Development of Particleboard from Green Coconut Waste

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Abstract. In this study, green coconut waste was successfully transformed into coconut fibre-based particleboards. In addition to urea-formaldehyde (UF), two types of green binder: BST00 (low ammoniated latex and epoxidized natural rubber latex-based) and BST20 (epoxidized natural rubber latex-based) were used in particleboard fabrication. The particleboards were fabricated using coconut pith and fibre with 15% binder loading through two pre-compression steps followed by a final hot compression at 140 °C for 15 mins at ~2.1 MPa. Board properties such as density, thickness swelling (TS), water absorption (WA), and internal bond (IB) strength were determined in accordance with JIS A 5908 standard, except for modulus of rupture (MOR) (ASTM D1037). BST00-bonded particleboards exhibit the poorest properties among the three samples, making BST00 the least effective binder. BST20-bonded particleboards show the best overall properties with the highest density of ~1 g/cm³, IB value of 0.416 MPa, MOR of 11.61 MPa, best water resistance with TS of 14% and WA of 24%. The UF-bonded particleboards have the highest MOR of 12.05 MPa. Overall, the UF- and BST20-bonded coir particleboards met the minimum JIS A 5908 requirement except density (0.4-0.9 g/cm³) and TS (<12%). The green binder BST20 has shown great potential to replace UF.

1. Introduction

Scientifically known as Cocos nucifera Linnaeus, the coconut is a monocotyledon palm that belongs to the palm family (Palmaceae or Arecales). Over the course of history, there are innumerable uses of coconuts, and every part of the coconut fruit can be used in a variety of ways. Well-known products of coconut include coconut oil, coconut water, coconut meat, traditional medicine, and as crafting materials. The coconut fruit is usually ovoid in shape, weighs from 1.2-2 kg, and comes in various sizes and colours depending on the stage of growth [1]. Generally, it takes about 12-months for a coconut to mature, but they are usable for drinking at just 6 months old. The coconut is made up of three layers: exocarp (thin outermost skin), mesocarp (fibrous husk), and endocarp (thick hard shell) within which is the coconut meat and water (figure 1). In fact, the exocarp and mesocarp made up the husk of the coconut fruit. The coconut fruit yields 40% of husk comprising 30% coir (coconut fibre) with dust or coconut pith (by-product of coir) making up the rest [1].

Coconut has been one of the most famous agriculture fruits in Malaysia. It is the fourth major industrial crop in Malaysia after oil palm, rubber, and paddy by comparison of total plantation area [2]. Malaysia ranked 10th in the list of coconut producing countries, producing approximately 650,000 tons...
of coconut in 2018. Patil & Benjakil reported that about 70% of coconuts in Malaysia are consumed domestically with the majority of coconuts consumed fresh whereas only 30% of coconuts are exported to other countries [3]. Moreover, up to 220 million coconuts need to be imported annually from other countries such as the Philippines and Indonesia, especially during the festive seasons. On average, the consumption of coconuts in Malaysia is about 611 million coconuts per year according to Malaysian Agricultural Research and Development Institute (MARDI). This large consumption of coconut has led to a high amount of coconut wastes which has become one of the biggest biowastes in Malaysia.

In the past decades, coconut husk has been mainly thrown away or burnt after use due to the low cost of disposal. It is estimated that about 55 billion coconuts are produced yearly around the world, yet only 15% of the husk fibres are actually recovered for use, leaving most husks abandoned. This is a waste of natural resources and can cause environmental pollution. However, it is slowly gaining attention as the environmental issues are deteriorating rapidly over recent years. Coconut fibres or coir are seen as a new substitute for wooden materials in today’s furniture industry which can help to reduce deforestation. Moreover, coir is also being developed and used in making car seats, mattresses, and other components in the automotive industry. Coconut husk can also be processed to produce coco peat and coir which involves industrial applications such as the manufacturing of furniture, carpet, and others. In fact, board materials made from coconut husk have high sustainability and excellent mechanical properties due to the presence of lignin which strengthens the fibres [4]. In addition, coconut husk is an eco-friendly material. This can help to reduce the consumption of wood which in turn reduces or slows down the progress of deforestation and global warming.

