Multiple Responses Injection Moulding Parameter Optimisation Via Taguchi Method for Polypropylene-Nanoclay-Gigantochloa

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Abstract. Recently, the reinforcement of natural fibres into the polymer has been the main topic due to ecological which can sustain the life of our earth. Natural plant fibre composite has advantages in production in manufacturing product due to biodegradability and environmental protection. The injection moulding process is a major interest within the field of manufacturing technology because of the issue of archive the good quality of the product while minimizing the defect of the product that has been produced. Therefore, this research purpose describes the effects of gigantochloa scortechinii (natural fibre) mix with the polypropylene-nanoclay by using multiple objective optimisations for instance Taguchi Orthogonal Array method for injection moulding processing condition towards multiple responses such as melt flow index, flexural strength, warpage, and shrinkage. The compounding material used in this research is polypropylene, nanoclay, the compatibilizer which is polypropylene graft maleic anhydride (PP-g-MA), and gigantochloa scortechinii which known as bamboo fibre. For comparison purpose, the contents of natural fibre selected are 0wt.%, 3wt.% and 6wt.% towards the processing condition which are packing pressure, melt temperature, screw speed and filling time. Based on the signal to noise ratio analysis results, the highest value of S/NQP is at 6wt.% which is 160.6451 dBi followed by 3wt.% (158.1919 dBi) and 0wt.% (134.8150 dBi). Furthermore, the most influential parameter changed with the existence of Gigantochloa Scortechinii from melt temperature into packing pressure. In conclusion, the optimum values for multiple responses have been affected by the present of Gigantochloa Scortechinii.

1. Introduction

In the manufacturing process, injection moulding had been preferable because it can yield large quantities of products with cost savings and a reasonable period. Yet, effective control of parameter is one of the key elements of achieving good productivity and quality. Polymer matrix plays a major role as a cushioning material that can protect brittle fibre towards the impact and can absorb vibration energy to prevent the component structure from any seismic damage [1]. Additionally, copolymers display fast phase transitions while the homopolymer combination is relatively continuous [2]. For polypropylene, propylene homopolymer is the most used general-purpose form. It consists of a semi-crystalline, solid form of propylene monomer only and Polypropylene copolymer is spontaneously classified into copolymers and frames made of the polymerisation of propene or ethanol. For our information, the MFI increase caused a decrease in binder viscosity [3].
Throughout the plastics industry, strengths and weaknesses are critical elements in the quality and performance of the product. In this research, it is ensured that the effects of using Gigantochloa Scortechinii and nanoclay with a minimized defect are investigated such as poor flexural strength, shrinkage, and warpage. In the polymer industry, the highest possible system rate must be ensured to achieve an appropriate added value. The value of the components cannot be diminished at the same time. Nonetheless, laboratory tests are often not realistic and do not predict exactly whether chemicals impact materials. Consequently, surface analysis can be carried out directly within the injection moulding machine. The needs of finding a suitable composition between the polymer nanocomposites will be the next challenges. Therefore, the application that related material characterization for reference can be obtained and the injection moulding system streamlined further [4]. The composite properties are usually influenced by the amount of filling fraction, the aspect ratio, composite harmonization, and other mathematical factors. However, the properties of the substance were not easily controlled to consistently produce a product without defects. The needs to improve manufacturing conditions are also a priority in the development cycle for injection moulding [5]. Optimization of the processing requirements is essential for injection moulding. Settings shall rely on the technological competence and skills of the testing and error process without sufficient details.

This research was aimed to perform material characterization towards the selected formulation of polypropylene-nanoclay-Gigantochloa Scortechini (PPNCGS). The investigation for the effect of formulation wt.% of fibre and the suitable processing condition through preliminary experiment toward melt flow index, flexural strength, warpage, and shrinkage will be discussed. Furthermore, optimize the processing conditions which is melt temperature, packing pressure, screw speed and filling time for polypropylene-nanoclay towards S/N ratio via the Taguchi Optimization Method for the prepared sample.

