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MECHANICAL, PHYSICAL AND THERMAL PROPERTIES OF RATTAN FIBRE-BASED BINDERLESS BOARD

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About 50% is of harvest is wasted when producing rattan furniture. With such huge amount of waste, we undertook a study to convert rattan waste into binderless board with superior properties. This study compared the mechanical and physical properties and morphologies of binderless boards manufactured from rattan fibres with boards made from kenaf, coconut husk and sugarcane bagasse using hot press process. Raw fibres were characterised using scanning electron microscopy and thermal analysis to study their suitability in producing self-bonded board, and then dried in the oven before being hot pressed at a pressure of 147.5 kPa. Modulus of rupture (MOR), internal bonding strength, thickness swelling and water absorption of the manufactured binderless boards were evaluated based on the Japanese Industrial Standards. Results showed that rattan binderless boards exhibited slightly lower MOR and higher internal bonding strength with good dimensional stability compared with the rest of the binderless boards. It was concluded that rattan fibres have high potential to be used as binderless boards under hot press conditions.

Keywords: Natural fibres, kenaf, coconut husk, sugarcane bagasse, hot press

INTRODUCTION

The demand for particleboards is continuously growing mainly in the construction sector, such as for walls and ceiling panels. Most of the commercial particleboards are bonded using formaldehyde-based adhesive, which has negative effects on human health and the environment (Okuda & Sato 2004). Binderless boards were introduced to overcome issues regarding human health and environment that arose in fabrication of particleboards. At the same time, agricultural wastes such as biomass from rattan, sugarcane (bagasse), coconut husk and kenaf are anticipated to increase in the next few years if these wastes are not disposed efficiently. Most of these wastes have become a burden to the environment due to open burning and illegal dumping (Olorunnisola & Adefisan 2002, Luo & Yang 2012).

Binderless boards have been developed using lignocellulosic materials such as kenaf (Okuda & Sato 2004), coconut husk (van Dam et al. 2004), bagasse (Widyorini et al. 2005) and oil palm (Hashim et al. 2011). Although at lab-scale production, properties of the binderless boards produced were acceptable and comparatively as good as commercial boards. Kenaf is amongst the most popular materials used in producing binderless boards (Okuda & Sato 2004, Xu et al. 2006, Juliana et al. 2012). It is a fast-growing annual plant that have various applications including building materials, sound insulation as well as reinforcement for composite. Kenaf core has low density and is light and porous which makes it suitable to be used in producing binderless board, although it has low lignin content with high content of hemicellulose (Widyorini et al. 2005, Xu et al. 2006). For the production of binderless boards, lignin is among the important components that act as binder between fibres, while hemicellulose is not favourable as it absorbs moisture. Coconut husk fibres have high volume of lignin, i.e. almost 37%, which contributed to tougher and stiffer fibres compared with other natural fibres (van Dam et al. 2004). In Malaysia, sugarcane bagasse is not widely utilised especially in composite material.

Rattan is a lignocellulose material, and its chemical content is an important factor in its utilisation. Generally, rattan stem consists of holocellulose (71–76%), cellulose (39–58%), lignin (18–27%) and starch (18–23%) (Jasni & Krisdianto 2012). The cellulose and lignin contents correlate significantly with rattan strength. Higher cellulose content increases the modulus of rupture (MOR) of the rattan. Greater lignin content provides stronger bonds between rattan fibres. Rattan is composed of thick walled, heavily lignified and partly sclerified parenchyma cells and vascular bundles (Weiner & Liese 1988), which is good for mechanical interlocking in the production of binderless boards. Thus, these chemical properties are important indicators to identify the optimal utilisation of rattan. Physical (fresh and air-dry water contents, shrinkage and density) and mechanical properties (bending strength) are also taken into account when considering the utilisation of rattan, particularly for large-diameter rattan (Olorunnisola & Adefisan 2002, Jasni & Krisdianto 2012).

