Physical and mechanical properties of binderless medium density fiberboard (MDF) from coconut fiber

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Abstract. Coconut fiber is a natural fiber extracted from coconut coir, a by-product of coconut based product. It is a potential material for fiberboard because it contains high cellulose and lignin which is similar to wood. Binderless medium density fiberboard (MDF) from coconut fiber was produced to reduce the consumption of wood and the emission of synthetic adhesives such as urea formaldehyde using lignin as natural binder. The purpose of this research were to determine the physical and mechanical properties of MDF from coconut fiber based on SNI 01-4449-2006 and JIS A 5905:2003 and to investigate the effect of oxidation treatment, additional paraffin, and pressing time to the physical and mechanical properties of the fiberboard. The results showed that the fiberboards produced on this research had medium density of 0.44-0.56 g/cm³ which met the standard for MDF. Most of fiberboards from coconut fiber obtained in this study met the standard for physical properties such as density, moisture content, thickness swelling, and screw holding power. However, the mechanical properties such as modulus of elasticity, modulus of rupture, and internal bond of the fiberboards had not met the SNI 01-4449-2006 and JIS A 5905:2003 because of the lack of materials strength.

1. Introduction
The high consumption of wood as raw material of timber industry affect the deforestation rate. Wood consumption in Indonesia reaches 80 million m³ [1]. According to CIFOR [2], wood supply from natural forest is only 22 million m³ per year. The wood supply in forest would be depleted if there is no available alternative to replace wood natural fiber as raw material. Non-wood natural fiber can be used as substitute of wood natural fiber. It has many advantages such as easy to harvest in relatively shorter time compared to tree and easy to cultivate. Lignocellulosic natural fibers derived from non-wood natural sources are abundantly available in the nature. One of the example is coconut coir which is by product of coconut fruit. Coconut coir is the largest part of coconut fruit which is about 35% of the total weight of coconut. Lignocelluloses from coconut coir can be used as raw material for coconut fiber or commonly known as coco fiber. The processing of coconut coir into coco fiber can produce long fiber, short fiber, and coir dust with each different utilization [3].

Coconut plantations spread across the Indonesian archipelago. In year 2010, the total area of coconut plantation was 3.7 million ha consisting smallholder plantation (98.14%), state-owned plantation (0.10%), and large private estate (1.73%). In year 2010, coconut production was 3.26 million ton which consisted of 3.18 million tons of smallholder plantation, 2.33 million tons of state-owned plantation, and 80.97 thousand tons of large private estate [4]. Coconut plantations are located almost across Indonesia archipelago, where the largest is in Sumatra with areal 1.20 million ha (32.90%), then Java 0.903 million ha (24.30%), Celebes 0.716 million ha (19.30%), Bali, NTB and NTT 0.305 million ha (8.20%), to Maluku and Papua 0.289 million ha (7.80%), and the least is Kalimantan with 0.277 million
ha (7.50%). Coconut is cultivated by farmers either in the field or in front of their houses. Coconut occupy area approximately 3.70 million ha or 26% from 14.20 million ha total plantation area in Indonesia [5].

Coconut coir have a relatively similar chemical component with wood. It contains 8.5% hemicelluloses; 21.07% cellulose; 29.23% lignin; 14.25% pectin and 26% water [6], hence it can be used as raw material of fiberboard. Fiberboard is a type of composite produced from fiber of wood or another material that have lignocelluloses which mixed with adhesive or other binder and then pressed in high temperature [7]. The production of fiberboards from coconut coir and fibers adds value to these materials and may reduce the environmental burden related to husks disposal [8]. Fiberboard has higher added value and promising market than the other products made from coconut coir such as doormat, broom, and rope. FAO stated that between 2009 and 2013, the global market for fiberboards increased by 35%.

Fiberboards are usually manufactured from lignin resin, which are pressed at high temperatures [8]. Fiberboards usually use synthetic adhesive or binder such as urea formaldehyde, melamine formaldehyde or phenol formaldehyde. Those adhesives were known for its formaldehyde emission which can pollute to the environment, therefore this research utilize lignin contained in coconut coir itself as natural adhesive. It is used in order to reduce the dependence of petroleum-based synthetic adhesive, reduce environmental pollution and reduce cost of the adhesive [9].

