RUBBERWOOD PARTICLEBOARD MANUFACTURED USING EPICHLOROHYDRIN-MODIFIED RICE STARCH AS A BINDER

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The objective of this study was to investigate the properties of experimental particleboard panels manufactured using rice starch and epichlorohydrin-modified rice starch with added urea formaldehyde as binders. The physical and mechanical properties of the panels having two density levels, namely 0.60 g/cm^3 and 0.80 g/cm^3 were evaluated as a function of adhesive types. Thermal analysis and morphology of the samples were also determined employing Differential Scanning Calorimetry and Scanning Electron Microscopy, respectively. The panels having 0.80 g/cm^3 density level made with modified starch to which 2% urea formaldehyde was added had the highest mechanical properties. These panels had average values of 23.05 N/mm^2, 3691.50 N/mm^2, and 0.64 N/mm^2 for modulus of rupture, modulus of elasticity and internal bond strength, respectively. It appears that rice starch modified with epichlorohydrin could have a potential to be used as a binder to manufacture particleboard panels with satisfactory properties within the perspective of an environmentally friendly approach.

Keywords: epichlorohydrin, rice starch, particleboard, mechanical properties, Differential Scanning Calorimetry, Scanning Electron Microscopy

INTRODUCTION

The conversion of low-quality timber resources into value-added products, especially into composite wood panels, is an important industry trend in many countries. In the manufacture of structural and non-structural wood composites, including oriented strand board, fiberboards and particleboards, the adhesion process holding components together plays a significant role onthe overall properties of the product. The American Society for Testing and Materials (ASTM) defines "adhesive" as a substance that has the capability to hold materials together by surface attachment. The presence of the adhesive among wood components holds the composite materials together through the cohesion force. Better cohesion improves the strength of the wood composite, especially when complete contact between the material and the adhesive is achieved, so that the members subjected to a certain amount of force distribute and transfer the stress efficiently from one member to another.[1,2]

Commonly used adhesives in wood composites industries, such as the particleboard industry, include synthetic resins, namely formaldehyde based binders, including urea formaldehyde (UF), phenol formaldehyde (PF) and melamine formaldehyde (MF). The extensive use of these resins is based on their ability to produce composite wood products with excellent properties at a low cost. [3]However, using formaldehyde-based resins in panel production may result in adverse environmental and health concerns due to formaldehyde emission.

Low production costs and comparable panel properties with those produced using other synthetic resins are also primary targets in developing a new adhesive. One of the alternatives to this approach could be to use starch

as a raw material to develop environmentally friendly adhesives, which can help reduce the dependence on non-renewable petroleum-based adhesives.[4] Starch is known as one of the bio-renewable materials in addition to sucrose and cellulose. However, starch has become a most valuable material due to its availability and ease of isolation in pure form, making starch easy to modify to improve its characteristics.[5] Starch is known to be of low cost and has the capability to impart a broad range of functional properties to products to be used in food and non-food industries.[6]

Rice is one of the early agricultural grain crops, along with wheat, barley, and corn, which becameprimary sources of starch.[7] Thailand, Vietnam, United States, Burma and Australia are major exporters and contributors to the world rice production, which is around 370 million tons per year. In Malaysia, the production of rice has been gradually increasing every year. To keep the price of rice as low as possible, the Malaysian government has targeted to increase the rice production, and responsible organizations, such as the Malaysian Agricultural Research & Development Institute (MARDI), have carried out several types of research to increase the production of rice in order to achieve the Malaysian government's mission.[8] Therefore, it would be possible to utilize rice starch as a raw material to produce at a low cost an environmentally friendly adhesive for use particleboard production.