The material cost is low as it can be collected and recycled easily from the coconut-based product stores. Therefore, recycling coconut wastes and extracting the coconut fibre to transform it into useful products can be a better solution to the environmental issue while saving disposal cost.

For decades, wood has been the main raw material for particleboards. Particleboard is readily manufactured from virtually any wood/timber material, including sawdust, mill residues and recycled wood as technology for particleboard manufacture advances. It is one of the oldest composites to be produced and has been the world’s dominant furniture panel. In Malaysia, the common species used to make particleboard is rubberwood. In recent years, the feasibility and properties of non-wood alternatives and agricultural residues have been investigated and studied. Brischke & Jones explicated that the main drivers for the intensification research in this area are wood scarcity, low cost of natural

Figure 1. Section diagram of a coconut [1].
fibres, and environmental awareness (deforestation) [5]. The centre of attention for most non-wood particleboard developments is the use of different kinds of natural fibres with preference on fibrous materials from crop plants due to their availability and easy accessibility [5].

Non-wood lignocellulosic materials, usually a variety of agricultural residues such as bamboo waste and bagasse, have also been used for particleboards with promising physical and mechanical properties [6]. These properties include the percentage of thickness swelling (TS) and water absorption (WA), internal bond (IB) strength, and modulus of rupture (MOR). The properties of particleboards made from various organic waste and agricultural residue are shown in table 1 [7]. Moreover, Ahmed et al developed one of the best coir particleboards using coir pith as the raw material [8]. The coir pith was mixed with 16% of melamine-urea formaldehyde (MUF) resin and pre-pressed into mats before being hot-pressed at 160 °C and 3 MPa for 5 min. The best properties of the produced particleboards are included in table 1.

In fact, urea-formaldehyde (UF) resin has been widely used in furniture industry including particleboard production due to its low cost, low curing temperature and good board mechanical properties [9,10]. However, the utilization of formaldehyde-based adhesives has raised concerns due to its carcinogenic and non-renewable nature [9]. Therefore, green binders such as protein-based and rubber latex-based adhesives are being investigated for the substitution of carcinogenic formaldehyde-based adhesives. In present study, green coconut waste will be transformed into coconut fibre-based particleboards using rubber latex-based green binder. The objectives of this study are to assess the suitability of green coconut fibre in the fabrication of particleboard using green binder and determine their physical and mechanical properties of the particleboards.

Table 1. Properties of particleboards made from different agricultural residues [7].

| Raw Materials               | Resin Used                              | TS (%) | WA (%) | IB Strength (MPa) | MOR (MPa) |
|-----------------------------|-----------------------------------------|--------|--------|-------------------|-----------|
| Wood waste chips            | Phenol formaldehyde                     | 7-18   | -      | 0.56-0.73         | 11.4-27.1 |
| Bagasse and industrial wood | Urea formaldehyde                       | 14.45-19.14 | - | 0.33-0.78         | 10.03-16.59 |
| particles                   |                                         |        |        |                   |           |
| Kenaf particles             | Urea formaldehyde                       | 26-34  | 65-70  | 0.51-1.52         | 15.1-19.6 |
| Bamboo waste                | Urea Formaldehyde                       | 6-7.1  | -      | 0.08-0.29         | 6.5-21.5  |
| Maritime pine               | Corn starch and urea formaldehyde       | -      | -      | 0.45-0.48         | 15-17     |
| Wheat straw                 | Urea and urease inhibitor NBPT<sup>a</sup> | 101-140.6 | - | 3.7-5.6           | 8.9-14    |
| Coir pith                   | Melamine-urea formaldehyde              | 22.55<sup>b</sup> | 40<sup>b</sup> | 1.52<sup>b</sup> | 24.65<sup>b</sup> |

<sup>a</sup> N-(n-Butyl)thiophosphoric triamide.
<sup>b</sup> Average values from the best sample.
2. Materials and method

2.1. Extraction of coconut pith and fibre
Green coconut husk was collected from coconut vendors in Setapak area and mechanically processed to remove exocarp and endocarp by using band saw, leaving only the pith and fibre. The ligno-cellulosic biomass was cut into 5-30 mm using a shredder and then oven-dried at 101 °C for 12 h.