Based on its structure, lignin is similar to phenol formaldehyde resins because both of them have chemical components which are almost the same as the phenolic group thus causing lignin to be used to substitute phenol formaldehyde. The potential of lignin as adhesive has inspired some researchers to develop methods which can activate lignin in wood directly so that wood fibers can bond itself without additional adhesive [10].

The methods that have been developed are oxidation method, hot steam injection method, and enzymatic treatment. Oxidation method was developed by using hydrogen peroxide and ferro sulfate to make binderless particleboard [11]. They were successfully made binderless particleboard with hydrogen peroxide and ferro sulfate to activate lignin component of wood particle. Additional material such as paraffin is needed to prevent water absorption in the particleboard or fiberboard. Paraffin has the ability to inhibit penetration of water on the finished product [12]. Considering those previous studies, we decided to investigate the characteristic of binderless fiberboard from coconut fiber with oxidation treatment, additional paraffin and pressing time.

2. Materials and method
The main material which is used in this research is coconut coir. Chemicals and other components used in the evaluation are hydrogen peroxide, ferro sulfate, paraffin and water. The tools and equipment used in this research are oven, desiccators, scales (analytical balance), baking pan, fiber container, hot press, mat (30x30 cm), spacer, aluminum foil, Instron mechanical testing tool Universal Testing Machine (UTM), kaliver, blender drum, compressor, sprayer gun, saw, mask and gloves.

This research was conducted in four steps. The first step was preparation of raw materials, followed by producing medium density fiberboard (MDF), conditioning, and testing the physical and mechanical properties of the MDF. In the preparation of raw materials, coconut coir was separated from impurities such as soil and skin of coconut meat which still attach to the coir. Process is continued with size reduction of coconut coir became ± 1-2 cm using ring flaker. The fibers then sun-dried and dried in oven at ± 50 ºC or equivalent to sun-drying temperature.

Process of producing board begin with weighing the fiber which is needed in accordance to materials counting to achieve density 0.6 g/cm³. After that, fiber was put into the blender drum and sprayed simultaneously with hydrogen peroxide (15% of dry particle material weight). The process continued with spraying of ferro sulfate (7.5% of hydrogen peroxide volume). For the finishing, paraffin 0.5% was sprayed to the fiber. Then, the processed fiber was placed on the mat (30x30 cm) with is previously covered with aluminum foil. After board is formed, it is then hot-pressed for 10 min and 20 min at
temperature 180 ºC and pressure of 25 kgf/cm². This method was modification from Suhasman [13]. Table 1 shows the combination of the treatment in this research.

| Treatment number | Treatment code | Oxidation | Paraffin | Pressing time (min) |
|------------------|----------------|-----------|----------|---------------------|
| 1                | O1P1T1         | Yes       | 0.5%     | 10                  |
| 2                | O1P1T2         | Yes       | -        | 20                  |
| 3                | O1P2T1         | Yes       | 0.5%     | 10                  |
| 4                | O1P2T2         | Yes       | -        | 20                  |
| 5                | O2P1T1         | No        | 0.5%     | 10                  |
| 6                | O2P1T2         | No        | -        | 20                  |
| 7                | O2P2T1         | No        | 0.5%     | 10                  |
| 8                | O2P2T2         | No        | -        | 20                  |

The expected density for this binderless fiberboard from coconut fiber is 0.6 g/cm³ (medium rate density). The usage of this kind of MDF is purposely for the interior which is sensitive to physical properties such as water absorption, thickness swelling, moisture content and density. The fiberboard is mainly used in furniture. Conditioning process of board was done for approximately one week in room temperature to homogenize moisture content of fiberboard and eliminate the stresses on the surface of board because of hot press process [14]. After the conditioning process, the samples were cut. The cutting pattern of samples for the physical and mechanical properties testing refers to SNI 01-4449-2006 and JIS A 5905:2003 standard.

