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SUITABILITY OF NATIVE AND MODIFIED CORN STARCH/POLYVINYL ALCOHOL (PVOH) AS AN ALTERNATIVE BINDER FOR PARTICLEBOARD MANUFACTURING

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Abstract

Particleboard still has a demand in the global market, however concerning about formaldehyde emission gas release from this product has encourage the researcher to seek other natural binder for particleboard manufacturing. The aim of this study is to investigate the suitability of native and modified corn starch blended with polyvinyl alcohol (PVOH) as an adhesive in particleboard manufacturing. Different ratios of corn starch and Polyvinyl alcohol (PVOH) were prepared in this study. The adhesive properties, physical and mechanical properties were evaluated as starch-based adhesive functionalities. The findings were revealed that swelling power (SP) and solubility for both native and modified corn starch were reacted when the temperature was reached up to 70 ºC. Higher viscosity was found in the 80 % corn starch mixed with 20 % of PVOH (270.67 cP). Both native and modified corn starches only can be used as wood adhesive within 36 hours after the blending process. The comparable performance in mechanical properties was found in the particleboard bonded with modified 80% of corn starch and 20% of PVOH (MC_80:20), achieved the values of 2054.73 N/mm^2, 10.86 N/mm^2, and 2.09 N/mm^2 for MOE, MOR, and IB, respectively. Dimensional stability properties for all the board panels in this study did not fulfill the JIS standard but successfully obtained the values < 50% and < 150% for the thickness swelling (TS) and water absorption (WA), respectively. The results show that corn starch-modified with PVOH could be a greener adhesive with comparable strength properties for particleboard manufacturing.

Keywords: - corn starch, starch-based modification process, PVOH, particleboard

1. Introduction

Wood-based panels such as oriented strand board (OSB), plywood, particleboard, and medium-density fiberboard (MDF), had reported will be increased up to $41 billion in the year 2022 (Sharma, Rao, and Krupashankara 2018). These panels are commercially used in the various wood industry. However, the typical adhesive used in particleboard manufacturing, such as urea-formaldehyde (UF), released a formaldehyde emission during the hot press process (Arias, Feijoo, and Moreira 2021). The formaldehyde emission released from this panel was considered a carcinogen that risks human health and environmental pollution (Oh et al., 2019). Adhesive bonding between the wood particles and a binder is critical in ensuring the panel can be used in various products and industries (Solt et al., 2019).

2. Literature Review

Starch is one of the resources that can be used as a wood adhesive for wood bonding (Arias, González-Rodríguez, et al., 2021). Corn starch can be used as an adhesive either in pure form or modification (Hamid et al. 2019). It was reported to have prominent particle size characteristics, strong surface polarity, high cohesive energy, and high softening temperature (A Moubarik et al. 2010); Bandara and Wu 2018). However, a previous study was suggested that the native corn starch should be modified before being used as an adhesive to enhance the mechanical and adhesive properties (Oktay, Kızılcan, and Bengu 2021). Higher bonding strength and water resistance can be achieved by combining starch with additives such as polyvinyl alcohol (PVOH), formaldehyde, isocyanates, and tannins (Qiao et al., 2014).

Polyvinyl alcohol was used as the tackifier in developing starch-based adhesive. The presence of hydroxyl groups in polyvinyl alcohol and starch was created a crosslinking reaction in the starch-based adhesive blending (Gadhave et al. 2020). Meanwhile, boric acid increases polyvinyl alcohol and starch (Gadhave, Mahanwar, and Gadekar 2019). However, it remains a challenge to make the starch-based adhesive more effective than commercial wood adhesive in terms of its mechanical properties and long-term durability (Islam et al., 2022). Therefore, this study aims to evaluate the performance of native or modified corn starch/PVOH suited as a binder in particleboard manufacturing in terms of adhesive and physical and mechanical properties.

3. Methodology

3.1 Material Preparation

The food-grade corn starch powder was procured from the local supplier. The nutrient content in 1 kg of corn starch contained a carbohydrate of approximately 91.2g and 0.4g for lipid content and protein content, respectively. Approximately 1 packet of 1 kg of corn starch flour was used in this study. Urea-formaldehyde (UF) was procured from Malayan Adhesives & Chemicals Sdn Bhd, Shah Alam, Selangor, Malaysia. Meanwhile, the particleboard raw materials consisting of 70% Acacia mangium and 30% mixed hardwoods were supplied by a local particleboard company in Negeri Sembilan, Malaysia.

