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Influence of Wax and Resin Content on the Properties of Three-Layer Rubberwood Particleboard

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ABSTRACT. In this study, the effects of resin and wax content as well as board density on the modulus of rupture (MOR) and internal bonding (IB) and thickness swelling (TS), were investigated. Three-layer particleboard was made with rubberwood particles. Different urea formaldehyde (UF) resin contents (%) were applied on the surface/core/surface layer of the particleboard, namely 10/7/10, 11/8/11 and 12/9/12. Three different dosages of wax (0, 0.5 and 1%) were added into the UF resin and blended with the rubberwood particles during particleboard fabrication. Particleboard with two densities was produced, which are 680 kg/m^3 and 750 kg/m^3. The results revealed that the wax content exerted an insignificant effect on the MOR and IB of the particleboard, but it greatly improved the TS of the board. Meanwhile, resin content was observed to reduce the TS and increase the MOR of the particleboard. Particleboard with higher density had better MOR and IB. However, the TS value increased also along with increasing board density. Unfortunately, all the boards produced in this study did not meet the minimum requirement of TS value as specified in JIS A 5908, which should be lower than 12%. The optimisation study recommended that a higher wax content (1.47%) be used to achieve the targeted TS. Nevertheless, it is not viable from the economic point of view, and another option has to be considered to lower the TS of the particleboard.

Keywords: Dimensional stability, Density, Particleboard, Relationship, Resin content

INTRODUCTION

Particleboard is a wood-based product that is low in cost and budget-friendly compared to plywood and solid wood. However, one of the most significant shortcomings of particleboard is that it has poor dimensional stability, especially when used in a moist environment (Kwon et al., 2013). In most cases, the dimensional instability of wood-based panels can be inferred from their thickness swelling (TS) measurements. This swelling should be avoided at all costs as it can have a functional and a visual impact on panel performance. Swelling of thickness is the most prominent effect when the panels are exposed to moisture. Almost all the variables in the manufacturing process, such as the

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type of wood being used, the particle geometry, board density, resin level, blending efficiency, and pressing conditions, influenced the thickness swelling of particleboard (Baharoğlu et al., 2014). A better understanding of these variables' effects, along with the application of special treatments such as water repellents and dimensional stabilisers, should make it possible to exert some degree of control over the thickness swelling.

According to Rowell and Banks (1985), two types of treatments are utilised to lessen the propensity of wood to absorb moisture and change its dimensions. These treatments are water repellents and dimensional stabilisers. Commercial water repellents applied to wood have almost always been of the simple, non-chemically bonded type, primarily based on paraffin wax panels. Because it is a hydrophobic substance, wax effectively prevents water from penetrating it (Rosenfeld et al., 2022). Wax-sizing has been used for dimensional stabilisation of wood for a very long time (Baharoğlu et al. 2014; Xu et al. 2009; Kwon et al. 2015), and it is the additive that is used the most frequently in modern times.

Apart from the addition of wax, the resin is one of the most important factors determining the particleboard's bending strength and thickness stability (Sarmin et al., 2013). The resin serves as a binding agent, connecting the hydrophobe that has a low level of adhesion to the interfibril spaces of the cell wall (Humar and Leasr, 2013). The density of the boards is also one of the influencing factors that affect particleboard's physical and mechanical properties (Warmbier et al., 2013; Maraghi et al., 2018). A better understanding of the effects that these factors should allow for more control over the thickness swelling. In this study, the effects of the three main influential factors, i.e. resin content, wax loading and board density, on the dimensional stability and mechanical properties of the particleboard were investigated. Furthermore, Response Surface Methodology (RSM) was applied to determine the best combination to produce particleboards that meet the Japanese Industrial Standard (JIS) requirement for application in moist interior environments such as the kitchen.

METHODOLOGY

Particleboard Fabrication

Rubberwood particles with 3% moisture content (MC) were used for the three-layer particleboard manufacture. Melamine-fortified UF resin with 60-65% solid content supplied by Aica Malaysia Sdn. Bhd., Senawang was used as a binder. The variables in this study were density (680 kg/m^3 and 750 kg/m^3), resin content (7-9% for core layer and 10-12% for surface layers) and wax content (0, 0.5 and 1%). In commercial particleboard plants, the application of UF resin content is 8% for the core layer and 11% for the surface layers. Meanwhile, the wax applied is not more than 1% or usually maintains around 0.5%. Therefore, these parameters were used as a benchmark to develop the experimental design of the study. The experimental design is shown in Table 1. In the core layer of each panel, a hardener composed of ammonium chloride was applied at a loading of 3.8% based on the resin's weight, while only 1% was used in the surface layer. To control the final density of the boards, rubberwood particles, after being blended with different amounts of resin and wax, were reweighed before forming into the mat. The formed mats were then pressed at 180 °C for 270 s. Particleboard with 340 mm x 340 mm x 12 mm (l x w x t) was produced. Three board replicates were produced for every variable level. A total of 54 boards (18 variables x 3) were produced in this study.

