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Modelling of the Tensile Properties of Calcium Carbonate Filled Polypropylene Composite Materials with Taguchi and Artificial Neural Networks

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Abstract: In this experimental study, Taguchi experiment design and Artificial Neural Networks methods were used to optimize the Tensile strength of polypropylene / calcium carbonate composite materials depending on their production parameters and filler ratios in different percentages by weight.

The long-term strength (life or time) values of materials are usually obtained as a result of long-term tests also after production. For example it's known that tensile strength of polypropylene based material is decreased depending upon time after production. But changes to tensile properties, depending upon CC filler content of PPH/CC composite materials, after a long storage period which follows its production are still unclear. In this context, in this study, Tensile strength properties optimization of the calcium carbonate (CC) filled polypropylene homopolymer (PPH) composite, depending on the injection parameters is studied via Taguchi Experimental Design Method and Artificial Neural Networks (ANN). To examine the effect of injection parameters the injection pressure, the melt temperature and mold temperature impose conditions are used. CC-filled composite samples have been produced at different injection parameters by injection molding based on Taguchi experimental design method. Samples were stored for 12 months without daylight comfort conditions. Tensile tests for samples are made according to the ISO 527 standard. By this experimental study, parameter optimizations for Tensile strength properties of the PPH / CC composite materials have been revealed. At the second phase of the study, a fully connected feedforward Artificial Neural Network is utilized for modeling the Tensile strength properties of CC filled PP composite materials.

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Keywords: Polypropylene homopolymer, calcium carbonate, tensile properties, experimental design, artificial neural networks

1. INTRODUCTION

Polypropylene (PP) is a frequently used material for small or big, kitchen or bathroom, electrical or electronics household appliances and in computer technology. During the production of goods with PP of raw material can be used several methods, before only in order to reduce the cost of the product. However nowadays to improve the mechanical (Kolařík and Jančář, 1992), thermal and electrical properties, some kind of filling materials are added while forming operation is done. Within this scope, especially polypropylene homopolymer (PPH) materials, with micro particle filling substance such as talc, calcium carbonate and as a reinforcement substance glass fiber, are preferred because of their high rigidity and good thermal performances. Another reason of their preferability is the high price-volume-performance relation of this material, compared to commonly use other materials (Pukánszky, 1995). 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, 2005). 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 substantially. Besides, it is known that particle shape, particle distribution and filler amount rate have a considerable influence on system performance (Wah et al., 2000). Wollastonite, Kaolin, Talc, and Calcium Carbonate (Zuiderduin et al., 2003) substances are the ones which are used conventionally.

In production environments with many multi-level design and/or production parameters, it is very difficult to achieve the best possible solutions. Experimental design methods enable low cost and effective results to be produced in environments with numerous parameters that affect the results. Similarly, heuristic and meta-heuristic methods that offer near-optimal solutions in acceptable time and

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cost in very different decision environments are widely used.

The aim of this study is to determine the production parameter levels of PPH/CC composites with expected quality performance. Considering the benefits, the Taguchi experimental design method is used to determine the best parameter levels, and also Artificial Neural Networks is used in the modelling of the experimental results.

2. EXPERIMENTAL DESIGN

2.1. Materials

In this study, the PPH raw material has been used which has a commercial name Y101 Sumitomo Polypropylene (Sumitomo Chemical Asia) and values with 900 kg/m^3 density and 15 g/10 min (230°C/2.16 kg) Melt Flow Rate (MFR). The other values of PPH given from the manufacturer (Revision 20120525) is 1700 MPa Flexural Modulus, 34 MPa Tensile stress at yield, 28 MPa Tensile stress at break and 2 kJ/m^2 Izod impact (notched) at 23°C are some of the mechanical properties for injection molding applications, according to ASTM D standard. As the filling substance, the CC mineral with the commercial name Omyacarb 5-KA (Omya Madencilik A.Ş.) was used. Some of the main properties of CC mineral substance, which is obtained of mine site from Turkey - Karabiga, given in Table 1 (Date 31.03.2011)

2.2. Composite Preparation

For the PPH/CC composite raw materials production, twin-screw extruder (Coperion Werner and Pleiderer ZSK 25 P8.2 E WLE) has been used which has (L/D) 45 mm screw length and (L) 1125 mm helix length. The CC filled PPH composite raw materials were produced by different weight amount ratio (20, 30 and 40%) with physical modification method. The production has been performed in extrusion with fixed parameters and under the conditions of 950 rpm rotation speed, 30 kg/h production capacity, between 180°C to 245°C zone temperatures and 30°C cooling water bath temperatures. Each composite raw material has been dehumidified at 50°C for 4 hours.

