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Optimisation of Processing Condition for Flexural Strength of Polypropylene-Nanoclay-Gigantochloa Scortechinii Nanocomposites

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Abstract: Now a days, plastic injection moulding for various types of polymer composites has been in high demand. However, an optimised processing condition is vital to ensure the desired properties of the product can be achieved.Therefore, this research was carried out to optimise the injection moulding processing condition of polypropylene-nanoclay-Gigantochloa Scortechinii. In this study, the $L93^4$ Taguchi Optimisation Method was used to obtain the optimum processing condition, which consist of the 9 trials, 3 levels and 4 processing conditions. The selected processing conditions were processing temperature, packing pressure, screw speed and filling time. In terms of material preparation, the Gigantochloa Scortechinii fibre was heated at a temperature of 120°C. The fibres were then mixed with polypropylene, polypropylene-grafted-maleic anhydride and nanoclay according to the formulation. The mixing process was performed using a roll mill mixer. Next, the flexural test samples were produced by using injection moulding process according to the orthogonal arrays setup from the Taguchi Optimisation Method. The flexural strength tests were done by using universal testing machine. As a result, the maximum flexural strength was 23.3380 MPa. The optimum value for processing temperature was 160°C, packing pressure was 112 MPa, screw speed was 144 rpm and the filling time was 3 seconds. In conclusion, the optimum processing condition has been achieved with factors that influenced flexural strength. This results can be used as a reference for future injection moulding manufacturing process.

Key words: Injection moulding, polypropylene, nanoclay, Gigantochloa Scortechinii, nanocomposites, Taguchi Optimisation Method

INTRODUCTION

Injection moulding is one of the methods that were highly regarded in the industry. This is because, this method can produce in large of quantities and also can save the time and cost to produce a product. However, an optimised processing condition is vital to ensure the desired properties of the product can be achieved (Chanda and Roy, 2008). In terms of optimisation, Taguchi Optimisation Method had introduced several statistical approaches to define the optimum processing condition as well as the most contributable factor towards the selected responses.In injection moulding process, several established researchers have achieved great results by adopting this method. Previous researchers have clearly define the effect of processing conditions towards various type of response and materials (Tsai *et al*., 2009; Tanyildizi, 2009; Ozcelik *et al*., 2010; Ozcelik, 2011; Mehat and Kamaruddin, 2011). A number of past researches which are related to this project also have been performed by the researchers (Othman *et al*., 2012a, b; Mohd *et al*., 2013; Ibrahim *et al*., 2014; Othman *et al*., 2014; Hilmi and Yulis, 2012; Muhammad *et al*., 2013) whereby the findings shall be used as the guidance for selecting the factors and level in this study.

A review had mention that polypropylene-clay has become more commonly developed polymer composites due to it was widely used, naturally abundance and high aspect ratio (Chanda and Roy, 2008; Tsai *et al*., 2009; Tanyildizi, 2009; Ozcelik *et al*., 2010). As for further reference, the researcher had summarised details about the preparation, properties and the application of polypropylene-nanoclay polymer nanocomposites (Ray and Okamoto, 2003). However, the effects of clay content, the mixing of other fillers and the selection of appropriate processing conditions have been always the issues that affecting the properties of the injected moulded art effacts (Rajesh *et al*., 2012).

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Natural fiber reinforced polymer composites is an emerging area in polymer science. These natural fibers are low coast fibers with low density and high specific properties. These are biodegradable and non-abrasive. The natural fiber composites offer specific properties comparable to those of conventional fibers composites. Natural fibers are classified according to their source such as plant, animal or mineral. There are many varieties of plant fibers liked hairs (cotton, kapok), fiber-sheaf of dicotylic plants or vessel-sheaf of monocotylic plants (e.g., flax, hemp, jute and ramie) and hard fibers (sisal, henequen and coir). The advantages of natural fibers, such as sisal or flax for example, their relatively high stiffness, a desirable property in composites, and their relatively low cost, a desirable economic value. The disadvantages are their relatively high moisture sensitivity and their relatively high variability of diameter and length. The moisture sensitivity of natural fibers can be reduced but an additional process step is required. This step raises their cost but may still afford an overall cost-effective product (Wallenberger and Weston, 2003). In this study "buluh semantan" or Gigantochloa Scortechinii was used as the reinforcement material in polypropylene. Bamboo fiber can be used as reinforcement in polymer, with the aid of compatibilizer, considering mechanical properties, processing and environmental aspects. Figure 1 shows the example of buluh semantan gained from typical forest at Malaysia.

MATERIALS AND METHODS

Experimental: The block diagram for the experiment process was shown in Fig. 2.

