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Modelling of injection moulded polypropylene-grass composite

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Abstract

This study was carried out to develop empirical models for predicting the mechanical properties of injection moulded polypropylene-grass composite. The two screw plunger injection moulding machine with maximum clamping force of 70 tons and shot capacity of 3.0oz was used to produce Polypropylene-Grass composite at barrel temperature which ranged from 210ºC to 310ºC. The mechanical properties obtained from the experimental investigation of the produced polypropylene-grass composite were used to develop the empirical models for tensile strength, proof stress, percentage elongation and flexural strength respectively. The developed models were validated using coefficient of determination (R^2) and mean absolute percentage error (MAPE). The coefficient of determination obtained ranged from 0.9213 (92.13%) to 0.9911 (99.11%) which indicates that a substantial good fit was achieved by the models developed. The mean absolute percentage error of the developed models ranged from 0.12% to 6.53% which was below 10% recommended. The values obtained from the validation of these models were therefore found to be satisfactory and shows good predictability of the models.

Keywords: barrel temperature, composite, empirical model, injection molding, mechanical properties, polypropylene

1. Introduction

Technological development depends on the progress in the field of material sciences [1]. The research and development of new materials together with its design is the engine that drives economic progress [3]. That is to say, today, technology depends greatly on scientific research of materials, and this contributes to economic growth of any nation. Moreover, there are inadequate empirical and interactive models to predict mechanical properties of composites [1]. This had resulted to most failure in the manufacture of these composites. The utilization of process control and process monitoring are rarely fully implemented for the production of injection moulded products [9]. This may be due to a poor scientific understanding of the moulding process based on the complexities of the process containing multiple variables affecting the final part. Injection moulding is a very complex process and its process variable like barrel temperature, injection pressure, the material flow rate, mould temperature and flow pattern usually influence the properties of polymeric materials.

Osarenmwinda *and Nwachukwu* [1] focused *on* the development of empirical models, the models were developed using previously obtained experimental data to estimate properties of produced composite material from agro waste (sawdust and palm kernel shell). The empirical model was used to predict the properties of composite material (hardness, yield strength, ultimate tensile strength, modulus of elasticity, modulus of rupture, internal bond strength, density, thickness of swelling and water absorption) taking the inputs as percentage sawdust composition and percentage palm shell composition respectively. The empirical model was developed using "Mathematical Product" software program expressing the outputs in the quadratic form. The model performances were found to be satisfactory and show good predictability.

komeil *et al* [2] examined the designing, modelling and manufacturing of light weight carbon nanotubes/polymer composite nano-fibers for electromagnetic interference shielding application. A Light weight conductive multi-walled carbon nanotubes (MWCNTs)/polyvinyl alcohol (PVA) composite was used. Nano-fibers were prepared by electro-spinning process with an aim to investigate the potential of such nanofibers as an effective electromagnetic interference (EMI) shielding material. The influence of MWCNTs content, thickness, and frequency on the EMI shielding of conductive MWCNTs/PVA composite nanofiber was investigated. These experiments were designed by response surface methodology (RSM) and quadratic model was used to determine the responses. The predicted responses were in good agreement with the experimental results according to RSM model. The RSM analysis confirmed that MWCNTs content and thickness were the main significant variables affecting the absorption shielding effectiveness [2]. Moreover, the sample thickness has no significant influence on the reflection shielding effectiveness. The obtained RSM results confirmed that the selected RSM model presented suitable performance for evaluating the involved variables and prediction of EMI shielding parameters [2].

Chunping *et al* [4] carried out a study aimed to model fundamental bonding characteristics and performance of wood composite. In their work, mathematical model and a computer simulation model were developed to predict the variation of inter-element (strand) contact during mat consolidation. The mathematical predictions and the computer simulations agree well with each other. Their results showed that the relationship between the inter-element contact and the mat density was highly nonlinear and was significantly affected by the wood density and the element thickness.

Klewpatinond *et al* [5] examined the influence of injection moulding conditions on the impact strength of a thermoplastic. The results indicated that environmental conditions influenced the moulded part quality to varying degrees and that the environmental conditions should be controlled for applications with tight tolerances.