2.3. Experimental Design

Only in one experimental study, it is not possible to evaluate all possible conditions if there are many parameters that are effective on the results (Düğenci et al., 2015). In this study, filler amount, nozzle temperature, injection pressure and mold temperature parameters were examined. The Taguchi L9 orthogonal experiment design was used for considering three different levels of four factors (Barker, 1994). The levels determined for each factor are as shown in Table 2.

Table 1. Particle size distribution

Particle Size	Method	Unit	Typical Value
Average dia. d(0.5)	ISO787/7	µm	6
Top Cut, d(0.98)		µm	28.00
Below 2 µm		%	22
Sieve 45 µm		%	0.1

Table 2 Control factors and levels

Factors		Level 1	Level 2	Level 3
CC filler amount (by wt.)	A	20%	30%	40%
Nozzle temperature	B	200°C	230°C	260°C
Injection pressure	C	165 bar	145 bar	115 bar
Mold temperature	D	10°C	30°C	50°C

Table 3. Taguchi L9 orthogonal array

Exp.No	CC filler amount (by wt.)	Nozzle temp.	Injection pressure	Mold temp.
1	20%	200°C	165 bar	10°C
2	20%	230°C	145 bar	30°C
3	20%	260°C	115 bar	50°C
4	30%	200°C	145 bar	50°C
5	30%	230°C	115 bar	10°C
6	30%	260°C	165 bar	30°C
7	40%	200°C	115 bar	30°C
8	40%	230°C	165 bar	50°C
9	40%	260°C	145 bar	10°C

Analyses of experimental data were performed with the Minitab 17 program. As a result of the analysis, it is seen in Fig.1 that the CC Filler amount parameter is the most effective parameter for the response variable Tensile strength. The most suitable parameter levels for producing composite materials with expected properties are shown in Table 3. Tensile strength Means, Analysis of Variance and finally Taguchi Model Summary are represented in Table 4, 5 and 6, respectively.

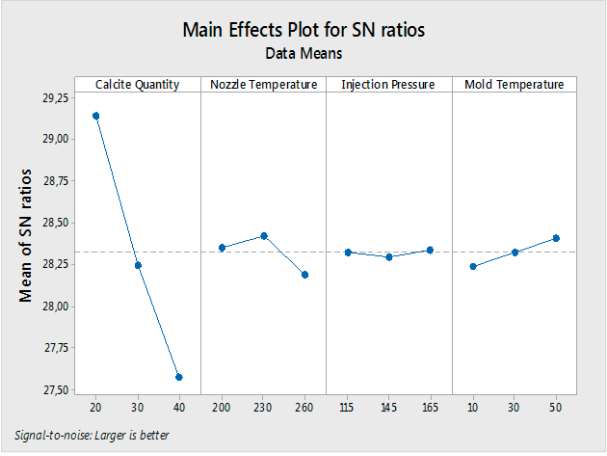

Fig.1. Main effects plot for S/N ratios

Table 4. Response table for tensile strength means

Level	CC filler amount (by wt.%)	Nozzle temp. (°C)	Injection pressure (bar)	Mold temp. (°C)
1	**28.65**	26.22	26.15	25.9
2	25.84	**26.43**	26.1	26.15
3	23.93	25.77	**26.17**	**26.37**
Delta	**4.72**	0.66	0.08	0.47
Rank	1	2	4	3

As shown in Fig. 1 and Table 4, the CC Filler amount is the most effective parameter on Tensile strength of material. As the amount of CC fill increases, the Tensile strength of the material decreases considerably. The parameter levels that optimize the response variable were determined as Level 1 for CC filler/additive quantity, Level 2 for nozzle temperature, and Level 3 for injection pressure and mold temperature.

