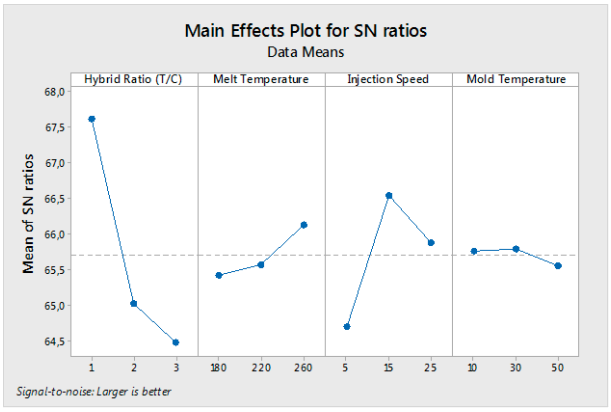

Fig. 1. The main effects plot for S/N ratios

As can be seen from Fig. 1, the Young's modulus value of the material is influenced significantly by the different levels of the talc/colemanite fill rate parameter.

Table 5. Analysis of variance

Factors	DF	Adj SS	Adj MS	F-Value	P-Value
Hybrid fillers	2	4661160	2330580	97.450	0.000
Nozzle temp.	2	239315	119658	5.000	0.012
Injection pres.	2	1352599	676300	28.280	0.000
Mold temp.	2	19607	9804	0.410	**0.667**
Error	36	860988	23916	-	-
Total	44	7133671	-	-	-

Table 6. Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
154.6	87.93%	85.25%	81.14%

4. ARTIFICIAL NEURAL NETWORK MODEL

Artificial Neural Networks (ANN) has good generalization ability for the test data while learning the relations from a training data. The McCulloch and Pitts neuron model is the basic model for ANN (McCulloch and Pitts, 1943).

The Multi Layer Perceptron (MLP) is the feed forward structure of the ANN which is used in this study given in Fig. 2. As seen in Fig.2, one input layer, one or more hidden layer(s) and one output layer constitute the structure of ANN. Although, some connections can be masked, In general, ANN layers are fully connected to each other's (Haykin, 1999). The backpropagation algorithm is widely used to reduce the error between target value and the output of the ANN (Rumelhart et al., 1986).

The target data of the training and testing sets are given in Fig. 3. The ranges of parameters are given in Table 7.

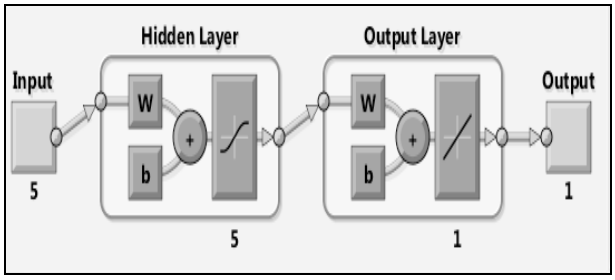

Fig. 2. Structure of MLP ANN

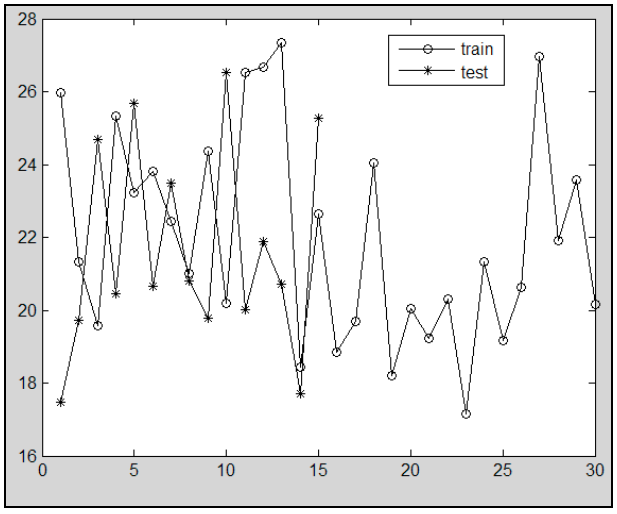

Fig. 3. Change of target vectors of test and train data

Table 7. The range of data to be tested in ANNs by means of training

TC ratio	GC ratio	Nozzle temp.	Injec. speed	Mold temp.	Young's Modulus
5	5	18	5	10	17.14 ~ 27.35
7.5	7.5	22	15	30	
10	10	26	25	50	