1.1. Polypropylene-Nanoclay Material Characterization
Polypropylene has been produced in large amounts and commonly used in automobile components since 1959, because of its high volume and its low cost. The propylene market has increased substantially, primarily because of its use as a precursor in the manufacture of polypropylene for packaging materials and other commercial products. Nanocomposites, known as improved matrix products, have been used to produce multiple properties by combining one or two different nanomaterials. Both products and manufacturing facilities received major reactions to them. Polypropylene-Nanoclay is one example of these mixtures. Besides, PP-g-MA was used as a Lertwimolnun-based consistency agent to improve clay distribution. It is recognized that a compatibilizer for high shear stress is needed for a fair scattering of clay platelets in such a non-polar resin. However, PP-g-MA had a detrimental effect on the degree of influence of PP and its presence revealed that its mixing capacity was increased [6].

Characterization relates to the specific or general method by which the structure and properties of a substance are analysed and determined. Differential scanning calorimetry (DSC) is a thermoanalytic method for differentiation scanning and thermogravimetric analysis (TGA) is a tool used to calculate the weight of a sample in a changing temperature over time. TGA is a thermoanalytic procedure in which the thermo-balance, combination of an electronic micro-balance with a furnace, and the correct temperature control device monitors changes in the sample mass [7].

Gigantochloa Scortechinii or bamboo has added such composite and engineered material to the market in recent years. The development in bamboo supposes that materials such as the mechanical properties node need to be better understood. Besides, bamboo with power and modulus is excellent in mechanical properties at present [8].

1.2. Mechanical Properties and Quality Performance
The mechanical modifications are made up of fillers, impact modifications and nucleating agents. The mechanical properties of plastics are changed. Mechanical property modifications are also plasticizers. The alteration of mechanical properties takes place by nature, size, type, distribution, and change in the microstructure of the polymer matrix which the filler brings. Recently the work has taken place with the
modification by connecting agents as well as with the addition of compatible agents on bamboo fibre reinforced composite with specific weights percent of bamboo fibre, without any alteration. Shrinkage of dental resin materials is associated directly with the degree to which the double carbon bonds are converted to single bonds after polymerization [9]. Warpage in plastic object upon moulding is classified as a dimensional distortion. It has to do with shrinkage directly. Melt Flow Index (MFI) also an important parameter for determining the flow properties of the polymer at the melting point when the standard weight is applicable. Furthermore, bamboo's flexural ductility was significantly improved properties of strength but moderately less flexibility than wood [10].

1.3. Optimization of Injection Moulding Processing Conditions
Injection moulding is a very common method for the manufacture of reinforced plastics. However, it is difficult to identify the key causes of factors that affect the processing state in each sample. In an effective optimization system such as an answer surface tool, all impact variables must also be tracked effectively during the manufacturing cycle. There were substantial needs to optimize new materials like the mixture of natural fibres with nanocomposite polymer used in the injection moulding process. Because of that, Taguchi Optimization Approach was one of the most important approaches to find. Besides, the Implementation of the Taguchi orthogonal array resulted in density optimization [11].

2. Methodology
The experiments start with the preparation of materials and the selection of a machine. Then, the next step was performing the injection moulding process according to the orthogonal arrays. Then, the measurement of the melt flow index, warpage, shrinkage, and flexural strength was taken. Factor/Level selection and utilisation of orthogonal array shall be determined before the signal to noise ratio was calculated to produce the optimisation results.