Modification of rice starch has been carried out by some researchers to enhance its overall characteristics, as compared to those of its native form. Modification of rice starch through the acetylation process by using acetic anhydride was carried out by González and Pérez.[9]According to their study, acetylation of rice starch affected its composition, physical and chemical character-ristics as well as its functional and rheological properties due to the presence of high acetyl groups in this modified starch. Another modification of rice starch was carried out by Yeh and Yeh[10] through the cross-linking reaction by using phosphorous oxychloride ($POCl_3$), hydroxypropylated with propylene oxide and dual-modified with both reagents. The results indicated that cross-linking of rice starch improved the bonding of rice starch molecules, while hydroxypropylation of rice starch loosened its structure, which affected the gelatinization temperature of rice starch. Through a dual-modified starch procedure, it was revealed that the cross-linking reduced the degree of subsequent hydroxypropylation, while hydroxypropylation increased the level of subsequent cross-linking. Wang and Wang[11] also conducted a research project on the structures and physicochemical properties of acid-thinned corn, potato and rice starches. In this work, it was concluded that the functionality of starches after the modification was influenced by their native molecular structures and their physicochemical properties as a result of the acid treatment.

However, the modification of rice starch through the cross-linking reaction by using epichlorohydrin as its reagent has not been studied yet, neither has its application in particleboard manufacturing been reported yet. Epichlorohydrin is mostly employed to make a thermosetting polymer, namely epoxy. Epichlorohydrin is usually produced in a multi-step process using propylene and chlorine as raw materials.[12] Epichlorohydrin is known as a proper cross-linking reagent, despite its toxicity. According to Jyothi *et al*.,[13] the modification of starch with epichlorohydrin as reagent results in the formation of distarch glycerols. The ether linkages between the cross-links and the hydroxyl groups will form starch granules. Moreover, minimal residual levels of epichlorohydrin are expected in the final products, as it will hydrolyse due to the high temperature during the production process. Consequently, the toxicity of epichlorohydrin from final products would be negligible. Therefore, this study aims to investigate and compare the properties of particleboard panels manufactured from rubberwood raw material using epichlorohydrin-modified rice starch (EMRS), native rice starch (NRS) and epichlorohydrin-modified rice starch with added UF resin (EMRSUF). Based on the findings of this work, it is expected that such binders could have a potential to be commercialized as green adhesives in the particleboard industry.

EXPERIMENTAL

Starch modification and particleboard manufacturing

Rice starch supplied by Sigma-Aldrich was modified according to the methodology described by Jyothi *et al*.[13]Approximately 40 ml distilled water was added to 20 g rice starch powder and mechanically stirred until it was completely dissolved. In the next step, rice starch solution was placed in a water bath,

gradually increasing the temperature to 90 °C, while continuously stirring it using an overhead stirrer. Once the temperature of the solution passed 55 °C, epichlorohydrin was added to the rice starch solution at a ratio of 1:4 (w/w). The addition of epichlorohydrin into the starch solution will cause the formation of ether linkages between the cross-links and hydroxyl groups of the starch granules.[14] The mixture was continuously stirred until its temperature reached 90 °C and left to cool to room temperature before it was used in particleboard manufacturing.

Five particleboard panels for each set were manufactured with two targeted densities, namely 0.60 g/cm^3, 0.80 g/cm^3 and using two pressing times of 15 min and 20 min. The thickness of the particleboardwas set to 0.5 cm and was controlled by a thickness bar. Rubberwood (*Hevea brasiliensis*) particles were obtained from HeveaBoard Sdn Bhd located at Seremban, Negeri Sembilan, Malaysia. Particles were dried in an oven to a moisture content of about 2% prior to the application of starch as adhesive. Fifteen percent starch-based on the oven-dry weight of the raw material was mixed manually with rubberwood particles. Approximately 2% urea formaldehyde (UF) based oven-dry weight resin was also added to 13% starch adhesive in the preparation of the epichlorohydrin-modified rice starch for the UF added resin panel. Later, a mat with the dimension of 20.1 cm by 20.1 cm by 0.5 cm was manually formed. Pre-pressing of the mat was done by cold pressing. The mat was then pressed at a temperature of 165 °C using a pressure of 5 MPa for 15 and 20 min, respectively. The panels were then conditioned in a climate room at a temperature of 25 ± 2 ºC and a relative humidity of 65 ± 2% for several days before thetest.

