MULTIPLE RESPONSE TAGUCHI OPTIMISATION FOR INJECTED MOULDED POLYPROPYLENE NANOCLAY GIGANTOCHLOA SCORTECHINII PROCESSING AND FIBRE CONTENT, FOR BUILDING APPLIANCES

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ABSTRACT

This study examines the impact of compounding gigantochloa scortechinii (GS) and polypropylene-nanoclay components through multiple response optimisations. Taguchi Orthogonal Array method is employed to optimise the injection moulding process parameters, including melt flow index, flexural strength, warpage, and shrinkage. The research started with simulation analysis of the injection moulding process to assess the suitability of the design sample according to ISO 178 (flexural bar shape). The compounding materials used in this study consisted of polypropylene, nanoclay, a compatibilizer called polypropylene graft maleic anhydride (PP-g-MA), and GS (gigantochloa scortechinii), commonly known as bamboo fibre. To facilitate comparison, three different contents of natural fibre were selected: 0wt.%GS, 3wt.%GS, and 6wt.%GS. These contents were tested under various injection moulding processing conditions such as packing pressure, melting temperature, screwing speed, and filling time. Based on the analysis of the signal- to-noise ratio, the highest S/N_{QP} value was observed at 6wt.%GS, measuring 160.6451 dB, followed by 3wt.%GS (158.1919 dB) and 0wt.%GS (134.8150 dB). Moreover, the presence of Gigantochloa Scortechinii caused a shift in the most influential parameter, altering it from melting temperature to packing pressure. In order to validate the optimised results, a test was conducted to determine the percentage of improvement of multiple responses. Next, the test also compared the effects of GS content under the optimised injection moulding processing conditions. These optimised results served as a recommended reference and prediction approach, specifically in terms of looking at the impact of compounding polypropylene-nanoclay-gigantochloa scortechinii in the plastic manufacturing process. Essentially, the findings of this study could contribute towards broader and more efficient applications of building appliances such as frame, pavement and tiles

ABSTRAK

Penyelidikan ini berkenaan kesan percampuran *gigantochloa scortechinii* (GS) terhadap *propylene-nanoclay* melalui pengoptimuman pelbagai respon. Kaedah Tatasusunan Ortogonal Taguchi digunakan untuk mengoptimumkan parameter proses pengacuan suntikan, termasuk indeks aliran cair, kekuatan lentur, lenturan dan pengecutan. Penyelidikan dimulakan dengan analisis simulasi proses pengacuan suntikan untuk menilai kesesuaian sampel terhadap reka bentuk mengikut ISO 178 (bentuk bar lentur). Bahan kompaun yang digunakan dalam kajian ini terdiri daripada *propylene*, *nanoclay*, penyerasi yang dipanggil *polypropylene graft maleic anhydride* (PP-g-MA), dan GS (*gigantochloa scortechinii*), biasanya dikenali sebagai gentian buluh. Untuk tujuan perbandingan, tiga kandungan gentian asli yang berbeza iaitu formulasi 0wt.%GS, 3wt.%GS, dan 6wt.%GS telah dipilih. Kandungan ini telah diuji di bawah pelbagai keadaan pemprosesan pengacuan suntikan, termasuk tekanan pembungkusan, suhu cair, kelajuan skru dan masa pengisian. Berdasarkan analisis nisbah isyarat, nilai S/N_{QP} tertinggi adalah pada 6wt.%GS, bernilai 160.6451 dB, diikuti oleh 3wt.%GS (158.1919 dB) dan 0wt.%GS (134.8150 dB). Selain itu, kacukan *Gigantochloa Scortechinii* menyebabkan perubahan dalam parameter yang paling berpengaruh daripada suhu cair kepada tekanan pembungkusan. Untuk mengesahkan keputusan yang dioptimumkan, ujian penilaian peratusan peningkatan terhadap pembaikan telah dijalankan untuk menentukan peratusan peningkatan terhadap pelbagai respon dan membandingkan kesan kandungan GS di bawah keadaan pemprosesan pengacuan suntikan yang dioptimumkan. Keputusan yang dioptimumkan ini berfungsi sebagai kaedah rujukan dan ramalan yang disyorkan khusus untuk *polypropylene-nanoclay-gigantochloa scortechinii* dalam proses pembuatan. Dapatan kajian ini menyumbang kepada penggunaan sektor perkakas bangunan seperti rangka tingkap, turapan dan jubin.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Percentage
^{o}C	Degree Celcius
min	Minit
µm	Micrometer
Mm	Milimeter
cm	Centimeter
m	Meter
s	Second
g	Gram
kg	Kilogram
l	Litre
ml	Millilitre
ŋ	Viscosity
ASTM	American Society for Testing and Materials
ISO	International Organization for Standardization
KPa	Kilo Pascal
Mpa	Mega Pascal
GPa	Giga Pascal
TS	Tensile Strength
YM	Young Modulus
MJ/kg	Megajoule Per Kilogram
MFI	Melt Flow Index
wt.%	Weightage Percentage
0wt.%GS	Formulation Zero Percent Weightage Gigantochloa Scortechinii
3wt.%GS	Formulation Three Percent Weightage Gigantochloa Scortechinii

6wt.%GS	Formulation Six Percent Weightage Gigantochloa Scortechinii
PP	Polypropylene
NC	Nanoclay
BF	Bamboo Fibre
GS	Gigantochloa Scortechinii
PP-g-MA	Polypropylene Grafted Maleic Anhydride
MAPP	Maleic Anhydride Grafted Polypropylene
NaOH	Sodium Hydroxide
S/N	Signal to Noise Ratio
S/N_{QP}	Total Signal to Noise Ratio
dBi	Decibels
TGA	Thermogravimetric Analysis
DSC	Differential Scanning Calorimetry
D.O.E	Design Of Experiment
L_93^4	Nine Trial, Three Level, Four Factor

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CHAPTER 1

INTRODUCTION

This chapter discussed the background of the study, in addition to problem statements, objectives, the scope of study, significance of the study, hypothesis and thesis layout.

