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Properties of fibreboard (FBs) and recycle fibreboard (rFBs) and analysis of their wastage after recycling

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Abstract. Fibreboards (FBs) bonded by urea-formaldehyde (UF) resin derived from industry were intended to undergo cyclist test, a simulation of recycling activity. Objective of this study was to compare quality of FBs before and after recycling including analyse its wastage. Methods of this study were consisted of evaluation physical and mechanical properties of FBs before recycling, cyclist test, remanufacturing FBs, evaluation recycle FBs (rFBs), comparing the properties between FBs and rFBs and analysing the wastage of recycling activity both solid residue and liquid disposal. Results of this study showed physical and mechanical properties of FBs changed after recycling presumably because of the difference in reproduction method. Some physical properties showed better quality, while the mechanical properties performed decrease drastically. Cyclist test predicted that FBs were more resistant in 3 (three) cyclist compared to that of rFBs. There was wastage of recycling consisting of macro solid fibre with length dimension of 1000.51±339.21μm and micro solid fibre with variation in distribution size. Liquid disposal (LD) contained nitrogen (N) with amount 0.05% presumably from sol fraction of UF resin. These findings suggested that remanufacturing of rFBs was feasible even though wastage of recycling activity was inevitable. Fortunately, LD can be utilized further for example for fertilizer because the N content exists.

1. Introduction
One of wood-based panel types, fibreboards (FBs), has been substituted solid wood since degradation of natural forest decreased rapidly and plantation forest become trends worldwide. FBs has been used as raw material of furniture: shelving, kitchen worktops, interior signage; furnishing interior: decorative mouldings, cupboard, kitchen set; building complements: door filler, sliding doors, office dividers, laminate flooring, office dividers, walls, ceilings and other wood industrial products [1,2]. FBs are manufactured using low grade quality wood which is converted into fibre by pulping process [3]. Thermosetting resin is used as the binder for dry process production and Urea Formaldehyde (UF) resin is primarily used adhesive for bonding it [4]. Since UF resin is susceptible to hydrolysis, wastage
of these products is overabundance. Further, in the tropical countries like Indonesia, where the relative humidity is higher, these products are prone to damage. Various destructions such as creep, cleavage, and crack make these products become garbage and they need to be disposed carefully because of its contaminant. Dry process FBs is consisting of at least two parts namely 90% wood fibre and 10% resin adhesive [3].

Currently, there were at least three recommended choices for dealing with wood litter, namely incinerating, land filling disposal, and recycling [5]. Even though choice either burning or land filling has been conducted for treating this rubbish particularly in the United States [6], both treatments have had negative effects to environment. Incinerating will allow hazardous gases such as CO (Carbon monoxide), NOx (Nitrogen oxides), Sox (Sulphur oxides), PAHs (Polycyclic aromatic hydrocarbons), dioxins, and PCB (Polychlorinated biphenyls) depends on type combustion used [7] while direct disposing as mulch to improve soil condition and prevent erosion caused some disadvantages such as high energy consumption, toxic methane gas/bad odor release and slower reaction kinetics [5]. Therefore, recycling is one of good options for handling FBs wastages.

Here, a simulation for recycling such of materials has been presented. FBs were immersed into water for separating between wood fibre and adhesive components. It is believed that recycled fibre can be utilized as raw material for remanufacturing FBs. Some scientists have been evaluated quality of FBs made of recycle fibre recently. For instances, Mantanis et al. [8] successfully remanufactured FBs made of recycle and virgin fibre with a ratio of 25:75 in industrial scale. Hong et al. [9] also examined the quality of FBs made of 10, 20 and 30 parts recycle fibre. They found that a mixture of 20% recycle fibre resulted in better physical and mechanical properties compared to those of 10% and 30%. Comprehensively, Lubis et al. [10] examined fibre morphology originated from recycling FBs, nitrogen (N) content within the recycle fibre, and also physical and mechanical characteristics of resulted recycle boards with various mixture of recycle fibre up to 100%. They found only 10% recycle fibre can replace virgin fibre in producing FBs. From this point, activity of recycling of FBs is feasible, and solid wood residue can be utilized as raw material of recycle FBs.