Table 1. Particleboard made with different densities, wax content and resin usage

Board type	**Density (kg/m^3)**	**Wax content (%)**	**Resin usage (%)**	
			Core layer	**Surface layer**
1	680	0	7	10
2	680	0	8	11
3	680	0	9	12
4	680	0.5	7	10
5	680	0.5	8	11
6	680	0.5	9	12
7	680	1	7	10
8	680	1	8	11
9	680	1	9	12
10	750	0	7	10
11	750	0	8	11
12	750	0	9	12
13	750	0.5	7	10
14	750	0.5	8	11
15	750	0.5	9	12
16	750	1	7	10
17	750	1	8	11
18	750	1	9	12

Properties evaluations

The boards were conditioned for seven days at a temperature of 20 ± 2°C and relative humidity of 65 ± 5% prior to the physical and mechanical properties evaluation. Mechanical properties such as modulus of rupture (MOR), internal bonding (IB), and physical properties such as thickness swelling were evaluated according to Japanese Industrial Standard A5908:2003. The particleboard samples were weighed and measured for their dimensions. Next, the samples' density was determined by dividing their mass over volume and was expressed in kg/m^3. For MOR, 5 replicates of samples having dimensions of 50 mm width x 230 length x 12 mm thickness were prepared. The samples were tested using a Universal Testing Machine (UTM) with a load crosshead speed of 10 N/mm^2. The maximum load before the rupture of the samples was recorded, and then the MOR was calculated. As for IB, 5 replicates of samples with dimensions of 50 mm width x 50 mm length x 12 mm thickness were prepared. The samples were then adhered to metal blocks and were tested using a Universal Testing Machine (UTM) with a load crosshead speed of 2 N/mm^2. The maximum load for the samples to break apart was recorded and was used to determine the IB strength. For thickness swelling evaluation, 5 replicates of samples with dimensions of 50 mm width x 50 mm length x 12 mm thickness were soaked in water at room temperature. The samples' thickness was measured before and after 24 h soaking in water, and the difference in thickness before and after soaking was calculated and expressed in percentage (%).

Response surface methodology (RSM) and central composite design

RSM was used to systematically investigate and optimise the effects of two independent variables (resin usage and wax content) on particleboard's mechanical and physical properties. Design Expert Software was used to create the central composite design (State Ease, Design Expert 9). A 13-run central composite design was created using RSM. Particleboards were made using the recommended parameters, and the data obtained were used for optimisation.

Statistical Analysis

The data was statistically analysed to ensure the variables under investigation were significant. The Statistical Package for the Social Sciences (SPSS) procedure for analysis of variance (ANOVA) was used to analyse the data at a confidence level of $P \leq 0.05$. The three factors were density, wax content, and resin usage. The relationship between the main effects and the properties of particleboard was evaluated using Pearson's correlation.

RESULTS AND DISCUSSION

The MOR values for all types of particleboards are shown in Figure 1. Particleboard with a density of 680 kg/m^3 and 750 kg/m^3 had a modulus of rupture (MOR) that varied between 11.52 to 16.03 Nmm^{-2} and 13.68 to 21.34 Nmm^{-2}, respectively. The minimum MOR requirement must be met is 13.00 Nmm^{-2}, as specified by JIS A 5908. Most of the boards, except for board types 1, 7, and 9, met the minimum MOR requirement established by JIS A 5908. Type 1 particleboard was made with 0% wax and the lowest resin content. Therefore, it is expected that it has inferior mechanical properties. Meanwhile, types 7 and 9 are made with 1% wax content. Wax is hydrophobic, and it will interfere with the curing of the adhesive and negatively affect the properties of the board (Papadopoulos, 2006). Therefore, boards with high wax content tend to have inferior properties.