2.2. Binders
In collaboration with Malaysian Rubber Board (LGM), green coconut fibre-based particleboards were produced using two green binders, BST00 and BST20, provided by LGM. Commercial binder, UF was purchased from S.A. Wood Chemicals Sdn. Bhd. The BST00 is a formulation designed for wallpaper adhesive which comprises low ammoniated latex and epoxidized natural rubber latex. In contrast, BST20 is a new formulation designed by LGM to test for the suitability as binder particleboard fabrication. The base material is epoxidized natural rubber latex.

2.3. Fabrication of particleboards
Briefly, the prepared coconut pith and fibre were mixed with binder in the ratio of 200 g of pith and fibre to 30 g of binder (15%). A blender was used to mix the mixture to achieve homogeneous distribution of binder and to further reduce the coconut pith and fibre into smaller size. After mixing, pre-compression was performed twice at 80 °C for 1 min to compact the mixture. A steel mould with the dimensions of 180×175×9 mm (length × width × thickness) was used. First, 100 g of pith and fibre with 15 g of binder will be pre-compressed in the mould cavity. Then, another 100 g of pith and fibre with 15 g of binder will be added on top of the pre-compressed mixture for the second pre-compression step. The pre-compacted mixture was hot pressed at 140 ºC for 15 mins at a pressure of ~2.1 MPa using a hydraulic hot compression machine (Labtech hydraulic hot press) to produce the coir particleboard [11]. In this manner, UF-, BST00- and BST20-bonded coir particleboards were fabricated.

2.4. Test procedure
All fabricated particleboards were cut into 160×155 mm rectangles by trimming 20 mm thick strips along the edges. Test specimens were cut from particleboard and the following properties were determined in accordance with Japanese Industrial Standard (JIS A 5908, 2003) except for bending strength test (to determine MOR) which follows the ASTM D1037 standard.

2.4.1. Physical characterisation. The densities ($\rho$) of the particleboards were calculated by taking the ratio of mass ($m$) over volume ($v$), as in equation (1), measured using 100×100 mm test specimens as outlined in the JIS A 5908 standard. Thickness swelling (TS) and water absorption (WA) tests were performed according to JIS A 5908 standard. Specimens of 50×50 mm were cut out from the density test specimens. The initial thickness ($t_i$) and mass ($m_i$) of the test specimens were measured and recorded before immersing them into the water at 25 °C for 24 h. After the immersion process, the final thickness ($t_f$) and mass ($m_f$) of the specimens were measured. The percentage of TS and WA were calculated using equation (2) and equation (3).

\[
\rho = \frac{m}{v}
\]  
\[
TS = \left(\frac{t_f - t_i}{t_i}\right) \times 100\%
\]  
\[
WA = \left(\frac{m_f - m_i}{m_i}\right) \times 100\%
\]
2.4.2. **Mechanical characterisation.** Specimens were cut out from each particleboard with dimensions of 152×76×9 mm in accordance with ASTM D1037 standard to determine modulus of rupture (MOR) via three-point bend test. The test was conducted using a hydraulic universal testing machine (GoTech TCS-2000) with a load cell of 20 kN at a speed of 12 mm/min (compression). The MOR was then calculated from load deflection curves according to equation (4). Internal bond (IB) strength of the particleboards was determined in accordance with JIS A 5908 standard using 50×50 mm specimens at a test speed of 2 mm/min (tensile) by using the same hydraulic universal tester machine. The IB was calculated using equation (5).

\[
\text{MOR} = \frac{3PL}{2bd^2} \tag{4}
\]

\[
\text{IB Strength} = \frac{P_s}{2bl} \tag{5}
\]

Where \(P = \) maximum load (N), \(L = \) length of span (mm), \(b = \) width (mm), \(d = \) thickness of specimen (mm), \(P_s = \) rupture load (N), \(l = \) length of the specimen (mm).