3.2 Corn Starch Based Adhesive Modification Process and Particleboard manufacturing

The corn starch based adhesive was modified as illutrated in Figure 1. Meanwhile the particleboard manufacturing process was preparesd as a method explained in the Figure 2.

Figure 1: The flowchart process of corn starch modification with PVOH.

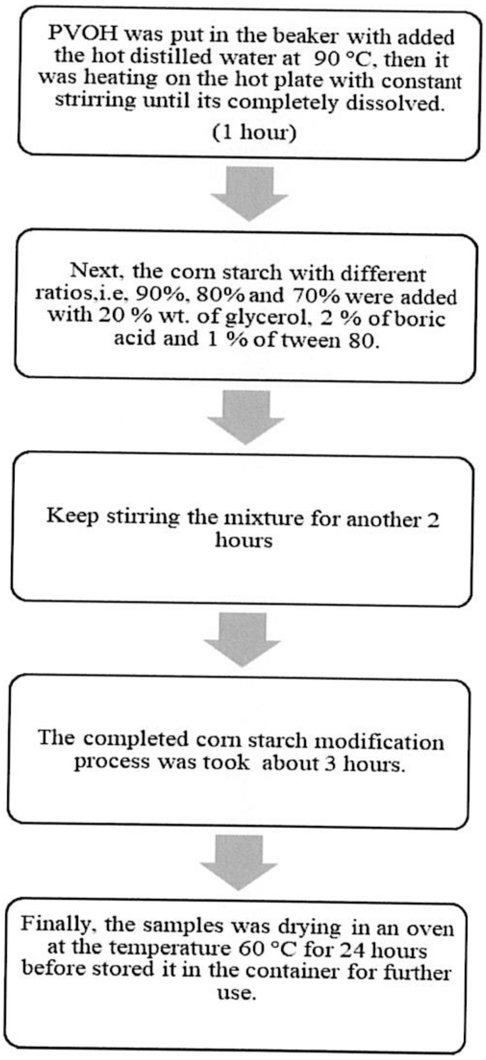
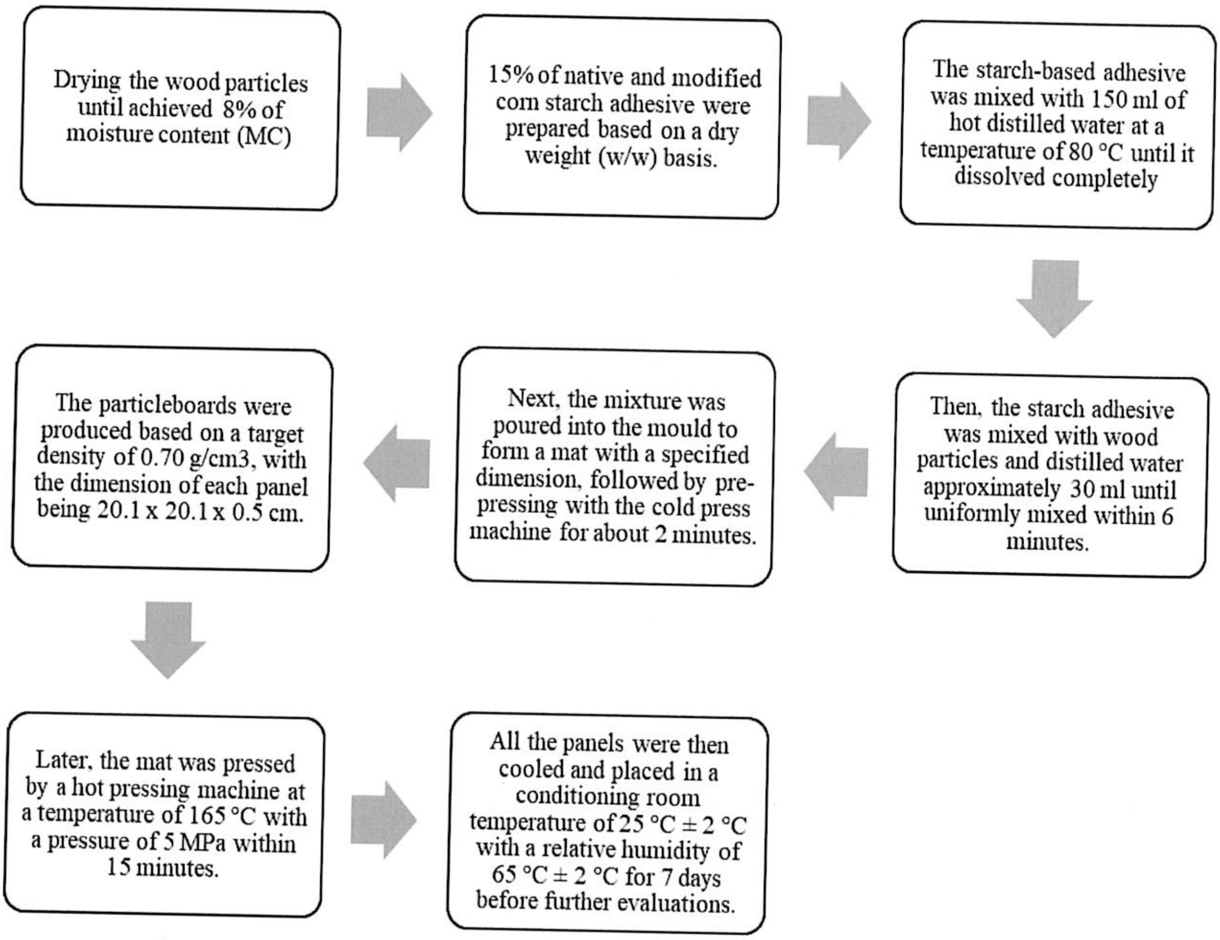