About 50% of harvest is wasted during manufacturing of rattan furniture. The wastes are generated from cutting, debarking, skinning and coring process, in chips and powder form. To overcome the problem of disposing rattan waste, this research was conducted to primarily study the suitability of using rattan as raw material in the production of binderless boards compared with kenaf, coconut husk and sugarcane bagasse, where the suitable materials should meet the minimum requirement of board standards. Optimum parameters for manufacturing binderless boards from kenaf, coconut husk and sugarcane bagasse were identified from previous studies (Okuda & Sato 2004, van Dam et al. 2004, Widroyoni et al. 2005, Hashim et al. 2011, Juliana et al. 2012), while the parameters for rattan were based on results of thermal analysis.

MATERIALS AND METHODS

All fibres were collected from available wastes from industrial factories (rattan and kenaf) and market (coconut husk and bagasse). The fibres obtained were ground to fine powder using electronic blender and sieved into particles ranging from 50 to100 μm in size.

Characterisation of raw materials

To understand the structure of each material that contributed to bonding of fibres and affected properties of the binderless board produced, scanning electron microscopy (SEM) observations were done to analyse surface morphologies of the natural fibres. Fibres were mounted onto a copper stub and coated with a thin layer of gold using ion sputter coater. Thermal gravimetric analyses and differential scanning calorimetry were carried out to determine the thermal stability of fibres and their decomposition kinetics as well as their volatile contents. The analyses were performed by gradually raising the temperature up to 600 °C at a heating rate of 20 °C min^{-1} in nitrogen atmosphere. Plots of weight loss of samples against temperature showed the thermal transitions in the materials.

Fabrication of binderless boards

Fibre powder was dried in an oven for 3 days at 40 °C to reduce moisture content before hot press. The powder was poured into a 11 cm × 11 cm stainless steel mould and was hand-pressed before being placed inside a hydraulic hot press machine and pressed under various conditions as shown in Table 1.

Testing of specimen boards

MOR and internal bonding strength of the binderless boards were measured by three-point bending test and tensile test respectively using

Table 1 Parameters used for hot press process

Parameter	Fibre (Part of fibre)			
	Rattan (Whole)	Kenaf (Core)	Sugarcane bagasse (Pith)	Coconut husk (Husk)
Pressing temperature (°C)	180	180	160	155
Preheat time (min)	3	3	1	1
Pressing time (min)	7	5	4	3
Preheat pressure (kPa)	49.1	49.1	49.1	49.1
Pressing pressure (kPa)	147.3	147.3	147.3	147.3

universal testing machine. Dimensional stability (i.e. thickness swelling and water absorption) of the binderless boards was determined by measuring weight and thickness of the specimens before and after 24 hours of soaking in water. All values were compared with the Japanese Industrial Standards A-5908 for Particleboards (JIS 2003). SEM micrographs were used to examine pressed surfaces and cross-sections of the binderless boards.

RESULTS AND DISCUSSION

Characterisation of raw materials

Morphological analysis of raw materials

Morphology of each type of fibre helped in elucidating the bonding mechanism formed during production of binderless boards. SEM micrographs of raw materials (rattan, kenaf, coconut husk and sugarcane bagasse) are presented in Figures 1(a)–(d) respectively. Agglomerations, which consisted of lignin, cellulose and hemicellulose constituents, could be clearly seen on the surface of rattan (Figure 1a). These constituents underwent chemical modification which contributed to the self-bonding and better interlocking between fibres when sufficient heat was applied during fabrication of the binderless boards using hot press process (Widyorini et al. 2005, Rowell 2012). This improved the strength of the binderless board, as seen in its mechanical properties. SEM micrograph for kenaf showed the presence of impurities such as ash and wax (Figure 1b). Hemicellulose and lignin are the cementing materials in this plant cell wall, and fibre bundles were strongly bonded to each other (Widyorini et al. 2005, Mancera et al. 2008). Pores observed in the micrographs helped in interlocking chemical constituents during hot press. Coconut husk had agglomerations, pores and intercellular gaps in the form of shallow cavities which could be clearly observed on the surface of the fibres (Figure 1c). The intercellular spaces in coconut husk fibre are usually filled with lignin, as binders, and fatty substances that hold individual cells firmly in the fibre (Khan & Alam 2012). Sugarcane bagasse had compact, rough and thick-walled fibre cells interlinked with pith (Figure 1d). Bagasse fibre is made up of parallel strips and is superficially covered with extractives consisting of hemicellulose, cellulose and lignin (Chandel et al. 2013).