3. **Results and discussion**

3.1. **Physical characterisation**

All particleboards have smooth surfaces with light brown colour and some dark patches. Figure 2 shows two pieces of UF-bonded coir particleboards. A sweet coconut scent was also felt from all the particleboards. In fact, fibre scent is also found on oil palm fibre and sugarcane bagasse-based particleboards. This fibre scent can be attributed to the hydrolysis occurred in the biomass or due to modification of chemical constituents during hot compression [10].

![Figure 2. UF-bonded coir particleboards.](image)

3.1.1. **Bulk density.** According to JIS A 5908 standard, the density of particleboards should be between 0.4-0.9 g/cm³. However, the average densities of the UF-, BST00-, and BST20-bonded coir particleboards were 0.939, 0.925 and 1.022 g/cm³, respectively (figure 3). They are slightly higher than the criteria stated in JIS A 5908 standard. Nevertheless, these coir particleboards can be classified as high-density particleboards. The UF- and BST00-bonded particleboards have a similar density of about 0.92-0.94 g/cm³, while BST20-bonded particleboards have the highest density of ~1 g/cm³. This shows that the BST20-bonded particleboards were more densely packed and compacted, and that BST20 attests to be a more effective binder at 15% binder content. Lee et al found that higher density of particleboard may increase MOR of particleboard and reduce percentage of TS [12]. Their findings are in line with the testing result stated in subsection 3.1.2.
3.1.2. **Thickness swelling and water absorption.** The percentage of TS and WA of a particleboard are essential. They measure the effects of moisture on a particleboard, and the lower the percentage, the better the water resistance of the particleboards. Figure 4 and figure 5 present the average values of TS and WA, respectively for UF-, BST00- and BST20-bonded coir particleboards. It was found that the BST00-bonded boards showed the least resistance against water penetration and exhibited the highest percentage of TS after immersion in water for 24 h. Percentage of TS and WA values of UF-bonded particleboards were 16.86% and 37.88%, respectively. The TS and WA values for BST20-bonded particleboards improved at a moderate level compared to UF-bonded particleboards. They showed 14% of TS and 23.95% of WA, best results among the three types of particleboards. However, based on the JIS A 5908 standard, Type 8 particleboard should not exceed 12% swelling in thickness after 24 h immersion in water [10]. None of the samples meet the general requirement of TS in the JIS standard. Though the JIS standard does not specify the acceptable WA values, Harshavardhan et al stated that WA is an important property for non-wood based particleboard. Generally, the WA percentage should not exceed 40% [7].
The poor water resistance of BST00-bonded boards was justifiable since the BST00 binder was originally formulated and designed for wallpaper adhesives. According to research done by Araújo Junior et al., the covalent cross-linking bonds found in inter-fibre bonding plays an important role in water resistance of particleboards since the bonds are more stable than hydrogen bonds in water. Moreover, cellulosic in green coconut fibre tend to attract water and clutch water molecules through hydrogen bonds due to the availability of the hydroxyl groups [10]. Araújo Junior et al suggested that strong inter-fibre bonding can improve the water resistance of green coconut fibre-based particleboards [10]. Besides, Baskaran et al found that the rate of water penetration into a particleboard is highly influenced by pressing temperature, pressure, and time [13]. Hence, the greater water resistance of the UF- and BST20-bonded coir particleboards can be attributed to the hot compression parameters employed in this study, compared to the parameters of MUF-bonded coir pith particleboards produced by Ahmed et al [8]. The wetting of the commercial binder UF and epoxidized natural rubber latex based BST20 binder with green coconut pith and fibre may also be better under this hot-press parameter. Besides, the physical properties (TS and WA) of the BST20 bonded boards can be considered as one of the best among other non-wood agriculture residues-based particleboards listed in table 1. The better performance of BST20-bonded particleboards compared to UF-bonded counterparts, with respect to TS and WA, also suggests that BST20 binder has the potential to replace UF in particleboard fabrication.

