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# Multiple Responses Injection Moulding Parameter Optimisation via Taguchi Method for Polypropylene-Nanoclay-Gigantochloa Scortechinii

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**Abstract:** This study describes the effects of the optimization of multiple responses of melt flow index, flexural strength, warpage, and shrinkage for the samples made from the blend of polypropylene-nanoclay and Gigantochloa Scortechinii fibre. The contents of fiber were fixed at 0wt.%, 3wt.% and 6wt.%. Processing condition selected were packing pressure, melt temperature, screw speed and filling time. The overall quality performances that need to be improved upon the optimisation were melt flow index, flexural strength, warpage, and shrinkage. This research started by drying the fibres at 120°C. After that, mixed with polypropylene, 15wt.% of polypropylene grafted maleic anhydride (compatibilizer) and 1wt.% of nanoclay. Samples with 0wt.% of fibers were also prepared for comparison purpose. The mixing process was performed by using twin screw Brabender mixer machine and the pallets were produced using used Brabender pelletizer with diameters from 1 to 4 mm. The multiple responses optimization process was accomplished by adopting the Taguchi L9 orthogonal array. Based on the results, for 0wt.% of fibre loading, the validated S/NQP was 134.8150 dBi at melt temperature 165°C, packing pressure 40%, screw speed 35% and filled time 1 second. For the result for 3wt.% of fibre loading, the validated S/NQP was 158.1919 dBi at melt temperature 170°C, packing pressure 35%, screw speed 35% and filled time 3 seconds. As for the 6wt.% of fibre loading, the validated S/NQP was 160.6451 dBi at melt temperature 175°C, packing pressure 35%, screw speed 25% and filled time 2 seconds. The most influential parameter for 0wt.% of fibre was melt temperature. However, the parameter changed to packing pressure with the presence of fibre. The existence of Gigantochloa Scortechinii fibre was also proven to affect significantly towards flexural strength, melt flow index, warpage, and shrinkage. In conclusion, the optimum values of the flexural strength, the warpage and the shrinkage for samples made from polypropylene-nanoclay-Gigantochloa Scortechinii had been achieved.

**Keywords:** Nanoclay, Polypropylene, Gigantochloa Scorthecinii

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## 1. Introduction

In manufacturing process, injection moulding had been preferable because it can yield large quantities of products with cost savings and reasonable period. Yet, an effective control of parameter is one of the key elements of achieving good productivity and quality. Non - Newtonian material is exhibited in numerous areas, and is important for several areas of research, from industrial to technical applications such as concrete engineering, geology, polymers and composites, the manufacture of plastics, paint flows, hemorheology, cosmetics, adhesives and many more [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, 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 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 [4]. The needs of finding the suitable composition between the polymer nanocomposites will be the next challenges. Therefore, 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 market for propylene has increased substantially, primarily because of its use as a precursor in the manufacture of polypropylene for packaging materials and other commercial products [6]. 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 [7].

Characterization relates to the specific or general method by which 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 [8].

Gigantocloa 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. In addition, bamboo with power and modulus has been shown to be excellent in mechanical properties at present [9].

### 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 the 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 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 [10]. 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 [11].

### 1.3 Optimization of Injection Moulding Processing Conditions

Injection moulding is evidently 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. 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. By reason of that, Taguchi Optimization Approach was one of the most important approaches to find. Besides, Implementation of the Taguchi orthogonal array resulted in density optimization [12].

## 2. Materials and Methods

The experiments start from the preparation of materials and the selection of machine. Then, the next step was performing injection moulding process according to the orthogonal arrays. Then, the measurement of 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 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.

The specimen is characterized by using the differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) that have been shown in figure 1 The fibers must be pre-heated to a temperature of 120 °C before compounding, to reduce the fibers' 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 with a SLM 50Fy granulator.

The mould and injection moulding machine were 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).