The experimental design was using completely randomized design with factorial 2x2x2 and twice repetition. Statistical analyses were performed using SPSS 16.0 software and Microsoft Office Excel. Distribution of data and significance value were analyzed by ANOVA using 95% confidence interval and 5% significant interval. In case of significance difference lower than 0.05, Duncan Multiple Range Test (DMRT) was used to identify treatments with significant difference.

3. Result and discussion

3.1. Coconut coir characteristic

Coconut is known for its great usefulness as seen in the many uses of its parts. Its roots, leaves, trunk, and fruit can be utilized and processed into variety of products. Coconut fruit consists of different components, namely coconut coir, coconut shell, coconut flesh, and coconut water. Dried coconut flesh, also known as copra as the main product has a high economic value in industry. Meanwhile coconut husk or coconut coir, coconut shell and coconut water as the by product can also be processed into various commercial products. Coconut coir is the outermost layer of coconut fruit covering the coconut shell. It has two layers: the outer layer (exocarpium) and inner layer (endocarpium). The endocarpium is composed of fine fibers called coir which has many commercial uses such as for material in producing rope, sack, pulp, carpets, brushes, mats, heat and sound insulation, filter, car seat filler, and board [3]. Coconut coir composition examination [6] referring to Indonesia national standard (SNI) carried out by Standardization Research Facility is presented in Table 2.
Table 2. Chemical composition of coconut coir and coconut fiber compared with wood.

| No | Components         | Coir   | Fiber | Wood |
|----|--------------------|--------|-------|------|
| 1  | Lignin (%)         | 29.23  | 45.84 | 25-30|
| 2  | Cellulose (%)      | 21.07  | 43.44 | 40-50|
| 3  | Hemicellulose (%)  | 8.50   | 0.25  | 20-30|
| 4  | Pectin (%)         | 14.25  | 3.00  |      |
| 5  | Water (%)          | 26.00  | 5.25  |      |

Due to the chemical composition similarity between coconut coir and wood fiber, coconut coir can be used as the material in producing fiberboard. Commonly fiberboards are made from lignocellulosic materials mixed with adhesive or binder and hot pressed into a certain shape [7]. The characteristic of fiberboard can be examined by testing the physical properties (density, moisture content, thickness swelling, and water absorption) and mechanical properties (internal bond, modulus of rupture, modulus of elasticity, and screw holding power) refers to JIS A 5905:2003 and SNI 01-4449-2006.

3.2. Density
Density relates to the porosity or the proportion of hollow space volume. As a consequence, the higher the density, the higher the strength it will be [15]. The result of variance test on density using ANOVA shows that the significance value is 0.009. It is lower than 0.05 which means that there are significant difference among the treatments. Duncan test were carried out as a follow up to compare the means and investigate significant difference among treatment combinations. There are three groups of value a, ab, and b which indicate value equivalence among the same group. Figure 1 shows the density of the fiberboard. The density of fiberboards was between 0.4-0.84 g/cm³ for medium density fiberboard (MDF).

The highest density was 0.56 g/cm³, found on the treatment combination O2P2T2. The initial hypothesis refers to a previous study which stated that the highest density will be achieved by treatment combination O1P1T2 because oxidation could increase the inner fiber bond while longer compression time would allow the fiber bond to contact well and more compact.

However the mean density of O2P2T2 and O1P1T2 based on Duncan test was not significantly different. The Oxidation and paraffin addition do not significantly influence the density. Meanwhile compression time shows a significant effect on the binderless MDF density, where the value increase along with the pressing time addition. Longer pressing time (20 min) resulted in higher density than the shorter one (10 min). The density of all treatment combinations has achieved the standard of JIS A 5905:2003 and SNI 01-4449-2006. The other factor that influence the density is moisture adjustment at conditioning process which could increase the thickness of the fiberboards [16].

3.3. Moisture content
Moisture content is the physical properties of fiberboard that indicate the amount of moisture in a material. Based on the ANOVA test, the significance value is 0.000 (< 0.005) thus implying that there is a significant difference between the treatment combinations. Duncan test was then performed to identify which treatment combinations are significantly different and which are not. The moisture content means value were then grouped into a, b, and c where the treatment combinations value in the same group is not significantly different as shown in Figure 2.

