Effects of Hot-Press Temperature and Mix Proportions on Mechanical Behaviours of Hybrid Coconut Fibre Particleboard

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Abstract. This paper represents the process in selecting the suitable hot press temperature, resin content and percentage of proportion for sawdust and coconut fibre in producing particleboard by investigating the mechanical behaviours (BS EN 310: 1993) and physical properties (BS EN 323:1993, BS EN 324). The process begins with preparation of materials which are sawdust and coconut fibre that were sieved and retained at 5mm sieve with oven-dried. The mixing process of this hybrid particle board which consist from sawdust and coconut fibre with the additional of resin (Urea Formaldehyde) being sprayed and hot pressed. The thickness and density for this experiment were fixed with targeted at 16mm and 650 kg/m³ respectively. The hot press temperature was manipulated varies from 140 °C, 160°C and 180°C, resin content varies from 6%, 8% and 10%, while the percentage of proportion (%) of sawdust (SD) to coconut fibre (CF) varies from 100SD:0CF, 70SD:30CF, 50SD:50CF, 30SD:70CF and 0SD:100CF of weight. The particleboards were conditioned to room temperature for 7 days before tested for physical and mechanical properties. The results show that the suitable hot press temperature is 160°C, resin content at 8% and percentage of proportion for sawdust to coconut fibre are 30SD:70CF and 0SD:100CF respectively in accordance to BS EN 312:2010.

1. Introduction

Different sources of natural fibres, as alternatives to concrete formulation, are explored which can be divided into two categories: farm or agricultural waste and commodity crops. For example, agriculture waste types of natural fibres that have been used in the formulation of green concrete and other building materials are bagasse, bamboo leaf ash, coconut coir, rice husks, palm oil fuel ash, wood chips, wheat straw, bananas, stroke and sisal; while natural fibre from commodities crops such as kenaf, jute and hemp [1].

The fibre of coconut is widely available. Various investigations were carried out into the use of coconut fibre in a matrix polymer composite. It has a less thermal conductivity and a good weight to strength ratio. It is environmentally friendly. Coconut fibre is a brilliant alternative to environmentally
harmful materials the use of the building material [2]. From external shell of coconut fruit, the coconut fibre also known as coir is extracted. Coconut is mainly grown in tropical and sub-tropical regions. Ghana produces approximately 305,000 tonnes of coconut annually, and it generates many waste throughout the country. Coconut fibres are usually available in three main ways, (1) long fibre bristle, (2) short fibre mattress, and (3) decorticated (mixed fibre lengths). The engineering application of coconut fibre is not well known, but it has good engineering properties. The dimensions of coconut fibre are different and are thought to depend on the type, location and maturity of the coconut plant. The length to diameter (aspect proportion) of the fibre, which determines its application, is affected the flexibility and breakup of the fibre. The main compositions of the coconut fibre are cellulose, hemicellulose and lignin, which affects both the physical and mechanical characteristics of the fibre [3].

Coconut fibre has been chosen in this study due to its material, which contain of hardest natural fibre, with the percentage of lignin content are more than 30 percent [4] as shown in Table 1. The function of lignin to make the fibres tougher and more rigid by supplying compressive strength to the tissue and fibre as well as tightening up the cell wall to protect the carbohydrates against chemical or physical harm. Coconut fibres can be 4-6 times higher in strain than other fibres. In addition, coconut fibre does not lose its strength on storage and expose to sunlight. The coconut fibre density is important in determining the overall weight necessary for the coconut fibreboard panel. Due to its properties, the use of coconut fibre in furniture manufacturing is growing. Research has shown that coconut fibre is stronger than wood fibre [4].

| Chemical Composition (%) | Physical Properties |
|--------------------------|---------------------|
| Halocellulose (56.3%)    | Density = 1.2 g/cm³ |
| α-cellulose (44.2%)      | Elongation at break = 30% |
| Lignin (32.8%)           | Tensile Strength = 175 MPa |
| Ash (2.2%)               | Young Modulus = 4 to 6 GPa |
|                          | Water Absorption = 130 - 180% |