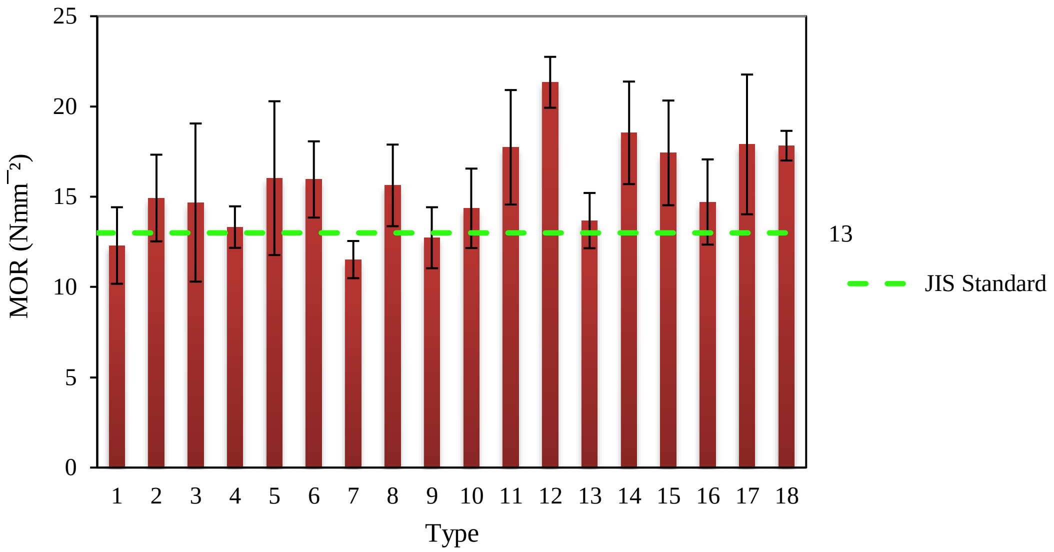

Figure 1. Average MOR values for particleboard made with different densities, wax content and resin usage.

Figure 2 depicts the distribution of the IB values for every type of particleboard. Internal bond strength for all types of boards is greater than the minimum requirement of 0.2 Nmm^{-2} specified by JIS A 5908. The average values for particleboard with a density of 680 kg/m^3 and 750 kg/m^3 ranged from 0.40 to 1.52 Nmm^{-2} and 1.18 to 2.09 Nmm^{-2}.

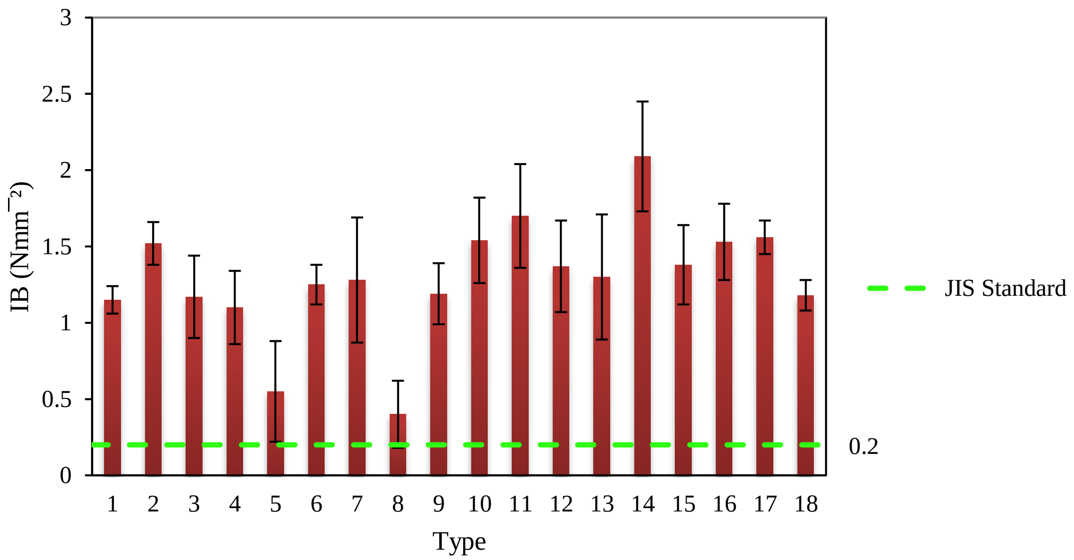

Figure 2. Average IB values for particleboard made with different densities, wax content and resin usage

The main effects (resin and density) affect the MOR of the particleboard significantly, as shown in Table 2. Wax content was found to have no significant effects on both MOR and IB of the particleboard, while resin content was found only exerts significant effects on MOR. On the other hand, density was found to be the only main effect that significantly influences the MOR and IB properties of the particleboard.