Related to water disposal, it can be used as fertilizer because of rich of N content. UF resin adhesive contained leached chemical component or sol fraction [11]. Grigbsy et al. [12] investigated residue and water disposal of FBs bonded UF resin after water soaking. They found that N existed in both fibre and water. Further Lubis et al. [13] investigated N content within both solid residue and extract solution after hydrolysis in recycling practice of FBs.

In this contribution, quality of industrial FBs was compared to recycle FBs (rFBs) and wastage after recycling activity was analysed either chemically or morphologically in order to evaluate its feasibility as fertilizer for non-food plants seedling. Thus, the objective of this study was to compare physical and mechanical properties of commercial FBs versus rFBs and to determine impurities occurring in water disposal after recycling activity of FBs.

2. Materials and Methods

2.1. Materials

Either commercial FBs purchased from PT Mandiri Jaya, Jakarta or industrial FBs donated by PT Canang Indah, Medan, became main object observation of this research. Both types of FBs were confirmed using UF resin as the binder. UF resin with solid content of 60.52% and ammonium chloride (NH\textsubscript{4}Cl) as hardener were donated by PT Canang Indah Medan for binding rFBs.

2.2. Methods

2.2.1. Evaluation physical and mechanical properties of FBs

Both types of FBs were cut and referred into test specimens according to Japanese Industrial Standard/JIS [14]. The specimens were then exposed to physical examinations such as density and moisture content (MC). The calculation of density used digital balance and veneer caliper, and it was conducted in ambient temperature around 27-31°C. Measurement of thickness swelling and water absorption was
carried out both in 2 hours and 24 hours. Investigation of mechanical properties was based on JIS standard with aid of Tensilon Universal Testing Machine. One-point loading was applied for determining Modulus of Elasticity (MOE) and Modulus of Rupture (MOR). An Internal Bonding (IB) test was also determined for evaluating bonding strength of the FBs. Each parameter test was measured 8 (eight) in replications without considering type of the FBs.

2.2.2. Remanufacturing FBs and evaluation of their properties

All specimens used in physical and mechanical properties testing were then soaked in water. After the specimens swelled, they underwent hand-stirring for fibres separating completely. A resulted mixture of water and fibre then was filtered using a fabric screen for separating between solid and liquid residue. Solid residues, hereafter recycle fibre, and then underwent sunlight drying. For reaching a target MC of $\pm$ 5%, recycle fibres were oven-dried using laboratory oven.

Remanufacturing rFBs was carried out in a laboratory scale used a column-type hydraulic hot-press. A thickness of 10 mm with dimension of 25 x 25 cm and density of 0.75 g/cm$^3$ were the target size of the FBs. Composition of the adhesive was 8% UF resin based on solid and 3% NH$_4$Cl as hardener. For adhesive curing, temperature of hot-press was set at 120°C for 15 minutes. Prior to evaluation its properties, each rFBs was conditioned in room temperature for 2 weeks. Physical and mechanical properties examination was done as same procedure of evaluation the FBs referring standard [14].

2.2.3. Cyclist test

FBs and rFBs were cut into 5 x 5 cm in size. Each group was consisted of at least five specimens thus totally there were 10 samples. Cyclist test was comprised of cycles of five treatment steps, i.e., first: measurement of initial thickness dimension, second: soaking in 1000 mL water at ambient temperature for 24 hours, third: measurement of thickness swelling dimension, fourth: drying in laboratory oven at $(103\pm2)^{\circ}C$ for 48 hours, and fifth: measurement of oven dry thickness dimension [15]. This cycle was applied until the samples were not possible to be measured their thickness because of sample damage, such as cleavage or crack. Thickness measurement was conducted using a digital veneer caliper. Resulted data were presented, tabulated and compared between FBs and rFBs.