3.2. Mechanical characterisation

3.2.1. Internal bond strength. The IB strength refers to the strength of the bonding of the separate fibrous layers and the force required to delaminate or separate these layers. The average IB strength of the particleboards was heavily influenced by the type of binder used as illustrated in figure 6. The BST20-bonded particleboards exhibited the highest average IB of 0.416 MPa while the IB value for UF- and BST00-bonded particleboards were 0.343 and 0.180 MPa, respectively. All three types of particleboards exceeded the JIS IB requirement for Type 8 particleboard which is 0.15 MPa.

However, even the highest IB values were comparatively lower than those reported by Ahmed et al which saw an average IB strength of 1.52 MPa for 16% MUF bonded coir pith boards [8]. The IB values reported by Ahmed et al are also in agreement with Magniont and Palumbo that saw an improvement in IB strength of particleboards when using spherical vegetal pith [14,15]. Further, MUF is a more superior but more expensive binder than UF. Theoretically, the IB values should be higher due to the pre-compression procedure that results in the increase of inter-fibre cross linking bonds [10]. However, Bajwa et al assessed the quality of the particleboards using a mixture pith and fibre, and they saw a huge
decrease in IB strength [16]. The lower IB values may possibly be due to mixture of coir pith and fibres which lead to uneven particle size distribution. The other reason may be due to the weak links between the two pre-compressed layers, resulting in weak bonding between particles at the layer-layer interfaces. This problem could be addressed by employing a single pre-compression step or by applying a thin layer of binder in between the layers prior to pre-compression. The higher IB values for BST20-bonded particleboards implied that the epoxidized natural rubber latex-based binder might have developed enhanced bonding of the particles under the effects of heat and temperature, resulting in better inter-fibre bonding characteristics compared to UF and BST00. During the hot compression, curing process takes place and the binder bonded well with coir pith and fibres.

**Figure 6.** The effect of binders on internal bond strength of coir particleboards.

3.2.2. Modulus of rupture (MOR). The MOR or bending strength is an important property in particleboard classification based on the JIS A 5908 standard. According to figure 7, the average MOR for static bending of UF-, BST00- and BST20-bonded particleboards were 12.05, 8.13 and 11.61 MPa, respectively. As stated by the requirements of JIS A 5908 standard for Type 8 particleboard, the particleboards must have a minimum MOR of 8 MPa in which all three samples exceeded this value.

**Figure 7.** The effect of binders on modulus of rupture of coir particleboards.

The higher MOR values obtained for the particleboards produced with UF and BST20 may be explained by the physical and anatomical characteristics of the green coconut pith and fibre as well as
by correlations between these factors and the processing parameters of hot compression [17]. Variation in lignocellulosic content in the green coir pith and fibre may lead to the difference between specimens since the composition of natural fibre is uncontrollable. Nevertheless, the MOR of these particleboards were considered average compared to other non-wood based particleboards. For reference, Araújo Junior et al produced binderless fibreboards (1.2 g/cm$^3$) with a MOR of 18 MPa using unripe coir pith and fibre with uniform particles sizes of up to 4 mm at 210°C and 15.7 MPa for 4 mins [10]. Meanwhile, Ahmed et al fabricated MUF-bonded coir pith boards (uniform 30 mesh pith size with a density of 0.75 g/cm$^3$) with a whopping MOR of 24.65 MPa at 160 °C and 3 MPa for 5 mins [8]. This stressed that uniform and even particle size distribution of the pith or fibres is critical to the mechanical properties of particleboards. The temperature and pressure applied during the hot compression should also be increased to obtain particleboards with greater MOR. Unlike other natural fibres that have high cellulose content, green coconut pith and fibre have higher lignin content instead. Lignin is a natural binding compound which requires higher temperature and pressure to activate due to the strong intramolecular bonding through the carbon-to-carbon bond linkages [7,9]. Therefore, at 140 °C and 2.1 MPa, the bonding capability may be moderate during hot compression and thus results in an acceptable MOR, though the pressing time was much longer (15 mins).