Adeyemi and Adeyemi [6] developed empirical formulas based on the diffusion model and the drying data (i.e moisture ratios, with drying times) of the composite from sawdust were computed and presented for various curing temperature and at different percentages of hardener resin addition.

This study therefore focused on the modelling of injection moulded polypropylene-grass composite.

2. Materials and Methods

2.1 Equipment and Tools with Their Specifications

1. Two stage-screw plunger Injection machine, Fox and Offord, 70 tons two stage-screw plunger.
2. A toggle clamp attached to the injection end of injection moulding machine.
3. The mould was made of Silicon – killed forging quality steel AISI type H140 treated to 252 –302 Brine 11. Such steel was used for moulds that require high quality parts, long production runs and is safe to use at high clamping pressures.
4. Monsanto Tensometer, Type ‘W’ Serial No. 8991 was used for tensile testing experiment.

2.2 Materials Used For Processing

a. The grass used for this research work is giunea gra**ss** (*Panicum maximum*)**;**

b. The Plastic material used for this study was Polypropylene (PP).

2.3 Preparation and Processing of Grass

The harvested grass was washed and soaked with dilute sodium hydroxide (NaOH) of concentration 0.10mol/dm^3 for 6 hours to ensure effective bonding between the grass and the Polypropylene materials. The grass was ground to granules using crushing machine. The grasses were first air dried in the sun and later transferred to an oven and dried at 105^{o}C. It was continuously monitored until moisture content of about 4$\underline{+}$ 0.2% was obtained [7]. The ground grass was screened to a particle size of 300μm diameters using vibrating sieve machine.

2.4 Mixing, compounding and production of composites

Polypropylene (PP) was mixed with ground grass in the proportion (20:80, 30:70, 40:60, 50:50, 60:40, 70:30 and 80:20 respectively) .The prepared Polypropylene-grass composite was blended in a cylindrical container until a homogenous mixture was obtained in the composite. The homogenous mixture of the composite was feed into the hopper of injection moulding machine and was produced at various barrel temperature ranging from 210^{o}C to 310^{o}C respectively.

The produced composite was evaluated for mechanical strength (tensile strength, proof stress, percentage elongation and flexural strength). In this research work, all empirical models were developed using experimental values (E) obtained from the produced composite tensile strength, proof stress, percentage elongation and flexural strength results. The empirical model was used to predict the mechanical properties of the composite material (Tensile Strength, Proof Stress, Percentage Elongation and Flexural Strength) by taking the inputs as percentage by volume of plastics (M), percentage by volume of grass (K) and barrel temperature (T).

The output was obtained through the interaction between M, K and T. A quadratic model of second order regression was obtained for the plastic-grass composites for mechanical strength (Tensile Strength, Proof Stress, Percentage Elongation, and Flexural Strength). A code was written in a MATLAB program (MATLAB software, version 7.5.0 (R2007b) to investigate the interactions of the various process parameters of the developed empirical model. The empirical model was expressed in the form shown in Equation 1

$$Y=\text{Constant}+\alpha_1T+\alpha_2M+\alpha_3K+\alpha_4TM+\alpha_5TK+\alpha_6MK+\alpha_7T^2+\alpha_8M^2+\alpha_9K^2 \quad (1)$$

Where M= Percentage by volume of plastic (%)
K= percentage by volume of grass (%)
T= Temperature (^{o}C)
Y= Output (Mechanical Properties)

Where α_1, α_2, α_3, α_4, α_5, α_6, α_7, α_8, and α_9 are the coefficient of T, M, K, TM, TK, MK, T^2, M^2, and K^2 respectively

2.5 Validation of the Models Developed

The mean absolute percentage error, and coefficient of determination were used to validate the model. They were determined using Equation 2 and 3 respectively.

