Application of liquefied adhesive made of oil-palm stem for particleboard binder

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Abstract. In order to evaluate the quality of liquefied adhesive made of oil-palm stem, this research compared results of physical and mechanical testing of particleboard bonded by liquefied adhesive made of oil-palm stem (LA), urea-formaldehyde (UF) and isocyanate (IC), respectively. LA was produced in laboratory and for decreasing its viscosity; it was mixed with thinner prior to spraying. UF and IC were commercially type, represented interior and exterior application, respectively. Both applications were following the standard procedure. Results of this study showed quality of the physical and mechanical properties of the particleboard bonded by LA were in between particleboard bonded by UF and particleboard bonded by IC, for instance value of MOE (kgf/cm²) was 10594 (UF) < 23529 (LA) < 24413 (IC) and MOR (kgf/cm²) was 5.37 (UF) < 18.14 (LA) < 25.35 (IC). These results indicated that LA was a promising adhesive even though in this case it can be used for interior application only.

1. Introduction

Agricultural and forestry sectors generate enormous lignocellulosic biomass materials, not only from main yield but also from harvesting residues, such as volumes of thinning and pruning, branches and twigs. In oil-palm plantation, because of monocotyledon, the abundant biomass could derive from the stem. After 25-30 years of planting, the oil-palms do not produce fruit anymore, therefore they are usually felled down and then the stem are left to decay or are burnt in the plantation area [1].

Anatomically, oil-palm stem consists of vascular bundles embedded in parenchyma tissues [1]. The presence both of these parts affects the properties of the stem [2], therefore it is important for considering them when we convert it into value added products.

Some scientists have been investigated the oil-palm stem by utilized whole part of the stem by making laminated products [3], producing plywood-based veneer [4], or impregnating products using thermosetting or thermoplastics resin [5]. The other scientists have been separated between the two and utilized only one part, for instance they only used parenchyma tissue for obtaining sugar (glucose and xylose) [6] and producing starch for making wood adhesive [7]. By contrast, only limited reports employed vascular bundles for raw materials, for example making composite plastics with polyethylene matrix [8] and producing oriented strand board (OSB) in laboratory scale [9].

Therefore, in this study, utilization of vascular bundles derive from oil-palm stem was investigated. The vascular bundle was liquefied through liquefaction process involving thermo-chemical reaction and resulting in various bio-copolymer such as coatings, various polymers, carbon fibers, foams, including adhesives [10]. This work is feasible because vascular bundles is one of lignocellulosic materials.
material having characteristics similar with wood with lignin content up to 22% [11,12]. In addition, in the recent review publication [13], both virgin and waste lignocelluloses materials have been succeeded to be converted into wood adhesives. Typical virgin feedstock that can be used as raw material for liquefied adhesive was kenaf core, bagasse, sugar beet pulp, coppice willow, wood (softwood and hardwood), and bamboo. Residue materials that were reported can be utilized as raw material for liquefied adhesive consisted of agricultural residues (rice husk, rice straw, coconut husk, coconut shell, corn stover, cornstalk, corn cob, cotton stalk, wheat straw, soybean straw, hazelnut shell, hazelnut seed coat, olive husk, olive stone); bamboo shoot shell; oil palm empty fruit bunch; rapeseed cake; grapevine cane; date seed; forest residues and wood waste including wood sawdust, pine bark, oak bark, white birch bark, cork; recycling and food waste like newspaper, furniture sawdust, coffee waste defatted cake, coffee waste powder, garbage, potato peel, and apple pomace [13].

Because this work is the first report on utilization of vascular bundles as raw material for making wood adhesives, this study then compared the quality of resulted bonding by liquefied adhesive and commercial ones (urea-formaldehyde and isocyanate).

2. Materials and methods

2.1. Preparation of the materials

Oil-palm stem was planned using planer machine. Resulted particles then were immersed in the water for 8 hours for separating between vascular bundles and parenchyma. The vascular bundle will be remained in the sieve as residue and the parenchyma will be passed the sieve as filtrate. Resulted vascular bundles were air-dried, grinded into 20-60 mesh in size and oven-dried (103+2)°C for 24 hours.

2.2. Production of liquefied adhesive

100 g oven-dry vascular bundle with moisture content 5% was placed into beaker glass. 25 ml H2SO4 98% (5% phenol weight) was added and stirred gently for 30 minutes. The mixture then was conditioned in sealed beaker glass. After 24 hours, 500 ml liquid phenol (hereafter melted in 60°C) was added into the mixture and then stirred gently until appear homogeneous. Sodium hydroxide (NaOH) 40% was added until the pH 8, then formaldehyde 37% was added with ratio phenol and formaldehyde of 1:1.2. The mixture then was filtered using Whatman paper number 1 and the extract was heated 90°C in the water bath for 2 hours. The extract then was kept in glass bottle prior to applying.

2.3. Application for making particleboard

The resulted liquefied adhesive has high viscosity; therefore, addition of solvent is needed in order to decrease the viscosity. In this case, commercial paint thinner was added with ratio thinner and liquefied adhesive of 0.8: 1 so the spraying application could be applied for particleboard’s binder.