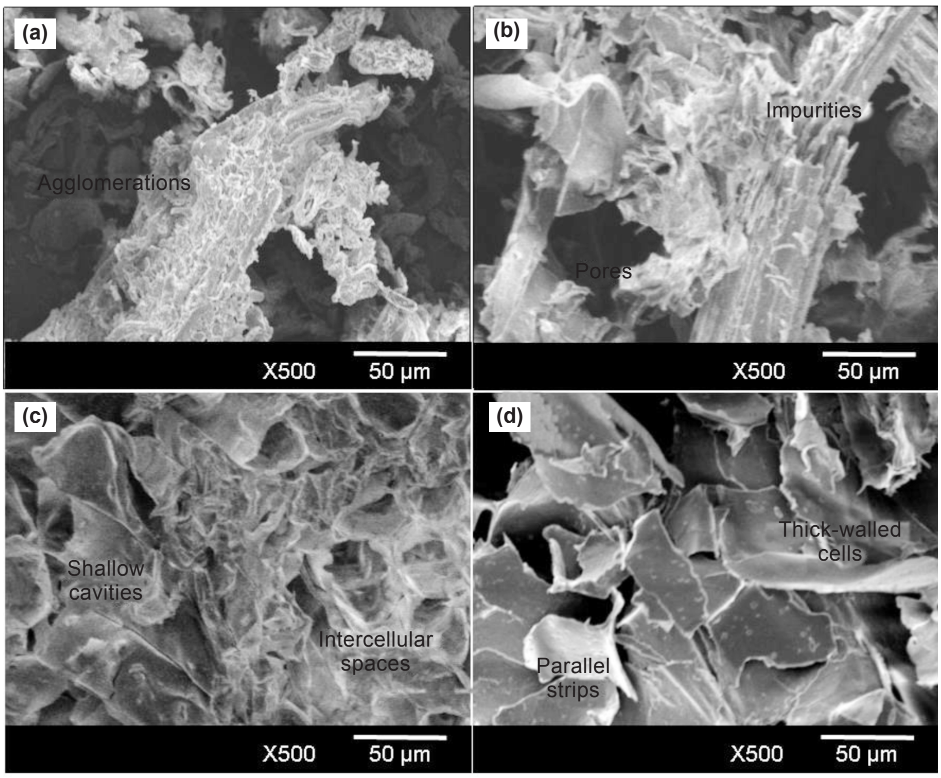

Figure 1 Scanning electron micrographs showing structure of (a) rattan, (b) kenaf, (c) coconut husk and (d) sugarcane bagasse

Thermal analysis of raw materials

Figure 2 shows the thermal gravimetric analysis for each material. Each of the lignocellulosic material contains cellulose and lignin which have different degrees of resistance towards high temperature. Thermal behaviour of the fibres depends mostly on their chemical composition, structure and degree of crystallinity (Fisher et al. 2002). All fibres in this study showed three-step degradation processes. The first degradation step occurred at 36 to 42 °C, and about 5% of mass was lost. This indicated that moisture loss occurred within that temperature range through vapourisation of water from fibres (Hashim et al. 2011, Khan & Alam 2012). Rapid loss in mass occurred at temperature range of 180 to 240 °C in second degradation step due to decomposition of hemicellulose, carbon dioxide and water inside the material. Inflection points in the third degradation step occurred at temperatures 365.9, 400.1, 380.2 and 300.4 °C for rattan, kenaf, coconut husk and sugarcane bagasse respectively. These materials had weight loss of approximately 50%. Thermal decomposition of rattan fibres showed slightly lower thermal stability compared with the rest of the fibres. It is important to avoid exposing the fibres to these inflection points as they will start to degrade and lose most of their strength.

The differential scanning calorimetry graph for each type of fibre after endothermic process is given in Figure 3. Sugarcane bagasse had the highest melting point at 214.7 °C, followed by coconut husk (200.8 °C), rattan (177.4 °C) and kenaf (167.2 °C). Melting points are important to ensure that sufficient heat is applied to enable lignin to flow out of the core of fibres to the surface to be used as natural binder (Mancera et al. 2008). Rattan, kenaf, coconut husk and sugarcane bagasse had eutectic points ranging from 137 to 160 °C (Figure 3).