Moisture content of all samples achieved the standard of JIS (5-13%) and SNI (max 13%). Commonly as the density gets higher, the moisture content will become lower [17]. Moisture content is essential in keeping the stability of the MDF. Based on Duncan test, the means of moisture content value for O1P1T2, O1P2T2, O2P1T2, and O2P2T2 are not significantly different. However they are significantly different with the rest treatment combinations. It implies that 20 min compression time has
a significant effect on the moisture content. The shorter compression time will cause the water inside the board to not fully evaporate to the surface [18]. The moisture will accumulate below the board surface thus decreasing board’s physical and mechanical properties.

3.4. Water absorption

Water absorption is the ability of fiberboard to absorb water after being immersed in water for 24 h. JIS (2003) and SNI (2006) do not set any standard for water absorption. However this measurement is needed to investigate the resistance of the fiberboard to water, especially for exterior purpose where the board will be directly exposed to weather like humidity and rain [19].

Based on ANOVA test, the significance value of samples’ water absorbance capacity is 0.001. It is lower than 0.005 which implies that there are significant difference between the treatment combinations. Duncan test was then performed to identify which treatment combinations are significantly different and which are not. The means value was then grouped into a, b, bc and c where the treatment combinations value in the same group is not significantly different, as shown in Figure 3.

3.5. Thickness swelling

Thickness swelling will increase along with the increase of water absorption. Based on ANOVA test, the significance value is 0.000. It is lower than 0.005 which implies that there are significant difference between the treatment combinations. Duncan test was then performed to identify which treatment combinations are significantly different and which are not. The means value was then grouped into a, ab, bc, c and d where the treatment combinations value in the same group are not significantly different as shown in Figure 4.

Thickness swelling standard based on and SNI is maximum 17% for MDF type 30. Samples with oxidation, paraffin 0.5% and without paraffin at 20 min of pressing time achieved the standard with thickness swelling value of 8% and 12% respectively. The smallest value is the best to anticipate water to be absorbed into the board through particle pores and hollow spaces between particles slowly [20]. Average thickness swelling of samples with oxidation are lower than that without oxidation at the same pressing time. This phenomenon could be caused by cross bond between radical molecules which occurs during oxidation will be more compact within or by cross bond between hydroxyl molecules [21]. Radical molecules produced during oxidation create covalent bond during hot-pressing so that the bond would be stronger and more stable. Based on Duncan test, samples with oxidation and 20 min of pressing time tend to have lower value. It means that oxidation and 20 min of pressing time influence the thickness swelling.

3.6. Modulus of elasticity (MOE)

MOE is a number that measures a material’s resistance to being deformed elastically when a force is applied to it. It is defined as the ratio of tensile stress to tensile strain below the elasticity limit thus it only strains temporarily and back to its initial shape if the force was released [22]. Tensile elasticity is effected by the type and the component of adhesive, adhesion holding capacity, and fiber length [7].

On this measurement, all samples have not achieved both JIS (2003) and SNI (2006) which minimum value of MOE is 8200 kgf/cm² for MDF type 5. Based on ANOVA test, the significance value of MOE is 0.001 so there are significant difference between the treatment combinations. Duncan test was then performed to identify which treatment combinations are significantly different and which are not. The means value was then grouped into a, and b where the treatment combinations value in the same group are not significantly different while the treatment combinations value in different group is significantly different as shown in Figure 5.

3.7. Modulus of rupture (MOR)

MOR characterizes the bending strength of a material. It defines material’s ability to resist deformation under load. Higher MOR of a board means higher quality it has [22]. Similar to MOE, MOR is also influenced by the type and the component of adhesive, adhesion holding capacity, and fiber length.
MOR of the samples in this study have not achieved both JIS (2003) and SNI (2006) (minimum 51 kgf/cm$^2$). In this study, lignin of the coconut coir during the hot compression was not fully reacted with the hydroxyl radicals that was formed at oxidation. The covalent bond that was produced by the reaction was not strong enough to hold the applied weight. The value of MOR not only depends on the bonding strength among fibers, but also the individual fiber strength and fiber geometry. Severe steam treatment conditions might result in a high degree of hydrolysis or modification of the chemical components, causing a reduction in the fiber strength. Based on ANOVA test, the significance value is 0.000. It is lower than 0.005 which implies that there are significant difference between the treatment combinations.