The production of fibreboards from coconut husks has been studied by A. Lucia et. al in 2004 and discovered that coconut coir and fibre have high percentage of lignin, which is more than 130 °C hot thermally durable and can produce fibreboards without any chemical binders [5]. Recently, particleboards have different properties, including maximum design flexibility for easy production lines, reliable quality, dimensional variety, physical characteristics that are easy to use. There are a lot of application of particleboard as furniture, insulation material such as sound and thermal insulation, wall panel, wall bracing, partition and other industrial products. The characteristics of particleboards are influenced by many factors, including wood species, fibre structures, density, hardness, compressibility, particles type and size, and particle drying technology [6]. The medium-size particle demonstrated the best performance for binder-less and melamine urea formaldehyde (MUF) bonded boards. When 16% MUF were used the bonded board of MUF showed the best performance. According to Ahmed (2016), the quality of the product with 16% MUF greater than binder-less coir pith board. Coconut coir board can provide sustainable, affordable and durable materials for construction and packaging as well as wood substitutes [7]. Urea formaldehyde is also used for indoor panels at moderate costs. However, these binders are not waterproof and emit formaldehyde toxic and carcinogenic. All these binders present problems for health and the environment. A reduced use of formaldehyde induces bad mechanical features of particle boards is well known. As formaldehyde reduction does not solve the toxic emissions, this adverse effect is therefore offset by plating or chemical changes [8].

According to El-Kassas et. al (2013), the properties of the produced fibreboards are dependent on the average density and the resin contents [9]. In his study, Akinyemi (2016) observed that the panel density increased as sawdust composition declined, up to the peak at 25% and then a drastically drop
in value. However, as the proportion of corn cob increased, the density of particleboard slightly increased but a significant drop was observed after peak at 75% corn cob. Compared to the sawdust panels, the corn cob panels were of lower density. The density obtained is comparable to densities of particleboards in wood production industries of 590 and 800 kg/m$^3$ [10]. While in her study, Paridah (2014) found out that particleboards with 10% resin and 50:50 (RW:KS) have the highest strength (19.08 MPa) while particleboards with 70:30 (RW:KS) show a higher strength (2.23 GPa). The RW:KS ratio has more impact than the resin level on the thickness swelling (TS) and water absorption (WA). Hybrid particleboards made of 70% RW and 30% KS, 10% resin content shows all good property and is equivalent to 100% RW (control) samples. It concluded that kenaf stem can substitute rubber-wood particles of up to 50%, but resin levels must be maintained at 10% and higher because a lower level of resin (68%) dramatically reduces particleboards’ strength [11].

The pre-pressed mats were pressed for 5 min in a hot press and the temperature and pressure were controlled at 160 °C and 3 N/mm$^2$ [7]. The pressing cycle was then conducted using the daylight press at pressing plate temperature of 180 °C and under adequate pressure to achieve the targeted panel density and thickness. The panel was pressed for a time of 12–13 s/mm of the panel thickness [9]. The pressing process has the following time, temperature and pressing specifications: i) for the HDF fibreboard, 220 °C and 320 kgf/cm$^2$ for 4 minutes; ii) for the MDF fibreboard, 210 °C and 320 kgf/cm$^2$ for 4 minutes.; iii) and for the MDF UF fibreboard, 160°C and 100 kgf/cm$^2$ for 10 minutes.

![Graph of temperatures of center layer against pressing time](image)

**Figure 1.** The graph of temperatures of center layer against pressing time [12]

### 2. Materials and Methodology

Sawdust particle and resin used in this study are courtesy from Heveaboard Sdn Bhd. The urea-formaldehyde (UF) resin with a solid content of 64 ± 1% was used for the experimental panels. This UF resin is currently used for the particleboard manufacturing on an industrial scale and has a dynamic viscosity of 150 to 250 cps at 30 °C and gel time reactivity of 120 to 160 s at 100 °C. Coconut fibre were prepared by shredding and crushing long fibres by using hammer mill crushing machine. After that, the coconut fibre sieve using horizontal handmade wood sieve of 5 mm, 3mm, 1 mm and pan as well as for sawdust. After that, sawdust and coconut fibre retained at 5 mm will be separated for board making and the particle size analysis using vertical sieve shaker. Both sawdust and coconut fibres then were oven-dried at 80 °C for 24h to reduce the moisture content of materials.

The sawdust, coconut fibre and resin will be weighed to respective percentage proportion before to be mixing and blending together in drum mixer for 10 minutes. The design of percentage proportion of sawdust and coconut fibre are based of targeted density. The target density of the experimental panels
was 650 kg/m³, which is the average density of the 16-mm particleboard manufactured in industrial conditions from wood particles. UF resin was added to the single-mat configuration at a level of 6 wt%, 8 wt% and 10 wt%, based on the weight of the particles.

