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THE EFFECT OF BLACK LIQUOR ON RATTAN WASTE BINDERLESS BOARD (BPB) PRODUCED VIA DIGESTION-HOT PRESSING (DHP) PROCESS

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ABSTRACT

This paper investigates the feasibility of integrating Black Liquor (BL) on a Binderless Board (BB) from rattan waste that has undergone a Digestion-Hot Pressing process (DHP). In this project, the BL was produced by means of a kraft pulping process and was characterized in terms of its viscosity, alkalinity and functional group (using FTIR). The BB was fabricated on laboratory scales by adding different compositions of BL (0% BL, 10% BL, 20% BL and 30% BL) to the rattan waste. Performance evaluation was executed to study the effect of BL on the properties of BB. The BB with 30% BL gave the highest strength values of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE), while BB with 20% BL gave the highest value of internal bond (IB) strength. However, the BB with 0% BL, which performed as control, had the lowest dimensional stability properties in terms of Water Absorption (WA) and thickness swelling. Higher amounts of BL increased the properties of rattan waste BPB due to increase in lignin content and so reducing the void spaces among particles. Therefore, adding BL into BB resulted in positive effects on the properties of BBs produced.

Keywords: binderless particleboard, rattan waste, black liquor, properties.

INTRODUCTION

Nowadays, there are growing demands for environmental-friendly products for building construction and furniture industries. This is mainly due to the rapid growth of human population as well as alarming environmental problems [1]. Board production, in these industries, mainly use toxic synthetic adhesives that produce negative effects on human health. In addition, most adhesives are non-renewable and degradable, leading to environmental pollution. In order to solve these issues, researchers have developed a new green product called Binderless Board (BB). Binderless board, known as self-bonding board, is a board made of lignocellulosic materials without any synthetic adhesives [2]. The researchers found several agricultural resources and forest plants that are biodegradable and suitable to substitute the limited forest woods, such as oil palm [1], banana bunch [3], coconut husk [4], kenaf [5], bamboo [6], *Typha* [7] and many more.

Rattan is one of the raw materials used in the furniture industry and offers a good return of profit. It is also preferred because of its strong, durable structure and flexible properties. However, rattan waste is being produced and disposed through burning. This emits huge amounts of carbon dioxide gas and ash into the atmosphere, hence causing air pollution and affecting human health. One alternative to this dilemma is to utilize rattan waste by converting it into value-added products, such as boards. This is safer and more beneficial to human beings and also to the environment. Since there are no adhesives being added, the main self-bonding factor of BB is the lignin-furfural linkages generated during hot pressing process [8, 9]. Lignin has unique properties and several studies have investigated the use of lignin as a natural adhesive in BB production. Black liquor (BL) is the liquid by-product from the pulping process and contains the following: water, highly dissolved organic components (lignin, carbohydrates – cellulose and hemicelluloses), extractives, and inorganic components from cooking chemicals [10]. This study is aimed at evaluating the properties of BBs produced in using rattan waste and adding BL from a kraft pulping process as its binder.

MATERIALS

Rattan waste was obtained from a furniture company located in Perak, Malaysia. The rattan waste came in the form of chips and was sieved manually to remove bigger chips, as well as dust, rubbish, and any unwanted particles. The chips were then blended and sieved into powder particle size of less than 100µm. The powder was packed in plastic bags and placed in an oven at 40°C to reduce moisture content at 10%.

PRODUCTION AND EVALUATION OF BLACK LIQUOR

BLACK liquor production

500 grams of rattan waste chips were used for black liquor (BL) fabrication. The chips were digested by means of a kraft pulping process and put through a rotary digester for approximately 2 hours. The digester contained a liquor to fibre ratio of 4:1 and a combination of alkaline cooking liquor composing of sodium hydroxide (NaOH) and sodium sulfide (Na_2S) at 200 psi and steam pressure at a temperature of 170˚C respectively. At the end of the process the final products attained were rattan waste pulp and BL. The BL obtained from this process was

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characterized for its basic properties. The viscosity test was done using viscometer. At the same time, Fourier Transform Infrared Spectroscopy (FTIR) was conducted to determine chemical groups inside the rattan waste BL within the range of 4000 to 515 cm^{-1} at 4 cm^{-1} resolution using a Spectrum One Perkin Elmer FTIR machine.