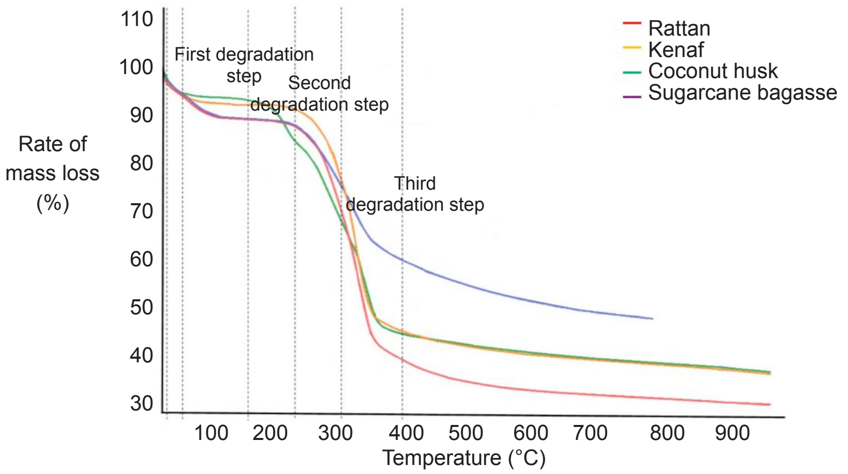

Figure 2 Thermal gravimetric analyses for rattan, kenaf, coconut husk and sugarcane bagasse

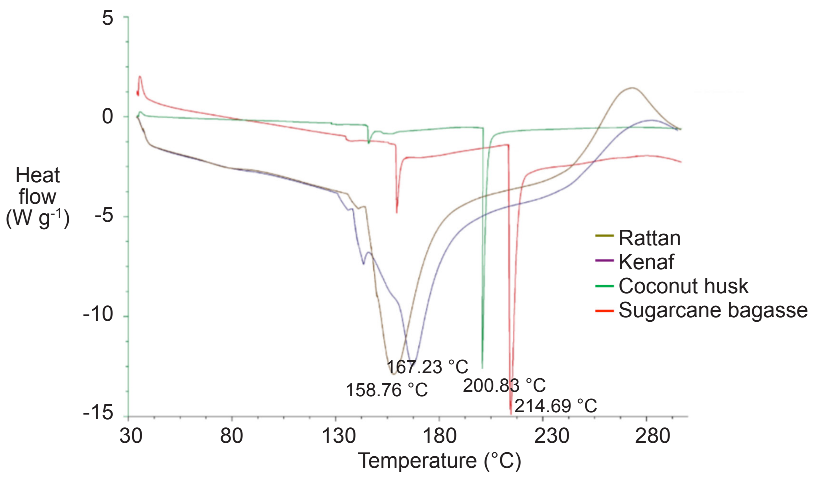

Figure 3 Differential scanning calorimetry for rattan, kenaf, coconut husk and sugarcane bagasse

Mechanical properties of binderless boards

MOR and internal bond strength values for the four binderless boards are illustrated in Figures 4 and 5 respectively. Kenaf binderless board had the highest MOR value (52.8 MPa), followed closely by rattan (48.8 MPa). Kenaf and rattan binderless boards met the minimum MOR requirement of 18.0 MPa recommended by JIS (2003). MOR of 17.82 MPa obtained in this study for sugarcane bagasse binderless board was about 90% higher than the value obtained by Widyorini et al. (2005). MOR value for coconut husk binderless board (9.52 MPa) was almost 80% lower than that reported by van Dam et al. (2004). The huge differences in these values could be attributed to diversity in characteristics of the natural fibres in terms of their processing, harvesting, usage as raw materials in the market and other factors (e.g. storage, ecosystem and disposal area), even though they belong to the same family (Rowell 2012). MOR value does not only depend on bending strength between fibres but also on the geometry (size and shape) and strength of individual fibre (Panyakaew & Fotios 2011, Juliana et al. 2012).