2.2.4. Analysis of the recycling wastage

Water disposal originated from recycling activity, hereafter cyclist test, was analyzed its contaminant comprised of individual solid fibre, micro fibre, and N content. Bright-field microscope was used for measuring length and diameter individual of solid fibre with 100 replications. Micro fibre was analysed using particle size analyser (PSA) Malvern Mastersizer 3000 Hydro EV in micron scale with 2 replications. Result of analysis was tabulated and classified according to the diameter class of the particle. N content was measured using Kjeldahl method.

3. Results and Discussions

Different from previous work [8-10] which combined recycle fibre and virgin fibre, this study was intended to use all recycle fibre for producing rFBs. However, simulation of recycling of FBs in this study resulted in 75% yield. Commercial/industrial of 8 (eight) FBs specimens were only capable to make 6 (six) rFBs specimens. This condition was influenced by recycling activities such as dissolving of solid fibre residue during board soaking, fibre drying under sunlight as well as under laboratory oven, and trimming sawing for making specimens. All of these made volume of fibre decreased thus reducing the quantity of resulted boards.

3.1. Properties of FBs and rFBs

Table 1 and 2 showed physical and mechanical characteristics of both FBs and rFBs comparing to that of standard, respectively.
### Table 1. Physical properties of FBs versus rFBs

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>FBs</th>
<th>rFBs</th>
<th>JIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm$^3$)</td>
<td>0.76 ± 0.02</td>
<td>0.57 ± 0.04</td>
<td>&gt; 0.35</td>
</tr>
<tr>
<td>MC (%)</td>
<td>8.52 ± 0.22</td>
<td>2.40 ± 1.36</td>
<td>5-13</td>
</tr>
<tr>
<td>Thickness swelling 2 h (%)</td>
<td>13.66 ± 1.14</td>
<td>10.93 ± 1.83</td>
<td>-</td>
</tr>
<tr>
<td>Thickness swelling 24 h (%)</td>
<td>18.10 ± 1.51</td>
<td>27.47 ± 1.07</td>
<td>12</td>
</tr>
<tr>
<td>Water absorption 2 h (%)</td>
<td>55.84 ± 7.25</td>
<td>51.28 ± 21.89</td>
<td>-</td>
</tr>
<tr>
<td>Water absorption 24 h (%)</td>
<td>70.20 ± 4.77</td>
<td>151.15 ± 19.68</td>
<td>-</td>
</tr>
</tbody>
</table>

Remarks: resulted data were measurement of 8 replications for FBs and 6 replications for rFBs, respectively

Density and MC of commercial/industrial FBs were fulfilling the standard however after remanufacturing both properties decreased. Laboratory work with standard equipment presumably affected the quality. For instance, hot-press used in this study was different from in industrial plant. We used a column-type hydraulic hot-press while in industrial scale usually use continuous hot-press [3]. Composition of the final board also influenced the final properties of the boards. Mantanis et al. [8] reproduced industrial scale of FBs, the optimum condition was reached at 25% recycle fibre and 75% virgin fibre.

Generally, interior panel products, such as binderless (wet process) FBs or FBs bonded UF resins showed dimensional instability particularly when they contacted or exposed to high moist. Thickness swelling and water absorption examinations on these products proved this phenomenon. Here, either FBs or rFBs was bonded by UF resins. UF resin itself has prone to hydrolytic degradation therefore, dimensional instability was inevitable. Mechanism of degradation of this product included penetration of water molecules into the UF resin within the bond-line either in inter-phase or interface. This situation initiates hydrolysis reaction chain; water attacks the hydroxymethyl (CH$_2$OH) end group, and then splits either C-N-C or C-N-O bonds from the methylene or ether linkages in UF resin [16]. These occurrences resulted in fibre movement, swelling and shrinking thus chemical species degrades into a simpler species [17]. In other words, sol fraction leaches and dissolves in water [18]. Breakage of FBs here enables this board for recycling thus resulted in either simpler species or sol fraction can be used as source of nutrient for plants.