3.3. Summary of result

Table 2 summarizes the important characteristics of particleboards and the effect of binders on the properties. BST20-bonded boards exhibited the best overall performance with the highest IB strength of 0.416 MPa, high MOR of 11.61 MPa, and the lowest TS and WA of 14% and 23.95%, respectively. The MOR, IB strength, TS, and WA for UF-bonded particleboards were 12.05 MPa, 0.343 MPa, 16.86%, and 37.88%, respectively. This indicates that BST20 is a compelling alternative to UF as binder in particleboard production. As a whole, it was an impressive feat of turning green coconut waste (husks) into particleboards as UF- and BST20-bonded particleboards met most of the JIS standard requirements for Type 8 particleboard except for TS and density. In fact, most of the agriculture residue and non-wood based particleboards showed poor water resistance where the TS is usually more than 20% and WA of more than 40%, as seen in table 1. However, the values for mechanical properties were on the lower side compared to most non-wood based particleboards, mainly due to uneven particle size distribution. The pressing time and resin ratio can greatly influence the physical and mechanical properties of particleboards [7]. Moreover, the appearance of the particleboards produced were typical of the conventional boards and have a sweet coconut scent as well as smooth surfaces. Besides, coatings can be applied to the boards for improved aesthetics and resistance to water such as wallpapers (as shown in figure 8), lacquered paint, wood veneers, and continuous press laminates. These particleboards can have numerous applications such as used for internal furniture, decorative partitions walls, and insulation boards. However, it is necessary to further improve dimensional stability and mechanical performance for exterior applications.

| Samples | Density (g/cm$^3$) | TS (%) | WA (%) | IB Strength (MPa) | MOR (MPa) |
|---------|-------------------|--------|--------|-------------------|-----------|
| UF      | 0.939             | 16.86  | 37.88  | 0.343             | 12.05     |
| BST00   | 0.925             | 20.40  | 40.60  | 0.180             | 8.13      |
| BST20   | 1.022             | 14.00  | 23.95  | 0.416             | 11.61     |
3.4. Recommendations for future work

It is imperative to ensure the uniformity of the particle size distribution as it significantly influences the bonding of the fibres and mechanical properties of the particleboards. A possible way to achieve this is to use a power cutting mill or a laboratory-type hammer mill to obtain uniform particle size distributions of over 80% on average. Besides, coconut pith and fibre should be separated before size reducing processes and used in particleboard fabrication separately. Next, in order to meet the density requirement of the JIS standard, lesser raw materials should be used (instead of 200 g) at the same binder loading of 15%. As a matter of fact, the binder content of particleboards is usually capped at 10-15% to cater for the formaldehyde emission regulation. With the use of green binder such as BST20, the binder content can be increased to produce particleboards of higher quality in terms of physical and mechanical properties. Nonetheless, the cost of a particleboard increases with binder content, and thus a balance between these two factors should be realized. Furthermore, an increase in pressing temperature and pressure could enhance the mechanical properties of the particleboards. In fact, several factors influence the types of bonding formed and the final properties of particleboards such as types of binder used, binder content, and moisture content as well as hot-pressing temperature, time, and pressure. Therefore, the optimization of these parameters is critical to obtain the desired properties, depending on the final application of the boards.