Figure 2: The basic particleboard manufacturing process.



3.3 Starch Adhesive Properties Evaluation

Swelling power and solubility was determined based on the previous methods (Sulaiman et al., 2013). Approximately 1 g of starch was weighed and poured into a 50 ml centrifuge tube with a coated screw cap. About 10 ml of distilled water was added to the samples. Each native and modified corn starch was prepared in three samples for this experiment. Then, all the tubes were shaken for 2 minutes with a portable shaker before being heated at different temperatures at 50 °, 60 °C, 70 °C, 80 °C, and 90 °C for 40 min in a water bath, respectively. After the samples were heated, each sample was cooled at room temperature for 30 minutes and centrifuged at 3000 rpm for 20 minutes. The materials adhered to the centrifuge tube wall are considered the sediment and weighed (Ws). Then, the supernatant was dried to constant weight (W1) in an oven-dry at a temperature of 100 °C. The water-soluble index (WSI) and swelling power (SP) were calculated as Equation (1) and Equation (2).

$$WSI = [W_1/0.1] \times 100\ \% \qquad (1)$$

$$SP = W_s / [0.1\ (100\ \% - WSI)] \quad (g/g) \qquad (2)$$

The solid content of native and modified corn starches was measured using a method adapted from a previous study (Sulaiman et al., 2013). Approximately 1 - 2 g of starch was weighed before drying in the oven at 105 °C ± 2 °C for 3 h. After 3 hours, the samples were put in a desiccator for approximately 10 min to obtain a constant weight. Then the samples were reweighed again to obtain the oven-dry (OD) weight. A duplicate sample was prepared for native and modified corn starch samples. The percentage of solid content was calculated based on Equation (3):

$$\textit{Solid content, \%} = \frac{\textit{Total mass of the sample after drying}}{\textit{The total mass of the sample before drying}} \times 100 \qquad (3)$$

The viscosity of native and modified corn starches was measured using a Brookfield DVII Viscometer with a spindle size No.7 at 100 pm. Approximately 10 % (w /v) of the samples was placed in a 50 ml test tube and dissolved in 25 ml of distilled water. The samples were heated in a water bath at a temperature of 80 °C ±2 °C for 10 minutes to allow all the samples to be dissolved completely. Then, the viscosity properties were analyzed with three readings for each sample type. The pot life evaluation was prepared by mixing the starch with distilled water at approximately 80 °C until it forms a paste and left inside the container until it became too thick to be spread.