Weight% Talc Ratio, Weight% Colemanite Ratio, Nozzle Temperature, Injection Speed and Mold Temperature are defined as inputs of the MLP. The output of MLP is Young's Modulus. When the output layer of the neuron's activation function is chosen linearly, the activation functions of neurons in the hidden layer are chosen hyperbolic tangent. In one hidden layer with five neurons is used. The initial weights of the network are determined using Nguyen-Widrow algorithm (Nguyen and Widrow, 1990). Numbers of 30 and of 15 out of 45 data are used in training and testing, respectively. Percent of Mean Squared Error (MSE) values obtained for both training and testing data are calculated as 7.7953% and 24.0032%, respectively. The regression analysis of training and testing stages are given in Fig. 4 and Fig. 5, respectively.

R^2 values of training and testing values are computed as 0.84447 and 0.75225, respectively.

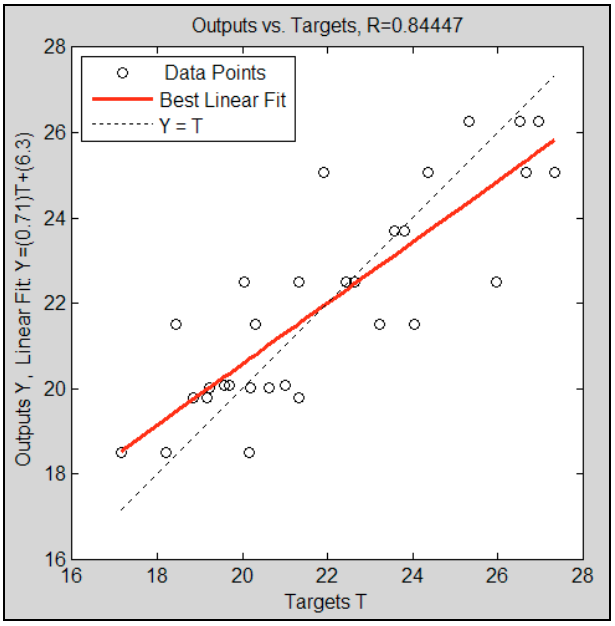

Fig. 4. The regression analysis of training stage.

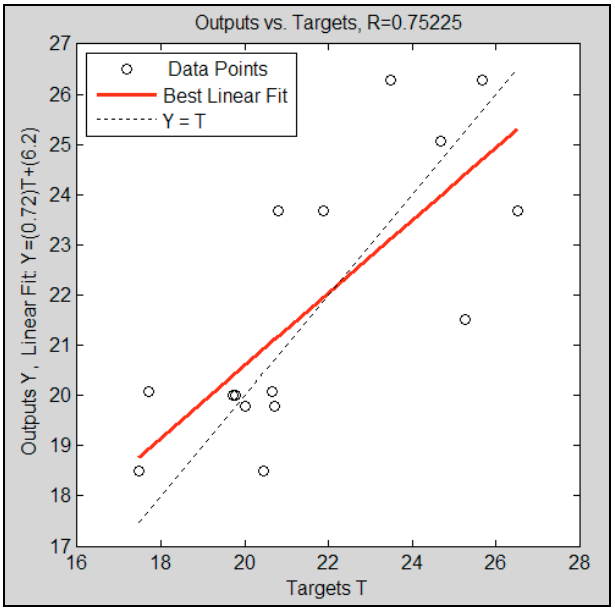

Fig. 5. The regression analysis of testing stage.