1.1 Background of study

Injection moulding is commonly used in the huge production of plastic parts especially for polymer processing techniques in the plastic industry. Polymer materials have been widely used due to their affordable prices. Moreover, they can be formed into complicated shapes while in the melting state. Natural fibres have various advantages over synthetic fibres, making them appealing as reinforcement components in composite materials (Prakash *et al*., 2018). The performance of this polymer system could also be upgraded to finer properties with the presence of natural fibres as filler materials. Reinforcement of natural fibres into polymers has become the most popular topic in the plastic industry due to the beneficial values for mechanical properties. For instance, it is a comparable substitution of glass fibres. Moreover, it could achieve particular strength as compared to carbon fibre.

In addition, in terms of saving our ecology and environment, it is essential to sustain earth's life, biodegradability and environmental protection (Lau *et al*., 2018b; Vilaseca *et al*., 2018). Furthermore, most of these polymer nanocomposites were transformed into useful parts by using injection moulding processes. However, these injected moulded parts are very prone to defects. Any changes in the injection moulding variables could affect the process stability and the quality of the manufactured parts. Nonetheless, a good quality product depends on the selection of materials, designs of moulding and processing parameter settings (Dzulfikar *et al*., 2022). The synthesis of knowledge about the injection moulding process might then lead to solutions in producing good products. Therefore, it is essential to consider the needs to optimise and prioritise the processing conditions in the injection moulding manufacturing process since previous results have shown improvements to the responses (Miza *et al*., 2017).

In this study, the sample material comprising compounding gigantochloa scortechinii (GS) and polypropylene-nanoclay elements were designed according to ISO 178 (flexural bar shaped) by using Solidwork software. It is then analysed using the Autodesk Moldflow software for simulation purposes. Injection moulding machines, NESSEI NP7-1F type, were used to produce the sample which relate to the design in the simulation process. Polypropylene (PP), Nanoclay (NC), maleic anhydride-modified PP oligomer (PPgMA), and Bamboo fibres were used in this study. This study also used a local type of bamboo, Gigantochloa Scortechinii. In Malay, it is locally known as “buluh semantan”. The combination of sample materials, Polypropylene-Nanoclay-Gigantochloa Scortechinii was utilised by means of Rotary Plastograph Brabender. It was based on three fixed formulations, which are 0 wt.%GS, 3 wt.%GS and 6 wt.%GS. These elements established the foundation in examining the impacts of gigantochloa scortechinii reinforcement in polypropylene-nanoclay on thermal stability (thermo gravimetric analysis (TGA) and differential scanning calorimetry (DSC)), flow behaviour analysis (melting flow index (MFI) and rheological properties), mechanical properties (flexural strength), product defects (shrinkage and warpage), and recycling capability performance (tensile and hardness test).

Next, multiple responses such as warpage, shrinkage, flexural strength, and melting index were analysed using the Design of Experiment (DOE) based on the Taguchi Optimisation Orthogonal Array ($L9^3{}_4$) method to optimise the injection moulding process parameters such as the melting temperature, packing pressure, screw speed and filled time. Essentially, this research aims to achieve the best result for multiple responses using the signal to noise ratio analysis and mean effect plot analysis based on optimised injection moulding processing conditions.

Finally, the outcome of this research could contribute as a reference for manufacturing industries. It could also serve as a prediction approach tailored to the production process of polypropylene-nanoclay-gigantochloa scortehcinii. It is hoped that this research would also pave the way for a more widespread and efficient use of building appliances items, particularly for the manufacturing and plastic industries.

1.2 Problem statement

Injection-moulded products, particularly with complex sample designs, are prone to defects. It is one of the unsettling issues for manufacturers as these raise concerns on whether or not their products could be manufactured. Due to this issue, businesses would apparently incur significant losses as they are unable to ascertain the ability to manufacture products which have zero defects. Consequently, simulation procedures to modify the designs and parameters is necessary in order to reduce the defects on manufacturing products.

In the plastic composites manufacturing business, it is essential to understand the properties which make up the materials, particularly when combining plastic and natural fibres. Polymeric resin is a type of hydrophilic fibre, whereas natural fibres are a type of hydrophobic fibre. Due to their high moisture content, property inconsistency, flammability, and poor bonding properties with the polymeric resin, natural fibres used as the reinforcement for the polymer could have inconsistent mechanical properties. Recycling and reprocessing of materials are most commonly used nowadays to overcome such disadvantages. This is particularly true especially when thermoplastic is combined together with natural fibres. In fact, recycling polymeric materials is an economical and environmentally friendly strategy, particularly in the case of polymers with huge manufacturing volumes. During recycling, polymers are susceptible to thermal, thermo-oxidative, and mechanical deterioration. These processes might alter their internal structures and properties, and result in inconsistent mechanical properties after undergoing several cycles of processes. Unfortunately, the plastic industries still lack the knowledge regarding the properties of polymers upon undergoing the recycling processes.