Black liquor evaluation

The final products from the pulping process were pulp and BL. The pulp was a dark brown colour and formed clumps during drying. From the visual analysis, the BL produced was a weak, black liquor with 20% dry solid content. The rest was liquid that was also dark brown in colour but with a foul smell. The rattan waste was cooked and dissolved in cooking liquors, which chemically separated the rattan waste fibres into pulp by degrading the lignin and retaining the carbohydrates. The highly modified residual lignin of pulp caused the BL produced turning into dark brown colour. The foul smell came from the reaction of mixing with cooking liquor during pulping process. The viscosity of the black liquor was about 8.4 centipoise (cP), a measure which is considered moderate viscosity. Low viscosity means little friction is involved when BL is in motion and can easily flow to the fibres. This is important in the manufacturing process of BB to ensure that the BL mixes well with fibres. This viscosity of BL was influenced by dry solid content and the chemical composition of BL [11].

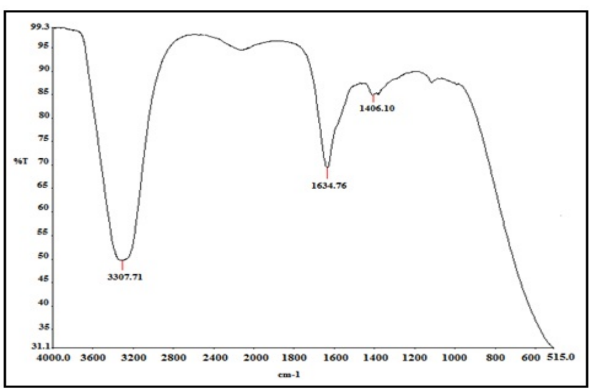

Figure-1. The FTIR spectra of black liquor rattan waste from pulping process.

The FTIR spectra illustrated in Figure-1 is the patterns for rattan waste BL. The spectrum shows the basic structures of natural fibers which have strong broad hydroxyl (OH bond) stretching from 3200 – 3600 [12], C=O bond stretched at 1634.76 usually presence in non-conjugated ketones, carbonyl and in ester groups, as well as C-N bond stretched at 1406.10. The regions between 1800 and 1100 are usually compare bands assigned to the main components of wood and natural fibers cellulose, hemicelluloses and lignin [13]. It showed that main component in BL contained lignin, which acts as thermoplastic polymer, that able to soften at high temperature and become harden when it turned cold. Lignin acts as substitution of synthetic resin for board manufacturing.

FABRICATION AND EVALUATION OF BINDERLESS BOARD

Binderless board fabrication

For one week the BB samples were kept under air-dry conditions with a temperature of 20±2°C and relative humidity of 65±5% in order to obtain constant weight. The mechanical and physical tests were conducted according to the Japanese Industrial Standard JIS A-5908 Particleboard [14]. The morphological tests of BBs were conducted using an Olympus Optical Microscope (OM) and Scanning Electron Microscopy (SEM) to observe the morphologies of the BBs at different compositions. The samples were observed under 200X magnification for OM and under 500X magnification for SEM after being coated with a thin layer of gold (Au) to avoid charging under an electron beam.

The three-point bending tests were executed using Universal Testing Machine at the speed of 10 mm/min per load in order to get the values of MOR and MOE. The IB tests were done by applying vertical tension load of 2 mm/min loading speed onto the surface of BBs. Meanwhile, the BB samples were labelled according to their compositions for a dimensional stability test. The initial mass (W_i) and initial thickness (t_i) of the samples were measured using an analytical balance and a vernier calliper before all the samples were fully immersed in water for 24 hours at room temperature. The water on the surface of the BB was wiped off at the end of the test, before the final weight (W_f) and thickness (t_f) was measured and recorded. The WA and TS was then calculated.