Table 2. Significant probabilities for study variables and interaction (MOR and IB)

	Modulus of rupture			Internal bond		
	F value	Pr > F		F value	Pr > F	
Wax	0.792	0.457	ns	2.862	0.063	ns
Resin	21.505	0.000	***	0.229	0.796	ns
Density	34.297	0.000	***	36.136	0.000	***

*** indicates significance level at P≤0.01
** indicates significance level at P≤0.05
ns indicates no significance

The TS values for a different type of particleboard are depicted in Figure 3. The particleboard with 680 kg/m^3 and 750 kg/m^3 had a thickness swelling from 15.19 to 22.93%, while the particleboard with 750 kg/m^3 had a thickness swelling from 15.26 to 24.91%. All the boards manufactured in the study did not comply with the standards established by JIS A 5908, which state that the maximum allowable level of TS is 12 %.

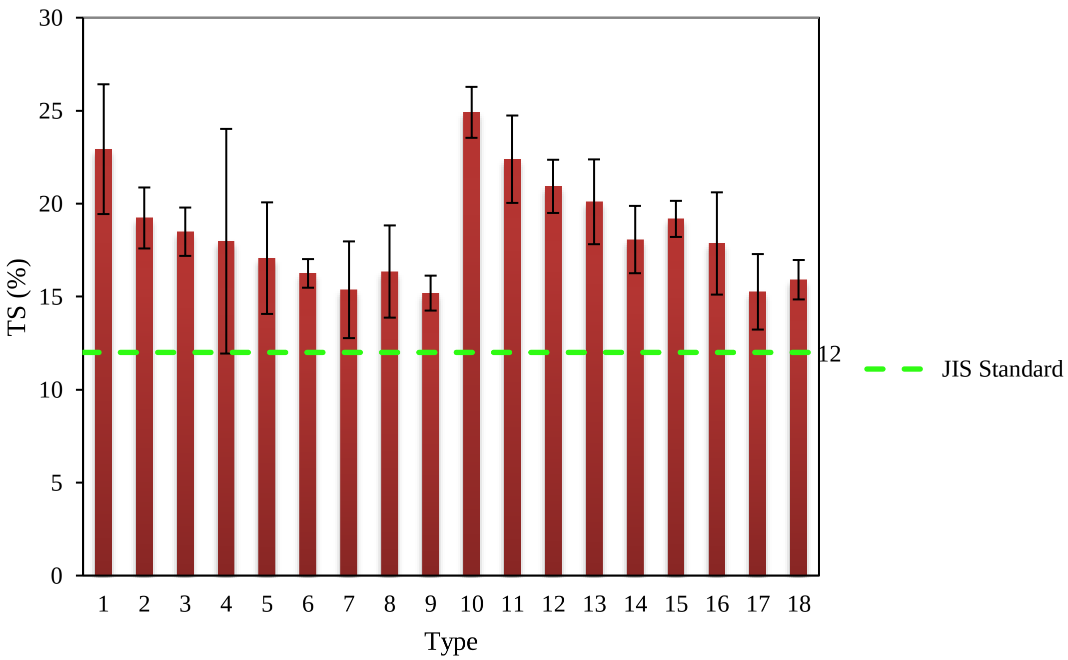

Figure 3. Average TS values for particleboard made with different densities, wax content and resin usage

The particleboard produced with 7/10% (core/surface) of resin at the target density of 750 kg/m^3 without the addition of wax exhibited the greatest amount of TS. At the constant of 0% wax content, the TS value for the boards decreased when the resin usage was increased from 7/10% to 9/12%, indicating that resin content significantly affects the TS of the particleboard. The findings of the ANOVA (Table 3) showed a strong statistical significance for each of the main effects (wax, resin, and density) on the TS.

Table 3. Significant probabilities for study variables and interaction (TS)

	Thickness swelling		
	F value	**Pr > F**	
Wax	74.944	0.000	***
Resin	13.406	0.000	***
Density	22.51	0.000	***

*** indicates significance level at $P \leq 0.01$
** indicates significance level at $P \leq 0.05$
ns indicates no significance

Correlation between particleboard properties and study variables

Pearson's correlation between the various properties and variables is displayed in Table 4. According to Table 4, it was discovered that wax content has a significant effect on TS reduction. However, at the same time, it also reduces the strength properties of the particleboard, but not significantly. Meanwhile, particleboard's MOR values increased as a result of the addition of resin, which concurrently lowered the board's TS value. Density also exerts a significant effect on the MOR and IB of the particleboard. The higher the density, the higher the MOR and IB values of the particleboard. However, TS is also higher in particleboard with higher density.