2.4. Evaluation the quality of resulted particleboard

In order to evaluate the bonding quality, liquefied adhesive with addition of solvent was applied for particleboard bonding. Particleboard was made from jabon (Anthocephalus cadamba) woods derived from local sawmill. The woods were classified as sawmill waste; therefore, they were sieved (30 mesh in size) and oven-dried (until 5% moisture content) prior to making particleboard.

Particleboard was made by mixing wood particles with 10% liquefied adhesive based on oven dry wood particle. Target dimension and density of the particleboard was 25 cm x 25 cm x 1 cm and 0.75 g/cm³, respectively. Hot press was applied in temperature of 130°C and 25 kg/cm² in the periods of 10 minutes for making curing the liquefied adhesive.

For comparison, both urea-formaldehyde (UF) as interior wood adhesive and isocyanate as exterior wood adhesive were also used for making particleboard using similar procedure. Only in UF resin,
catalyst of ammonium chloride (NH₄Cl) 20% (w/v) was added 5% based on solid content of UF resin. This step was carried out for making curing the UF resin.

Particleboard was produced four replications for each adhesive; therefore, there were 12 resulted boards. Prior to testing, the resulted particleboards were conditioned for 7 days and cut into specimens according to Japanese Industrial Standard (JIS) A 5908 (2003). Physical properties of particleboard were measured using gravimetric procedures, consisted of density, moisture content, thickness swelling for 2 and 24 hours, and water absorption for 2 and 24 hours. Mechanical properties of particleboard were tested using Universal Testing Machine (UTM) Tensilon RTF-1350, comprised of modulus of elasticity (MOE), modulus of rupture (MOR) and internal bonding (IB).

The values of physical and mechanical properties for each parameter were tabulated. The data then were statistically analysed and Duncan’s multiple range tests (DMRT) were done for the quantitative measurements of adhesive differentiation (liquefied adhesive, UF, and isocyanate) to examine statistical significance at a p value of 0.05.

3. Results and discussion

3.1. Physical properties
Physical properties of particleboard were comprised of density, moisture content, thickness swelling, and water absorption. Figure 1 showed the density of the resulted particleboard. The values were below the target density and DMRT result showed there was no significance difference among the adhesives. This means all of the adhesives have similar character when they interact with wood particles. Prior to spraying using spray gun, all of the adhesives were in liquid form. They passed-out spray gun’s nozzle with uniform size. Droplets were stick on the surface of wood particle. With aid of high temperature from hot-press, the droplets were then hardened, cured and bonded the wood particles.

![Figure 1. Density of the particleboard](image)

Figure 2 showed moisture content of the particleboard. Even though the values seemed fluctuation, statistically there were no significant differences. UF resin adhesive exhibits higher value and standard deviation compared to those of liquefied adhesive (LA) and isocyanate (IC). UF resin contains water
originated from by-product of condensation reaction in production stage [14]. On the contrary, IC used water as the curing agent [15] while in this case LA used thinner as the solvent.

![Figure 2. Moisture content of the particleboard](image1.png)

![Figure 3. Thickness swelling of the particleboard](image2.png)

Tendency of moisture content resulted same pattern on thickness swelling as shown in Figure 3. Result of DMRT showed also there were no significant differences among the adhesives used either in 2 hours or in 24 hours observation. When adhesives cured, they will lose the moisture including the solvent. LA, UF, and IC were classified as thermosetting adhesives. When they were exposed to heat, they will harden, set, and form three-dimensional network.
Related to the performance, particleboard bonded by UF resin showed the highest thickness swelling. Indeed, UF resin is typical interior adhesive [14]; therefore, in moist condition the bonding is weak. By contrast and unexpectedly, LA showed better dimensional stability even though JIS standard did not fulfilled the value below 20% of thickness swelling.

![Figure 4. Water absorption of the particleboard](image)

Among the produced boards, IC-bonded particleboards performed with better properties compared to those of UF and LA-bonded boards, and UF-bonded particleboards were the worse in dimensional stability compared with those of others. However, DMRT’s result showed LA was different than UF both in 2 and 24 hours immersing in water. This phenomenon was understandable because the UF resin is not resistant to water and moisture, due to the hydrolysis of its amino-methylene bond [16].

3.2. Mechanical properties

Figures 5 and 6 showed the effect of adhesives used to the MOE and MOR, respectively. In these Figures, it is clear that the bending properties (MOE and MOR) improved when the particleboards were glued by LA or IC. DMRT’s result showed there was no significance different among the boards on MOE only. For MOR testing, LA was apparently different than IC and UF. It means that LA can compete IC as exterior adhesive and UF as interior adhesive. LA and IC can restrain the maximum compression and tension stresses on the surfaces area better than UF resin did. This can be understandable because typical LA adhesive was equivalent with phenolic-type resin adhesive [10,13,17].
Type of Adhesive

| Type of Adhesive | MOE (kgf/cm²) |
|------------------|---------------|
| LA               | 0             |
| UF               | 10000         |
| IC               | 20000         |
|                  | 30000         |
|                  | 40000         |

Figure 5. Modulus of elasticity of the particleboard

Unfortunately, internal bonding of LA resin was the worse compare to the others adhesive as shown in Figure 7. This phenomenon presumably the solvent of LA belonged to volatile material even though result of DMRT exhibited there were no significance different among the adhesives.