Binderless board evaluation

The morphologies of BB surfaces with different compositions of BL were observed using an optical microscope (OM) at 200X magnification are illustrated in Figure-2. The colour of BBs changed from light colour to dark brown colour as the percentage of BL composition increased from 0% to 30%. Figure-2(a) shows the BB with 0% BL has light colour as the BB did not contain any BL. It can be seen that the rattan wastes bonded together naturally without any use of chemical adhesive. Figure 2(b) and 2(c) clearly show that few dark spots were detected on the BB surfaces. This indicates the presence of BL, although it was not evenly distributed in rattan waste and agglomerated at certain places. However, the presence of BL was greater in the BB with 30% BL, as shown in Figure-2(d), compared to other BBs, where BL had filled most of spaces in the BB and no obvious dark spots were detected. The BB surfaces were compacted as a result of superior interlocking and adhesion between fibres that improved the properties of the BBs.

Figure-3 shows SEM micrographs at 500x magnification of cross sectioned BBs that have different

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BL compositions. In general, uniform homogeneous blends of compressed cell walls and degraded ground parenchymatous tissues can be clearly seen in all BBs produced. This is revealed in the mechanical interlocking between rattan waste particles. There are more voids occurring in BB, as shown in Figure-3(a), compared to other BBs. The voids reduced the strength of the BB produced, as has been proven in mechanical and physical tests. Figures-3(b) and 3(c) illustrate that BL filled the fibres. This can be detected from a few even surfaces shown in the above figures. It is found that BL agglomerates at certain areas of fibres, as supported by OM observations. These agglomerates can create stress concentration areas and act as a crack initiator.

