Optimization of Material Composition and Compression Molding Process Parameters to Maximize Mechanical Properties of Recycled Polypropylene (r-PP) Composite Reinforced with Ironwood Powder

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Abstract. It could potentially be possible to create more sustainable materials by using wood waste as reinforcement in recycled polymer material. This study aims to optimize material composition and compression molding parameters to maximize the mechanical properties of recycled polypropylene composites reinforced with ironwood powder using the Taguchi orthogonal L9 design of experiment. The composites were manufactured in two-step extrusion and compression molding. The parameter levels used in this study are ironwood loading of 10%, 20%, and 30% with the addition of three different levels of coupling agent and manufactured using the molding temperature of 165°C, 175°C, 185°C as well as pressure holding time of 3 minutes, 6 minutes, and 9 minutes. Tensile testing was conducted in accordance with ASTM D 638 type V standard. The S/N ratio analysis revealed different optimum parameters for tensile strength and elastic modulus. Therefore, the grey relation analysis was performed. It was found that the optimum composition and parameter variation for tensile strength and elastic modulus are 10% mass fraction of ironwood, 3% of MAPP, molding temperature of 165°C, and pressure holding time of 9 minutes. The ANOVA indicated wood powder loading as the most significant parameter on the mechanical properties of the composite. The material composed of recycled polypropylene and waste of ironwood can be considered a promising sustainable material for engineering-related applications.

1 Introduction

Plastic materials are increasingly produced and used globally for various applications, especially as packaging and consumables because plastics have lightweight and malleable properties [1-2]. The increasing amount of plastic waste accumulation in the environment seriously impacts human life and other ecosystems [3-4]. Plastic recycling could be one of the alternative solutions for reducing the impact of plastic waste on the environment [5-7]. In recent decades, plastic waste has been widely recycled for composite materials or as a mixture of construction materials [8-9].

Composite materials are multiphase materials consisting of two or more components that have special properties [10-11]. Composite materials are currently widely used in industries such as aerospace, automotive, wind turbine, marine, military, sports, entertainment, and structural applications [12]. In recent years, the use of thermoplastic polymer plastics as composite materials has increased significantly since they have high impact resistance, are easy to recycle, do not react chemically, and require shorter processing time [13-14]. The mechanical strength of polymer composites can be further improved by using natural fibers as reinforcement [15]. Natural fiber-reinforced polymer composites have several superior properties, such as low cost, light weight, biodegradability, good thermal and acoustic insulation, and high specific strength and stiffness.

Ironwood belongs to the classification of natural fibers that are abundant in availability and have the potential to be used as reinforcing materials for thermoplastic composites because of their good physical and mechanical properties and have good density, shrinkage, and elastic modulus properties [1618]. However, the application of ironwood powder as a composite reinforcement has limitations due to the high moisture content and lignin content which is an obstacle in the composite mixing process [19-20]. The incompatibility between the hydrophobic matrix and the hydrophilic reinforcement makes the mixing problem because the lack of compatibility between the matrix and the reinforced causes poor interfacial adhesion which can affect the performance and mechanical

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properties of the composite resulting in lower strength and shape deformation [21-22].

Alkalization is one of the chemical treatments used to improve the interfacial bond between wood powder and polymer matrix [23]. Alkalization treatment helps to reduce the lignin and cellulose content of sawdust and makes the sawdust clean [24]. It can be seen that fibers using the alkaline soaking method undergo significant changes to their physical and mechanical strength [17]. The addition of a coupling agent is also an effective way to improve the adhesion between the matrix and the composite reinforcement which results in the improvement of the composite mechanical properties [25-26].

According to Yadav et al., (2021) [27] material composition also affects the physical properties and mechanical properties of composites. In a study conducted by Kuo et al. (2009) polypropylene composites mixed with wood powder with the addition of coupling agents maleic anhydrite grafted polypropylene (MAPP) with a composition of 47% wood powder and 3-5% MAPP produced better tensile strength, modulus of rupture (MOR), and storage modulus compared to other polymers. According to Madhavi et al., (2021), the material composition of polypropylene, natural fiber, and compatibilizer has an effect on mechanical strength due to an increase in efficient chemical bonding which makes interface adhesion and mechanical properties, especially tensile strength and impact strength of the composite will increase [30].