Table 4. Pearson's correlation (r) between properties affected by the study variables

Property	Wax	Resin	Density
[1]TS	-0.816**	-0.327	0.319
[2]MOR	-0.139	0.557*	0.598**
[3]IB	-0.239	-0.066	0.602**

*Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level
[1]TS: thickness swelling, [2]MOR: modulus of rupture, [3]IB: internal bond strength.

Maraghi et al. (2018) found that as particleboard density increased, the MOR and IB of poplar wood slab, citrus branches, and beech twigs increased. According to the study, the MOR of the particleboard increased by as much as 27.1% when the density of the board was increased from 650 kg/m^3 to 750 kg/m^3, while IB was also slightly improved. Warmbier et al. (2013) made a similar observation, observing that particleboard made from willow wood increased in MOR and IB by 35 and 9%, respectively, when the board density increased from 600 to 660 kg/m^3. A study by Lee et al. (2017) revealed that the density of the particleboard had a positive correlation with MOR and IB. In the study, it was noted that the effects of density are higher in IB compared to that of MOR. The same observation, though only slightly, was made in this study. The magnitude of Pearson's correlation for the effect of density on IB (r=0.602) is slightly higher than that of MOR (r=0.598). The improved mechanical properties as the density increase are mainly attributed to the increased wood volume that ensures higher compaction (Lee et al., 2015).

Resin content is regarded as the main factor that affects the properties of the particleboard produced (Barragàn-Lucas et al., 2019). In this study, particleboard bonded with a higher level of UF resin exhibited the highest MOR value. A study by Bhadewad et al. (2018) showed the same observation where particleboard made from the highest level of UF resin had met the requirements of relevant standards. It was said that higher levels of resin facilitate stronger interfacial bonding between wood particles and, therefore, higher MOR value (Abd Rahman et al., 2019). According to Ghalehno et al. (2013), increasing the amount of resin resulted in a complete resin coating on the wood particle. Therefore, the number of bonding sites between the particle and resin increased, subsequently leading to improved MOR.

As for thickness swelling, Boruszewski et al. (2022) concluded that the resin level was the single most important factor in controlling particleboard swelling. Increased resin content results in a board with improved properties, particularly the ability to maintain its thickness. UF resin interacts with wood particles, and the curing of UF resin forms a hardened crosslinking structure. Therefore, particleboard with higher resin content tends to have higher resin interaction with the wood particles and is more stable when exposed to moisture (Hong et al., 2017). In general, particleboard with a target density of 680 kg/m^3 had lower thickness swelling than particleboard with a target density of 750 kg/m^3. If exposed to water for an extended period of time, higher-density boards swell more than lower-density boards, according to Böhm et al. (2019). Panels with a lower density will likely experience less swelling for two reasons. The first reason is that they contain less wood per unit area, resulting in a lower degree of hygroscopic response. The second reason is that they have less wood per unit volume, which causes swelling to be partially extended into the spaces between the particles (Lee et al., 2015). Khedari et al. (2003) have discovered increased thickness swelling with increasing particleboard density. For high-density boards, a high-thickness swelling value is very common.

In general, the addition of wax improved the thickness swelling of the particleboard significantly. According to the data in Figure 3, the TS values are significantly reduced after adding 0.5 and 1% wax to the board. The addition of wax to bagasse particleboard improved the thickness swelling after 24 hours, according to the findings of Xu et al. (2009). The wax gives particleboard its water-repellent properties. However, the water repellency achieved by adding wax is usually only temporary (Chen et al., 2020). The water resistance imparted by wax sizing to particleboard is primarily due to a reduction in capillary water flow.

The plots of swelling versus time for three different types of wood specimens are shown in Figure 4. In order to facilitate analysis and comparison, three distinct kinds of samples were chosen. Type 1 refers to the wood specimens that have not had any wax applied to them, Type 7 has the highest usage of wax (1%), and Type 9 refers to the boards with both the highest wax content and the highest resin usage.