Nonetheless, the process of identifying an optimum combination for polymer nanocomposites and natural fibre would be challenging too. Changes to the injection moulding manufacturing conditions might have impacted the stability of the processes, and the quality of the manufactured products. Thus, to prevent such quality control issues, it is important to estimate the amount of pressure, temperature, and time needed to mould a product so that it meets the required specifications. Therefore, the strategy to synthesise information regarding the injection moulding procedures might lead to creating the most suitable method to achieve the desirable results. Therefore, the primary consideration is to optimise the processing conditions in the injection moulding manufacturing processes.

In the current years, there is a steady increase in the use of thermoplastics in various areas such as in building and household appliances. Building appliances often require components with high structural integrity and durability to withstand continuous usage and environmental factors. In fact, creating materials which are able to resist continuous use and environmental variables while maintaining cost effectiveness is a critical challenge.

Possible solutions to address these challenges means that there is a need to optimise material selection, reinforce techniques, and consider the design in order to enhance the overall strength and longevity of building appliance components. In addition, as building appliances are often visible in homes and commercial settings, it is also important to address features such as aspects of aesthetic appeal. Other important features which are crucial for enhancing the overall appearance and marketability of the appliances include the aspects of achieving consistent and high-quality surface finishes and defect free factors such as warping, sink marks, or visible parting lines. Moreover, building appliances often rely on precise fitting of components to ensure proper functionality and installation. Thus, maintaining tight tolerances and dimensional accuracy during the injection moulding process is vital for seamless integration of various parts which could minimise assembly issues, and improve overall product performance.

Therefore, a key challenge involves matters such as selecting appropriate plastic materials for building appliance applications, balancing performance requirements and cost considerations. It is also important to identify cost effective, yet durable and heat resistant materials to reduce manufacturing expenses, while maintaining product quality. Essentially, there are several composite materials made of polymer and natural fibre used in the plastic manufacturing sector. However, little is known about the composites that are made of polypropylene and gigantochloa scortechinii. Thus, to fill the research gap, the goal of this study is to determine whether polypropylene or polypropylene mixed with gigantochloa scortechinii is superior by adapting the bamboo fibre gigantochloa scortechinii into polypropylene. Analysis was conducted to find out the reasons for the injection moulding product's defect based on shrinkage and warpage reaction, as well as its thermal stability, rheological properties, mechanical characteristics, and defect factors.

It is hoped that the outcome of this study would benefit building appliance manufacturers by providing them with valuable insights and guidelines to help them improve production process, reduce cost, and achieve industrial standard requirements. Eventually, consumers would also be able to benefit as they could buy materials which are of higher quality, better durability, aesthetically pleasing and sustainable environmentally.

1.3 Objectives

The objectives of this research are as follows:

i. To predict the suitability of the design sample in accordance with ISO 178 (flexural bar-shaped) using the injection moulding simulation method.
ii. To investigate the effects of reinforcing gigantochloa scortechinii on polypropylene–nanoclay in terms of thermal stability, flow behaviour, mechanical properties, product defects and recycling capability performance based on the injection moulding processes.
iii. To optimise melt temperature, screw speed, packing pressure and filling time as the injection moulding parameters for flexural strength, warpage, shrinkage and melt flow index.

Ultimately, the research aims to provide insights into essential elements such as suitability, performance, and optimisation of injection moulding conditions for polypropylene-nanoclay-gigantochloa scortechinii materials. It is hoped that the findings of this study would contribute towards the advancement of material science and manufacturing processes.

1.4 Scope of study

The scopes of this research are divided into three sections, mainly simulation, screening and optimisation processes.

Simulation process:

i. An ISO 178 sample was designed using SolidWorks 2019 software and analysed with MoldFlow Adviser 2014.

Screening Process:

i. The specified raw material was polypropylene, a homopolymer type, Titan Pro 6331, acquired from Titan Petchem (M) Sdn. Bhd. The compatibilizer is a functionalised polypropylene-grafted-malaeic anhydride (PP-g-MA) which contains 1 wt % of maleic anhydride (OREVAC C100), gigantochloa scortechinii (bamboo fibre) with bamboo skin included and nanoclay.
ii. The reproduction of Polypropylene-Nanoclay-Gigantochloa Scortechinii uses the Rotary Plastograph Brabender approach, based on fixed formulation of 0 wt.%, 3 wt.% and 6 wt.%.
iii. Thermal stability analysis is based on Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC) analysis which determines the thermal stability.
iv. Using Plastomer (Ceast type 684) to measure the melt flow index of the compounded polypropylene-nanoclay-Gigantochloa Scortechini.
v. The rheological properties, including flow curve, viscosity curve, flow behaviour index (n) and yield stress (σ) of the compounded polypropylene-nanoclay-Gigantochloa Scortechinii were measured using Capillary Rheometer.
vi. The product defects (warpage and shrinkage), mechanical properties (flexural test), impact test and hardness test for four-time recycling process were measured in accordance with ISO 178 design sample using injection moulding machine (NISSEI NP7-1F).

Optimisation Method:

i. Screw speed, melt temperature, packing pressure, and filling time were the injection moulding processing conditions.
ii. The design of the experiment (DOE) for injection moulding processing conditions followed the Taguchi Orthogonal Array Method ($L9_3^4$).
iii. Minitab 17 was utilised for statistical analysis and evaluated according to Taguchi Orthogonal Array Method ($L9_3^4$) in order to optimise the processing conditions.

iv. Multiple responses consisting of shrinkage, warpage, flexural and melt flow index were determined via Taguchi Method L9 orthogonal array with three sets of replications.