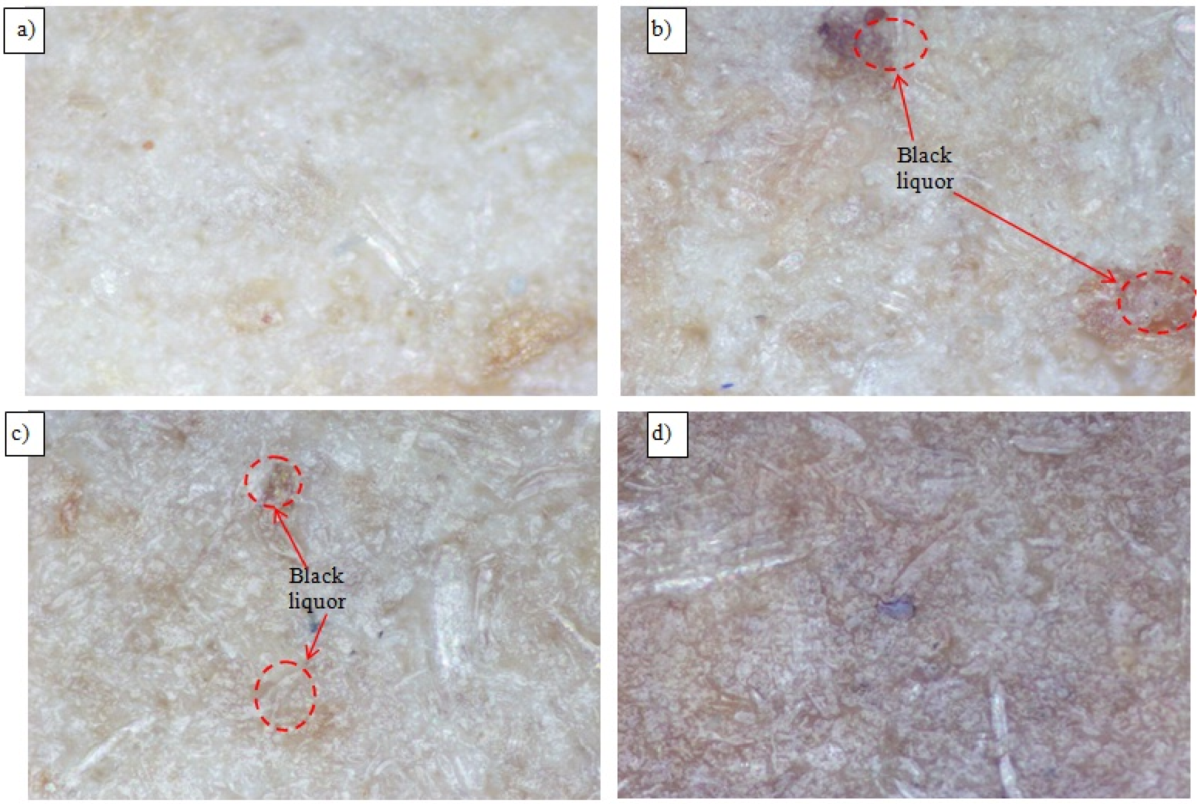
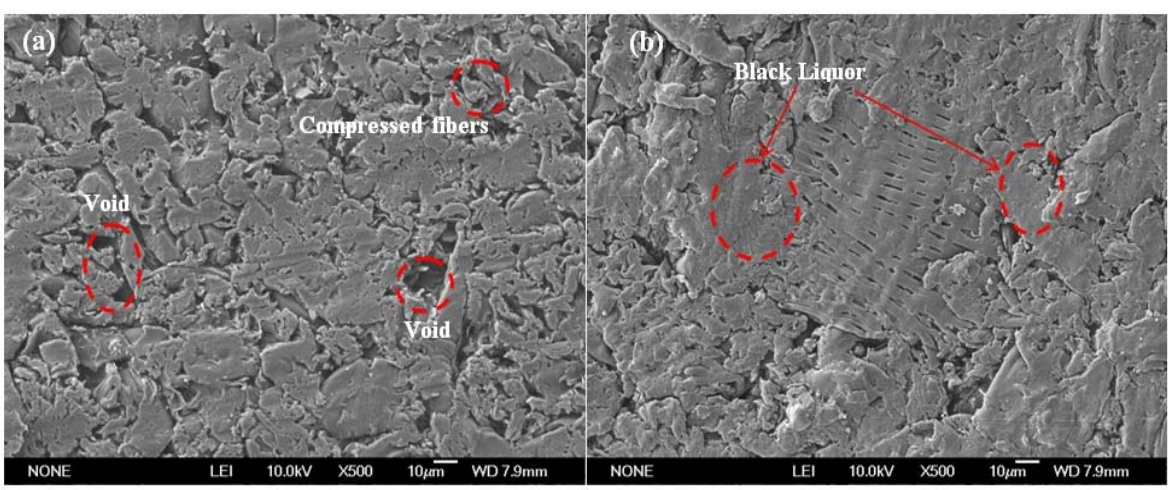


Figure-2. The morphology of different BB surfaces at 200x magnification under OM with BL compositions of (a) 0% BL, (b) 10%BL, (c) 20%BL and (d) 30%BL.