Evaluation of starch properties

The swelling power and solubility of the rice starch were determined according to the methodology applied by Ačkar *et al.*[15] Suspensions of 5% rice starch were prepared by dilution in distilled water. Starch suspensions were heated at 50, 60, 70, 80 and 90 °C for 30 min with continuous stirring. Hot dispersions were cooled to room temperature and centrifuged at 2000 rpm using a GS-15 centrifuge, Beckman, Germany for 10 min. The supernatant formed was decanted. The solubility of the rice starch was determined by the weight of sediment over the dry weight of starch, as shown in Equation 1:

$$\text{Solubility, \%} = \frac{\text{Mass of starch in supernatant, g}}{\text{Mass of starch in aliquot, g}} \times 100 \quad (1)$$

The swelling power was calculated using Equation 2:

$$\text{Swelling power, \%} = \frac{\text{Mass of wet residue, g}}{\text{Mass of dry residue, g}} \times 100 \quad (2)$$

The degree of crosslinking (DC) of the modified starch was also qualitatively measured based on the methodology stated by Chatakanonda *et al.*[16] The measurements were carried out based on the rheological properties of starch by using a rotary rheometer (AR1000-N). The starch slurry was heated up from 30 °C to 95 °C at 12 °C/min and then held at a temperature of 95 °C for 2 min. In the next step, the temperature of the mixture was reduced from 95 °C to 30 °C at an interval of 12 °C/min for cooling and finally held for another 2 min. The DC values of the samples were calculated using Equation 3:

$$\text{Degree of crosslinking} = (A - B) / A \times 100 \quad (3)$$

where A is the peak viscosity of the native rice starch sample and B is the peak viscosity of the modified starch.

Properties of particleboard panels

The physical properties of a panel, including density, moisture content, thickness swelling (TS) and water absorption (WA), were evaluated based on the Japanese Industrial Standard (JIS).[17]Panels were cut to a size of 5 cm x 5 cm. Fifteen samples were taken from each set of panels and were used for density, TS and WA tests, respectively, while moisture content value was taken from the average reading of 5 samples. The measurement of the length, width, thickness and mass was carried out for each sample and the values obtained were used to calculate the actual density of the panels. The evaluation of TS and WA was carried out by measuring the thickness and weight of each sample before the samples were soaked in distilled water. The increase in the thickness and weight of each sample was recorded after they were soaked in water for 2 h and 24 h. The moisture content value was determined using the mass reading of the samples before and after the samples were dried in an oven until the samples reached their constant weight.

The mechanical properties of the panels, including modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) strength, were also determined based on the Japanese Industrial Standard (JIS).[16] Ten samples of a size of 5 cm x 20 cm were cut from each panel set for MOR and MOE tests, respectively, while 15 samples with a size of 5 cm x 5 cm were cut for the internal bond strength test. All mechanical tests were carried out on an Instron Testing System Model 5582 using crosshead speeds of 10 mm/min and 2 mm/min for bending and internal bond strength tests, respectively.

Differential Scanning Calorimetry (DSC) analysis of the samples

The melting temperature (T_m) was determined using Perkin Elmer Thermal analysis (Model DSC 8000) with an empty pan as a reference. A weighed powder sample of the panel of approximately 5 mg was placed into the aluminium pan. The sample was transferred to the heating container before being heated up at a heating rate of 10 °C/min over a temperature

range between -15 °C and 280 °C under nitrogen atmosphere. The melting temperatures were determined by inspecting the DSC curves obtained from this analysis.

Scanning Electron Microscopy (SEM) analysis of the samples

Small cubes were cut from a cross section of the particleboard panels. The sample was glued to a stub using tape and then was coated using a Polaron SC515 SEM coating system (Fisons Instruments) in a thin layer of gold to make it conductive. A Scanning Electron Microscope (Model Supra 50 VP) was used to examine the sample with a voltage acceleration of 15 kV.

RESULTS AND DISCUSSION

Properties of starch

Figures 1(a) and 1(b) illustrate the swelling power and solubility for both native and modified rice starch, respectively. The observations on these two graphs revealed that the swelling power and solubility of starch increased as the temperature increased from 50 °C to 90 °C. This observation is common, as also reported by other researchers. Starch comprises certain components, such as amylose, which is able tosolubilize in water. This allows the starch granules to be attacked by water and increases the swelling power of starch. The increase in the swelling power also enhanced the solubility of the samples.[18] The swelling and solubility of the samples were decreased by modification with epichlorohydrin, suggesting that some cross-linking could have taken place. This isbecause the cross-linking between modified starch granules will restrain these starch granules from being swollen and extremely soluble in water at a specified temperature.