1.5 Significant of study

Essentially, this research aims to resolve issues regarding the suitability of product design, reinforcement of natural fibre into polymer composite, and injection moulding processing conditions by optimising the multiple responses, including melt flow index, warpage, shrinkage, and flexural strength based on gigantochloa scortechinii fibre content. The significance of this study lies in its contribution to the scientific understanding of the injection moulding simulation process, the investigation of gigantochloa scortechinii as a reinforcement material in polypropylene-nanoclay composites, and the optimization of injection moulding processing conditions for multiple responses. By closely interconnecting these objectives, this research aims to advance the field by providing valuable insights into the fundamental principles of injection moulding, exploring innovative reinforcement options, and identifying optimal processing conditions. Such interconnected objectives not only strengthen the scientific interest of this study but also pave the way for impactful recommendations and practical applications especially on building appliances. This research would serve as a baseline for future manufacturing purposes by analysing the fibre content and processing conditions that result in the most excellent product properties. The findings might also be used as a guideline for strengthening and expanding the material's methodological and material-based reliability. Consequently, this study is significant and could be useful to the manufacturing industry especially to employees, the building appliance sector and also society in general.

1.5.1 Manufacturing industry

There are several significances of utilising natural fibre as a composite material in the manufacturing industry:

i. *Enhanced Sustainability*: Natural fibres are renewable resources that can be sustainably sourced. By incorporating them into manufacturing processes, we

REFERENCES

Agha, A., Parker, S., & Patel, M. (2020). Polymerization shrinkage kinetics and degree of conversion of commercial and experimental resin modified glass ionomer luting cements (RMGICs). *Dental Materials*, *36*(7), 893–904.

Agote, I., Odriozola, A., Gutierrez, M., Santamaría, A., Quintanilla, J., Coupelle, P., & Soares, J. (2001). Rheological study of waste porcelain feedstocks for injection moulding. *Journal of the European Ceramic Society*, *21*(16), 2843–2853.

Amin, A. M., Ibrahim, M. H. I., Hashim, M. Y., Marwah, O. M. F., Othman, M. H., Johar, M. A., & Ng, C. H. (2017). Green density optimization of stainless steel powder via metal injection molding by Taguchi method. *MATEC Web of Conferences*, *135*.

Azaman, M. D., Sapuan, S. M., Sulaiman, S., Zainudin, E. S., & Khalina, a. (2013). Shrinkages and warpage in the processability of wood-filled polypropylene composite thin-walled parts formed by injection molding. *Materials and Design*, *52*, 1018–1026.

Bagalkot, A., Pons, D., Clucas, D., & Symons, D. (2019). A methodology for setting the injection moulding process parameters for polymer rapid tooling inserts. *Rapid Prototyping Journal*, *25*(9), 1493–1505.

Ben Trad, M. A., Demers, V., Côté, R., Sardarian, M., & Dufresne, L. (2020). Numerical simulation and experimental investigation of mold filling and segregation in low-pressure powder injection molding of metallic feedstock. *Advanced Powder Technology*, *31*(3), 1349–1358.

Bensingh, R. J., Machavaram, R., Boopathy, S. R., & Jebaraj, C. (2019). Injection molding process optimization of a bi-aspheric lens using hybrid artificial neural networks (ANNs) and particle swarm optimization (PSO). *Measurement: Journal of the International Measurement Confederation*, *134*, 359–374.

Bodaghi, M., Simacek, P., Advani, S. G., & Correia, N. C. (2018). A model for fibre washout during high injection pressure resin transfer moulding. *Journal of Reinforced Plastics and Composites*, *37*(13), 865–876.

Bonse, B. C., Mamede, M. C. S., Costa, R. A., & Bettini, S. H. P. (2010). *EFFECT OF COMPATIBILIZER AND BAMBOO FIBER CONTENT ON THE MECHANICAL PROPERTIES OF PP-G-MA COMPATIBILIZED POLYPROPYLENE / BAMBOO FIBER COMPOSITES*. 4–8.

Chafidz, A., Ali, M. A. H., & Elleithy, R. (2011). Morphological, thermal, rheological, and mechanical properties of polypropylene-nanoclay composites prepared from masterbatch in a twin screw extruder. *Journal of Materials Science*, *46*(18), 6075–6086.

Deng, L., Liang, J., Zhang, Y., Zhou, H., & Huang, Z. (2017). Efficient numerical simulation of injection mold filling with the Lattice Boltzmann method. *Engineering Computations (Swansea, Wales)*, *34*(2), 307–329.

Domenek, S., Berzin, F., Ducruet, V., Plessis, C., Dhakal, H., Richaud, E., & Beaugrand, J. (2021). Extrusion and injection moulding induced degradation of date palm fibre - polypropylene composites. *Polymer Degradation and Stability*, *190*, 109641.

Dzulfikar, M., Respati, S. M. B., & Nasikin, M. (2022). Mechanical Properties of Injection Molded Recycled High Density Polyethylene (rHDPE) Blends with pellets Low Density Polyethylene (pLDPE). *Journal of Chemical Process and Material Technology*, *1*(1), 39.

Felder, S., Vu, N. A., Reese, S., & Simon, J. W. (2020). Modeling the effect of temperature and degree of crystallinity on the mechanical response of Polyamide 6. *Mechanics of Materials*, *148*(June).

Finkeldey, F., Volke, J., Zarges, J. C., Heim, H. P., & Wiederkehr, P. (2020). Learning quality characteristics for plastic injection molding processes using a combination of simulated and measured data. *Journal of Manufacturing Processes*, *60*, 134–143.