Absolute percentage

$$\text{Error}=/\frac{Experimental\ value-Predicted\ Value\ X100\%}{Experimental\ Value}| \quad (2)$$

$$\text{Coefficient of Determination, } R^2 =\left[1-\frac{\sum(Yi-\hat{Y})^2}{\sum(Yi-\bar{Y})^2}\right] \quad (3)$$

Where Y_i= Experimental value
$\hat{Y} = Predicted\ value$

The Assumptions made in this Model are as follows:

1. The composite was produced from high Polypropylene and guinea grass.
2. The injection pressure remained constant i.e. 160kg/mm^2.
3. Guinea grass with particle size of 300μm was used.
4. All the composite production parameters were kept constant except percentage by volume of material and barrel temperature of the injection moulding machine.

3. Results and Discussion

3.1 Empirical Model Development

The empirical model developed for PP-Grass composite for tensile strength, proof stress, percentage elongation and flexural strength are shown in Equation 4-7 respectively.

$$\text{Tensile Strength for PP} - \text{Grass Composite}\ (6_T) = -172.4409 - 0.0460T + 0.7486M + 0.4670K + 0.0137TM + 0.0274TK - 0.0445MK - 0.0033T^2 + 0.0291M^2 - 0.0768T^2 \quad (4)$$

$$\text{Proof Stress for PP} - \text{Grass Composite}(6_P) = -86.3029 + 0.0419T + 1.2555M + 0.5556K + 0.0030TM + 0.0124TK - 0.0207MK - 0.0013T^2 + 0.0096M^2 - 0.0391T^2 \quad (5)$$

$$\text{Percentage Elongation for PP} - \text{Grass Composite}\ (P_E) = -3.3481 + 0.0010T + 0.0295M - 0.0123K + 0.0003TM + 0.0006 - 0.0007MK - 0.0001T^2 + 0.0005M^2 - 0.0017T^2 \quad (6)$$

$$\text{Flexural Strength for PP} - \text{Grass Composites}\ (EI) = -65.3512 - 0.3944T + 1.3150M + 1.2742K + 0.0007TM + 0.0053TK + 0.0059MK + 0.0004T^2 + 0.0012M^2 + 0.0074T^2 \quad (7)$$

Figure 1-4 shows the effect of barrel temperature on the tensile strength, proof stress, percentage elongation and flexural strength for PP-Grass composite for both Experimental (E) and Predicted (P) values respectively.

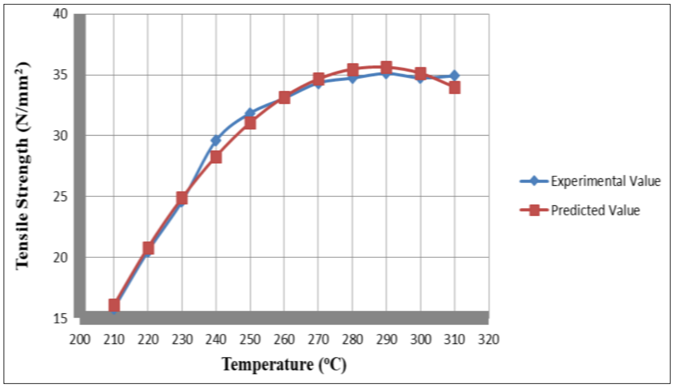

Fig 1: Effect of Barrel Temperature on Tensile Strength for PP-Grass Composites, Experimental (E) and Predicted (P) Values

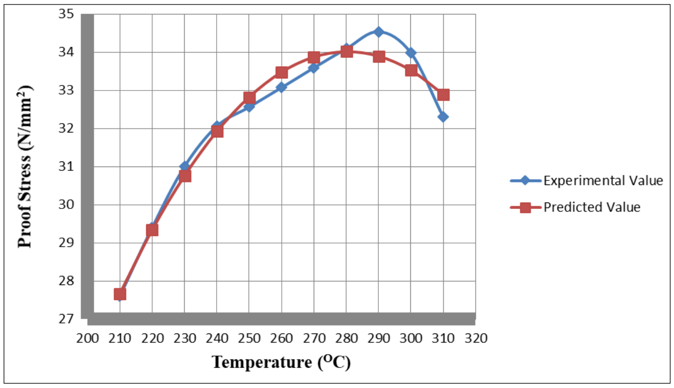

Fig 2: Effect of Barrel Temperature on Proof Stress for PP-Grass Composite, Experimental (E) and Predicted (P) Values