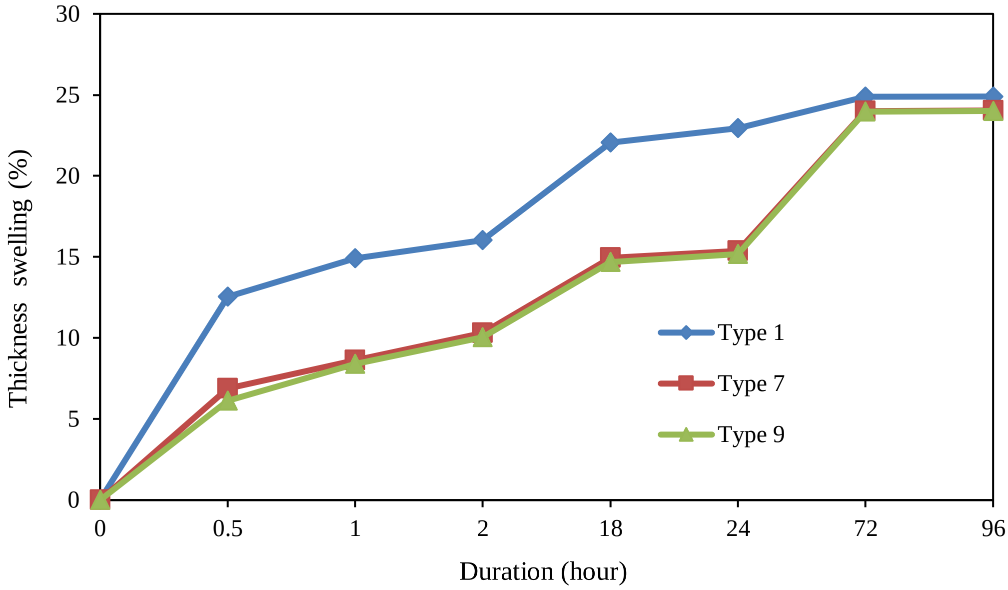

Figure 4. Swelling versus time plot for particleboard made with different densities, wax content and resin usage

According to Figure 4, applying wax and resin together (Type 7 and 9) slows down the water absorption rate of particleboard. However, over time, the amount of swelling that occurs is almost identical to that of untreated wood. The swelling patterns displayed in Figure 4 obeyed the type I hypothetical model of swelling versus time proposed by Rowell and Banks (1985). This model indicated that the wax and resin treatment only improved the boards' water repellency for a short period but that the boards' dimensional stability remained unchanged.

The water uptake rate can be significantly reduced by providing a water barrier or rendering the wood hydrophobic (Humar and Lesar, 2013). The wax acts as a barrier against water, preventing water from penetrating the surface spontaneously. Water repellents applied to wood either fill in the cell lumina or are deposited on the external and, to some extent, on the internal pore surfaces, both of which contribute to the surface's hydrophobic properties. The amount of water repellent that is applied is directly proportional to the amount of water that is repelled. Because of this, the water cannot naturally seep into the pores of the wood due to the action of capillary forces, and the water absorption rate is consequently restricted (Can and Sivrikaya, 2019).

It has been demonstrated by both Lesar et al. (2011) and Brischke and Melcher (2015) that treating wood with these types of non-chemically bonded water repellents provides significant control of water uptake for a reasonable amount of time. The eventual loss of water-repellent effectiveness may be associated with the failure of the bond between the cell wall and the deposit, largely due to the degradation of the wood surface. This failure may be associated with time. The phenomenon of preferential wetting, described earlier, can happen even in wood treated with a water-repellent. When the material that repels water is subjected to water for an extended period, the hydrophobic substances are dislodged by the water, which results in a reduction in the effectiveness of the treatment. The relatively weak Van der Waals bond between wood and deposits is then succeeded by a more robust hydrogen bond between wood and water.

Optimisation by response surface methodology (RSM) in compliance with the Japanese Industrial Standard (JIS)

All of the boards manufactured in this study did not meet the minimum requirement for TS, which should be less than 12%, according to JIS A 5908. The effects of the two independent variables, resin usage and wax content, on the particleboard's mechanical and physical properties, were systematically investigated with the help of a response surface methodology (RSM) technique implemented using MINITAB v16.1 software. The optimisation was carried out so that conditions for the best possible properties of particleboard, in particular for TS, could be predicted. The levels of the independent variables, both as coded and as measured by actual data, are presented in Table 5.