Composite processing also affects the mechanical properties of the composite. Processing with compression molding is widely used for processing thermoplastic composites because of its simplicity and low cost [31]. Compression molding also offers high efficiency, low internal stress, low bending deformation, good mechanical stability, and excellent product repeatability to provide a strong competitive advantage in mass production for the industry. In addition, processing parameters in compression molding that also affect composite properties include preheating temperature, molding temperature, molding pressure, pressure holding time, cooling rate, exhaust pressure, exhaust times, and blank holder force [32]. According to Tatara (2017), molding temperatures that are too high will cause brittleness, decreased mechanical strength, and poor surface quality of composite specimens. Meanwhile, if the heat is too low, the viscosity will increase and the material may not melt enough (for a long time), especially in areas where the volume of heat is limited. Meanwhile, according to Tharazi et al (2017), heating time affects the tensile strength of the composite with increasing heating time the tensile strength increases. While variations in the amount of pressure in compression molding affect the impact strength of the composite [35].

This study analyses the effect of material composition and compression molding process parameters of recycled polypropylene plastic with a mixture of ironwood powder using MAPP as a coupling agent. In this study, the control parameters used are the composition of ironwood powder, the mass fraction of MAPP, molding temperature, and pressure holding time. Taguchi grey relation analysis was used to optimize the process parameters. The optimization method is expected to determine the appropriate composition variation and process parameter settings for the manufacture of recycled polypropylene plastic composite specimens with ironwood powder blends in order to obtain optimum mechanical properties.

2 Materials and Method

2.1 Materials

In this study, the material used as a matrix is recycled polypropylene (PP) polymer with ironwood powder (*Eusideroxylon Zwageri*) reinforcement derived from waste from the wood processing industry in East Kalimantan. The wood powder was in the size of 80-100 mesh as suggested by Syarief et al. (2022). Alkali treatment was carried out on ironwood powder using Sodium Hydroxide (NaOH) at a concentration of 2% for 24 hours with distilled water, then dried in an oven at 80°C for 48 hours [37] [17].

2.2 Experimental Design

This study explores the effect of variations in composition and process parameters on the mechanical properties of composites. The composition and parameter variations used were ironwood (A), MAPP (B), molding temperature (C), and pressure holding time (D). The Design of Experiments was conducted using the Taguchi orthogonal L9 method to obtain parameter optimization results. The S/N ratio larger the better was used for tensile strength and elastic modulus. Analysis of Variance (ANOVA) was used to determine the contribution of the effect of each parameter on tensile strength and elastic modulus. While grey relation analysis is used to find the results of multiple responses of tensile strength and elastic modulus to get one best response value. This experiment was conducted with 5 (five) replications for each parameter combination. Table 1 shows the variable composition variation and compression molding parameters, while Table 2 shows the L9 orthogonal matrix.

Table 1. Variable parameters

Code	Process Variables	Unit	Level 1	Level 2	Level 3
A	IW	%	10	20	30
B	MAPP	%	0	3	5
C	MT	°C	165	175	185
D	PHT	minutes	3	6	9

Table 2. Orthogonal Matrix L_9

Exp. #	Control Parameters			
	IW	MAPP	MT	PHT
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

2.3 Processing of Composites Samples

Recycled polypropylene and ironwood powder are melted with an extruder machine at barrel temperatures of 175 ºC, 180 ºC, 185 ºC, and 190 ºC [38]. After the extrusion process was completed, 4 mm pellets were obtained which were then processed by compression molding according to the parameters set in Table II with a compression molding pressure of 30 bar based as suggested by (2016) and Tharazi et al., (2017).

2.4 Mechanical Properties of the Composites Samples

Specimens were prepared in accordance with ASTM D638 type V tensile test standard in a dog bone shape with a size of 63.5x9.53x3.2 mm. The test was conducted using a Universal Testing Machine (UTM) Zwick Roell Type Z020 with a tensile test loading speed of 5 mm/minute. Tensile testing was carried out 5 times replication for each sample experiment.