Material preparation: The materials used in this study are Polypropylene, Polypropylene-grafted-Maleic Anhydride (PPgMA), nanoclay and bamboo fibre. The specific type of bamboo fibres that were use was Gigantochloa Scortechinii. The mixture of polypropylene, nanoclay, PPgMA and bamboo fibre were measured based on the formulation (wt.%). The formulation was 5 wt.% of bamboo fibre, 75 wt.% of polypropylene, 15 wt.% of PPgMA and 5 wt.% of nanoclay. This formulation was obtained based on previous research conducted by the researchers (Othman *et al*., 2012a, b; Mohd *et al*., 2012).

The material preparation starts from processing the bamboo fibres. The fibres was chopped and refined to become short fibres, as shown in Fig. 3.

The Gigantochloa Scortechinii fibres need to be pre heated at 120°C. The processing of mixing was made by using Roll Mill Mixer machine to make it into

Fig. 1: Gigantochloa Scortechinii (Buluh semantan) from typical forest at Malaysia

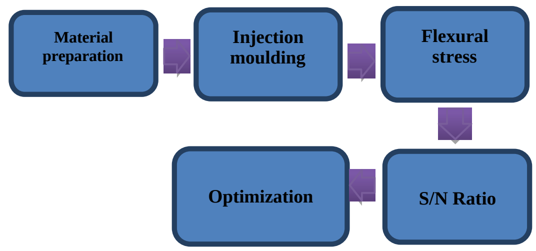

Fig. 2: Block diagram of the experiment processes

Fig. 3: Bambo fibres before mixing process

compounding. After that the mixture was formed into small pieces or it is called pallets by using Granulator SLM 50 Fy machine.

Injection moulding and orthogonal array: In this study, the injection moulding process using NISSEI NP7-1F machine was the primary method for producing a flexural (bar) shaped of specimens. The Taguchi Optimisation Method that was chosen for this study was L934 (9 trials, 3 levels, 4 processing conditions). This method was preferred in order to find the optimal values of the process to improve the quality characteristics. The processing conditions that were chosen were processing temperature, pressure packing, filling time and screw speed. These four processes with three different levels which was low, medium and high.

Table 1: Orthogonal array with flexural strength and S/N ratio

Trials	Processing temperature (°C)	Packing pressure (MPa)	Screw speed (rpm)	Filling time (sec)	Flexural strength (Mpa)	S/N ratio (dBi)
1	160	96	120	1	17.5610	24.8930
2	160	112	144	2	23.3380	27.3613
3	160	128	168	3	22.3982	17.0043
4	165	96	144	3	22.4207	27.0130
5	165	112	168	1	19.2566	25.6916
6	165	128	120	2	17.8128	15.0146
7	170	96	168	2	15.1650	23.6169
8	170	112	120	3	17.2577	24.7396
9	170	128	144	1	13.5147	22.6161

Flexural strength samples were injected mould from the experiments to be tested. There are 27 samples for 9 trials to be tested. The effects of several process parameters based on the Taguchi's orthogonal design were determined effectively from the matrix of experiments. As for the orthogonal array for this experiment, the detail was stated as shown in Table 1.

Measuring flexural stress: Flexural strength is a process that examines the failure (fracture) occurs when the maximum stress reaches a critical value called the burst strength or flexural strength. It is to test the reliability of detention in order to be in bending specimens and will never break. The specimen will bend and half outside (below) will experience tension and the other half will compress. The flexural strength of a material is defined as its ability to resist deformation under load. For materials that deform significantly but do not break, the load at yield, typically measured at 5% deformation/strain of the outer surface is reported as the flexural strength or flexural yield strength. The Universal Testing Machine (UTM) has been utilised to assess the flexural strength of the specimen in this research.

Measuring signal to noise ratio and optimisation: In this experiment by adopting the Taguchi Optimisation Method, the signal to noise ratio need to be measured, in order to examine the reliability of bending without breaking a specimen of specimens. The outcomes that need to be monitored in this study was the results of flexural strength which was influenced by the settings of four processing conditions. In addition, the optimised processing condition for the injection moulding will be the final findings.

The signal to noise ratio for larger the better quality characteristics was usually used for a desired output such as strength, critical current and so on. The formula for the signal to noise ratio for the larger-the-better quality characteristic is also a logarithmic function.The equation for signal to noise (SS/N) ratio specifically for the larger the better characteristic is (Megat-Yusoff *et al*., 2011):

$$S/N = -\log\left|\frac{1/y_1^2 + 1/y_2^2 + ... + 1/y_n^2}{n}\right|$$

Where:

Y_1, Y_2 = The value of strength until nth test

n = The total number of data points

By using Minitab 16 Software, the data of signal to noise ratio were obtained (Megat-Yusoff *et al*., 2011).