3.4 Physical and Mechanical Test Evaluations

The physical and mechanical properties were tested according to Japanese Industrial Standard (JIS) A 5908, 2003 (Japanese Industrial Standard A 5908 2003). The moisture content (MC), basic density test, thickness swelling, and water absorption were tested for physical properties. Meanwhile, the bending strength test, such as modulus of elasticity (MOE), modulus of rupture (MOR), and internal bonding test (IB), was done for mechanical properties. Ten (10) samples from each type of board were cut at 5 cm x 20 cm for bending strength tests. The fifteen (15) samples from each type of board panel with 5 cm x 5 cm x 0.5 cm were used for the internal bonding test (IB). The test was carried out on an Instron Testing Machine Model 5582 using crosshead speeds of 10 mm/min and 2 mm/min for bending strength and internal bonding test, respectively.

3.5 Statistical Analysis

The mean comparisons were performed with the Duncan Multiple Test at $p \leq 0.05$. The results of the evaluation were expressed as mean and standard deviation.

4.0 Results and Discussion

4.1 Adhesives properties

Figures 3 and 4 illustrated the swelling power and solubility of native and modified corn starches. Both graphs were shown an increase as the temperature was increased from 60 °C to 80 °C. Both native and modified corn starches were more effective when the temperature increased to 70 °C. It may cause by the crosslinking had occurred in the corn starch and polyvinyl alcohol (PVOH). This finding is also found in oil palm starch modification, suggesting that the binder can be more resistant to moisture (Mohamad Amini, Hashim, and Sulaiman 2019).

Figure 3: Swelling power (SP) of native and modified corn starch-based adhesives.

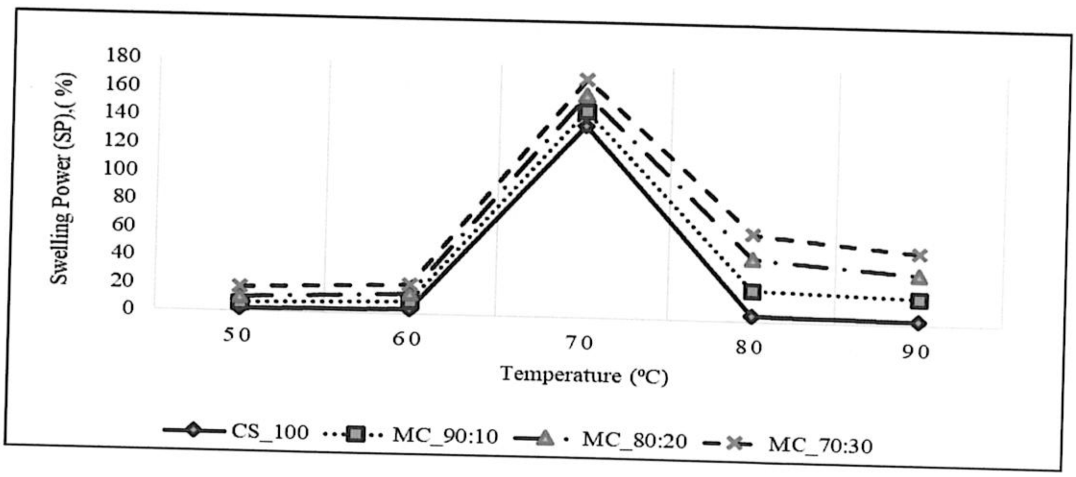
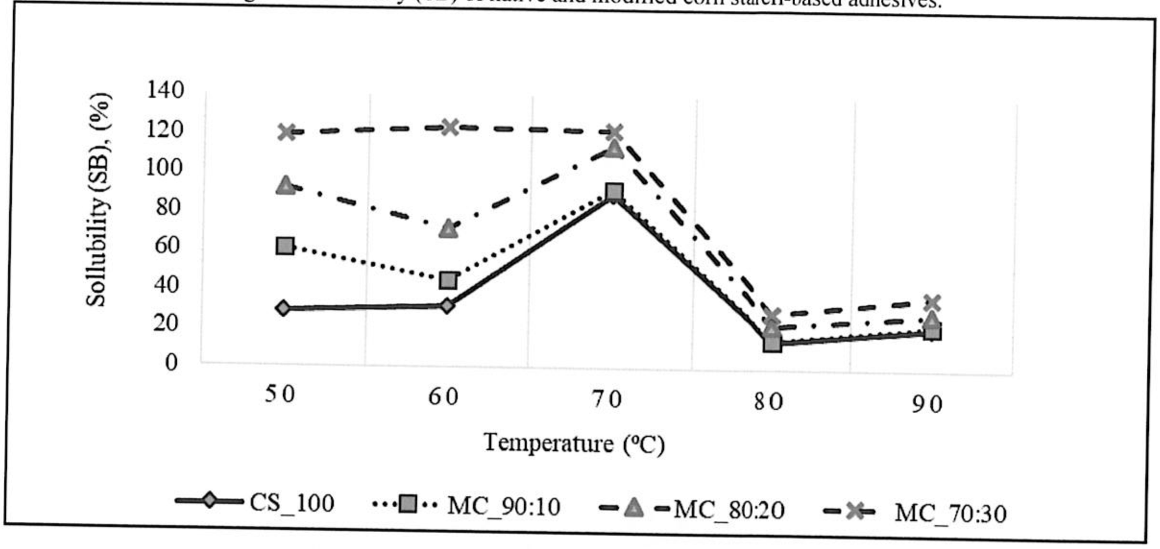