3 Optimization Techniques

This paper describes the Taguchi grey relation analysis method for optimizing multi-response problems. In the first stage, the optimization was performed using the Taguchi approach for each response separately, and then the multi-response value was calculated using grey relation analysis (GRA).

3.1 Taguchi Method

The Taguchi method uses rigorous experimental design to optimize process parameters [39-41]. This method can also be used to minimize the number of experiments. The experimental method uses orthogonal tables to study a large number of variables with a small number of experiments, especially to determine the choice of production process parameters [42]. The advantages of using the Taguchi experimental method include reproducibility, ease of determining experimental variables, small number of experiments, and easy-to-understand analysis [39]. Taguchi determines the loss function as the deviation between experimental and target values, which is then written in the form of mean squared deviation (MSD) and signal-to-noise (S/N) ratio. In this research, five replications were conducted with replication determining the variance index called signal-to-noise (S/N) ratio. The S/N ratio is determined by the equation:

$$S/N = -10 \log_{10} (MSD) \tag{1}$$

It employed the larger-the-better formula for the two responses of tensile strength and elastic modulus, calculated using the following equation.

$$S/N = -10 \,Log \left(\frac{1}{n}\Sigma_{i=1}^{n}\frac{1}{y_1^2}\right) \tag{2}$$

3.2 Analysis of variance (ANOVA)

Analysis of variance was used to see significant parameter contributions affecting the response values. It determined the percentage value of the contribution affecting the response variable.

3.3 Grey Relation Analysis

Grey relation analysis (GRA) was used to reduce a multi-response problem to a single objective decision-making problem by combining the entire range of performance characteristic values for each response into a single value [43]. The stages to determine grey relation analysis include data pre-processing, grey relation coefficient, and grey relation grade for further analysis. In pre-processing, normalization is performed on the S/N ratio by converting the original order of the S/N ratio into a decimal order between 0.00 and 1.00 for comparison called grey relation generation [44]. The equation for normalization is as follows
Small the better equation for normalization:

$$x_{ij} = \frac{max\left(y_{ij}\right) - y_{ij}}{max\left(y_{ij}\right) - min\left(y_{ij}\right)} \tag{3}$$

The larger-the-better equation for normalization:

$$x_{ij} = \frac{y_{ij} - min\left(y_{ij}\right)}{max\left(y_{ij}\right) - min\left(y_{ij}\right)} \tag{4}$$

Data normalization is followed by the calculation of grey relation coefficients (GRC) determined by the equation:

$$\varepsilon_i(t) = \frac{\Delta min + \delta\Delta max}{\Delta_{oi}(t) + \delta\Delta max},\ 0 < \varepsilon_i(t) \leq 1, \tag{5}$$

The grey relation grade (GRG) provides information about the strength correlation between the performed experiments which is calculated by averaging over each of the GRCs the larger of which is considered the ideal case. The GRG equation can be calculated by:

$$\varepsilon(y_0,y_i)=G_i=\frac{1}{q}\sum_{t=1}^{q}\varepsilon_i(t), \qquad (6)$$

4 Result and Discussion

4.1 Probability plots of the response variables

The probability plot measures the distribution of the experimental data as in the Anderson Darling Test (ADT) test used for the context of the distribution. A powerful statistical tool generally used to detect outliers or most deviations from normality, used for validation of the normality assumption. Looking at the graph from Figure 1 shows that the experimental data for all responses both tensile strength and elastic modulus are near the fitted line, and the Anderson Darling Test (ADT) statistical value is relatively low while the p-value is greater than 0.05 so it can be assumed the data follows a normal distribution. Therefore, further analysis and optimization can be performed.