The percentage for the degree of cross-linking (DC) of the modified rice starch adhesive used in this study was 76.38%. This value is quite high as compared to that obtained previously by Xiao *et al.*[19] This study showed a positive correlation between the degree of cross-linking and the swelling power of starch, as well as its solubility. A high percentage of the cross-linking degree leads to a smallrate of swelling power and solubility of the starch. This observation is also in agreement with the results reported in previous works.[13,20]

Properties of particleboard panels

Tables 1 and 2 display average values for physical and mechanical properties of the panels manufactured with a target density of 0.60 g/cm^3 and 0.80 g/cm^3. From Table 1, it can be noted that the panels produced at 0.60 g/cm^{3}density with 15 and 20 min pressing times had only slight differences in the actual density values within all the types of panels manufactured. The same trend was also observed for the panels with the density level of 0.80 g/cm^3, as shown in Table 2. The average moisture content reading for all types of 0.60 g/cm^3 panels were in the range of 5.64-6.83% and 5.67-6.78% for 15 and 20 min pressing times, respectively, as shown in Table 1. While for all types of 0.80 g/cm^3 panels, the average moisture content value was in the range of 5.75-6.74% and 6.34-6.53% for 15 and 20 min pressing times, respectively (Table 2). It appears that there is only an insignificant difference in moisture content values among all the types of the panels manufactured. All moisture content values ranged from 5 to 13% in this work and met the JIS requirement.

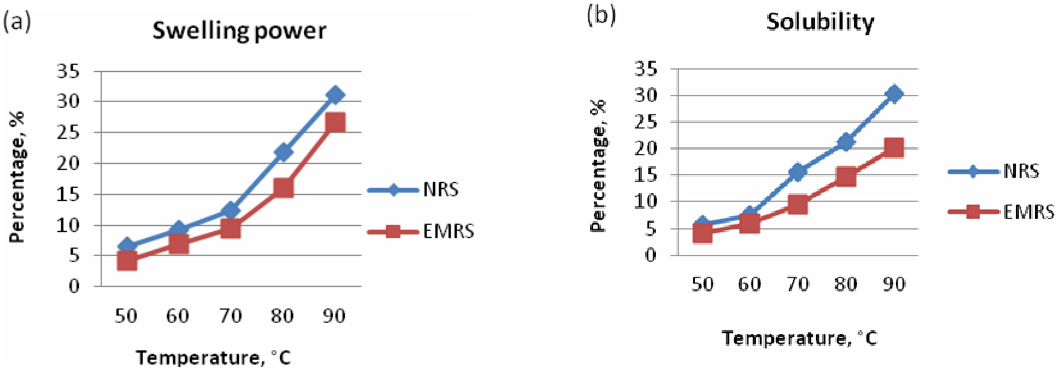

Figure 1: (a) swelling power and (b) solubility of native rice starch (NRS) and epichlorohydrin-modified rice starch (EMRS)

Table 1
Physical and mechanical properties for different types of particleboard panels with 0.60 g/cm^3 targeted density