Figure 4: Solubility (SB) of native and modified corn starch-based adhesives.



Another study revealed that the starch swelling power and solubility tended to increase when the temperature was set from 50 °C to 90 °C (Sulaiman et al., 2016). Generally, increases in swelling power are directly proportional to solubility properties.

Table 1: Adhesive properties of native and modified corn starch-based adhesives involved in this study.

Samples	Solid content at 105 °C ± 2 °C	Viscosity at 80 °C (Centipoise), cP	Pot Life (Hours)
CS_100	32.71(10.28)a	124.33(4.04)a	36 (0.00)a
MC_90:10	30.38(0.33)a	224.33(4.04)b	36 (0.00)a
MC_80:20	29.83(1.81)a	270.67(6.08)c	36 (0.00)a
MC_70:30	30.44(0.83)a	262.00(11.53)c	36 (0.00)a

Note: Data is expressed as means; values in parentheses show standard deviations. Values with the same letter are not significantly different ($p< 0.05$). CS_100: 100 % of corn starch; MC_90:10: 90 % of corn starch: 10 % PVOH; MC_80:20: 80 % of corn starch: 20 % PVOH; MC_70:30: 70 % of corn starch: 30 % PVOH.

Table 1 shows the basic adhesive properties of native and modified corn starch obtained in this study. The solid content for native and modified corn starch obtained from this study ranged from 29 .83 % to 32.71 %. Higher solid content would give a higher ability to the corn starch creates a new bonding between the adhesive and wood particles, thus will improve the mechanical properties of particleboard (Siddaramaiah, Raj, and Somashekar 2004; Amine Moubarik et al. 2010). However, higher solid content will affect higher viscosity values of the starch-based adhesives and will reduce the pot life properties (Salleh et al., 2015). The higher viscosity values in all modified corn starch obtained values ranged from 224.33 cP to 270.67 cP compared to native corn starch, only obtained with a value of 124.33 cP. Mixing the corn starch with PVOH tends to increase the viscosity properties. However, there is no significant difference found in pot life results for both native and modified corn starch-based adhesives, which only can use within 36 hours only. Longer pot life will give the wood adhesive that can be stored at room temperature.

4.2 Particleboard Properties

Table 2 shows the physical properties of particleboard obtained in this study. The values revealed for moisture content (MC) and density was obtained ranged from 7.12 % to 7.31% and 0.69 g/cm3 to 0.75 g/cm3, respectively. All the MC and density values were passed the minimum qualifications in the JIS standard for type 8 indoor particleboard. Performance of dimensional test also tabulated in Table 2. The thickness swelling (TS) did not meet the minimum requirement of 12%, as stated in the JIS standard. The TS has successfully obtained values below 50% and 150% for water absorption (WA). The lowest value was found in MC_70:30 due to less corn starch in the mixture. The starch has a hydrophilic characteristic, reflecting a higher water uptake in the samples.

Table 2: Physical Properties of Particleboard involved in this study.