Fischer, J. M. (2013). Introduction to Injection Molding. In *Handbook of Molded Part Shrinkage and Warpage*.

Fitzgerald, A., McDonald, P., Devine, D., & Fuenmayor, E. (2021). Transfer and optimisation of injection moulding manufacture of medical devices using scientific moulding principles. *Journal of Manufacturing and Materials Processing*, *5*(4).

Golmakani, M. E., Wiczenbach, T., Malikan, M., Aliakbari, R., & Eremeyev, V. A. (2021). Investigation of wood flour size, aspect ratios, and injection molding temperature on mechanical properties of wood flour/polyethylene composites. *Materials*, *14*(12).

Graupner, N., Ziegmann, G., Wilde, F., Beckmann, F., & Müssig, J. (2016). Procedural influences on compression and injection moulded cellulose fibre-reinforced polylactide (PLA) composites: Influence of fibre loading, fibre length, fibre orientation and voids. *Composites Part A: Applied Science and Manufacturing*, *81*, 158–171.

Heaney, D. F. (2019). Handbook of Metal Injection Molding. In *Handbook of Metal Injection Molding*.

Hussain, M. Z., Khan, S., & Sarmah, P. (2020). Optimization of powder metallurgy processing parameters of Al2O3/Cu composite through Taguchi method with Grey relational analysis. *Journal of King Saud University - Engineering Sciences*, *32*(4), 274–286.

Inácio, A. L. N., Nonato, R. C., & Bonse, B. C. (2018). Mechanical and thermal behavior of aged composites of recycled PP/EPDM/talc reinforced with bamboo fiber. *Polymer Testing*, *72*, 357–363.

Jiang, J., Liu, X., Lian, M., Pan, Y., Chen, Q., Liu, H., Zheng, G., Guo, Z., Schubert, D. W., Shen, C., & Liu, C. (2018). Self-reinforcing and toughening isotactic polypropylene via melt sequential injection molding. *Polymer Testing*, *67*, 183–189.

Kalpakjian, S., & R. Schmid, S. (2020). Manufacturing engineering and technology. In *Pearson* (8th ed., Vol. 25, Issue 1). Pearson.

Karthikeyan, K., Nagamadhu, M., Jaiprakash, M., Kiran, & Shariff, M. (2019). Effect of drilling parameters on natural fiber reinforced with chaired epoxy poly urethane foam composites using grey relational analysis. *Materials Today: Proceedings*, *24*, 2193–2203.

Khamis, S. Z., Othman, M. H., Hasan, S., & Ibrahim, M. H. I. (2017). Characterizetion of Flexural Strength, Warpage and Shrinkage of Polypropylene-Nanoclay-Nanocomposites Blend with Gigantochloa Scortechinii. *IOP Conference Series: Materials Science and Engineering*, *226*(1).

Khamis, S. Z., Othman, M. H., Hasan, S., Main, N. M., Masrol, S. R., Shaari, M. F., Ibrahim, S. N., & Salim, S. (2019). Multiple Responses Optimisation in Injection Moulding Parameter for Polypropylene-Nanoclay-Gigantochloa Scortechinii via Taguchi Method. *Journal of Physics: Conference Series, 1150*(1).

Lau, K., Hung, P., Zhu, M.-H., & Hui, D. (2018a). Properties of natural fibre composites for structural engineering applications. *Composites Part B: Engineering*, *136*(September 2017), 222–233.

Lau, K. tak, Hung, P. yan, Zhu, M. H., & Hui, D. (2018b). Properties of natural fibre composites for structural engineering applications. *Composites Part B: Engineering*, *136*(September 2017), 222–233.

Laufer, N., Hansmann, H., & Koch, M. (2017). Rheological Characterisation of the Flow Behaviour of Wood Plastic Composites in Consideration of Different Volume Fractions of Wood. *Journal of Physics: Conference Series*, *790*(1), 012017.

Lee, S. K., Park, E. Y., Park, T. S., & An, S. K. (2021). Mechanical Properties of PP/Glass Fiber/Kenaf/Bamboo Fiber-reinforced Hybrid Composite. *Fibers and Polymers*, *22*(5), 1460–1465.

Li, H., Liu, K., Zhao, D., Wang, M., Li, Q., & Hou, J. (2018). Multi-objective optimizations for microinjection molding process parameters of biodegradable polymer stent. *Materials*, *11*(11).

Li, K., Yan, S., Zhong, Y., Pan, W., & Zhao, G. (2019). Multi-objective optimization of the fiber-reinforced composite injection molding process using Taguchi method, RSM, and NSGA-II. *Simulation Modelling Practice and Theory*, *91*, 69–82.

Lienhard, J., Discher, D., & Hohe, J. (2020). Strain rate dependent damage evolution in long glass fiber reinforced polypropylene. *Composites Science and Technology*, *189*(January), 108007.

Lin, C. C., Lee, G. H., & Wang, Y. J. (2018). Design and fabrication of gypsum mold for injection molding. *Journal of the Chinese Institute of Engineers, Transactions of the Chinese Institute of Engineers,Series A*, *41*(2), 160–167.

Lu, Y., Jiang, K., Liu, Y., Zhang, Y., & Wang, M. (2020). Study on mechanical properties of co-injection self-reinforced single polymer composites based on micro-morphology under different molding parameters. *Polymer Testing*, *83*(December 2019), 106306.