Type of particleboard	Pressing time (min)	Physical properties						Mechanical properties		
		Actual density (g/cm^3)	Moisture content (%)	Thickness swelling (%)		Water absorption (%)		Bending strength (N/mm^2)		IB (N/mm^2)
				2 hour	24 hour	2 hour	24 hour	MOR	MOE	
NRS	15	0.56 (0.04)	5.64 (0.19)	48.56 (10.93)	63.43 (10.22)	140.16 (9.54)	156.77 (10.15)	10.08 (1.65)	1651.73 (295.99)	0.23 (0.14)
EMRS		0.64 (0.05)	5.34 (0.43)	28.98 (8.26)	35.31 (5.17)	99.52 (7.11)	125.39 (7.77)	13.52 (1.91)	2546.29 (736.64)	0.39 (0.18)
EMRSUF		0.63 (0.02)	6.83 (1.27)	24.63 (4.20)	32.19 (5.41)	93.01 (3.01)	102.27 (3.95)	15.56 (2.11)	2851.50 (457.46)	0.61 (0.12)
NRS	20	0.56 (0.04)	5.67 (0.15)	60.48 (15.93)	75.99 (15.10)	149.88 (7.59)	175.89 (8.26)	9.56 (1.65)	1821.27 (276.40)	0.22 (0.04)
EMRS		0.64 (0.03)	5.25 (0.39)	30.32 (6.82)	45.01 (3.88)	103.38 (6.23)	127.91 (6.04)	12.73 (1.64)	2264.01 (321.61)	0.35 (0.17)
EMRSUF		0.63 (0.04)	6.78 (1.67)	28.35 (6.19)	40.06 (7.96)	96.82 (5.77)	103.54 (3.87)	14.10 (1.74)	2737.37 (254.88)	0.50 (0.13)

[a]data is expressed as average;
[b]values in parenthesis indicate standard deviation;
[c]NRS: nativerice starch, EMRS: epichlorohydrin-modified rice starch, EMRSUF: epichlorohydrin-modified rice starch impregnated with UF resin, MOR: modulus of rupture, MOE: modulus of elasticity, IB: internal bond strength

Table 2
Physical and mechanical properties for different types of particleboard panels with 0.80 g/cm^3 targeted density

Type of particleboard	Pressing time (min)	Physical properties						Mechanical properties		
		Actual density (g/cm^3)	Moisture content (%)	Thickness swelling (%)		Water absorption (%)		Bending strength (N/mm^2)		IB (N/mm^2)
				2 hour	24 hour	2 hour	24 hour	MOR	MOE	
NRS	15	0.79 (0.03)	5.75 (0.30)	68.75 (19.11)	85.86 (12.98)	135.49 (17.42)	173.34 (12.33)	14.57 (1.46)	2970.49 (431.92)	0.30 (0.07)
EMRS		0.80 (0.04)	5.43 (0.18)	46.59 (8.23)	67.33 (8.48)	94.97 (7.18)	127.81 (7.53)	16.17 (1.62)	3195.71 (574.51)	0.52 (0.02)
EMRSUF		0.79 (0.02)	6.74 (0.19)	44.67 (10.35)	67.10 (9.69)	92.93 (6.22)	99.24 (4.28)	23.05 (1.95)	3691.50 (362.96)	0.64 (0.21)
NRS	20	0.80 (0.03)	6.34 (0.62)	61.67 (9.04)	81.77 (11.58)	111.93 (17.24)	148.18 (21.16)	13.93 (1.75)	2893.71 (428.50)	0.28 (0.08)
EMRS		0.81 (0.04)	6.10 (0.70)	45.49 (5.75)	60.49 (5.80)	93.95 (2.79)	106.59 (8.44)	15.20 (1.94)	2547.98 (646.28)	0.45 (0.13)
EMRSUF		0.78 (0.02)	6.53 (0.10)	32.19 (10.51)	59.70 (5.33)	77.75 (13.96)	92.99 (2.51)	18.17 (1.78)	3435.86 (533.99)	0.64 (0.11)

[a]data is expressed as average
[b]values in parenthesis indicate standard deviation
[c]NRS: nativerice starch, EMRS: epichlorohydrin-modified rice starch, EMRSUF: epichlorohydrin-modified rice starch impregnated with UF resin, MOR: modulus of rupture, MOE: modulus of elasticity, IB: internal bond strength