Type of Adhesive

| Type of Adhesive | MOR (kgf/cm²) |
|------------------|---------------|
| LA               | 0             |
| UF               | 5             |
| IC               | 10            |
|                  | 15            |
|                  | 20            |
|                  | 25            |
|                  | 30            |
|                  | 35            |

Figure 6. Modulus of rupture of the particleboard
Type of Adhesive  
LA  UF  IC
Internal Bonding (kgf/cm²)
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35

**Figure 7.** Internal bonding of the particleboard

4. Conclusions

According to physical and mechanical properties evaluation on particleboard, wood adhesives based on liquefied biomass made of vascular bundles oil-palm stem waste can be compete with interior type formalin-based adhesives (UF resin) and exterior type petroleum based adhesive (isocyanate). The use of solvent in LA resin should be considered for improving its characteristics.

References

[1] Lim SC and Gan KS 2005 Characteristics and utilization of oil-palm stem *Timber Technology Bulletin* 35 (Malaysia: Forest Research Institute Malaysia)

[2] Ramle SFM, Sulaiman O, Hashim R, Arai T, Kosugi A, Abe H, Murata Y and Mori Y 2012 Parenchyma and vascular of oil-palm *Lignocellulose* 1(1) p 33-44

[3] Darwis A, Massijaya MY, Nugroho N, Alamsyah EM and Nurrochmat DR 2014 Bond ability of oil-palm xylem with isocyanate adhesive *Jurnal Ilmu dan Teknologi Kayu Tropis* 12(1) p 39-47

[4] Feng LY, Tahir PM and Hoong YB 2011 Density distribution of oil-palm stem veneer and its influence on plywood mechanical properties *Journal of Applied Sciences* 11(5) p 824-831

[5] Rosli F, Ghazali CMR, Abdullah MMAB and Hussin K 2016 A review: characteristics of oil-palm trunk (OPT) and quality improvement of palm trunk plywood by resin impregnation *BioResources* 11(2) p 5565-5580

[6] Mansor H and Ahmad AR 1990 Carbohydrates in the oil-palm stem and their potential use *Journal of Tropical Forest Science* 2(3) p 220-226

[7] Salleh KM, Hashim R, Sulaiman O, Hiziroglu S, Nadhari WNAW, Karim NA, Jumhuri N and Ang LZP 2015 Evaluation of properties of starch-based adhesives and particleboard manufactured from them *Journal of Adhesion Science and Technology* 29(4) p 319-336

[8] Lubis MJ, Risnasari I, Nuryawan A and Febrianto F 2009 The quality of composite board made of waste oil-palm stem (Elaeis guineensis Jacq.) and recycle polyethylene (PE)
Nuryawan A 2010 Pembuatan papan unting berbahan dasar vascular bundles (ikatan pembuluh) dari batang kelapa sawit [Making planks made from vascular bundles from oil palm trunks] Nomor permohonan paten [Patent application number] P00201000838

Ugovšek A, Budija F, Kariž M and Šernek M 2011 The influence of solvent content in liquefied wood and of the addition of condensed tannin on bonding quality Drvna Industrija 62(2) p 87-95

Chew TL and Bhatia S 2008 Catalytic processes towards the production of biofuels in a palm oil and oil-palm biomass-based biorefinery Journal of Bioresource Technology 99(17) p 7911-7922 DOI: 10.1016/j.biortech.2008.03.009

Nuryawan A, Dalimunthe A and Saragih RN 2012 Sifat fisik dan kimia ikatan pembuluh pada batang kelapa sawit [Physical and chemical properties of oil palm trunk vascular bundles FORRESTA: Indonesian Journal of Forestry 1(2) p 34-40

Jiang W, Kumar A and Adamopoulos A 2018 Liquefaction of lignocellulosic materials and its applications in wood adhesives-A review Industrial Crops & Products 124 p 325-342

Singh AP, Causin V, Nuryawan A and Park BD 2014 Morphological, chemical and crystalline features of urea–formaldehyde resin cured in contact with wood European Polymer Journal 56 p 185–193

Nuryawan A and Alamsyah EM 2019 Thermal Properties of Isocyanate as Particleboard’s Adhesive IOP Conf Series: Materials Science and Engineering 593 012004

Nuryawan A and Park BD 2017 Quantification of hydrolytic degradation of cured urea-formaldehyde resin adhesives using confocal laser scanning microscopy International Journal of Adhesion & Adhesives 74 p 1–5

Kunaver M, Medved S, Čuk N, Jasiukaitytė E, Poljanšek I and Strnad T 2010 Application of liquefied wood as a new particle board adhesive system Bioresources Technology 101 p 1361-1368

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