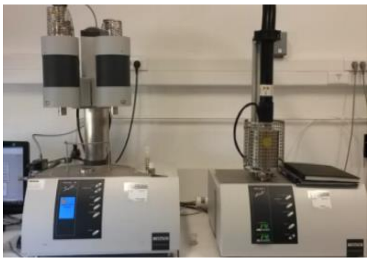

**Figure 1: TGA and DSC machine**

**Figure 2: Rotary Plastograph Brabender Mixer**

**Figure 3:Injection Moulding Nissei NP7-1F**

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 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:

$$S = \frac{L_C - L_M}{L_C} \quad \text{Eq. 1}$$

where $L_C$ is actual mould cavity length (mm) and $L_M$is average of actual sample length. There also equation that have been used to calculate the actual mould cavity length:

$$L_C = L[1 + \alpha \, (T_{mould} - T_{ambient}) \quad \text{Eq. 2}$$

where $\alpha$ is coefficient of thermal expansion for tool steel (6.45x10$^{-6/}$ °F ), $T_{mould}$ is mould temperature (°F), and $T_{ambient}$ is ambient temperature (°F). As for warpage, the calculation was stated as:

$$Z = h - t_a \quad \text{Eq. 4}$$

where Z is warpage of the plate (mm), h is maximum high of the plate (mm), and $t_a$ is average plate thickness (mm). As for 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:

$$\text{MFI} = \frac{427 \times L \times d}{t} \times 600 \quad \text{Eq. 5}$$

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:

$$\text{d} = \frac{W}{V} \quad \text{Eq. 6}$$

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

2.3 Factor/Level Selection, and Orthogonal Array

The orthogonal array selected for this analysis was L934 (9 trials, 3 stages and 4 parameters). This procedure was selected to determine the best parameter values to boost the output characteristics. The selected parameters are melting temperature, packing pressure, screw speed and filling time. These four-factor processing with three different levels which was low (1), medium (2) and high (3). The factors selection and level were shown in table 1. The samples were injected into the mold for processing. A total of 27 samples were tested for 9 experiments. Table 2 provided the specifics of the orthogonal array for this experiment.

**Table 1: Factor Selection and Level**

| Factors | Label | Unit | Level | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| Melt Temperature | MT | $^0$C | 165 | 170 | 175 |
| Packing Pressure | PP | %$^a$ | 30 | 35 | 40 |
| Screw Speed | SS | %$^b$ | 25 | 30 | 35 |
| Filling Time | FT | S | 1 | 2 | 3 |

where $^a$ for packing pressure 1% is equal to 1.6 Mpa and $^b$ for screw speed 1% is equal to 2.4 rpm.

**Table 2: Taguchi Orthogonal Array**

| MT$^a$ | PP$^b$ | SS$^c$ | FT$^d$ |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 165 | 30 | 25 | 1 |
| 165 | 35 | 30 | 2 |
| 165 | 40 | 35 | 3 |
| 170 | 30 | 25 | 3 |
| 170 | 35 | 30 | 1 |
| 170 | 40 | 35 | 2 |
| 175 | 30 | 25 | 2 |
| 175 | 35 | 30 | 3 |
| 175 | 40 | 35 | 1 |

[a] Melt Temperature ($^0$C), [b] Packing Pressure (%), [c] Screw Speed (%) and [d] Filling Time (s)

2.4 Measuring signal to noise ratio

In this experiment, the signal to noise (S/N) ratio must be determined by using the Taguchi test. The findings to be observed in this analysis were 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 the further it can stretch without fracturing. The strength of the moulded measure must be increased. The S/N ratio for large the 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 7.

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

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 ratio were performed by using Minitab 18 statistical software, together with the main effect plots and validation.