Mao, H., He, B., Guo, W., Hua, L., & Yang, Q. (2018). Effects of Nano-CaCO3 content on the crystallization, mechanical properties, and cell structure of PP nanocomposites in microcellular injection molding. *Polymers*, *10*(10).

Mazzanti, V., & Mollica, F. (2020). A review of wood polymer composites rheology and its implications for processing. *Polymers*, *12*(10), 1–23.

Md Radzi, M. K. F., Muhamad, N., Sulong, A. B., Haron, C. H. C., Razak, Z., Akhtar, M. N., Ismail, N. F., Tholibon, D., & Tharazi, I. (2018). Optimization of injection molding parameters: Improving mechanical properties of kenaf reinforced polypropylene composites. *Journal of Advanced Manufacturing Technology*, *12*(2), 107–120.

Meekum, U., & Khongrit, A. (2018). Toughening of wood-plastic composites based on silane/peroxide macro crosslink poly(propylene) systems. *BioResources*, *13*(1), 1678–1695.

Mensler, H., Zhang, S., & Win, T. (2019). A method for determining the flow front velocity of a plastic melt in an injection molding process. *Polymer Engineering and Science*, *59*(6), 1132–1145.

Meral, G., Sarıkaya, M., Mia, M., Dilipak, H., & Şeker, U. (2019). Optimization of hole quality produced by novel drill geometries using the Taguchi S/N approach. *International Journal of Advanced Manufacturing Technology*, *101*(1–4), 339–355.

Mihai, M., & Ton-That, M. T. (2018). Valorization of Triticale Straw Biomass as Reinforcement in Proficient Polypropylene Biocomposites. *Waste and Biomass Valorization*, *9*(10), 1971–1983.

Miza, A. T. N. A., Shayfull, Z., Nasir, S. M., Fathullah, M., & Hazwan, M. H. M. (2017). Optimisation of warpage on plastic injection moulding part using response surface methodology (RSM) and genetic algorithm method (GA). *AIP Conference Proceedings*, *1885*.

Moayyedian, M., Dinc, A., & Mamedov, A. (2021). Optimization of injection-molding process for thin-walled polypropylene part using artificial neural network and Taguchi techniques. *Polymers*, *13*(23).

Mohapatra, R. C. (2018). Experimental Study on Optimization of Thermal Properties of Natural Fibre Reinforcement Polymer Composites. *OALib*, *05*(04), 1–15.

Montanes, N., Quiles-Carrillo, L., Ferrandiz, S., Fenollar, O., & Boronat, T. (2019). Effects of Lignocellulosic Fillers from Waste Thyme on Melt Flow Behavior and

Processability of Wood Plastic Composites (WPC) with Biobased Poly(ethylene) by Injection Molding. *Journal of Polymers and the Environment*, *27*(4), 747–756.

Mulinari, D. R., Cipriano, J. de P., Capri, M. R., & Brandão, A. T. (2018). Influence of Surgarcane Bagasse Fibers with Modified Surface on Polypropylene Composites. *Journal of Natural Fibers*, *15*(2), 174–182.

Othman, M. H., Hasan, S., Khamis, S. Z., Ibrahim, M. H. I., & Amin, S. Y. M. (2017a). Optimisation of Injection Moulding Parameter towards Shrinkage and Warpage for Polypropylene-Nanoclay-Gigantochloa Scortechinii Nanocomposites. *Procedia Engineering*, *184*, 673–680.

Othman, M. H., Hasan, S., Khamis, S. Z., Ibrahim, M. H. I., & Amin, S. Y. M. (2017b). Optimisation of Injection Moulding Parameter towards Shrinkage and Warpage for Polypropylene-Nanoclay-Gigantochloa Scortechinii Nanocomposites. *Procedia Engineering*, *184*, 673–680.

Othman, M. H., Rosli, M. S., Hasan, S., Amin, A. M., Hashim, M. Y., Marwah, O. M. F., & Amin, S. Y. M. (2018a). The Optimisation of Processing Condition for Injected Mould Polypropylene-Nanoclay-Gigantochloa Scortechinii based on Melt Flow Index. *IOP Conference Series: Materials Science and Engineering*, *324*(1).

Othman, M. H., Rosli, M. S., Hasan, S., Amin, A. M., Hashim, M. Y., Marwah, O. M. F., & Amin, S. Y. M. (2018b). The Optimisation of Processing Condition for Injected Mould Polypropylene-Nanoclay-Gigantochloa Scortechinii based on Melt Flow Index. *IOP Conference Series: Materials Science and Engineering*, *324*(1).

Pandya, V. J., & Rathod, P. P. (2020). Optimization of mechanical properties of green composites by gray relational analysis. *Materials Today: Proceedings*, *27*, 19–22.

Pascual, J., Fages, E., Fenollar, O., García, D., & Balart, R. (2009). Influence of the compatibilizer/nanoclay ratio on final properties of polypropylene matrix modified with montmorillonite-based organoclay. *Polymer Bulletin*, *62*(3), 367–380.

Pina-Estany, J., Colominas, C., Fraxedas, J., Llobet, J., Perez-Murano, F., Puigoriol-Forcada, J. M., Ruso, D., & Garcia-Granada, A. A. (2017). A statistical analysis of nanocavities replication applied to injection moulding. *International Communications in Heat and Mass Transfer*, *81*, 131–140.

Pornwannachai, W., Ebdon, J. R., & Kandola, B. K. (2018). Fire-resistant natural fibre-reinforced composites from flame retarded textiles. *Polymer Degradation and Stability*, *154*, 115–123.