Table 5. Analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
CC filler amount (by wt.%)	2	169.121	84.5605	1604.30	0.000
Nozzle temp. (°C)	2	3.468	1.7338	32.89	0.000
Injection pres. (bar)	2	0.045	0.0226	0.43	**0.654**
Mold temp. (°C)	2	1.649	0.8243	15.64	0.000
Error	36	1.898	0.0527	-	-
Total	44	176.180	-	-	-

When the results of variance analysis in Table 5 are examined, it is seen that the injection pressure parameter has no significant effect on the model explanation (p-value > 0.05). According to the results in Table 6, it is understood that the model obtained by Taguchi Experimental Design is 98.32% successful to estimate the experimental data.

Table 6. Model summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.229584	98.92%	98.68%	**98.32%**

3. ARTIFICIAL NEURAL NETWORK MODEL

Artificial Neural Networks (ANN) Model generalized solution with the test data while learning the solution from a set of training for an alternative calculation method. Artificial opinion is stemmed from biological neural system (McCulloch and Pitts, 1943). ANN have neurons which generally are fully connected to each other's by means of layers. The Multi-Layer Perceptron (MLP) ANN structure which is used in this study given in Fig. 2 consists of one input layer (Xi), one or more hidden layer(s) and one output layer (yk). All the layers of the MLP are fully connected to each other's (Haykin, 1999). Developing an effective algorithm based on backpropagation of the error has made MLP ANN widely used (Rumelhart et al., 1986). The change of the training and testing target data is seen in Fig. 3. The ranges of parameters given in Table 7 are trained in a MLP. The gradient descent backpropagation learning algorithm is used in training Feed-Forward MLP. Matlab® program was used for all coding.

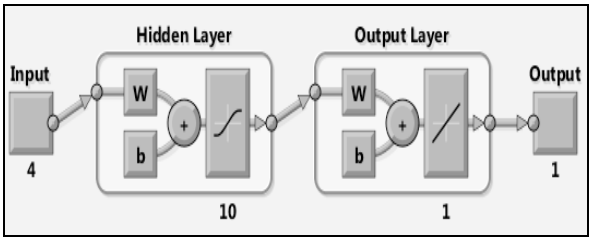

Fig.2. Structure of MLP ANN

The properties of ANN can be summarized as follows:

Calcite Quantity, Nozzle Temperature, Injection Pressure and Mold Temperature are the four inputs of the MLP.

There is one output as Tensile strength. Output layer of the neuron's activation function is chosen linearly.

The activation functions of neurons in the hidden layer is chosen hyperbolic tangent.

One hidden layer with ten neurons is used.

All the initial weights of the network are determined using Nguyen-Widrow algorithm (Nguyen and Widrow, 1990).

30 and 15 out of 45 data are used in training and testing, respectively.

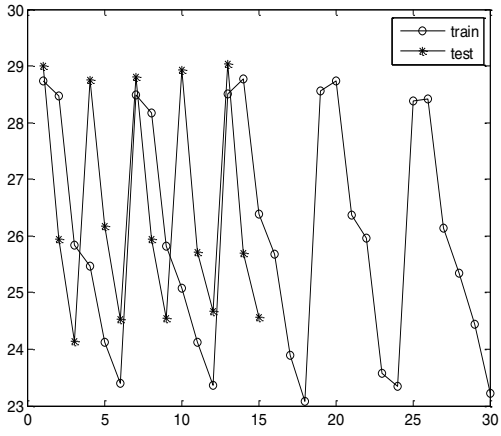

Fig.3. Change of target vectors of test and train data

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

CC filler amount (by wt.%)	Nozzle temp. (°C)	Injection pressure (bar)	Mold temp. (°C)	Tensile strength (MPa)
20	200	165	10	23.08~29.04
30	230	145	30	
40	260	115	50	