2.1 Preparation of Material
The components used in this analysis have been classified into two composites, samples of polypropylene-nanoclay without any fibre (0 wt. % fibre loading) was used to make a comparison, for instance, to determine whether any significant effects from the content of fibre towards the quality of the samples. The first mixture contained 3 wt.% of Gigantochloa Scortechinii (bamboo) fibre and the other one was 6 wt.%. The selected compounding materials for 3 wt.% of bamboo fibre composites were 81 wt.% of polypropylene, 15 wt.% of compatibilizer which is polypropylene-grafted-maleic anhydride (PPgMA) and 1 wt.% of nanoclay, while the mixtures for 6 wt.% of bamboo fibre composites were 78wt.% of polypropylene, 15 wt.% of compatibilizer which is polypropylene-grafted-maleic anhydride (PPgMA) and 1 wt.% of nanoclay.

![Figure 1. TGA and DSC machine.](image-url)
The specimen is characterized by using differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) that have been shown in figure 1. The fibres must be pre-heated to a temperature of 120 °C before compounding, to reduce the fibres' moisture content. The process of compounding was made by using a Rotary Plastograph Brabender mixer as shown in figure 2. Afterwards, the blend was shaped into small pieces or pallets using an SLM 50Fy granulator.

The mould and injection moulding machine was available in Polymer and Ceramic Laboratory, UTHM. Figure 3 shows the type of injection moulding machine used for this research, which is Nissei NP7-1F (Screw diameter: 19 mm, maximum screw speed: 350 rpm, and maximum clamp force: 69kN).

2.2 Measuring Shrinkage, Warpage, Flexural and Melt Flow Index

For this study, the consistency and properties required to be strengthened are flexural strength, warpage, melt flow index, and shrinkage. Such defects must be examined in comparison to the specimens during the injection moulding process. The flexural strength of the trials was measured using a universal testing machine based on ISO 178 three bending points. The machine that was used to measure the flexural strength test of 3-point bending was the Universal Test Machine Model AG-1 (SHIMADZU) 10kN. Furthermore, in this research, the calculation for shrinkage is based on the equation:

\[ S = \frac{L_C - L_M}{L_C} \]  

(1)

where \( L_C \) is actual mould cavity length (mm) and \( L_M \) is an average of actual sample length. There also an equation that has been used to calculate the actual mould cavity length:
\[ L_c = L[1 + \alpha (T_{\text{mould}} - T_{\text{ambient}})] \]  

(2)

where \( \alpha \) is coefficient of thermal expansion for tool steel (6.45 \( \times \) 10\(^{-6} \) /\(^\circ\)F), \( T_{\text{mould}} \) is mould temperature (\(^\circ\)F), and \( T_{\text{ambient}} \) is the ambient temperature (\(^\circ\)F). As for warpage, the calculation was stated as:

\[ Z = h - t_a \]  

(3)

where \( Z \) is the warpage of the plate (mm), \( h \) is the maximum high of the plate (mm), and \( t_a \) is the average plate thickness (mm). As for the melt flow index, The Melt Flow Index (MFI) can be measured for the polymer nanocomposite using the formula given in ASTM D1238. The formula can be seen below:

\[ \text{MFI} = \frac{427 \times L \times d}{t} \times 600 \]  

(4)

where \( L \) is time piston stroke for (25.4mm = 2.54 cm) (cm), \( d \) is material density (at least temperature) (g/cm\(^3\)), and \( t \) is time for \( L \). Besides, the density of a specimen was calculated by using the following equation:

\[ d = \frac{W}{V} \]  

(5)

where \( W \) is the weight of the extruded material for \( L \) (g) and \( V \) is extruded volume for travel \( L \) (1.80 cm\(^3\)) (cm\(^3\)).