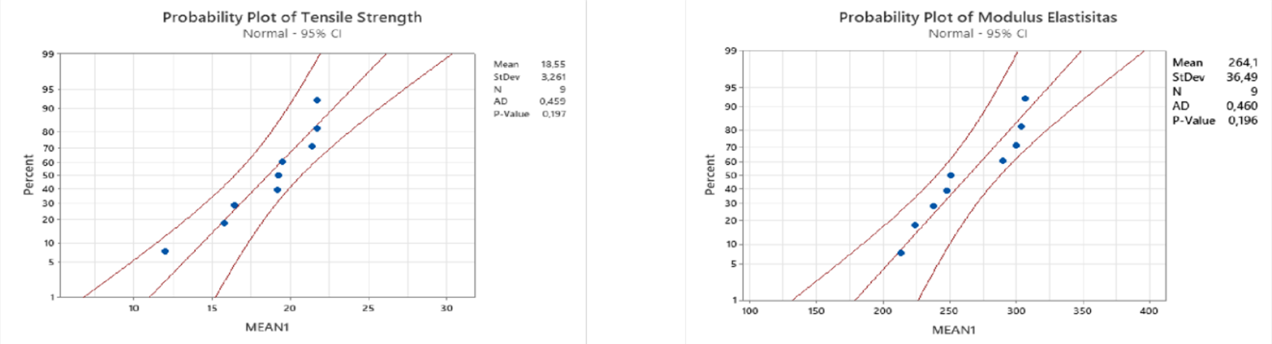


Fig. 1. Normal probability plots of the response variables tensile strength and modulus of elasticity

4.2 Effect of Parameters on Tensile Strength

The results of tensile strength testing for each treatment can be seen in Table 3 with five times replication for each parameter combination. The S/N ratio of the larger the better of the tensile strength is presented in Table 3.

Table 3. Mean and S/N ratio of tensile test result

No	Control Parameters				Tensile Strength (MPa)					Mean	S/N Ratio
	A	B	C	D	1	2	3	4	5		
1	10	0	165	3	23.1	20.1	22.0	20.6	22.9	21.74	26.7045
2	10	3	175	6	19.6	20.1	19.7	14.6	22.0	19.20	25.4023
3	10	5	185	9	21.5	20.2	19.2	16.6	19.9	19.48	25.6925
4	20	0	175	9	15.5	14.7	14.8	16.0	17.9	15.78	23.8971
5	20	3	185	3	21.3	19.3	17.8	19.0	18.9	19.26	25.6497
6	20	5	165	6	21.4	20.1	22.4	22.4	20.7	21.40	26.5843
7	30	0	185	6	16.4	16.0	16.0	17.2	16.4	16.40	24.2879
8	30	3	165	9	21.6	21.1	23.0	21.8	20.9	21.68	26.7067
9	30	5	175	3	12.7	12.7	11.2	12.2	11.2	12.00	21.5413

The optimization results for the calculation of the average tensile strength results were calculated for each parameter level used for the optimization of the Taguchi method orthogonal matrix experimental design. The results of the calculation are shown in Table 4.

Table 4. Mean tensile strength result for each parameter level

Symbol	Parameters	Tensile Strength (MPa)			Delta	Rank
		Level 1	*Level 2*	*Level 3*		
A	Ironwood (IW)	**20.14**	18.81	16.69	3.45	2
B	MAPP	17.79	**20.05**	17.63	2.42	3
C	Molding Temperature (MT)	**21.61**	15.66	18.38	5.95	1
D	Pressure Holding Time (PHT)	17.67	**19.00**	18.98	1.33	4

The plot of the average value S/N Ratio and the plot of means for tensile strength for each parameter are presented in Figure 2.