Prakash, K. G., Professor, A., B, M. K., Chandru, B. G., & Professor Assistant Professor, A. (2018). *Investigation on Flax Natural Fiber Reinforced Polymer Matrix Composites*.

Rabbi, M. S., Islam, T., & Islam, G. M. S. (2021). Injection-molded natural fiber-reinforced polymer composites–a review. In *International Journal of Mechanical and Materials Engineering* (Vol. 16, Issue 1). Springer.

Rashid, O., Low, K. W. Q., & Pittman, J. F. T. (2020). Mold cooling in thermoplastics injection molding: Effectiveness and energy efficiency. *Journal of Cleaner Production*, *264*, 121375.

Rosli, M. S., Othman, M. H., Amin, S. Y. M., & Azman, M. A. I. (2021). Multiple Responses Injection Moulding Parameter Optimisation Via Taguchi Method for Polypropylene-Nanoclay-Gigantochloa. *Journal of Physics: Conference Series*, *2129*(1).

Ryu, Y., Sohn, J. S., Kweon, B. C., & Cha, S. W. (2019). Shrinkage optimization in talc- and glass-fiber-reinforced polypropylene composites. *Materials*, *12*(5).

Saravana, S., & Kandaswamy, R. (2019). Investigation on the Mechanical and Thermal Properties of PLA/Calcium Silicate Biocomposites for Injection Molding Applications. *Silicon*, *11*(2), 1143–1150.

Schrank, T., Berer, M., Haar, B., Ramoa, B., Lucyshyn, T., Feuchter, M., Pinter, G., Speranza, V., & Pantani, R. (2022). Injection Molding Simulation of Polyoxymethylene Using Crystallization Kinetics Data and Comparison with the Experimental Process. *Polymer Crystallization*, *2022*.

Semlali Aouragh Hassani, F. Z., Ouarhim, W., Zari, N., Bensalah, M. O., Rodrigue, D., Bouhfid, R., & Qaiss, A. el kacem. (2019). Injection molding of short coir fiber polypropylene biocomposites: Prediction of the mold filling phase. *Polymer Composites*, *40*(10), 4042–4055.

Senthil Kumar, R., Gajendran, S., & Kesavan, R. (2020). Evaluation of Optimum Machining Parameters by AWJM for Granite through Multi Response Methods. *Materials Today: Proceedings*, *22*, 3056–3066.

Sharma, V. K., Kumar, V., & Joshi, R. S. (2020). Parametric study of aluminium-rare earth based composites with improved hydrophobicity using response surface method. *Journal of Materials Research and Technology*, *9*(3), 4919–4932.

Singh, G., Pradhan, M. K., & Verma, A. (2018). Multi Response optimization of injection moulding Process parameters to reduce cycle time and warpage. *Materials Today: Proceedings*, *5*(2), 8398–8405.

Singh, G., & Verma, A. (2017). A Brief Review on injection moulding manufacturing process. *Materials Today: Proceedings*, *4*(2), 1423–1433.

Somashekhar, S., Shanthakumar, G. C., & Nagamadhu, M. (2020). Influence of Fiber content and screw speed on the Mechanical characterization of Jute fiber reinforced Polypropylene composite using Taguchi Method. *Materials Today: Proceedings*, *24*, 2366–2374.

Sreedharan, J., & Jeevanantham, A. K. (2018). Optimization of Injection Molding Process to Minimize Weld-line and Sink-mark Defects Using Taguchi based Grey Relational Analysis. *Materials Today: Proceedings*, *5*(5), 12615–12622.

Trotta, G., Stampone, B., Fassi, I., & Tricarico, L. (2021). Study of rheological behaviour of polymer melt in micro injection moulding with a miniaturized parallel plate rheometer. *Polymer Testing*, *96*.

Tsagdi, A., Drossos, I., Georgiou, D., Exarhopoulos, S., Karasiotas, G., Kallitsis, J. K., & Kalogianni, E. P. (2021). Injection molded PP foams using food ingredients for food packaging applications. *Polymers*, *13*(2), 1–18.

Uematsu, H., Suzuki, Y., Iemoto, Y., & Tanoue, S. (2018). Effect of maleic anhydride-grafted polypropylene on the flow orientation of short glass fiber in molten polypropylene and on tensile properties of composites. *Advances in Polymer Technology*, *37*(6), 1755–1763.

Umor, M. Z., Mohd, A., Efendee, A. M., Khir, M., & Baba, N. B. (2022). Plastic filling simulation comparison analysis of the gating system in injection moulding parameter. *Journal of Achievements in Materials and Manufacturing Engineering*, *112*(2), 64–69.

Usman Jan, Q. M., Habib, T., Noor, S., Abas, M., Azim, S., & Yaseen, Q. M. (2020). Multi response optimization of injection moulding process parameters of polystyrene and polypropylene to minimize surface roughness and shrinkage's using integrated approach of S/N ratio and composite desirability function. *Cogent Engineering*, *7*(1).

Väisänen, T., Haapala, A., Lappalainen, R., & Tomppo, L. (2016). Utilization of agricultural and forest industry waste and residues in natural fiber-polymer composites: A review. *Waste Management*, *54*, 62–73.

Vandi, L. J., Chan, C. M., Werker, A., Richardson, D., Laycock, B., & Pratt, S. (2019). Extrusion of wood fibre reinforced poly(hydroxybutyrate-co-hydroxyvalerate) (PHBV) biocomposites: Statistical analysis of the effect of processing conditions on mechanical performance. *Polymer Degradation and Stability*, *159*(2019), 1–14.