Duncan test was then performed to identify which treatment combinations are significantly different and which are not. The means value were then grouped into a, b, bc, c and d where the treatment combinations value in the same group is not significantly different as shown in Figure 6.

3.8. Internal bond (IB)

Internal bond reflects the quality of mixing, shaping, and compression. It is also the best measure of the quality of board manufacturing because it shows the bonds between particles [15]. Based on ANOVA test, the significance value showed that there are significant difference between the treatment combinations as shown in Figure 11. The average value of bonding strength of all treatment combinations have not meet the standard from JIS (minimum 4.08 kgf/cm$^2$) and SNI (minimum 2.1 kgf/cm$^2$). This may be caused by covalent bonds resulting from oxidation and lignin were not interacting perfectly, so that the mixing of lignin and hydroxyl radicals that form a covalent bond is not strong and stable. On the other side, longer compression time (20 min) was still insufficient to produce good IB value. This low value indicates that the strength of the chemical bond formed on binderless MDF with oxidation treatment was still low.

Based on Duncan test, the IB value of sample with treatment combination O1P2T2 was not significantly different with that of O1P1T2, where the values are 0.30 kgf/cm$^2$ and 0.31 kgf/cm$^2$ respectively. This means that paraffin 0.5 did not have a significant effect on the adhesion. However the combination of oxidation and 20 min of pressing time have an impact as a result of some treatments that were significantly different.

3.9. Screw holding power

Screw holding power characterizes the ability of fiberboard in holding external screw load. Based on ANOVA test, there are significant difference between the treatment combinations. Duncan test was then performed to identify the significantly different between the samples as shown in Figure 12. JIS A 5908:2003 and SNI 03-2105-2006 standard for screw holding power are minimum 30 kgf dan 31 kgf respectively. All samples with oxidation treatment have achieved the standard, while the result of samples without oxidation treatment were below the standard. Bonds were formed on the surface of the fiber as a result of reaction between hydroxyl radicals and lignin during hot-compression. This caused the MDF to become denser. In general, screw holding capacity is positively related to density.

Combination of paraffin 0.5% addition, oxidation, and 20 min of pressing time results in the highest screw holding power. This could be caused by the integration of paraffin and fiber. In this case the melted paraffin was covering the fiber and causing the fiber to stick with one another with the presence of paraffin. As it closely attached to one another, hollow spaces between fibers were minimized and the density is higher. Duncan test showed that oxidation treatment gave significantly different result from without oxidation treatment. It means that oxidation is an important factor in MDF mechanical properties.
Figure 1. Density of the binderless MDFs from coconut fiber

Figure 2. Moisture content of the binderless MDFs from coconut fiber

Figure 3. Water absorption of the binderless MDFs from coconut fiber

Figure 4. Thickness swelling of the binderless MDFs from coconut fiber

Figure 5. MOE of the binderless MDFs from coconut fiber

Figure 6. MOR of the binderless MDFs from coconut fiber
4. Conclusion
The binderless medium density of fiberboards (MDF) was successfully produced from coconut fiber. The physical and mechanical properties of MDF from coconut fiber were determined using JIS and SNI standard. The results showed that the fiberboards produced on this research had medium density of 0.44-0.56 g/cm$^3$ which met the standard for MDF. Most of fiberboards from coconut fiber obtained in this study met the standard for physical properties such as density, moisture content, thickness swelling, and screw holding power. However, the mechanical properties such as modulus of elasticity, modulus of rupture, and internal bond of the fiberboards had not met the SNI 01-4449-2006 and JIS A 5905:2003 standard because of the lack of materials strength. The MDF with treatment combination of oxidation, paraffin 0.5% and 20 min of pressing time (O1P1T2) is suitable for interior usage while the MDF with treatment combination of oxidation, without paraffin, and 20 min of pressing time (O1P2T2) is suitable for exterior usage.