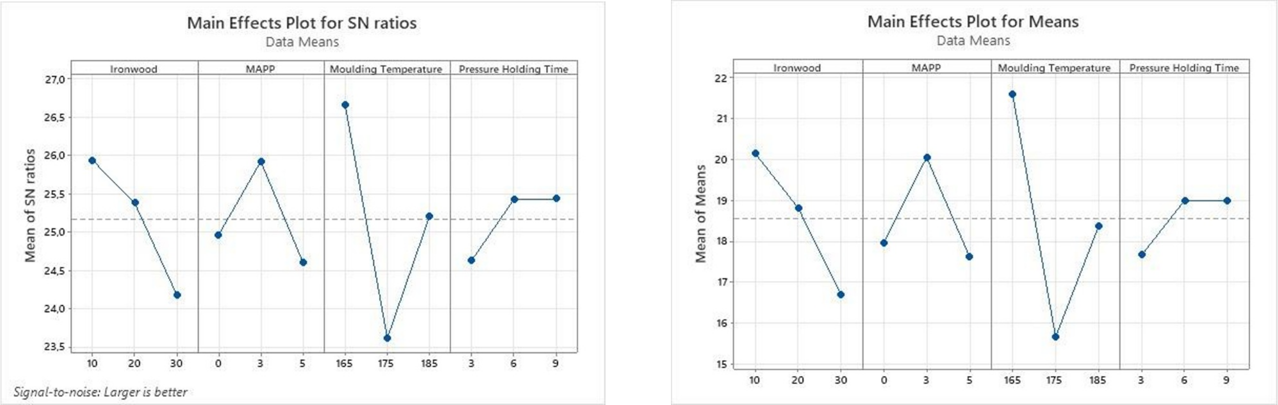


Fig. 2. Main effects plot for SN ratios and for means of tensile strength

Figure 2 shows the average graph and S/N ratio taken at the highest point so that the optimum response parameter combination is obtained to maximize tensile strength as shown in Table 5.

Table 5. Optimum response parameter tensile strength

Symbol	Parameter	Level	Value
A	IW	1	10%
B	MAPP	2	3%
C	MT	1	165°C
D	PHT	2	6 minutes

The ANOVA response in this study is the S/N ratio for tensile strength is displayed in Table 6.

Table 6. ANOVA result and parameter contribution with s/n ratio on tensile strength

Factors	Parameters	DF	Sum of square	Mean of square	Contribution
A	Ironwood	2	4.824	2.4119	21.12%
B	MAPP	2	2.768	1.3839	12.12%
C	Molding Temperature	2	13.978	6.9891	61.20%
D	Pressure Holding Time	2	1.269	0.6347	5.56%

Table 6 indicates that the largest contribution parameter is molding temperature with a percentage contribution of 61.20%, followed by ironwood loading with a percentage contribution of 21.12%. The percentage contribution of MAPP to tensile strength is 12.12% and pressure holding time is reported for the smallest percentage contribution to the response of 5.56%.

4.3 Effect of parameters on the modulus of elasticity

Table 7 shows the mean and S/N ratio for the modulus of elasticity, which is based on the criteria of the larger-is-better.

Table 7. Mean and s/n ratio of tensile test result

Experiment No	Control Parameters				Modulus of Elasticity (MPa)					Mean	S/N Ratio
	A	B	C	D	1	2	3	4	5		
1	10	0	165	3	371	221	372	321	236	304.2	49.0222
2	10	3	175	6	221	284	228	282	241	251.2	47.8568
3	10	5	185	9	292	301	291	339	313	307.2	49.7075
4	20	0	175	9	327	292	271	328	284	300.4	49.4777
5	20	3	185	3	290	323	237	340	260	290.0	49.0155
6	20	5	165	6	259	276	266	219	170	238.0	47.0943
7	30	0	185	6	211	234	274	151	200	214.0	46.0941
8	30	3	165	9	161	291	223	206	241	224.4	46.5256
9	30	5	175	3	249	289	244	227	230	247.8	47.7880

The optimization results for the calculation of the average matrix experimental design. The results of the calculation can elastic modulus results are calculated for each parameter level be seen in Table 8 used for the optimization of the Taguchi method orthogonal.

Table 8. Average results of elastic modulus of each parameter level

Symbol	Parameter	Modulus of Elasticity (MPa)			Delta	Rank
		Level 1	*Level 2*	*Level 3*		
A	Ironwood	**287.5**	276.1	228.7	58.8	1
B	MAPP	**272.9**	255.2	264.3	17.7	3
C	Molding Temperature	255.5	265.5	**270.4**	14.9	4
D	Pressure Holding Time	**280.7**	234.4	277.3	46.3	2

The plot of the mean S/N ratio and means for the elastic modulus for each are presented in Figure 3.