Table 5. Coded and actual levels of the independent variables

Variables	**Coded levels**		
	Low	**Middle**	**High**
	-1	**0**	**1**
Wax content (%)	0	0.5	1
Resin usage (%)	7	8	9

Based on the RSM, the predicted parameters to produce particleboard with optimum properties of TS, MOR and IB were obtained and are shown in Table 6. The main purpose of the optimisation was to keep the TS value below 12% while ensuring MOR and IB values met the minimum requirements specified in JIS A 5908.

Table 6. Predicted conditions for optimum properties of particleboard

Processing conditions		**Properties**			**Desirability**
		TS (%)	**MOR (N/mm^2)**	**IB (N/mm^2)**	
680 kg/m^3	1.47% Wax, 10.44/13.44% Resin	11.76	16.52	0.6	1
750 kg/m^3	1.47% Wax, 9.54/12.54% Resin	11.97	19.77	1.52	1

The results of the prediction show that the required TS value of less than 12% in accordance with JIS A 5908 can be obtained by increasing the wax content and resin usage to a higher level, as shown in Table 6. For particleboard with 680 kg/m^3, 10.44% UF in the core layer and 13.44% UF in the surface layers are recommended to achieve the targeted TS values. Meanwhile, for particleboard with 750 kg/m^3, 9.54% UF in the core layer and 12.54% UF in the surface layers are recommended. In addition, it was noted that 1.47% of wax is required to be added to achieve the targeted TS of less than 12%. However, this might not be an economically viable approach, and therefore other options have to be identified to reduce the TS of the particleboard.

CONCLUSION

The addition of wax had a significant impact on the thickness swelling value of particleboard. However, the addition of wax should be limited to 0.5% because further addition did not increase but caused a reduction in bending properties. Increased resin usage is also important in reducing thickness swelling and improving particleboard bending properties. However, due to the high resin cost, the amount of adhesive that can be added must be carefully considered from an economic standpoint. Some MOR values fell short of the standard, particularly for boards made with lower resin content and higher wax addition. The particleboards that did not meet the standard for MOR were all made with a target density of 680 kg/m^3. Overall, particleboards with a target density of 680 kg/m^3 had a lower thickness swelling value than particleboards with a 750 kg/m^3 density. The mechanical properties of higher-density particleboard outperform those of lower-density particleboard. The TS values did not meet the 12% standard value. RSM proposed that the required TS values (12%) be obtained by increasing the amount of wax to 1.47% and the resin usage. However, considering the high resin cost today, the addition of wax content and resin usage appears uneconomical. Furthermore, wax additions greater than 1% will not significantly improve dimensional stability and water absorption properties. Therefore, thermal treatment of the particles prior to particleboard production may be a viable method to lower the dimensional instability of particleboard. Further study should be focused on the optimisation of treatment temperature and time.

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AUTHOR CONTRIBUTIONS

Lee Seng Hua and **Lum Wei Chen** are responsible for conducting the research and drafting this manuscript. **Petar Antov, Ahmet Can, Widya Fatriasari** and **Aujchariya Chotikhun** are responsible for reviewing and editing the manuscript.

COMPETING INTEREST

The authors declare that there are no competing interests.

COMPLIANCE WITH ETHICAL STANDARDS

Not applicable.

REFERENCES

Abd Rahman, W. M. N. W., Yatim, A. A. M., Zlan, A. A. M., Kasim, J., & Yunus, N. Y. M. (2019). Effects of the resin content and particle size on the properties of particleboard made of neolamarckia and leucaena particles. BioResources, 14(3), 6079-6087.

Baharoğlu, M., Nemli, G., Sarı, B., Ayrilmis, N., Bardak, S., & Zekoviç, E. (2014). Effect of paraffin application technique on the physical and mechanical properties of particleboard. Science and Engineering of Composite Materials, 21(2), 191-195.

Barragàn-Lucas, A. D., Llerena-Miranda, C., Quijano-Aviles, M. F., Chóez-Guaranda, I. A., Maldonado-Guerrero, L. C., & Manzano-Santana, P. I. (2019). Effect of resin content and pressing temperature on banana pseudo-stem particle boards properties using full factorial design. Anais da Academia Brasileira de Ciências, 91, e20180302

Bhadewad, A. M., Sumthane, Y. Y., Nimkar, A. U., Khachane, S. M., Tyade, Y. B., & Harne, S. S. Different Percentage of Resin for Particle Board Manufacturing from ProsopisJuliflora. International Journal of Research in Agriculture and Forestry, 5, 31-38.