5. References
[1] Massijaya M Y 2003 Pemanfaatan limbah kayu dan karton sebagai bahan baku papan komposit: sifat-sifat dasar dan teknik pembuatan papan komposit dari limbah kayu dan karton [laporan penelitian hibah bersaing XI/J] (Bogor: Perguruan Tinggi Tahun Anggaran 2003)
[2] Center for International Forestry Research (CIFOR) 2007. Hutan tanaman dikelola intensif di Indonesia: Tinjauan tren terkini dan rencana terbaru
[3] Rindengan B, Lay A, Novarianto H, Kembuan H and Mahmud Z 1995 Karakterisasi daging buah kelapa hibrida untuk bahan baku industri makanan (Bogor: Badan Penelitian dan Pengembangan) pp 49
[4] Directorate General of Estate Crop 2010 Rencana strategis pembangunan perkebunan (Jakarta: Ministry of Agriculture)
[5] Nogoseno 2002 Reinventing agrabisnis per-kelapa nasional. Prosiding Konferensi Nasional Kelapa V (Bogor: Pusat Penelitian dan Pengembangan Perkebunan) pp 17–27
[6] Tyas SIS 2000 Studi netralisasi limbah serbuk sabut kelapa (Cocopeat) sebagai media tanam (Bogor: IPB University)
[7] Maloney TM 1993 Modern Particleboard and Dry Process Fiberboard Manufacturing (USA: Miller Freeman Publications)
[8] Freire A L F, Arauji C P, Junior, Rosa M F, Neto J A A and Figueiredo M C B 2017 Environmental assessment of bioproducts in development stage: The case of fiberboards made from coconut residues J. Clean. Prod. 3 1-37
[9] Pizzi A 1994 Advance Wood Adhesives Technology I (New York: Marcel Dekker, Inc)
[10] Widsten P A and Kandelbauer 2008 Laccase applications in the forest products industry: A review Enzyme Microb. Technol. 42 293–307
[11] Humphrey P E 2002 Proc. of the 6th pacific rim bio-based composites symposium & workshop on the chemical modification of cellulosics (Portland, Oregon, USA) p 149-153
[12] Forest Product Society 2010 Wood Handbook: Wood as an Engineering Material (Madison: USDA)
[13] Sufi EF, Susdiyanti T and Meigananti K B 2018 Utilization of Sengon Wood Saw Waste (Paraserianthes falcata) Becomes Fiberboard Jurnal Nusa Sylva. 18 1-8
[14] Manurung OMM 2011
[15] Haygreen J G and Bowyer JL 1986 Forest Products and Wood Science, an Introduction (Yogyakarta: UGM Press)
[16] Setyawati D, Sirait S M and Rahmaniah D 2008 Sifat-sifat papan komposit dari sabut kelapa, limbah plastik dan perekat urea formaldehida Jurnal Ilmu dan Teknologi Hasil Hutan. 1 94-103
[17] Setiawan B 2008 Papan partikel dari sekam padi (Bogor: IPB University)
[18] Li X, Li Y, Zhong Z, Wang D, Ratto J A, Sheng K and Sun X S 2009 Mechanical and water soaking properties of medium density fiberboard with wood fiber and soybean protein adhesives Bioresour. Technol. 100 3556-3562
[19] Lestari S and Kartika I A 2012 Pembuatan papan partikel dari ampas biji jarak pagar pada berbagai kondisi proses JAI 11 11-7
[20] Widiyanto A 2002 Kualitas papan partikel kayu karet (Hevea Brasiliensis Muell. Arg) dan bambu tali (Gigantochlon apus Kurz) dengan perekat likuida kayu (Bogor: IPB university)
[21] Widsten P, Qvintus-Leino P, Tuominen S and Laine J E 2003 Manufacture of fiberboard from wood fibers activated with fenton’s reagent (H₂O₂/FeSO₄) Holzforschung. 57 447–52
[22] Mardikanto T R, Karinasari L and Bahtiar E T 2011 Sifat Mekanis Kayu. (Bogor: IPB Press)