Fifteen types of panel were made, as indicated in Table 2. The panels were prepared under laboratory conditions using a hot press with plates of 450 mm x 450 mm in Timber Fabrication Laboratory, Universiti Tun Hussein Onn Malaysia. The particleboards were manually formed in wooden frames whose dimensions are 350 mm x 350 mm x 16 mm. Boards measuring 350 mm x 350 mm were then hot-pressed at 140 °C, 160 °C and 180 °C for 7 minutes under 2.5 to 3.0 N/mm² pressure. After pressing, the particleboards were conditioned at 20 °C and 65% relative humidity for 1 week before evaluating the physical and mechanical properties. The particleboards were first trimmed to avoid edge defects to a final size of 300 mm x 300 x 16 mm. Three replicate panels were made for each board type, and specimens for mechanical and physical testing were cut from each particleboard type.

**Table 2. Experimental Design for Board**

| Variable                          | Board Code | % Proportion | Adhesive (UF) Resin (%) | Hot-press Temperature (°C) |
|----------------------------------|------------|--------------|-------------------------|---------------------------|
|                                  |            | Sawdust     | Coconut fibre           | 6  | 8  | 10 | 140 | 160 | 180 |
| **1** (Different Hot-Press Temperature) | 100SD (1) | 100          | 0                        | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 70SD (1)   | 70           | 30                       | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 50SD (1)   | 50           | 50                       | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 30SD (1)   | 30           | 70                       | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 0SD (1)    | 0            | 100                      | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
| **2** (Different Resin Content)  | 100SD (2)  | 100          | 0                        | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 70SD (2)   | 70           | 30                       | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 50SD (2)   | 50           | 50                       | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 30SD (2)   | 30           | 70                       | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 0SD (2)    | 0            | 100                      | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 100SD (3)  | 100          | 0                        | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 70SD (3)   | 70           | 30                       | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 50SD (3)   | 50           | 50                       | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 30SD (3)   | 30           | 70                       | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
|                                  | 0SD (3)    | 0            | 100                      | ✓  | ✓  | ✓  | ✓   | ✓   | ✓   |
2.1. Determination of Density (BS EN 323:1993)

By adapting the methodology in BS EN 323:1993, the density to be determined by sampling and cutting of the test pieces in accordance to EN 326-1 where the side of nominal length of specimen is 50 mm. The dimensions and thickness at a point of the intersection of diagonals of each test piece should be measured in accordance to EN 325. After that, weighed the mass of each test piece. The density of a board shall be obtained by calculating the arithmetic mean of the densities of all the test pieces taken from the same board and is expressed in kg/m$^3$ to three significant figures [14]. The density $\rho$ of each test piece (in kg/m$^3$) shall be calculated from the equation (1):

$$\rho = \frac{m}{b_1 \times b_2 \times t} \times 10^6$$  

Where, $m$ is the mass of board, in gram, $b_1$, $b_2$ is the dimension of board, in millimetre and $t$ is the thickness of board, in millimetre.

2.2. Determination of Particleboard’s Modulus of Elasticity and Modulus of Rupture (BS EN 310:1993)

In accordance to BS EN 310:1993, the modulus of elasticity, $E_m$, can be calculated by using equation (2) by sampling and cutting of the test pieces and measured the width and thickness of each test piece according to EN 325 at the following points: the thickness at the intersection of the diagonals; the width at the mid-length whereas the width and thickness of test pieces are 50 mm and as specified in thickness group (16 mm, 20 mm and 32 mm). Adjust the distance between the centres of the supports, to within 1 mm of 20 times the nominal thickness of the panel, but not less than 100 mm and not more than 1 000 mm, in this study the distance is fixed to 200 mm. The load shall be applied at a constant rate of cross-head movement throughout the test. The rate of loading shall be adjusted so that the maximum load is reached within (60 ± 30) s. Measure the deflection in the middle of the test piece (below the loading head) [15].

$$E_m = \frac{(l_1)^3(F_2 - F_1)}{4b t^4(a_2 - a_1)}$$  

Where, $l_1$ is the distance between the centres of the supports, in millimetres, $b$ is the width of the test piece, in millimetres, $t$ is the thickness of the test piece, in millimetres, $F_2 - F_1$ is the increment of
load on the straight line portion of the load-deflection curve, in N which \( F_1 \) shall be approximately 10 % and \( F_2 \) shall be approximately 40 % of the maximum load and \( a_2 - a_1 \) is the increment of deflection at the mid-length of the test piece (corresponding to \( F_2 - F_1 \)).

The bending strength of each test piece shall be expressed to three significant figures. The bending strength for each group of test pieces taken from the same board is the arithmetic mean of the bending strengths of the appropriate test pieces, expressed to three significant figures [15]. The bending strength \( f_m \) (in N/mm²), of each test piece, is calculated from the equation (3),

\[
f_m = \frac{3 F_{\text{max}} l_1}{2 b t^2}
\]

Where, \( F_{\text{max}} \) is the maximum load, in Newtons and \( l_1, b, \) and \( t \) are in millimetres.