4. CONCLUSIONS

In the scope of the study, with two stages, it is aimed to optimize and model the Young's Modulus properties of low viscosity polypropylene talc/colemanite hybrid composite material, depending on the production parameters and the talc and colemanite filler amounts by different weight percentages.

In order to save time and cost, Taguchi Experimental Design method was used instead of full factorial

experimental analysis in the first phase of the study. As a result of the Taguchi analysis, it was determined that the hybrid ratio parameter has the most effect on the Young's modulus value. In addition, ANOVA test was applied to investigate the significance level of the effects of each parameter on the response variable. ANOVA analysis showed that the mold temperature parameter did not have a significant effect on the Young's Modulus response variable. The parameter levels that optimize the response variable were determined as Level 1(10TC+5GC) for CC filler/additive quantity, Level 3 (260°C) for nozzle temperature, Level 2 (15 mm/s) for injection speed and Level 2 (30°C) mold temperature.

Moreover, the MLP ANN method model the Young's Modulus for both training and testing results according to percent of MSE with R^2 parameters as 7.7953% with 0.8445 and 24.0032% with 0.7523, 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 0.7984 while Taguchi method has 0.8114. It can be said that the modelling of Young's Modulus with Taguchi and ANN models give satisfactory results for the experimental data.

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REFERENCES

Hadal, R.S., Dasari, A., Rohrmann, J., Misra, R.D.K. (2004). Effect of wollastonite and talc on micromechanisms of tensile deformation in polypropylene composites. *Materials Science and Engineering*, A 372, 296.

Haykin, S. (1999). *Neural Networks A Comprehensive Foundation*, Second Edition, Prentice-Hall Inc., 842.

Leong, Y.W., Abu Bakar, M.B., Mohd Ishak, Z.A., Ariffin, A., Pukanszk, B. (2004). Comparison of the Mechanical Properties and Interfacial Interactions Between Talc, Kaolin and Calcium Carbonate Filled Polypropylene Composites. *Journal of Applied Polymer Science*, 91, 3315-3326.

Loncher, R.H. and Matar, J.E. (1990). *Designing for Quality: An Introduction to the Best of Taguchi and Western Mehods of Statistical Experimental Design*, First edition, Chapman and Hall, USA.

Montgomery, D.C. (1997). *Introduction to Statistical Quality Control*, John Wiley&Sons Inc., Canada.

McCulloch, W.S., and Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity, *Bulletin of Mathematical Biophysics,* 5, 115-133.

Nguyen, D., Widrow, B. (1990). Improving the learning speed of 2-layer neural networks by choosing initial values of the adaptive weights. *International Joint Conference of Neural Networks,* 3, 21-26.

Premalal, H.G.B., İsmail, H., Baharin, A. (2002) Comparison of the mechanical properties of rice husk powder filled polypropylene composites with talc filled polypropylene composites. *Polymer Testing*, 21, 833-839.

Rumelhart, D. E., Hinton, G. E., Williams, R. J. (1986). Learning representations by back-propagating errors. *Nature,* 323, 533-536.

Wah, C.A., Choong, L.Y., Neon, G.S. (2000). Effects of Titanate coupling agent on rheological behavior, dispersion characteristics and mechanical properties of talc filled polypropylene. *Europian Polymer Journal*, 36, 789-801.

Wulin, Q., Mai, K., Zeng, H. (2000). Effect Of Silane-Grafted Polypropylene on The Mechanical Properties and Crystallization Behavior of Talc/Polypropylene Composites. *Journal of Applied Polymer Science*, 77, 2974-2977.

Zhou, Y. and Mallick P.K. (2002). Effects of Temperature and Strain Rate on the Tensile Behavior of Unfilled and Talc-Filled Polypropylene. *Part I: Experiments, Polymer Engineering and Science*, 42 (12) 2449-2460.

Zuiderduin, W.C.J., Wesrzaan, C., Hue'tink, J., Gaymans, R.J. (2003). Toughening of polypropylene with calcium carbonate particles, *Polymer,* 44, 261-275.