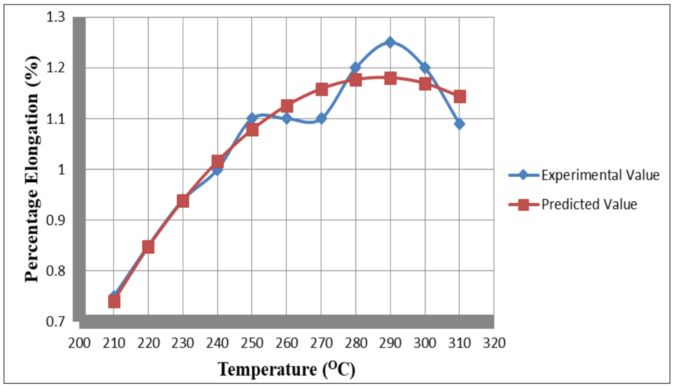

Fig 3: Effect of Barrel Temperature on Percentage Elongation for PP-Grass Composites, Experimental (E) and Predicted (P) Values

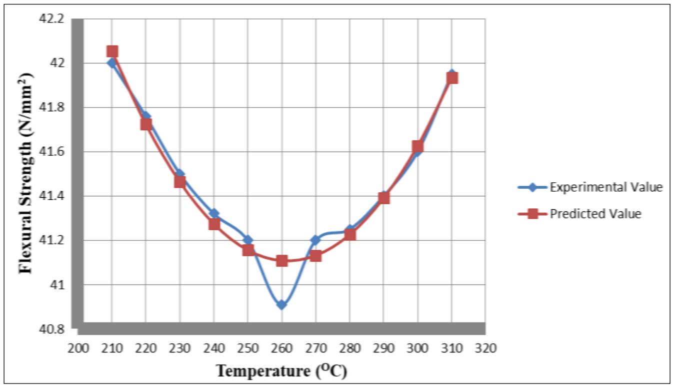

Fig 4: Effect of Barrel Temperature on Flexural Strength for PP-Grass Composites, Experimental (E) and Predicted (P) Values

3.2 Validation of models for PP-grass composite

The models were validated by comparing the predicted values from empirical model with experimental data. The predicted values were found to compare favourably with measured values. The models were validated using coefficient of determination (R^2) and mean absolute percentage error (MAPE). The coefficient of determination (R^2) were determined to be 0.9243 (92.43%) for tensile strength, 0.9213 (92.13%) for proof stress, 0.9911 (99.11%) for percentage elongation, and 0.9821 (98.21%) for flexural strength respectively. These values compare favourably with the value obtained by Chunping *et al.* [1] with coefficient of determination of 0.9311 (93.11%) for wood plastic composite. The values obtained in this study indicate that a substantial good fit was achieved by the regression models developed. Moreover, the mean absolute percentage error of predicted values from models when compare with the experimental values were determined to be 0.69% for tensile strength, 1.36% for proof stress, 2.98% for percentage elongation and 0.19% for flexural strength respectively. These values are significantly small and below the maximum error of 10% proposed by Liping and Deku [8]; Osarenmwinda and Nwachukwu [1]. These values were therefore found to be satisfactory and show good predictability of the model and its adequacy.

4. Conclusion

The study of the modelling of injection moulded polypropylene-grass composite has been achieved. Empirical Models were developed for predicting the mechanical properties (tensile strength, proof stress, percentage elongation and flexural strength) for the produced PP-Grass composite. The models were validated using coefficient of determination (R^2) and mean absolute percentage error (MAPE). The coefficient of determination (R^2) obtained ranged from 0.9213 (92.13%) to 0.9911 (99.11%) which indicates that a substantial good fit was achieved by the regression model developed. The mean absolute percentage error of the developed models ranged from 0.12% to 6.53% which was below 10% recommended. The values obtained from the validation of these models were therefore found to be satisfactory, and shows good predictability of the model and its adequacy. It is hopeful that the developed model will also be useful to researcher, industrialist and small scale manufacturer to ease the production of Polypropylene-grass composite.

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