3. Results and Discussions

The results obtained from this research are the density distribution, modulus of elasticity and modulus of rupture in all particleboards when the hot-press temperature varies from 140 °C, 160 °C and 180 °C as well as the results for modulus of elasticity and modulus of rupture in comparison between 100SD:0CF to 30SD:70CF and 0SD:100CF when the resin content varies from 6%, 8% and 10%. The results for modulus of rupture and modulus of elasticity were collected and presented in a bar graph as a comparison to requirements for non load-bearing boards for use in humid conditions (Type P3) particleboard from Table 4 in BS EN 312:2010.

3.1. Density of Board

Density distribution in particleboard are the mean from specimens as specified in Figure 3. After that the result represented in a bar graph as shown in Figure 3. First of all, the comparison between 100SD:0CF and 0SD:100CF when the hot-press temperature is 180 °C the density of particleboard are 513.526 kg/m³ and 675.416 kg/m³ respectively with differences of 136.474 kg/m³ and 25.416 kg/m³ where the particleboard with coconut fiber is more stable in density distribution. After that, when the hot-press temperature is 140 °C all particleboards have density more than targeted density of 650 kg/m³ where 702.963 kg/m³, 706.791 kg/m³, 696.702 kg/m³, 759.185 kg/m³ and 669.705 kg/m³ which differences range from 19.705 kg/m³ to 109.185 kg/m³. Meanwhile, when the hot-press temperature is 160 °C the density for all particleboards are 614.720 kg/m³, 666.737 kg/m³, 613.451 kg/m³, 696.383 kg/m³, 667.721 kg/m³ which differences range from 16.737 kg/m³ to 46.383 kg/m³.

In can be concluded that the range of differences of the density of particleboards when the hot-press temperature is 160 °C suitable in particleboard making because the density distribution more stable. According to E. Dieckmann et al. (2019), The pressing temperature should be between 150 and 160 °C, is crucial for developing optimal properties. [16].
3.2. Modulus of Elasticity in Bending and of Bending Strength (Modulus of Rupture) of Boards

Modulus of elasticity (MOE) in bending for all particleboards were tested and then compared in Figure 4. First of all, the comparison between 100SD:0CF and 0SD:100CF with hot press-temperature of 160 °C, both particleboards reached 2677 N/mm² and 2450 N/mm² respectively which passed 1950 N/mm², however with hot-press temperature of 180 °C the particleboard 0SD:100CF reached 2197.500 N/mm² which also passes the requirement for Type P3 particleboard while 100SD:0CF only reached up to 695.450 N/mm². Therefore, with hot-press temperature of 160 °C and the more percentage of coconut fiber in particleboard the better the MOE in bending. After that, the comparison between 70SD:30CF, 50SD:50CF and 30SD:70CF with hot-press temperature of 160 °C, only particleboard 70SD:30CF and 30SD:70CF passed the requirement which are reached 2740.500 N/mm² and 2689.000 N/mm² respectively while 50SD:50CF only reached up to 931.300 N/mm². Finally, when the hot-press temperature is 140 °C all particleboard have not passed the requirement where the MOE for 100SD:0CF, 70SD:30CF, 500SD:50CF, 30SD:70CF and 0SD:100CF are 1568.333 N/mm², 1576.833 N/mm², 963.667 N/mm², 1741.500 N/mm² and 893.833 N/mm² respectively.

Therefore, when the percentage of replacement of sawdust to coconut fibre as well as replacement of coconut fibre to sawdust reach 30% and the hot-press temperature of 160 °C the boards achieved and passes 1950 N/mm². Since the failure process varies depending on the pressing temperature, this is the case where peak fibre bonding induces fibre pull out at low temperatures (around 140 °C). Under perfect pressing conditions, fibre fracture and heavy bonding occur. Due to thermal erosion of feather fibres, brittle fracture happens at processing temperatures above 170 °C. [16]. According to Gul et al. (2017), the temperature range of 160–180°C is typically used to ensure complete solidification of different glues [17].
Figure 4. Bar Graph of Modulus of Elasticity for all Particleboards with Different Hot-Press Temperature

Figure 5. Bar Graph of Modulus of Elasticity for all Particleboards with Different Resin Content

Figure 6. Bar Graph of Modulus of Rupture for all Particleboards with Different Hot-Press Temperature

Figure 7. Bar Graph of Modulus of Rupture for all Particleboards with Different Resin Content