Vilaseca, F., Del Rey, R., Serrat, R., Alba, J., Mutje, P., & Espinach, F. X. (2018). Macro and micro-mechanics behavior of stifness in alkaline treated hemp core fibres polypropylene-based composites. *Composites Part B: Engineering*, *144*(February), 118–125.

Walale, A., Singh Chauhan, A., Satyanarayana, A., Venkatachalam, G., & Pradyumna, R. (2018). Analysis of shrinkage & warpage in ceramic injection molding of HPT vane leading edge core of a gas turbine casting. *Materials Today: Proceedings*, *5*(9), 19471–19479.

Wang, Y., Yan, Z., & Shan, X. (2018). Optimization of Process Parameters for Vertical-Faced Polypropylene Bottle Injection Molding. *Advances in Materials Science and Engineering*, *2018*.

Xu, H., Hu, N., Huang, Y., Wu, D., Liu, Y., & Liu, Y. (2018). Research on the experimental method of measuring internal stress of polymer sheet product by lamb wave. *Key Engineering Materials*, *773 KEM*, 106–110.

Yang, B., Liang, C. W., Lu, F. X., Chen, P., Chen, Q. T., Chen, J., Hu, L., Xia, R., Miao, J. Bin, Qian, J. S., Min, K., & Cao, M. (2019). Effect of Bamboo Flour (BF) Content on the Dynamic Rheological Characteristics of BF-filled High-density Polyethylene (HDPE). *Journal of Macromolecular Science, Part B: Physics*, *58*(2), 341–354.

Yang, W., Shi, S., & Zhan, J. (2022). Advanced manufacturing technology and modeling optimization based on moldflow analysis ——Take the design process of "Snowflake Bracket" as an example. *Journal of Physics: Conference Series*, *2174*(1).

Ying, J., Xie, X., Peng, S., Zhou, H., & Li, D. (2018). Morphology and rheology of PP/POE blends in high shear stress field. *Journal of Thermoplastic Composite Materials*, *31*(9), 1263–1280.

Zander, N. E., Gillan, M., Burckhard, Z., & Gardea, F. (2019). Recycled polypropylene blends as novel 3D printing materials. *Additive Manufacturing*, *25*(October 2018), 122–130.

Zhang, H., Fang, F., Gilchrist, M. D., & Zhang, N. (2019). Precision replication of micro features using micro injection moulding: Process simulation and validation. *Materials and Design*, *177*.

Zhang, J., He, W., Wu, Y., Wang, N., Chen, X., & Guo, J. (2019). The evolution of morphology, crystallization and static and dynamic mechanical properties of long glass-fibre–reinforced polypropylene composites under thermo-oxidative ageing. *Journal of Thermoplastic Composite Materials*, *32*(4), 544–557.

Zhang, J., Yin, X., Liu, F., & Yang, P. (2018). The simulation of the warpage rule of the thin-walled part of polypropylene composite based on the coupling effect of mold deformation and injection molding process. *IEEE Journal of Selected Topics in Quantum Electronics*, *25*(3), 593–601.

Zhang, S., Yao, W., Zhang, H., & Sheng, K. (2018). Polypropylene biocomposites reinforced with bamboo particles and ultrafine bamboo-char: The effect of blending ratio. *Polymer Composites*, *39*, E640–E646.

Zhang, T., Chen, K., Liu, G., & Zheng, X. (2019). Injection Molding Process Optimization of Polypropylene using Orthogonal Experiment Method Based on Tensile Strength. *IOP Conference Series: Materials Science and Engineering*, *612*(3).

Zhao, H., Liu, X., Sui, Y., Zhang, Y., & Zhao, G. (2017). Transition from the hierarchical distribution to a homogeneous formation in injection molded isotactic polypropylene (iPP) with dynamic mold temperature control. *Polymer Testing*, *60*, 299–306.

Zhao, N. yang, Lian, J. yuan, Wang, P. fei, & Xu, Z. bin. (2022). Recent progress in minimizing the warpage and shrinkage deformations by the optimization of process parameters in plastic injection molding: a review. In *International Journal of Advanced Manufacturing Technology* (Vol. 120, Issues 1–2, pp. 85–101). Springer Science and Business Media Deutschland GmbH.

Zheng, Z., Xia, W., Zhou, Z., & Wang, S. (2008). Numerical simulation of filling flow and determination of the process parameter in metal injection molding. *Journal of Computational and Theoretical Nanoscience*, *5*(8), 1597–1602.

1. Rosli, M. S., Othman, M. H., Amin, S. Y. M., & Azman, M. A. I. (2021). Multiple Responses Injection Moulding Parameter Optimisation Via Taguchi Method for Polypropylene-Nanoclay-Gigantochloa. Journal of Physics: Conference Series, 2129(1).

2. M.H.Othman, S.A.Osman, S.Y.M.Amin and M.S. Rosli (2018) Modelling Of Integral Hinges Via Cadmould 3d -F Injection Moulding Simulation, Journal Of Advanced Research In Dynamical And Control Systems, Elsevier , 12, 112, ISSN:1943023X

3. Othman, M. H., Rosli, M. S., Hasan, S., Amin, A. M., Hashim, M. Y., Marwah, O. M. F., & Amin, S. Y. M. (2018). The Optimisation of Processing Condition for Injected Mould Polypropylene-Nanoclay-Gigantochloa Scortechinii based on Melt Flow Index. IOP Conference Series: Materials Science and Engineering, 324(1).

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