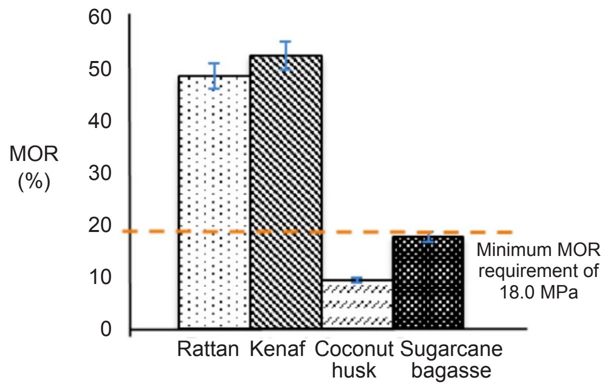

Figure 4 Modulus of rupture (MOR) of binderless boards produced

Rattan binderless board had the highest internal bond value of 14.0×10^{-3} MPa followed by kenaf, coconut husk and sugarcane bagasse binderless boards, with values of 4.9×10^{-3}, 1.4×10^{-3} and 1.1×10^{-3} MPa respectively (Figure 5). Internal bond values obtained for binderless boards in the study were extremely low compared with values reported by Okuda and Sato (2004), Widyorini et al. (2005) and van Dam et al. (2004); these authors produced thicker binderless boards using bigger moulds. Higher force was required to break thicker boards with higher internal bond values. Internal bond values are indicators of internal adhesion between lignin matrix and fibre inside the binderless board. Unfortunately, the binderless board failed to meet the minimum internal bond requirement of 0.3 MPa recommended by JIS (2003), although rattan had the strongest internal bond compared with the rest of the boards.

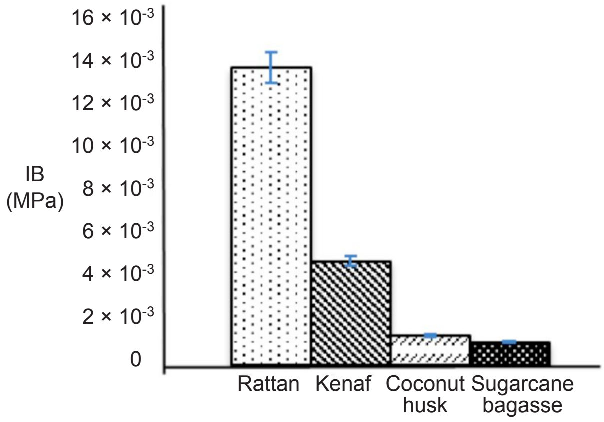

Figure 5 Internal bond (IB) strength of binderless boards produced

Physical properties of binderless boards

Rattan binderless board had the lowest value of water absorption (59.9%) and thickness swelling (43.1%) compared with the rest of the binderless boards (Figure 6). Coconut husk and sugarcane bagasse binderless boards had the highest values of water absorption (171.4 and 142.3% respectively) and thickness swelling (77.6 and 95.4%). High degree of thickness swelling in binderless boards made from natural fibres may be due to the internal structure of the particular fibres, the hygroscopicity characteristics of hemicellulose inside the fibres and the different densities of binderless boards produced (Sreekumar 2008, Sulaiman et al. 2009). Coconut husk and sugarcane bagasse had bigger particle pores, which meant that there were more voids between the particles to allow water absorption (Figure 1). On the other hand, rattan binderless board had low porosity and its fibre did not easily absorb water when immersed and did not easily release water when dried. Internal bond values also influenced dimensional stability of the binderless boards. Rattan and kenaf binderless boards had high