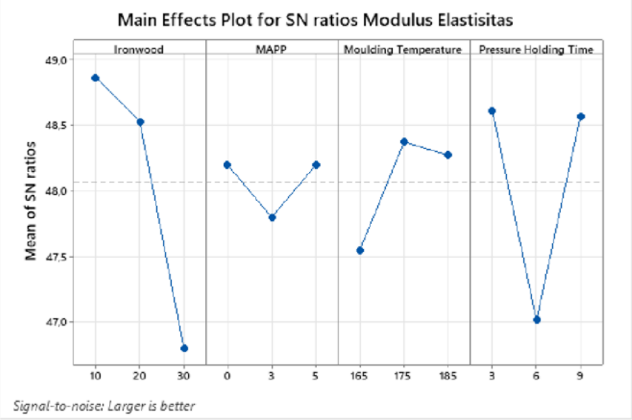


Fig. 3. Main effects plot for SN ratios modulus of elasticity

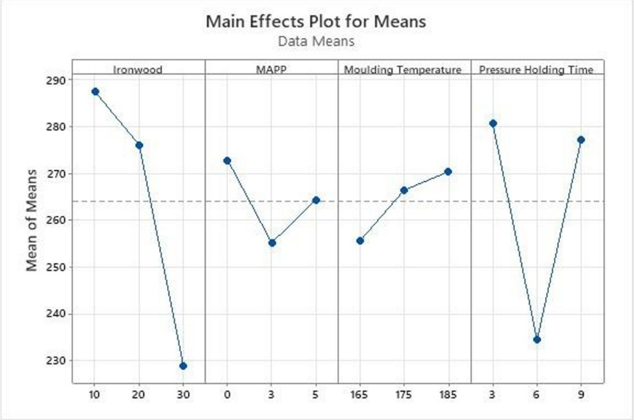


Fig. 4. Main effects plot for means modulus of elasticity

The average graph and S/N ratio are taken at the highest point, so that the optimum response parameter combination to produce the highest elastic modulus can be seen in Table 9.

Table 9. Optimum response parameter combination of elastic modulus

Symbol	Parameters	Level	Value
A	Ironwood (IW)	1	10%
B	Maleic Anhydrate Grafted Polypropylene (MAPP)	1	0%
C	Molding Temperature (MT)	3	185°C
D	Pressure Holding Time (PHT)	1	3 minutes

Table 10. ANOVA results and parameter contribution with S/N ratio on the modulus of elasticity

Factors	Parameters	DF	Sum of square	Mean of square	Contribution
A	Ironwood	2	7.3338	3.6669	53.03%
B	MAPP	2	0.3169	0.1584	2.29%
C	Molding Temperature	2	1.2196	0.6098	8.82%
D	Pressure Holding Time	2	4.9593	2.4796	35.86%

From Table 10, it can be concluded that the parameter with the largest contribution is ironwood loading with a contribution percentage of 53.03%. It was then followed by a pressure holding time with a percentage contribution of 35.86%. Meanwhile, the percentage contribution of molding temperature to the elastic modulus is 8.82% and MAPP loading gets the smallest percentage contribution to the elastic modulus response with 2.29%.

4.4 Grey Relation Analysis

Grey relation analysis is used effectively to solve complex multiple response optimization problems can be simplified into single response grade grey relation optimization. In this study, the normalized values for tensile strength and elastic modulus are calculated based on the larger the better expressed as follows and the results can be seen in Table 11.

Table 11. Normalization result of s/n ratio

S/N Ratio			**Normalization**	
Experiment	**Tensile Strength**	**Modulus of Elasticity**	**Tensile Strength**	**Modulus of Elasticity**
1	26.70	49.02	1.00	0.81
2	25.40	47.86	0.75	0.49
3	25.69	49.71	0.80	1.00
4	23.90	49.48	0.46	0.94
5	25.65	49.02	0.80	0.81
6	26.58	47.09	0.98	0.28
7	24.29	46.09	0.53	0.00
8	26.71	46.53	1.00	0.12
9	21.54	47.79	0.00	0.47
Min.	21.54	46.09		
Max.	26.71	49.71		

For response j of trial i, if the value of x_{ij} that has been processed by the data pre-processing procedure is equal to 1 or closer to 1 than the values of other trials, then the performance of trial i is considered the best for response j. Table 12 shows the deviation sequences.