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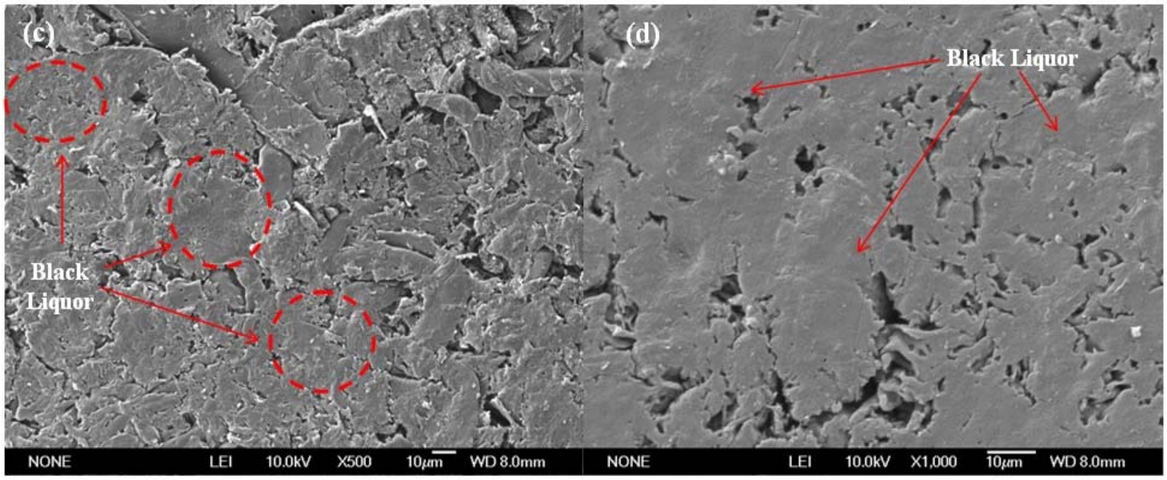

Figure-3. The micrographs of different BB cross section at 500x magnification under SEM with BL compositions of (a) 0% BL, (b) 10%BL, (c) 20%BL and (d) 30%BL.

Contrary to this, BL was distributed uniformly over the fibres in BB with 30% BL, as shown in Figure-3(d). The addition of BL enhanced interfacial adhesion between BL-fibres as the BL filled up most of the empty spaces between fibres. This observation was supported by the results from strength and dimensional stability properties of the BBs produced. Previous studies [10] state that BL containing high amounts of lignin acts as an adhesive to bind the particles together. Thus, the properties of BBs are enhanced with a higher amount of BL added, thus providing better interfacial bonding. Despite this, it is predicted that BL can only be added up to a limited amount, since excess BL can cause moisture trapped inside the BB due to evaporation of BL when heat is applied to a mixture of BL and fibres.

Figure-4 shows the results for MOR and MOE values, while Figure-5 shows the results for IB strengths of BB with a different composition of BL. The MOR and MOE strength properties of BBs increased with the increasing amount of BL compositions, with highest values of MOR being 16.2MPa and MOE being 1.6GPa, as exhibited by the BB with 30% BL. Typical BL from kraft pulping contained 39-54% of lignin, 23-35% of degraded carbohydrates, 3-5% extractives, and 18-25% of inorganic components [15].It is proven that lignin in BL produces better adhesion of the fibre-fibre interfaces and improves the compatibility between fibres, as verified in a morphological examination. All the BBs produced exceed the minimum requirements of the JIS A-5908 Particleboard [14] for MOR value of 8.0MPa. The amount of lignin used was found to be a significant variable affecting strength values of BB, other than the pressing temperature, as shown in previous studies [9]. The same pattern occurred for the values of IB strength, with the highest value obtained is 0.0084kPa for BB with 20% of BL. There is a slight decrease of IB value for BB with 30% of BL. This is due to the high amount of BL, which may cause an excess removal of lignin at the rattan waste surface [16]. All the BBs produced, however, did not meet the minimum requirement of JIS A-5908 Particleboard [14] for IB strength of 0.15MPa. Therefore, the strength properties of BBs can be improved by increasing pressing time in order to increase lignin deposition on the surface, and for distribution throughout the fibres during the hot pressing process [17].

WA and TS are the physical properties related to the dimensional stability of the boards, which give an indication towards board behaviour when used under conditions of severe humidity. Figure 6 demonstrates the results of WA and TS amongst BBs with different BL compositions. From the results, it can be observed that the BBs with 0% BL have the highest values of WA and TS. With the addition of 10% BL, both WA and TS values were reduced approximately 46% compared to the BB with 0% of BL. This indicates that black liquor did improve water resistance of the BBs as a result of the sticking behaviour of BL, which provides a strong bond between the fibres preventing water penetration into BBs. Meanwhile WA and TS values increased about 57% and 37% respectively, with the addition of 20% BL into the BBs. This increased 9% to 16% with the addition of 30% BL. This was caused by excess amounts of BL that evaporated during the hot-pressing process that is known to produce steam and water.