Figure 5 shows the comparison between particleboards 100SD:0CF with 30SD:70CF and 0SD:100CF with different resin content varies from 6%, 8% and 10%. With 6% of resin content all particleboards do not pass the requirement where the MOE only reached 1731.00 N/mm², 1457.50 N/mm² and 864.20 N/mm² for 100SD:0CF, 30SD:70CF and 0SD:100CF respectively. Meanwhile, at 8% of resin content all the particleboards passed the requirement by reached over 1950 N/mm² whereas 2677.00 N/mm² for 100SD:0CF, 2689.00 N/mm² for 30SD:70CF and 2450.00 N/mm² for 0SD:100CF. At last but not least, at 10% of resin content all particleboard does not pass the requirement by only reached 1917.00 N/mm² for 100SD:0CF, 1880.00 N/mm² for 30SD:70CF and 1380.00 N/mm² for 0SD:100CF. Therefore, 8% of resin content is suitable for particleboards to reached 1950 N/mm² as well as the 30SD:70CF reach the highest value of all is the suitable ratio proportion of sawdust and coconut fibers as a particleboard.
Bending strength or Modulus of rupture for all particleboards were tested and then compared in Figure 6. First of all, the comparison between 100SD:0CF and 0SD:100CF with hot press-temperature of 160 °C, only particleboard 0SD:100CF reached 20.690 N/mm² which passed 14 N/mm² while 100SD:0CF only reached up to 6.655 N/mm², however with hot-press temperature of 180 °C the particleboard 0SD:100CF reached 15.790 N/mm² which also passes the requirement for Type P3 particleboard while 100SD:0CF only reached up to 2.314 N/mm². Therefore, with hot-press temperature of 160 °C and the more percentage of coconut fiber in particleboard the better the modulus of rupture. After that, the comparison between 70SD:30CF, 50SD:50CF and 30SD:70CF with hot-press temperature of 160 °C, only particleboard 30SD:70CF passed the requirement which are reached 18.740 N/mm² while 70SD:30CF and 50SD:50CF only reached up to 11.780 N/mm² and 4.442 N/mm² respectively. Finally, when the hot-press temperature is 140 °C only particleboard 30SD:70CF passes the requirement which reached 19.533 N/mm² while other have not passed the requirement where the MOE for 100SD:0CF, 70SD:30CF, 500SD:50CF and 0SD:100CF are 10.033 N/mm², 11.869 N/mm², 8.796 N/mm² and 13.782 N/mm² respectively. According to Gul et. Al (2017), even at low temperature (140 °C), the MOR value is very close to standard value. At 160 °C, the MOR value is at its peak and if the temperature further to increase from 160 °C to 185 °C, the MOR behaves in reverse manner [17].

Figure 7 shows the comparison of bending strength or modulus of rupture between particleboards 100SD:0CF with 30SD:70CF and 0SD:100CF with different resin content varies from 6%, 8% and 10%. With 6% of resin content all particleboards do not passes the requirement where the MOR only reached 9.3115 N/mm², 12.588 N/mm² and 7.6481 N/mm² for 100SD:0CF, 30SD:70CF and 0SD:100CF respectively. Meanwhile, at 8% of resin content only two particleboards passed the requirement by reached over 14 N/mm² whereas 18.740 N/mm² for 30SD:70CF and 20.690 N/mm² for 0SD:100CF while 6.655 N/mm² for 100SD:0CF do not passes the requirement. At last but not least, at 10% of resin content only particleboard 100SD:0CF does not passes the requirement by reached 8.734 N/mm², meanwhile both 30SD:70CF and 0SD:100CF passed with 14.585 N/mm² and 21.38 N/mm² respectively. Therefore, 8% and 10% of resin content is suitable for particleboards to reached 14 N/mm² as well as particleboard 0SD:100CF reached the highest value of all is the suitable ratio proportion of sawdust and coconut fibers as a particleboard as well as 30SD:70CF as the more the proportion of coconut fibre the better the bending strength obtained.

4. Conclusion

All the particleboards of sawdust and coconut fibre were tested and compared with BS EN 312:2010 requirement for non load-bearing boards for use in humid condition (Type P3). The hot-press temperature used during compression varied from 140 °C, 160 °C and 180 °C, while the resin content varied from 6%, 8% and 10% and the ratio of proportion sawdust to coconut fibre by percentage of weight varied from 100SD:0CF, 70SD:30CF, 505SD:50CF, 30SD:70CF and 0SD:100CF. It is concluded that the suitable hot-press temperature is 160 °C, resin content is 8% and the proportion of sawdust to coconut fibre are 30SD:70CF and 0SD:100CF whereas the more the fibre the better the results obtained.

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