2.3 Factor/Level Selection, and Orthogonal Array

The orthogonal array selected for this analysis was L9\(^3\) (9 trials, 3 stages and 4 parameters). This procedure was selected to determine the best parameter values to boost the output characteristics. The samples were injected into the mould for processing. A total of 27 samples were tested for 9 experiments.

| Factors          | Label | Unit | Level 1 | Level 2 | Level 3 |
|------------------|-------|------|---------|---------|---------|
| Melt Temperature | MT    | °C   | 165     | 170     | 175     |
| Packing Pressure | PP    | %a   | 30      | 35      | 40      |
| Screw Speed      | SS    | s    | 25      | 30      | 35      |
| Filling Time     | FT    |      | 1       | 2       | 3       |

Table 1 shows four selected factor for this research which are the melting temperature (165°C, 170°C, 175°C), the packing pressure (30%, 35%, 40%) where 1%a is equal to 1.6Mpa, the screw speed (25%, 30%, 35%) where 1%b is equal to 2.4 rpm and filling time (1s, 2s, 3s). This four factor are categorized into three different levels which is low (1), medium (2) and high (3).
Table 2. Taguchi Orthogonal Array Method.

| Trial Number | Factors |
|--------------|---------|
|              | MT^a    | PP^b  | SS^c  | FT^d   |
| 1            | 165     | 30    | 25    | 1      |
| 2            | 165     | 35    | 30    | 2      |
| 3            | 165     | 40    | 35    | 3      |
| 4            | 170     | 30    | 25    | 3      |
| 5            | 170     | 35    | 30    | 1      |
| 6            | 170     | 40    | 35    | 2      |
| 7            | 175     | 30    | 25    | 2      |
| 8            | 175     | 35    | 30    | 3      |
| 9            | 175     | 40    | 35    | 1      |

Table 2 shows the Taguchi Orthogonal Array method where the factors are MT^a for Melt Temperature (°C), PP^b Packing Pressure (%), SS^c Screw Speed (%) and FT^d Filling Time (s). By using this method, the experimental procedure must follow the order of trial number which are one to nine including the value of each factors.

2.4. Measuring signal to noise ratio

In this experiment, the signal to noise (S/N) ratio must be determined by using the Taguchi optimisation method. The findings to be observed in this analysis are the product of the melt flow index, flexural strength, warpage, and shrinkage that were calculated by the setting of four-factor parameters. The optimised parameter for the injection moulding will be the final findings. The best result expected for flexural strength is further it can stretch without fracturing. The strength of the moulded measure must be increased. The S/N ratio for large better-quality characteristics was usually used for flexural strength and melt flow index analysis. As for warpage and shrinkage, the formula for the S/N ratio for the smaller the better-quality characteristics was chosen because lower defects were needed. A constitutive approach to solving multiple response problems by combining different reactions will then achieve the optimal set of processing conditions. Typically, the conventional method of evaluating more than one response was by measuring the response separately. In this research, to get the S/N ratio for quality performance of hinges (S/N_{QP}), the S/N for warpage, shrinkage, melt flow index and ultimate flexural strength have been added as stated in equation 6.

$$S/N_{QP} = S/N_z + S/N_s + S/N_{fs} + S/N_m$$

Where S/N_{QP} is signal to noise ratio for overall quality performance, S/N_z is signal to noise ratio for warpage, S/N_s signal to noise ratio for shrinkage, S/N_{fs} is signal to noise ratio for flexural strength and S/N_m signal to noise ratio for let flow index. All calculations of these S/N ratios were performed by using Minitab 18 statistical software, together with the main effect plots and validation.

3. Results and Discussions

The signal ratio for shrinking, warping, flexural strength and melt flow index properties of the samples is used to optimize performance. Taguchi method also develops an approximation of the S/N ratio to calculate the quality properties which differ from the preferred value. The smaller is the better properties for warpage and shrinkage analyzes of the S/N ratio [12]. Besides, the greater the better S/N ratio characteristics for the flexural strength and melt flow index analysis [13-14]. When the value of
S/N ratio for quality performance between each trial number for the formulation of 0%GS, 3%GS and 6%GS were acquired, each value was evaluated using conceptual S/N ratio to determine the optimum value for each parameter variable for case number of formulation 0%GS, 3%GS and 6%GS. The conceptual S/N ratio for bigger is better being used to gain the optimum value.