The results of TS and WA tests showed that the modification of rice starch improved the overall dimensional stability of the panels. The NRS panel showed less resistance to water absorption, resulting in higher mean values of TS and WA. These values decreased when modified rice starch was used as a binder, as in the case of EMRS type panels and panels made with modified starch with added UF resin having lower corresponding values. These results were observed for both 2 h and 24 h immersion periods. As discussed earlier, the reduction in swelling power and solubility of modified starch resulted in better TS and WA values of the panels. The cross-linking of starch reduced the swelling and solubility of starch because of its compact structure.[21] Thus, the use of modified starch as a binder reduced the TS and WA values by the reduction of its capability to absorb water compared to native starch, as reported by López *et al*., as well as Hamdi and Ponchel.[20,21] The UF resin is known to have poor water resistance compared to other commercially available synthetic resins, such as phenol formaldehyde.[22] However, the addition of UF to modified starch resulted in lower water absorption of the panels because high hydrolytic stability characterised the UF resin when it was cured at high temperature,[23] similar to the one used in this study. Another reason for this was better bonding of the UF resin with the wood particles. These properties enhanced the dimensional stability of the samples, as shown by the results obtained in this study.

As displayed in Tables 1 and 2, the TS values of the samples also increased with increasing density of the panels, while the reverse was observed for the WA values. This phenomenon is common, as reported by Khedari *et al*.[24] Cellulose is the primary component in rubberwood-rice starch particleboard, which is responsible for water uptake. The long chain molecules in fiber were pushed apart as the amorphous region in cellulose absorbed water. This resulted in thickness swelling of the sample, since the particles were compressed to each other in the panel during hot pressing.[25] Therefore, high-density particleboard had a high value of TS because of the large amount of particles existing in a panel, which means a largequantity of cellulose was present. Meanwhile, the lower mean value of WA, which occurred in high-density particleboard, was because the contact between particles was greater during the manufacturing of high-density particleboard, making them tightly compressed. This caused the starch present in the void spaces between the particles to be cured efficiently. Thus, the WA mean values were lower because only a small number of empty spaces were present in high-density particleboard for water storage.[26]

In this study, none of the TS and WA mean values of the specimens met the JIS requirement of 12% for 2 h soaking time. Further treatment needs to be carried out such as the use of a surface coating on particleboard, treating the particles with modified chemicals before panel manufacturing[27] or the addition of wax during the mixing of starch and particles[28] to have better TS and WA mean values to meet the requirement of JIS standard.

Mechanical properties of the panels

The mechanical properties, including MOR, MOE and IB strength, of the panels manufactured with 0.60 and 0.80 g/cm^3 target density were significantly improved by the use of modified rice starch with added UF resin. This is due to the alteration of native starch, resulting in the formation of a starch highly resistant to mechanical shear through the cross-linking reaction.[13] The cross-linking reaction occurring in the starch granules also contributed to better bonding between them and rubberwood particles. Meanwhile, the addition of UF into the modified starch gradually increased the mechanical strength of the panels beyond that of the panels manufactured using native or modified rice starch. The bonding strength was improved more by the presence of UF resin with modified starch due to the fact that UF resin provides better cohesion between the materials it glues.[29]

The mechanical properties of the panels increased with increasing density. With higher density, the bonding formed between the starch and the particles was stronger as a result of the higher compaction ratio of the particles. Therefore, the curing of the starch occurred more efficiently, which contributed to the high mechanical properties of the panels.[30] A large amount of particles in the high-densitypanel also ledto thehigh mechanical strength of the panel due to the largenumber of fibrous materials present, thus offering better resistance against higher mechanical load.[26]

Panels produced with 15 min pressing time had higher mechanical strength as compared to those manufactured with 20 min pressing time. This trend was found for both panels made with

0.60 and 0.80 g/cm^3 targeted density levels. All the mechanical strength values in this study met the JIS requirement for a panel with 0.5 cm thickness, which required 8 N/mm^2 and 0.15 N/mm^2 for MOR and IB strength, respectively.