Samples	Moisture Content (MC) (%)	Density (g/cm3)	Thickness Swelling (TS), (24 hours) (%)	Water Absorption (WA), (24 hours) (%)
CS_100	7.12(0.36)a	0.74(0.09)a	48.22(4.37)c	132.32(13.48)c
MC_90:10	7.27(0.28)a	0.75(0.05)a	46.54(2.62)cd	136.69(7.35)c
MC_80:20	7.13(0.12)a	0.75(0.01)a	43.95(4.12)bc	135.59(12.31)c
MC_70:30	7.08(0.05)a	0.73(0.04)a	40.60(3.30)b	107.54(8.78)b
UF_100	7.31(0.15)a	0.69(0.03)a	36.00(1.89)a	91.37(9.31)a

Note: Data is expressed as means; values in parentheses show standard deviations. Values with the same letter are not significantly different ($p < 0.05$). CS_100: 100 % of corn starch; MC_90:10: 90 % of corn starch: 10 % PVOH; MC_80:20: 80 % of corn starch: 20 % PVOH; MC_70:30: 70 % of corn starch: 30 % PVOH; UF_100: 100% bonded with Urea formaldehyde.

Table 3: Mechanical Properties of Particleboard involved in this study.

Samples	Modulus of elasticity (MOE) N/mm^2	Modulus of Rupture (MOR) N/mm^2	Internal Bonding (IB) N/mm^2
CS_100	2570.55(594.46)b	17.22(4.08)b	2.39(1.33)a
MC_90:10	1940.46(438.88)ab	9.23(2.11)a	5.13(1.52)b
MC_80:20	2054.73(428.39)ab	10.86(2.27)a	2.09(1.01)a
MC_70:30	1882.65(375.47)a	8.90(2.69)a	2.73(1.02)a
UF_100	2039.10(4.68.77)ab	12.24(2.87)a	5.19(0.83)b

Note: Data is expressed as means; values in parentheses show standard deviations. Values with the same letter are not significantly different ($p < 0.05$). CS_100: 100 % of corn starch; MC_90:10: 90 % of corn starch: 10 % PVOH; MC_80:20: 80 % of corn starch: 20 % PVOH; MC_70:30: 70 % of corn starch: 30 % PVOH; UF_100: 100% bonded with Urea formaldehyde.

Table 3 shows the mechanical properties findings of particleboard involved in this study. From the results, it can be revealed that CS_100, MC_80:20, and UF_100 (control samples) had passed the minimum required value of 2000 N/mm^2 for modulus of elasticity (MOE) as stated in the JIS standard. As expected, a low value was found in the MC_70:30 samples because of fewer corn starch ratios in the wood adhesives. Higher starch ratios such as in CS_100 samples had better mechanical properties, especially bending strength properties. Higher purity in corn starch content also supported the better wood adhesive properties and proportionally reflected the best physical and mechanical properties. All the samples had successfully passed the modulus of rupture (MOR), and internal bonding (IB) with the particleboard (CS_100) with 100% native corn starch has a higher value for MOR (17.22 N/mm^2), and MC_90:10 have a higher value for internal bonding (IB) test (5.13 N/mm^2) for particleboard samples bonded with both native and modified corn starch. The compatibility between corn starch and PVOH may attribute to the best adhesion properties, thus successfully enhancing the mechanical properties of particleboard. The findings also supported by previous work suggested that the degree of compatibility between starch and other biopolymers extensively varies depending on the specific biopolymer (Diyana et al., 2021).

5. Conclusion

i. Both native and modified corn starch types can be used as starch-based adhesives, especially for 100% corn starch (native) and 80% corn starch mixed with 20% PVOH (modified) samples.
ii. The better adhesive properties were found in the samples with higher starch content.
iii. Lower values for dimensional stability such as thickness swelling and water absorption were found in samples with less starch content.
iv. The best mechanical properties were successfully achieved in native and modified corn starch samples except for the particleboard bonded with 90% corn starch and 10% PVOH.
v. The role of PVOH as an adhesive and water repellent cannot be denied in this study.
vi. Other crosslinking methods and other additives should be added to the mixture to reduce the water uptake in the samples in the future study.

vii. The low molecule weight of PVOH is also considered in future work to enhance the crosslinking between starch and other additive in starch-based system.

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