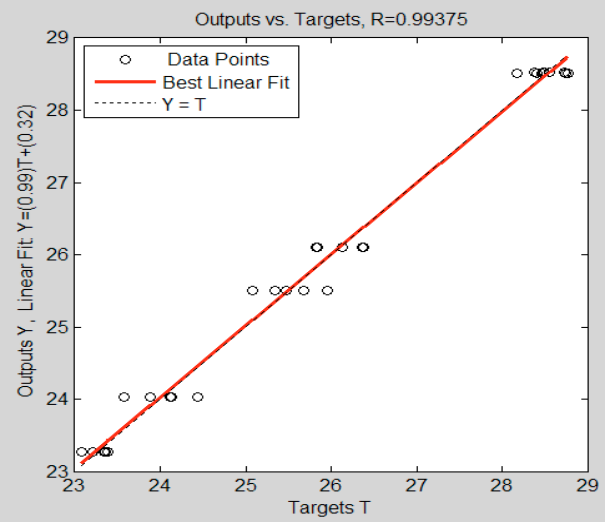

Fig. 4. The regression schema of training stage.

Percent of Mean Squared Error (MSE) values obtained for both training and testing data are computed as 0.1703% and 5.4491%, respectively. Moreover, the regression schema of training and testing stages which is represented by "postreg" Matlab® function is given in Fig. 4 and Fig.5, respectively. R^2 values of training and testing values are calculated as 0.99375 and 0.97448, respectively.

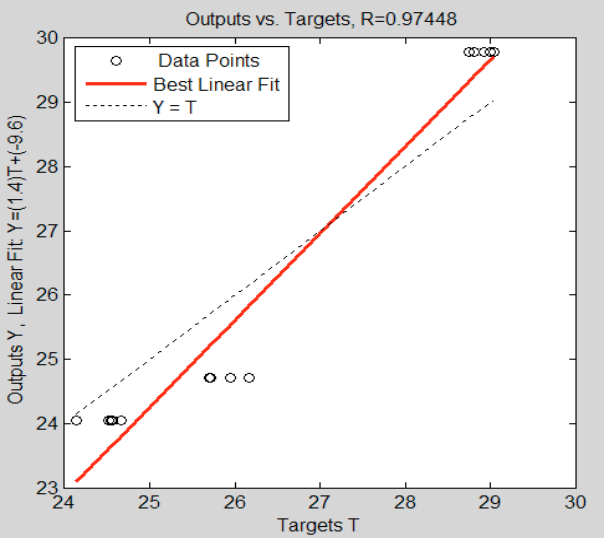

Fig. 5. The regression schema of testing stage.

4. CONCLUSIONS

Composites with different fillers / additives have a very common use in the manufacturing industry. Calcium carbonate (CC) is the most preferred filler / additive material in manufacturing due to its low cost and easy availability. The quality characteristics expected from the material may vary depending on the place of use in the manufacturing.

In this study, the effect of injection parameters on Tensile strenght properties of PPH / CC composite materials were investigated by modelling with both Taguchi experimental design method and Artificial Neural Networks.

In the first phase of the study, the Taguchi experiment design was used to determine the parameter levels optimizing the Tensile strenght of the PPH / CC composites, as it is costly and time consuming to perform a 3-level full factorial experimental study for 4 parameters. The Taguchi L9 experimental design and ANOVA results showed that the amount of CC filler is the most effective parameter on the Tensile strength of the material. It has been seen that the use of additive materials at lower rates is better for producing the material with the desired quality. The parameter levels that optimize the Tensile strenght of the PPH/CC composite material were determined as 20% for CC filler/additive quantity, 230°C for nozzle temperature and 115 bars for injection pressure and 50°C for mold temperature. The model obtained by Taguchi Experimental Design method has 98.32% R^2 value which successfully predict the experimental data.

In the second phase of the study, the feed forward multi-layer perceptron ANN was used to model the Tensile strength using the parameters which are shown in Table 7. 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 0.9841 while Taguchi method has 0.9832.

As a result of the study; the production and modelling of PPH/CC composite materials with expected quality performance has been achieved through the use of both Taguchi Experimental Design method and Artificial Neural Networks.

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