Differential Scanning Calorimetry (DSC) analysis

The DSC analysis was carried out to investigate the melting temperature (T_m) of the manufactured panels. The results are shown in Figure 2. The DSC curves of the panels constructed with 15 and 20 min pressing times are presented separately in Figures 2(a) and 2(b), respectively. The melting temperature (T_m) of the panels manufactured with 15 min pressing time was lower than that of the panels made with 20 min pressing time. Low onset temperature (T_o) was also observed for the same panels. Considering the type of binder used, NRS panels manufactured with both 15 and 20 min pressing times had the highest melting temperature compared to the others. The EMRSUF panels produced with both 15 and 20 min pressing times had the lowest melting temperature, as well as the lowest onset. This result corresponds with the findings of TGA analysis, which revealed that the panels manufactured using starch modified with epichlorohydrin with the addition of UF resin (EMRSUF) had the lowest thermal stability, followed by EMRS type of panels and NRS type of panels. According to this finding, the correlation among thermal analysis, crystallinity index and mechanical properties of the manufactured panels can be clearly observed. Panels with high thermal stability were found to have a high crystallinity index and low mechanical properties.[31]

Scanning Electron Microscopy (SEM) analysis

Figure 3 shows the typical SEM micrographs of the cross section for all types of panels with a target density of 0.80 g/cm^3 with different magnifications. As can be seen from this figure, all the types of binders used in this study were dispersed evenly, embedding in between the rubberwood particles. The cell wall structures of rubberwood particles for all the types of panels were compact due to the compressing pressure to which they were subjected during the manufacturing process.

However, this observation can only be clearly seen on the SEM micrograph of the EMRSUF panel (Figure 3c), followed by the SEM micrographs of the EMRS panel (Figure 3b) and of the NRS panel (Figure 3a).

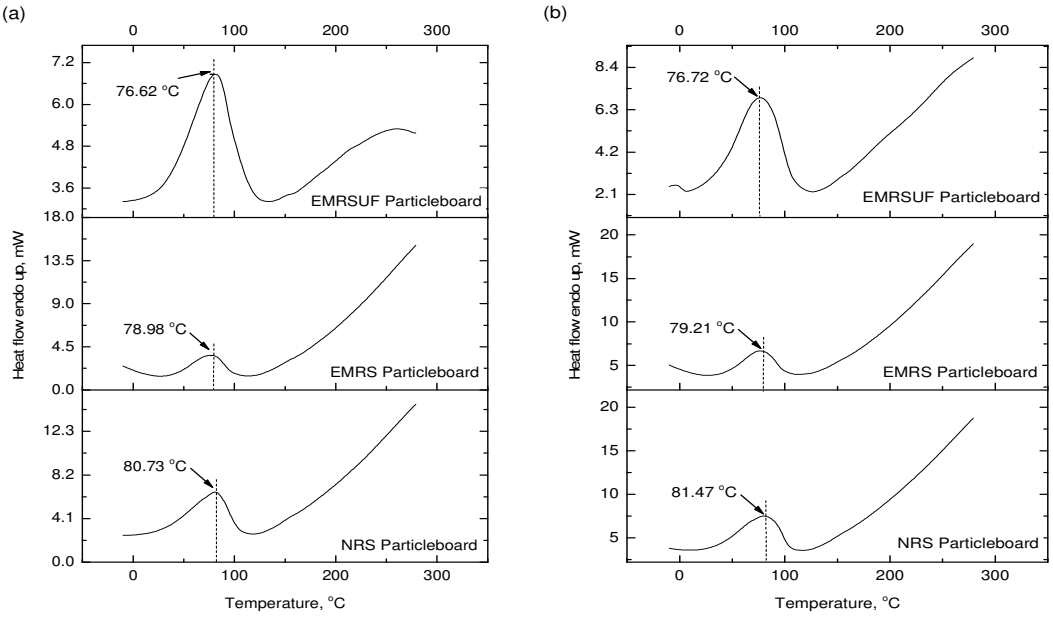

Figure 2: DSC curves of NRS, native rice starch; EMRS, epichlorohydrin-modified rice starch; and EMRSUF, epichlorohydrin-modified rice starch with added urea formaldehyde resin panels with 0.80 g/cm^3 target density manufactured with (a) 15 min, and (b) 20 min pressing time, respectively