Table 3. Multiple S/NQP Results for 0wt.%, 3wt.% and 6wt.% Fibre.

| Trial | S/NQP 0wt%  | S/NQP 3wt%  | S/NQP 6wt%  |
|-------|-------------|-------------|-------------|
| 1     | 42.1538164  | 43.70172748 | 43.99694033 |
| 2     | 42.20633856 | 43.86783549 | 44.03237171 |
| 3     | 42.59473855 | 43.81600406 | 43.91965261 |
| 4     | 41.53185505 | 43.98368485 | 43.98833425 |
| 5     | 41.98489494 | 43.94238438 | 43.97075004 |
| 6     | 41.3413429  | 43.73491264 | 43.9448317  |
| 7     | 41.76106243 | 43.82258453 | 44.11081028 |
| 8     | 41.78459683 | 43.81548906 | 44.11734966 |
| 9     | 42.14413153 | 43.53530101 | 43.89207378 |

Table 3 shows the multiple S/NQP results for 0wt.%, 3wt.% and 6wt.% fibre. Based on table 3, the highest value of S/NQP for 0wt% is 42.594 at trial number 3. For the S/NQP 3wt% and 6wt%, the highest value is at the trial number 4 and 8 with the value of 43.9836 and 44.1173.

3.1 Main Effect Analysis

The main effect analysis proved that the analysis of melt temperature, pressure packing, screw speed and filling time which from the utilization of signal to noise ratio for larger is better. For main effect analysis, figure 4, figure 5 and figure 6 shows the main effect plot for multiple S/NQP ratios for 0wt.%, 3wt.% and 6wt.%.

Figure 4. Main Effect Plot For Multiple S/NQP Ratio for 0wt.%. 
Based on figure 4 which is 0wt.% GS fibre, the highest value for each factor are 165°C for the melting temperature at level 1 with a maximum S/N<sub>QP</sub> ratio value of 42.32 dB, 40% of packing pressure at level 3 with a maximum S/N<sub>QP</sub> ratio value of 42.03 dB, 35% of screw speed at level 3 with a maximum S/N<sub>QP</sub> ratio value of 42.11 dB and 1 second of filling time at level 1 with a maximum S/N<sub>QP</sub> ratio value of 42.09 dB. Furthermore, based on figure 5, the highest value for each factor are 170°C of melting temperature at level 2 with a maximum S/N<sub>QP</sub> ratio value of 43.89 dB, 35% of packing pressure at level 2 with a maximum S/N<sub>QP</sub> ratio value of 43.88 dB, 35% of screw speed at level 3 with a maximum S/N<sub>QP</sub> ratio value of 43.86 dB and 3 seconds of filling time at level 3 with a maximum S/N<sub>QP</sub> ratio value of 43.87 dB. For figure 6, the highest value for each factor is 175°C of melting temperature at level 3 with a maximum S/N<sub>QP</sub> ratio value of 44.04 dB, 35% of packing pressure at level 2 with a maximum S/N<sub>QP</sub> ratio value of 44.04 dB. Furthermore, 25% of screw speed at level 1 with a maximum S/N<sub>QP</sub> ratio value of 44.02 dB and 2 seconds of filling time at level 2 with a maximum S/N<sub>QP</sub> ratio value of 44.03 dB.

3.2 Optimum Parameter and Optimum Result
The optimum parameter value has been achieved by combining each factor with the highest value of S/N<sub>QP</sub>. This result indicates the best setting for each parameter based on optimisation for multiple responses which are melt flow index, shrinkage, warpage and flexural strength.
Table 4. Optimum value based on the best combination parameter regarding the value of S/N Ratio.

| Fibre Formulation (wt.%) | Parameter        | S/NQP (dBi) |
|--------------------------|------------------|-------------|
|                          | Melt Temperature | Packing Pressure | Screw Speed | Filling Time |
| 0                        | 165°C            | 40%          | 35%         | 1s           | 134.8150    |
| 3                        | 170°C            | 35%          | 35%         | 3s           | 158.1919    |
| 6                        | 175°C            | 35%          | 25%         | 2s           | 160.6451    |