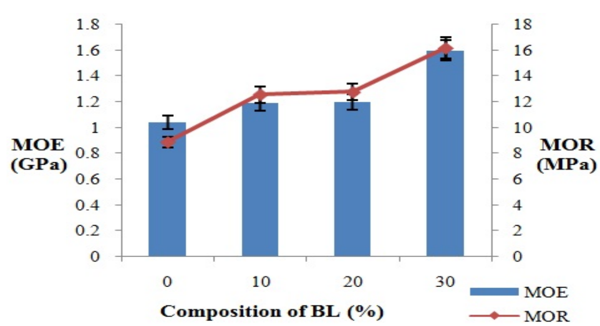

Figure-4. The graphs of MOR and MOE values for BBs with different BL compositions.

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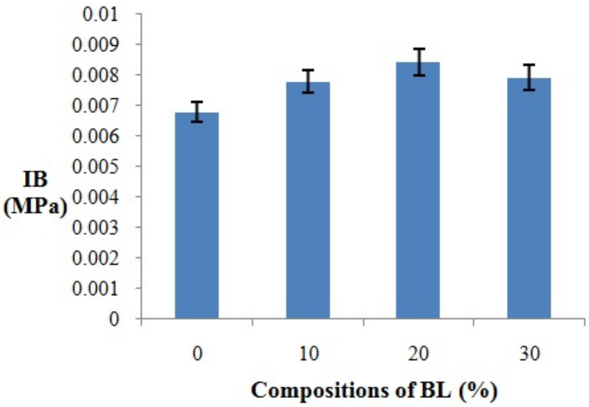

Figure-5. The graph of IB values for BBs with different BL compositions.

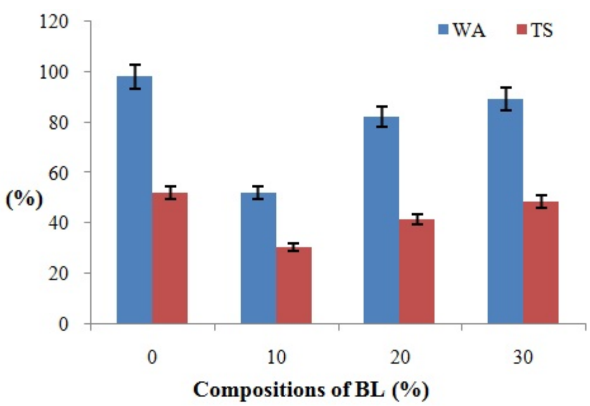

Figure-6. The graph of WA and TS values for BBs with different BL compositions.

These results were supported by Mancera *et al*. [18]. Their study found that the values of WA and TS of boards decreased as the amount of alkaline hydrolysed Kraft lignin increased. The standards [14] stated that the particleboard should not exceed 12% of TS values. As mentioned, none of the BBs were able to meet the requirements; therefore, future work is needed to improve dimensional stability of BB.

CONCLUSIONS

In this project, the black liquor of rattan waste was successfully produced using kraft pulping digestion process being used in the rattan waste binderless board production. BBs with four different compositions of BL of 0%, 10%, 20% and 30%, were fabricated via the hot-pressing process. The BB with 30% BL displayed the best mechanical properties, with the high values of MOR and MOE, as well as effective IB value. However, WA and TS at this composition were still high and did not meet the minimum requirement of board standard. The morphology test via OM and SEM showed that the fibre bonding and interfacial adhesion improved with increased amount of BL. It can be concluded, therefore, that BL is an effective natural substance that improves the properties of boards when added to BB production.

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