## 3. Results and Discussion

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 are the better properties for warpage and shrinkage analyzes of the S/N ratio [13]. Besides, the greater the better S/N ratio characteristics for the flexural strength and melt flow index analysis [14], [15]. When the value of S/N ratio for quality performance between each trial number for 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 show the multiple $S/N_{QP}$ results for 0wt.%, 3wt.% and 6wt.% fibre:

**Table 3: Multiple $S/N_{QP}$ Results for 0wt.%, 3wt.% and 6wt.% Fibre**

| Trial | SNRA M 0wt | SNRA M 3wt | SNRA M 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 | 41.34113429 | 43.73491264 | 43.94488317 |
| 7 | 41.76106243 | 43.82258453 | 44.11081028 |
| 8 | 41.78459683 | 43.81548906 | 44.11734966 |
| 9 | 42.14413153 | 43.53530101 | 43.89207378 |

### 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. At figure 4, for 0wt.% GS fiber, melt temperature labelled as one of the important factors that affect the sample, followed by screw speed, and then filled time and packing pressure sequentially. Furthermore, at figure 5 shows the factor effected for 3wt.% GS fiber formulation is melt temperature with the most effected with the highest slope gradient followed by packing pressure, filled time and screw speed as the last factor that affect the quality performance. As for 6wt.% GS fibre formulation at figure 6, the graph shows the analysis of melt temperature was most effected with the highest slope gradient, then pressure packing, and filled time are seconds factors was affected the results and screw speed are not the main factors was affect the quality performance.


**Figure 4: Main Effect Multiple S/NQP ratio for 0wt.% GS**

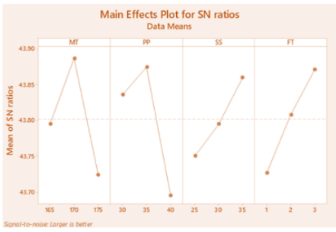


**Figure 5: Main Effect Multiple S/NQP Ratio for 3wt.% GS**

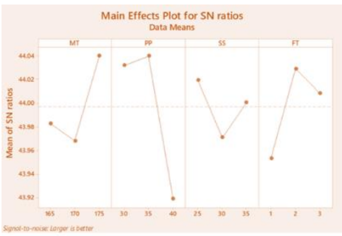


**Figure 6: Main Effect Multiple S/NQP Ratio for 6wt.% GS**

3.2 Optimum Parameter and Optimum Result

Optimum value is achieved based on the best setting combination parameter regarding the value of S/N ratio. For formulation 0% GS, 3% GS and 6% GS have the different value of the melt temperature, which is 165$^o$C, 170$^o$C, and 175$^o$C respectively. The value of S/N ratio for MFI were increased when the formulation of GS increase from 0% to 3% which 134.8150 to 158.1919 and keep increasing at the value of S/N ratio from 3% to 6% which is 158.1919 to 160.6451. For the highest value of quality performance regarding the S/N ratio is at formulation 6% GS which is 160.6451 dBi. Table 4 shows the optimum value based on the best combination parameter regarding the value of S/N Ratio:

**Table 4: Optimum value based on the best combination parameter regarding the value of S/N Ratio**

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

Table 5 shows the ranking of parameter for each fibre composition. Based on the table, melt temperature for 0wt.% GS located at first place. After that, screw speed placed for ranking number 2 followed by filling time and packing pressure. As for 3wt.% GS formulation, packing pressure ranked at the first place. Moreover, melt temperature slightly below than packing pressure which located at second ranking of parameter followed by filing time and screw speed as the last place. Furthermore, for 6wt.% GS formulation, packing pressure is ranked at the first place followed by filling time, melt temperature and screw speed, respectively.

**Table 5: The Ranking of Parameter for Each Fibre Composition**

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

## 4. Conclusion

In the conclusion, the optimum nanocomposites combination parameter of bamboo fibers was obtained by following several responses to maximize the flexural strength limit and the minimum warping and shrinkage value using the selected parameter. Based on the result, for 0wt.% of GS fibre, the validated $S/N_{QP}$ was 134.8150 dBi at melt temperature 165°C, packing pressure 40%, screw speed 35% and filled time 1 second. Furthermore, for the result for 3wt.% of GS fibre, the validated $S/N_{QP}$ was 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, the validated $S/N_{QP}$ was 160.6451 dBi at melt temperature 175°C, packing pressure 35%, screw speed 25% and filled time 2 seconds. To conclude, the optimization of 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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