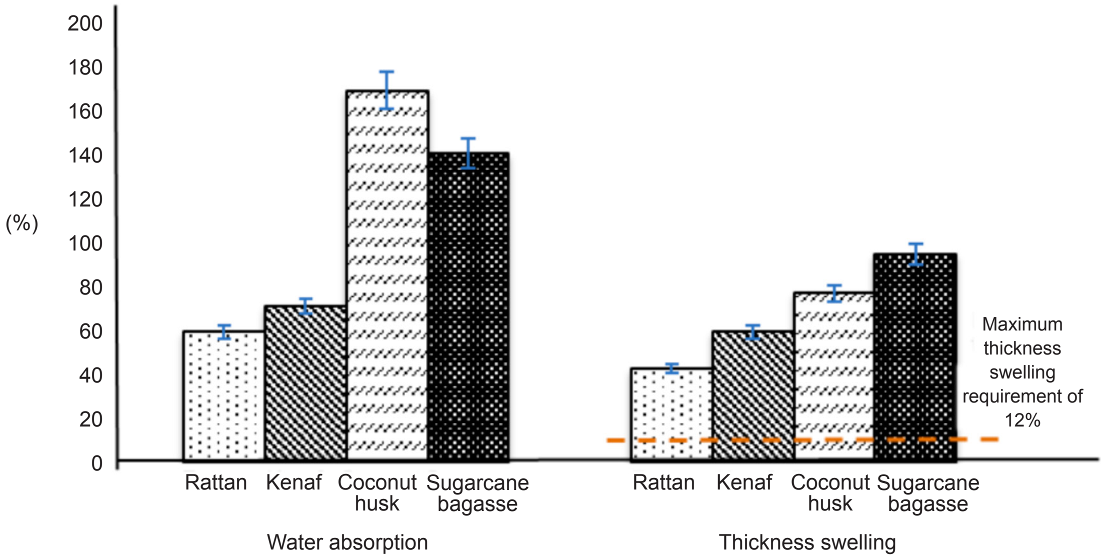

Figure 6 Dimensional stability (water absorption and thickness swelling) of binderless boards produced

internal bond values (Figure 5). This meant that the fibres were compacted and subsequently, no voids were produced and there was less water absorption, resulting in low dimensional stability (Boon et al. 2013).

Morphological analysis of binderless boards

SEM micrographs of cross-sections of rattan, kenaf, coconut husk and sugarcane bagasse binderless boards are presented in Figures 7(a)–(d) respectively, with the small frame at the top-right corners depicting the respective pressed surfaces. Based on these micrographs, in correlation with mechanical testing results, rattan binderless board (Figure 7a) had the clearest and smoothest surface, with less voids and hollow spaces between compacted fibres compared with the rest of binderless boards. This was due to oil–heat treatment of rattan at the early stage of rattan furniture manufacturing, where it was exposed to high temperature and oil uptake (Umar et al. 2016). This treatment forms a protective layer on rattan and washes out soluble components from the rattan fibres, resulting in cleaner pores and rougher fibre surfaces. Thus, interlocking between the rattan fibres is enhanced and dimensional stability of the board is improved. As seen from the cross-section of the rattan binderless board, most of the fibre cells were fully compressed.

From Figure 7(b), there were several holes that might have affected properties of kenaf binderless board and this was also reported by Anglès et al. (1999). Natural kenaf fibres are rich in carbohydrate content, which leads to good chemical interaction between fibres and resulting in enhanced mechanical properties in the binderless board (Sulaiman et al. 2009, Rowell 2012). During hot press process, chemical changes occurred and some hemicelluloses and lignin degraded (Okuda & Sato 2004). The properties of kenaf binderless board can be improved by applying higher pressing pressure to help compress the fibres and create strong bonds. Cross-section of the coconut husk binderless board illustrates loose fibres interlocking mainly on the upper side of the binderless board (Figure 7c). This was due to the variety of coconut husk fibre sizes, as well as the high loading agglomeration of fibres, which resulted in poor load transfer and caused decrease in mechanical properties (van Dam et al. 2004, Khan & Alam 2012). Cellular structure of sugarcane bagasse collapsed and became denser after the hot pressing (Figure 7d). About 80% of the porous structure of sugarcane bagasse was compressed compared with the raw fibres, thus reducing void fraction of fibres and enhancing mechanical properties of the board. However, pressed sugarcane bagasse binderless board showed more visible gaps and hollow spaces due to non-uniformity in the size and arrangement of the bagasse fibres. Numerous fibre pull-outs, detachments and voids could also be seen in the cross-section of the sugarcane