Table 12. Deviation sequences

Deviation Sequences		
Experiment Number	Tensile Strength	Modulus of Elasticity
1	0.00	0.19
2	0.25	0.51
3	0.20	0.00
4	0.54	0.06
5	0.20	0.19
6	0.02	0.72
7	0.47	1.00
8	0.00	0.88
9	1.00	0.53

Table 13 shows the grey relation coefficient and grade for each experiment

Table 13. Grey relation coefficient and grey relation grade

Experiment	**Grey Relation Coefficient**		**Grey Relation Grade**	**Rank**
	Tensile Strength	***Modulus of Elasticity***		
1	0.999	0.725	0.862	1
2	0.664	0.494	0.579	7
3	0.718	1.000	0.859	2
4	0.479	0.887	0.683	4
5	0.710	0.723	0.716	3
6	0.955	0.409	0.682	5
7	0.516	0.333	0.425	8
8	1.000	0.362	0.681	6
9	0.333	0.485	0.409	9

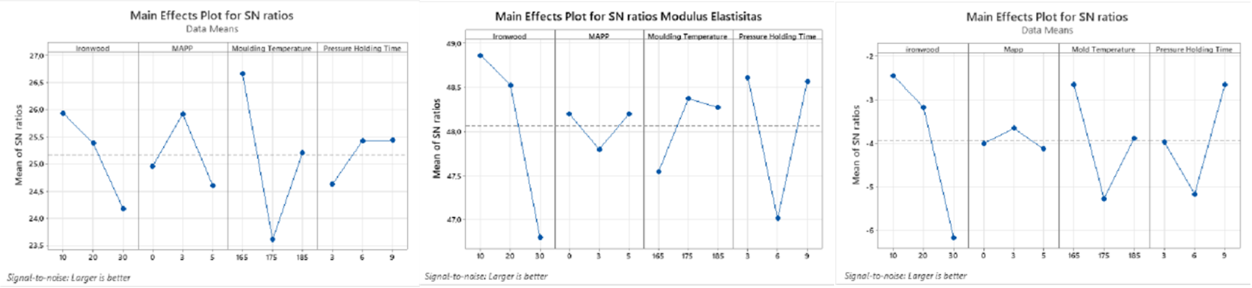
The average of the grey relation grade for each is shown in bold in Table 14, the better multi-performance controllable parameter level is calculated from Table 13, and characteristics are summarized in Table 14. The larger the grey relation grade,

Table 14. Response table of grey relation grade

Level	Ironwood	MAPP	Molding Temperature	Pressure Holding Time
1	**0.7668**	0.6567	**0.7416**	0.6625
2	0.6937	**0.6589**	0.5571	0.5619
3	0.505	0.65	0.6667	**0.7411**
Delta	0.2618	0.0089	0.1845	0.1791
Rank	1	4	2	3

Total mean value grey relation grade = 0.655

Normalization of the values presented in Table 11 was performed using the S/N ratio larger the better by converting the original sequence of S/N ratio into a decimal sequence between 0.00 and 1.00 for comparison called deviation sequences as presented in Table 12. Table 13 shows the grey relation coefficient and grey relation grade for each experiment. The highest grey relation grade is in experiment number 1 with 10% ironwood loading, 0% MAPP loading, molding temperature of 165°C, and pressure holding time of 3 minutes.



(a) (b) (c)

Fig. 5. Main effect plot of S/N ratio of (a) tensile strength, (b) modulus of elasticity, (c) grey relation grade