Table 4 shows the optimum value based on the best setting combination parameter regarding the value of the S/NQP ratio. For formulation 0wt.%, the optimum value for melt temperature is 165°C, packing pressure is 40%, screw speed is 35% and filled time is 1 second. For formulation 3wt.%, the optimum value for melt temperature is 170°C, packing pressure is at 35%, screw speed is at 35% and filled time at 3 seconds. Moreover, for formulation 6wt.%, the optimum value for melt temperature is at 175°C, packing pressure is at 35%, screw speed is at 25% and filled time at 2 seconds. For the comparison value of S/NQP, the value increased when the formulation increased from 0wt.% to 3wt.% which is 134.8150 to 158.1919 and keep increasing at the value of the S/N ratio from 3wt.% to 6wt.% which is 158.1919 to 160.6451. The highest value of S/NQP is at formulation 6wt.% which is 160.6451 based on multiple responses. This result shows that the formulation of 6wt.% is better compared to the 3wt.% and 0wt.% based on optimisation for multiple responses and the optimum value for each parameter has been achieved.

Table 5. The Ranking of Parameter for Each Fibre Composition.

| Fibre Formulation (wt.%) | Ranking of Factor | 1st  | 2nd  | 3rd  | 4th  |
|--------------------------|-------------------|------|------|------|------|
|                          |                   | Melt | Screw| Filling| Packing |
| 0                        |                   | Temperature | Speed | Time | Pressure |
| 3                        | Packing           | Melt | Packing | Filling | Screw |
|                          | Pressure          | Temperature | Pressure | Time | Speed |
| 6                        | Packing           | Filling | Packing | Melt | Screw |
|                          | Pressure          | Time | Pressure | Temperature | Speed |

Table 5 shows the ranking of the four factors for each formulation that affect the multiple responses which are the melt flow index, flexural strength, warpage and shrinkage. Based on formulation 0wt.%, the melt temperature is one of the most important factors that affect the multiple responses followed by screw speed, filling time and packing pressure. For formulation 3wt.%, packing pressure ranked in the first place followed by melt temperature, filling time and screw speed. Based on formulation 6wt.%, packing pressure is the most important factor that affects the multiple responses followed by filling time, melt temperature and screw speed. This result showed by adding natural fibre for instance gigantochloa scortechinii (bamboo fibre) into polypropylene, the main factor that affects the multiple response change from melt temperature into the packing pressure.

4. Conclusions

In the conclusion, the optimum value of four factors which is melt temperature, packing pressure, screw speed and filling time have been achieved based three fixed formulation by using Taguchi Orthogonal Array optimisation method for multiple responses (melt flow index, flexural strength, shrinkage and warpage). Based on the result, the value of S/NQP is 134.8150 dBi at melt temperature.
165°C, packing pressure 40%, screw speed 35% and filled time 1 second for the formulation 0wt.%.
Furthermore, the result for formulation 3wt.%, the S/N QP value is 158.1919 dBi at melt temperature
170°C, packing pressure 35%, screw speed 35% and filled time 3 seconds, respectively. As for the 6wt.%
of fibre loading formulation, the S/NQP value is 160.6451 dBi at melt temperature 175°C, packing
pressure 35%, screw speed 25% and filled time 2 seconds. This result shows that the formulation of
6wt.% is better compared to the 3wt.% and 0wt.% based on optimisation for multiple responses and the
optimum value for each parameter. Furthermore, by adding natural fibre for instance gigantochloa
scortechinii (bamboo fibre) into polypropylene, the main factor that affects the multiple response change
from melt temperature into the packing pressure. To conclude, the optimization of multiple responses
such as melt flow index, flexural strength, warp and shrinkage of Scortechinii polypropylene-nanoclay-
gigantochloa gives a promising development potential for improving the performance of the injected
mouldings.

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