Böhm, M., Kobetičová, K., Procházka, J., & Černý, R. (2019). Moisture sorption and thickness swelling of wood-based materials intended for structural use in humid conditions and bonded with melamine resin. IOP Conference Series: Materials Science and Engineering 549(1), 012042

Boruszewski, P., Borysiuk, P., Jankowska, A., & Pazik, J. (2022). Low-density particleboards modified with blowing agents—characteristic and properties. Materials, 15(13), 4528.

Brischke, C., & Melcher, E. (2015). Performance of wax-impregnated timber out of ground contact: results from long-term field testing. Wood science and technology, 49, 189-204.

Can, A., & Sivrikaya, H. (2019). Surface characterisation of wood treated with boron compounds combined with water repellents. Color Research & Application, 44(3), 462-472.

Chen, J., Wang, Y., Cao, J., & Wang, W. (2020). Improved water repellency and dimensional stability of wood via impregnation with an epoxidised linseed oil and carnauba wax complex emulsion. Forests, 11(3), 271.

Ghalehno, M. D., Nazerian, M., & Bayatkashkoli, A. (2013). Experimental particleboard from bagasse and industrial wood particles. International Journal of Agriculture and Crop Sciences (IJACS), 5(15), 1626-1631.

Hong, M. K., Lubis, M. A. R., & Park, B. D. (2017). Effect of panel density and resin content on properties of medium density fiberboard. Journal of the Korean Wood Science and Technology, 45(4), 444-455.

Khedari, J., Charoenvai, S., & Hirunlabh, J. (2003). New insulating particleboards from durian peel and coconut coir. Building and environment, 38(3), 435-441.

Kwon, J. H., Ayrilmis, N., & Han, T. H. (2013). Enhancement of flexural properties and dimensional stability of rice husk particleboard using wood strands in face layers. Composites Part B: Engineering, 44(1), 728-732.

Kwon, J. H., & Ayrilmis, N. (2015). Combined effect of acetylation and wax emulsion on physical and mechanical properties of particleboard. European Journal of Wood and Wood Products, 73, 845-847.

Lee, S. H., Lum, W. C., Zaidon, A., Fatin-Ruzanna, J., Tan, L. P., Mariusz, M., & Chin, K. L. (2017). Effect of post-thermal treatment on the density profile of rubberwood particleboard and its relation to mechanical properties. Journal of Tropical Forest Science, 29, 93-104.

Lee, S.H., Zaidon, A., Lum, W. C., San, H. P., Peng, T. L., & Chow, M.J. (2015). Properties of particleboard with oil palm trunk as core layer in comparison to three-layer rubberwood particleboard. Journal of Oil Palm Research, 27(1), 67-74.

Lesar, B., Pavlič, M., Petrič, M., Škapin, A. S., & Humar, M. (2011). Wax treatment of wood slows photodegradation. Polymer degradation and stability, 96(7), 1271-1278.

Maraghi, M. M. R., Tabei, A., & Madanipoor, M. (2018). Effect of board density, resin percentage and pressing temperature on particleboard properties made from mixing of poplar wood slab, citrus branches and twigs of beech.

Wood research, 63(4), 669-682

Papadopoulos, A. (2006). Property comparisons and bonding efficiency of UF and PMDI bonded particleboards as affected by key process variables. BioResources, 1(2), 201-208.

Rowell, R.M., & Banks, W.B. (1985) Water repellency and dimensional stability of wood. General Technical Report FPL-50. Madison, WI, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, pp.24.

Rosenfeld, C., Solt-Rindler, P., Sailer-Kronlachner, W., Kuncinger, T., Konnerth, J., Geyer, A., & van Herwijnen, H. W. (2022). Effect of Mat Moisture Content, Adhesive Amount and Press Time on the Performance of Particleboards Bonded with Fructose-Based Adhesives. Materials, 15(23), 8701.

Sarmin, S. N., Zakaria, S. A. K. Y., Kasim, J., & Shafie, A. (2013). Influence of resin content and density on thickness swelling of three-layered hybrid particleboard composed of sawdust and Acacia mangium. BioResources, 8(4), 4864-4872.

Warmbier, K., Wilczynski, A., & Danecki, L. (2013). Effects of density and resin content on mechanical properties of particleboards with the core layer made from willow Salix viminalis. Annals of Warsaw University of Life Sciences-SGGW. Forestry and Wood Technology, 84, 284-287.

Xu, X., Yao, F., Wu, Q., & Zhou, D. (2009). The influence of wax-sizing on dimension stability and mechanical properties of bagasse particleboard. Industrial crops and products, 29(1), 80-85.