As for the optimisation method, the signal to noise response table for flexural strength was constructed to find the optimum level from four factors and 3 levels based on the data taken from the flexural test of 5 wt.% of bamboo fibre, 75 wt.% of polypropylene, 15 wt.% of PPgMA and 5 wt.% of nanoclay. The highest value of S/N ratio indicate the best setting for the selected factor.

RESULTS AND DISCUSSION

Flexural strength results: Based from Table 1, results of the average flexural strength based on the trials have been attained. From the result, the highest flexural strength achieved was 23.3380 MPa for trial No 2. This value was used as the reference whether the optimization of processing condition produced a better result or vice versa.

S/N ratio and optimisation results: Table 1 shows the signal to noise ratio value for each trial of experiment. The best value is 27.3613 dBi for trial no 2. Table 2 shows the response values of signal to noise ratio for the flexural strength. In this experiment based on the signal to noise ratio differences between the highest and the lowest value, the most influential processing condition for flexural strength was processing temperature and then followed by filling time. Normally a high processing temperature may help to improve the mobility of polymer but at the same time it reduced the viscosity of polymer composites whereby mechanical forces might be needed to push the nanofillers and fibers.This state may become

Table 2: Response values of signal to noise ratio (dBi) for flexural strength

S/N ratio (dBi) Level	PT	PP	SS	FT
1	26.4195	25.1743	24.8824	24.4002
2	25.9064	25.9308	25.6635	25.3309
3	23.6575	24.8783	25.4376	26.2523
Diff.	2.7620	1.0525	0.7811	1.8521

#PT is Processing Temperature, PP is Packing Pressure, SS is Screw Speed and FT is Filling Time. Diff. is the Difference between the highest and the lowest signal to noise ratio values

Table 3: Best combination of processing condition

Factor	PT	PP	SS	FT
Max S/N	26.4195	25.9308	25.6635	26.2523
Level	1	2	2	3
Value	160 °C	112 MPa	144 rpm	3s

#PT is Processing Temperature, PP is Packing Pressure, SS is Screw Speed and FT is Filling Time. Max S/N is the maximum value of Signal to Noise ratio

constraints towards the melt composite to break up the original agglomerates. As another facts, processing temperature cannot be considered as a sole independent factor without considering the effects from screw speed and filling time. As the temperature increases, the viscosity decreases and reduced the shear rate required to break the clay aggregate and fiber structure. In addition, the diffusion might be improved in terms of polymer intercalation and migration of exfoliated platelets. However, a high temperature may cause degradation of clay surfactants and fiber structure, collapsing the inter layers galleries and leading to a loss of clay efficiency and fiber function, thus resulting to a dispersion of unintercalated tactoid particles (Mohd *et al*., 2012).

As being describe in data analysis earlier, highest value of S/N ratio indicate the best setting for the factor. From the results in Table 3, the best processing condition for processing temperature was 160°C, packing pressure was 112 MPa, screw speed was 144 rpm and the filling time was 3 sec. Previous research found that melt temperature and packing pressure at level 3 (highest range) shall provide the optimum level for flexural strength (Mehat and Kamaruddin, 2011). However, the setting of temperature might be different according to the material properties.

According another research, increasing the injection moulding holding pressure up to an optimal level of 80 bars could enhance mechanical properties of composites. This was due to induced crystallinity of the polymer molecular chains and orientation of the fibres. On the other hand, increasing injection temperature during processing might contribute towards a poorer mechanical performance of the composites. Typically composites should be processed at 70-80 bars and at injection temperature of 150°C to gain the optimum strength (Megat-Yusoff *et al*., 2011).

Nanocomposites produced from low melt flow homopolymer usually offer better mechanical properties. For instance, a low melt flow polypropylene with 6% of clay loading can produced up to 2804 MPa for tensile strength (Mohd *et al*., 2012). Based on previous researcher (Rajesh *et al*., 2012) the usage of lower values of processing condition for polypropylene-clay mixture should increase the Young Modulus up to 25% as compared with neat polypropylene. Furthermore, the usage of high values of processing condition can only produce a slight increment which was only 30% of Young Modulus as compared with neat PP. The previous research also informed that the influence of clay is much more visible at stress at break condition.

CONCLUSION

As for the conclusion, the optimum processing condition of polypropylene-nanoclay-Gigantochloa Scortechinii had been achieved by adopting the Taguchi Optimization Method whereby the maximum value of flexural strength can be attained by using the selected processing condition. The existence of nanoclay and Gigantochloa Scortechinii obviously giving a promising manufacturing opportunity and the findings of this research could be useful for more detailed studies and as a guideline for those who want participant or enhance the injection moulding process in the future.

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