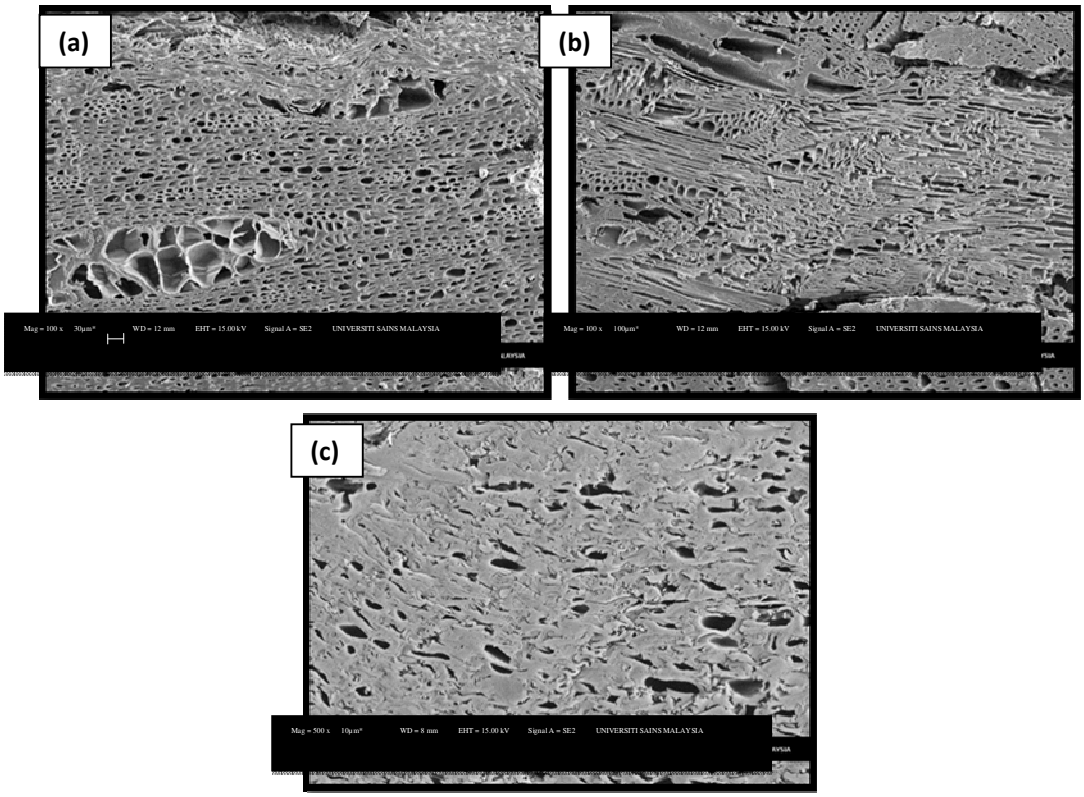

Figure 3: SEM micrographs showing cross section view of (a) NRS, native rice starch (b) EMRS, epichlorohydrin-modified rice starch and (c) EMRSUF, epichlorohydrin-modified rice starch with added urea formaldehyde resin panels with 0.80 g/cm^3 target density manufactured with 20 min pressing time

The compatibility between the UF resin and modified starch resulted in better bonding formed between the particles and the starch molecules in the EMRSUF panel. Consequently, higher physical and mechanical properties of the manufactured EMRSUF panels could be obtained compared to the other panelsmade by using native and modified starch without the addition of UF.

CONCLUSION

Based on the findings of this work, both mechanical and physical properties of the samples made using modified rice starch were enhanced. The addition of UF resin into the binder resulted in additional improvement of the panel properties beyond those of the panels manufactured by using native and modified rice starch only. The mechanical properties of the panels made in this work met the requirements of the JIS standard. However, the dimensional stability of the samples did not satisfy the minimum requirements stated in the above standard. This shortcoming, however, can be enhanced using several methods, as reported by the other researchers.

High thermal stability and high crystallinity index were found for the panels manufactured using native rice starch with 20 min pressing time. The lowest thermal stability and crystallinity index were found for the panels manufactured using modified rice starch with added UF resin with 15 min pressing time. The correlation among the thermal stability, crystallinity index and mechanical properties of the panels was observed in this study, where panels having high thermal stability and high crystallinity index had low mechanical properties. The SEM micrographs revealed that the panel manufactured using modified starch with added UF resin had a compact and tighter structure compared with the ones manufactured using native and modified starch only. This structure allowed better bonding to take place between the binder and the particles in the manufactured samples.

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