### Table 2. Mechanical properties of FBs versus rFBs

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>FBs</th>
<th>rFBs</th>
<th>JIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoE (N/mm$^2$)</td>
<td>1375± 166</td>
<td>290±126</td>
<td>Min 800 for type 5</td>
</tr>
<tr>
<td>MoR (N/mm$^2$)</td>
<td>27.8 ± 2.7</td>
<td>3.4± 2.4</td>
<td>Min 25 for type 25</td>
</tr>
<tr>
<td>IB (N/mm$^2$)</td>
<td>0.25 ±0.13</td>
<td>0.02 ±0.01</td>
<td>Min 0.2 for type 5</td>
</tr>
</tbody>
</table>

Remarks: resulted data were measurement of 8 replications for FBs and 6 replications for rFBs, respectively

All mechanical properties of industrial/commercial FBs met one of standard types of FBs, however, all mechanical properties belonged to rFBs were fail. The FBs standard is divided into 4 (four) group type of FBs, namely type 5, 15, 25 and 30 according to the bending strength. Poor strength of rFBs was presumably because of difference in reproduction method. Indeed, laboratory scale was different from industrial scale from raw materials, for example in application of gluing and pressing [8]. Because of owing lower strength of industrial/commercial FBs, this product has had also life used shortly. In order to predict and compare the life used of FBs and rFBs, results of cyclist test here were also presented.
3.2. Cyclist test
Cyclist test is an accelerated aging test to predict the life use of the board. It has significant effects on the safety and serviceability of the board over their lifetime [19]. Presented here is a comparison between cyclist tests exposed to FBs versus rFBs (Figure 1). It was clearly showed that Fig 1a exhibits a longer time for FBs undergoing to damage compared to that of belonged to Figure 1b. FBs needed 3 (three) cyclist longer to breakage compared to that of rFBs. FBs were also denser than that of rFBs, therefore FBs were more resistant to water.

Both cyclist tests of FBs and rFBs curves showed similar trends; after one cycle the thickness tend to increase continuously. Previous work on particleboards [20] showed distinct tendency, presumably because wood particles still have greater hysteresis properties comparing to those of wood fibres.

![Cyclist test curve measurement of FBs](image1)

**Figure 1a.** Cyclist test curve measurement of FBs

![Cyclist test curve measurement of rFBs](image2)

**Figure 1b.** Cyclist test curve measurement of rFBs
Related to wood fibre, there were two kinds of recycle fibre derived from FBs recycling, namely individual fibre and cut fibre or cell fragments, respectively. Both fibres were presented in analysis of recycling wastage section as follow.

3.3. Analysis of recycling wastage.
Wastage of recycling activity may be placed in the following categories, namely suspended solid (hereafter fibres and cell fragments), colloidal organic substances originating from the wood material, dissolved solids (soluble organic substances released from the wood material), soluble and insoluble chemical added during the manufacturing of FBs including adhesive resin [3]. As depicted in Figure 2, typical morphology of recycle fibre derived from recycling activity of FBs was shown. Result of measurement of length and diameter fibres were 1000.51±339.21 μm and 25.98±7.93 μm, respectively. Cell fragments and other aforementioned wastage could not be identified except their distribution of size. Figure 3 showed distribution of cell fragments and other aforementioned litter or contaminant found in water disposal of recycling FBs activity in this study. This group was consisted of micro solid waste.

Figure 2. Typical individual recycling fibre derived from recycling FBs under microscope measurement

Figure 3. Distribution of contaminant within water disposal of FBs recycling
Further, N content as part of sol fraction or chemical found in water disposal was analysed. Using Kjeldahl method, N content amount was 0.05%. This percentage was relatively small compared to that of previous study in particleboard [18] because of amount UF resin applied, type of wood fibre/particle and amount of water for soaking. All of these have influenced later if the water disposal will be used as liquid fertilizer.

4. Conclusion
Remanufacturing of rFBs was feasible even though the resulted quality was poor. Improvement properties of rFBs could be carried out depended on technical production such as application of gluing and pressing. Water or liquid disposal containing impurities can be utilized further for fertilizer because N content exist. Further study was recommended for implementing this finding such as for liquid fertilizer of non-food seedling.

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