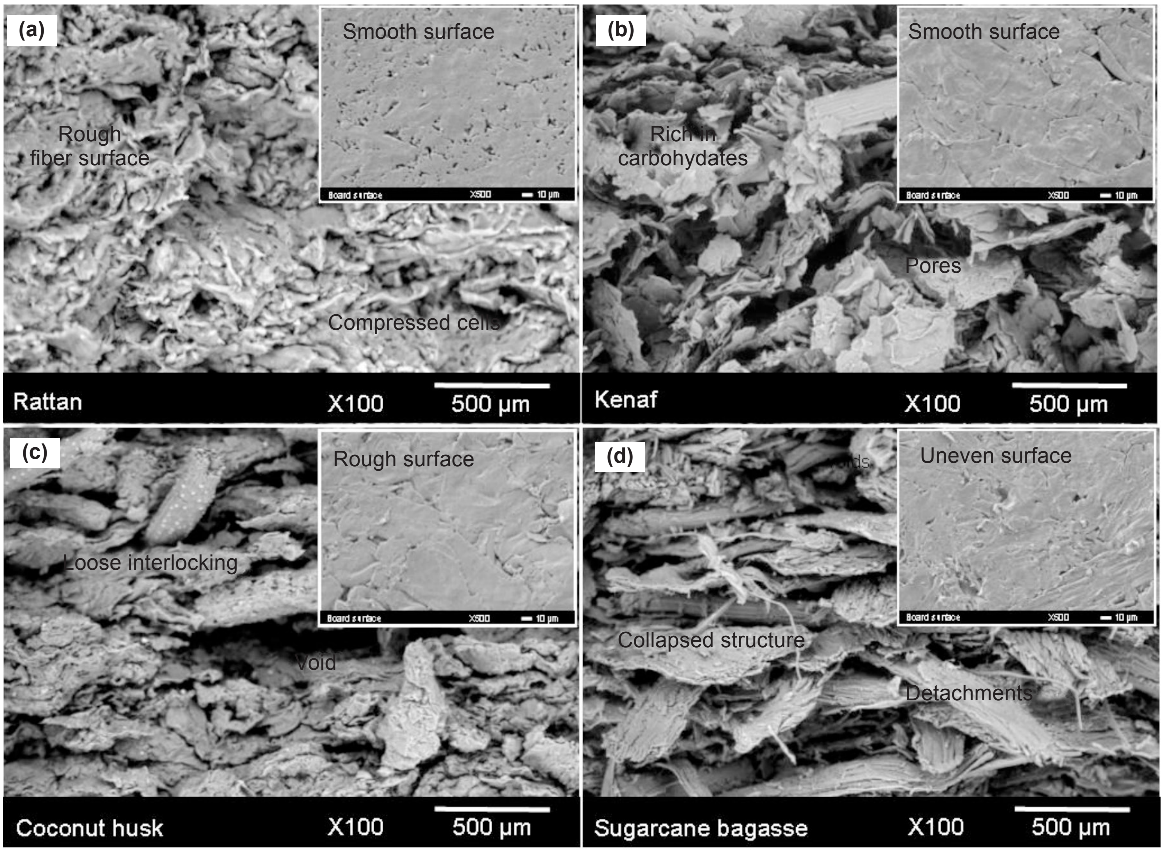

Figure 7 Scanning electron micrographs of cross-section and pressed surfaces of binderless boards produced for (a) rattan, (b) kenaf, (c) coconut husk and (d) sugarcane bagasse

bagasse binderless board. This resulted in poor interlocking between fibres causing failure and low strength in the binderless board.

CONCLUSIONS

Rattan binderless board was successfully manufactured with MOR of 48.8 MPa, internal bond 14.0×10^{-3} MPa, water absorption 59.9% and thickness swelling 43.1%. Strength of rattan and kenaf binderless boards met the minimum requirements of the Japanese Industrial Standards. This is supported by SEM micrographs for cross-section of board structures that showed compacted interlocking and good adhesion of rattan and kenaf fibres. On the other hand, coconut husk and sugarcane bagasse had low mechanical and physical properties due to voids and pores between fibres. The study showed that rattan fibres are suitable to be used as raw material in producing binderless board. Further tests such as thermal resistivity and degradation tests can be performed to add more usage and application of rattan fibre binderless boards in wider sectors.

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