4. Conclusion

In conclusion, green coconut wastes can be used in the fabrication of particleboards. Three types of samples were fabricated namely, UF-, BST00- and BST20-bonded coir particleboards. All three particleboard samples were subjected to various types of testing: density, TS, WA, and IB strength tests according to JIS A 5908 standard for Type 8 particleboard and ASTM D1037 standard for MOR. All the testing results on three different types of samples had fulfilled the standard’s requirements except the density and TS. Among the three different samples, BST00-bonded particleboards exhibited the lowest performance in terms of physical and mechanical properties whereas UF- and BST20-bonded particleboards showed similar performance metrics. The UF- and BST20-bonded particleboards have average densities of 0.939 and 1.022 g/cm³, respectively. The values of TS and WA for UF- and BST20-bonded samples are 16.86% and 37.88%, and 14.0% and 23.95%, respectively. Moreover, in terms of mechanical properties, UF-bonded sample has an average IB of 0.343 MPa and MOR of 12.05 MPa.
while BST20-bonded sample has highest values of IB of 0.416 MPa and slightly lower MOR of 11.61 MPa. As such, BST20 has the potential and ability to replace the commercial carcinogenic binder UF due to the similar physical and mechanical properties, and the ability to meet most of the requirements stated on the JIS A 5908 standard. In addition, the binder content of UF is usually limited to 10-15% due to formaldehyde emission. With the use of BST20, the binder loading can be increased to produce a better-quality particleboard with improved physical and mechanical properties as BST20 is not bound by this constraint. Therefore, there is a huge opportunity in the market should a real optimized working BST20 bonded coir particleboard be developed.

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References
[1] Tetra Pak 2016 Coconut Handbook (Tetra Pak International S.A.)
[2] Sivapragasam A 2008 2nd IPICEX
[3] Patil U and Benjakil S 2018 J. Food Sci. 83 8
[4] van Dam J E G, Martien J A, Edwin R P, Jacintha C, Cristina A, Fidel J and Aurora P 2005 Ind. Crops Prod 24 2006
[5] Brischke C and Jones D 2017 Performance of bio-based building materials (Elsevier Woodhead Publishing: Duxford)
[6] Stark N, Cai Z and Carll C 2010 Wood Handbook ed R J Ross (Forest Products Laboratory: Madison, Wisconsin) chapter 11 pp 11.1-11.28
[7] Harshavardhan A, Ranjitha J and Muruganandam L 2016 Int. J. of ChemTech Res. 9 1
[8] Ahmed E, Das A K, Hannan M O and Shams M I 2016 Bangladesh J. Sci. Ind. Res. 51 3
[9] Pizzi A and Mittal K 2017 Handbook of adhesive technology (CRC press)
[10] Araújo Junior C, Coaquira C, Mattos A, de Souza Filho M, Feitosa J, Morais J and de Freitas Rosa M 2017 Waste Biomass Valorization 9 11
[11] Lee S H, Ashaari Z, Lum W C, H’ng P S, Tan L P, Chow M J, Chai E W and Chin K L 2015 J. Oil Palm Res. 27 67-74
[12] Ong T K, Choo H L, Lee S M and Kong K Y 2020 IOP Conf. Ser.: Mater. Sci. Eng. 815 012010
[13] Baskaran M, Hashim R, Sulaiman O, Awalludin M F, Sudesh K, Takamitsu A and Akihiko K 2017 Waste Biomass Valorization 10 1
[14] Magniont C 2010 PhD Thesis Université Toulouse III-Paul Sabatier
[15] Palumbo M 2015 PhD Thesis Universitat Politècnica de Catalunya
[16] Bajwa D S, Sitz E D, Bajwa S G and Barnik A R 2015 Ind. Crops Products 75
[17] Oliveira S L, Mendes R F, Mendes L M and Pereira T 2016 Materials Research 19 4