Based on Table 13, the average grey relation grade for each parameter can be summarized or optimized according to Table 14 where the most optimal value in each parameter is written in bold and indicates the better the performance characteristics. From Figure 4, the GRA indicates that 10% of ironwood loading obtained the optimum response to maximize tensile strength and modulus of elasticity. This is in accordance with the findings of Ahmad et al., (2022); Hongsriphan., (2016); and Flores-Hernández et al., (2014) that the composition of wood fiber content has a significant effect and plays a major role in tensile strength and elastic modulus with the lowest composition of wood fiber content producing the optimum tensile strength and elastic modulus. The 3% of MAPP content (level 2) obtained optimum results in maximizing both tensile strength and modulus. This is in accordance with the findings of Asgary et al., (2013) and Ashori & Nourbakhsh., (2011) that the mechanical properties of tensile strength and modulus of elasticity reached optimum conditions at 3% MAPP composition by weight. A molding temperature of 165°C (level 1) showed optimum results for tensile strength and elastic modulus. This is in accordance with the findings of Govindaraju et al., (2014) and El-Shekeil et al., (2013) that molding temperature plays a major role and has a significant effect on the mechanical properties of tensile strength and elastic modulus. Pressure holding time of 9 minutes (level 3) showed optimum results for tensile strength and modulus of elasticity. This is in accordance with the findings of Tharazi et al., (2017) and Dai et al., (2021) that the mechanical properties of tensile strength and modulus of elasticity reached optimum results with a pressure holding time parameter of 9 minutes.

4.5 Analysis of variance (ANOVA) of grey relation grade

Analysis of variance (ANOVA) is the method used in this study to determine which control parameters significantly affect performance characteristics. This was achieved by separating the variability of the total grey relation grade, as measured by the sum of squared deviations from the mean of the total grey relation grade into the contribution by each control parameter. The ANOVA results for the grey relation grade are shown in Table 15.

Table 15. Result analysis of variance (ANOVA) grey relation grade

Factors	Parameters	DF	Sum of square	Mean of square	Contribution
A	Ironwood	2	0.109460	0.054730	52.22%
B	MAPP	2	0.000129	0.000065	0.06%
C	Molding Temperature	2	0.051671	0.025835	24.65%
D	Pressure Holding Time	2	0.048364	0.024182	23.07%

The ANOVA results for grey relation grade are shown in Table 15. The results show that the percentage contribution of ironwood composition, molding temperature, and pressure holding time are 55.22%, 24.65%, and 23.07%, respectively. These three parameters significantly affect the grey relation grade and ironwood composition is the most significant parameter among others for several performance characteristics. Table 15 shows the results of analysis of variance (ANOVA) of grey relation grade show that MAPP composition with a contribution percentage of 0.06% has no statistically significant effect on multiple performance characteristics. It can be noted that MAPP composition may have an effect on some performance characteristics individually and the effect may not be significant as has been done in this study.

5 Conclusion

The effect of variations in composition and compression molding parameters on the tensile strength of recycled polypropylene composites reinforced with ironwood powder which has the most influence on tensile strength is molding temperature with a percentage of 61.20%, followed by ironwood at 21.12%, MAPP 12.12%, and pressure holding time 5.56%. Then for the effect of variations in composition and compression molding parameters on the modulus of elasticity of recycled polypropylene composites reinforced with ironwood powder, ironwood has the largest percentage of influence, namely with a percentage of 53.03%, followed by a pressure holding time of 35.86%, molding temperature 8.82%, and MAPP 2.29%. Meanwhile, based on the grey relation analysis conducted on the tensile strength and modulus of elasticity of the recycled polypropylene composite reinforced with ironwood powder, it shows that the percentage of contributions that have a significant effect based on grade, namely the composition of ironwood (level 1) 10%, molding temperature (level 1) 165 °C, and pressure holding time (level 3) 9 minutes is 55.22%, 24.65%, and 23.07% and only MAPP (level 2) 3% has no significant effect with a percentage of 0.06%.

The best composition and parameter variations of the compression molding process to maximize the tensile strength of recycled polypropylene composites reinforced with ironwood powder are 10% ironwood, 3% MAPP, molding temperature 165 °C, and pressure holding time of 6 minutes. Then for the best composition and parameter variations of the compression molding process to maximize the modulus of elasticity of the recycled polypropylene composite reinforced with ironwood powder, namely ironwood 10%, MAPP 0%, molding temperature 185 °C, and pressure holding time 3 minutes. Based on the grey relation analysis carried out on tensile strength and modulus of elasticity, the best composition and parameter variations of the grade obtained are with ironwood 10%, MAPP 3%, molding temperature 165 °C, and pressure holding time 9 minutes.

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