Cyclist test on particleboards and utilization of their liquid disposal for fertilizer

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Abstract. Cyclist test on particleboards (PBs) bonded urea-formaldehyde (UF) resin was intended to be carried out in order to predict their degradation thus recycling of these products was possible. In this contribution, PBs bonded by five types of UF resins namely 0.95; 1.05; 1.15; 2.00; and commercial were examined using cyclist test. The test consists of cycles of five treatment steps, i.e., measurement of initial thickness dimension, immersion in water at ambient temperature for 24 h, measurement of swelling thickness dimension, drying in convection oven at (103+2)°C for 24 h, and measurement of oven-dry thickness dimension. This cycle was applied until the specimens were not possible to be measured their thickness because of broken-down of the PBs. Further, water disposal in this experiment, then was utilized as fertilizer to Swietenia mahagoni seedlings. Observation on growth parameters (stem height and diameter) and biomass parameters (dry weight of top and root) of the seedlings were conducted for 12 weeks after planted. Result of this study showed PBs bonded by low mole of UF resins (0.95; 1.05 and 1.15) have had faster degradation compare to those of 2.00 and commercial one. Both growth and biomass parameters of the seedlings increased but statistically not different among the samples. These findings suggested that PBs bonded UF resins can be recycled using water-soaking process and the liquid disposal of this activity can be utilized as fertilizer.

1. Introduction

Urea-formaldehyde (UF) resin is the most used adhesive worldwide for bonding of wood products, including fibreboards (FBs) [1] and particleboards (PBs) [2] because of its beneficial such as ease to synthesis, low cost to produce and simple to manufacture [3]. The occurrence of UF resins involves reactions between urea and formaldehyde through addition and condensation polymerization, respectively [4]. Characteristics of this resin is influenced mainly by composition of formaldehyde to urea (F/U) mole ratio [5], i.e. viscosity, gel time, solid content [6,7], penetration behaviour [8,9], thermal properties [6,10], micro-morphology [7,11], including its formaldehyde emission (FE) [12]. Increasing F/U mole ratio will result in better strength bonding as well as higher FE; and vice versa.
To date, application of low F/U mole ratio of UF resins is recommended because of health and safety reason [13]. High FE caused discomfort for inhabitants in indoor environment, sick building syndrome of occupants [14], thickening of mucosa membrane [15] and further carcinogenic illness [16]. Unfortunately, lowering F/U mole ratio of UF resins resulted in dimensional instability as well as lower in mechanical properties of the wood composite products, particularly for FBs [12,17,18] and PBs [5,19]. Therefore, products made from these panels such as modern furniture, kitchen set, or non-structural building component like partition, insulation, wall-sheathing or interior furnishing were prone to damage. In addition, because amino-methylenic bond within the UF resin is susceptible to moisture and water [20], wastage originated from these materials was abundant.

Currently, there were at least three recommended options for dealing with wood waste consisting of incinerating, land-filling disposal, and recycling [21]. Generally, the first option will cause air pollution. Further because either FBs or PBs is consisting of two parts namely at least 85% wood fibre/particle and 4-15% resin adhesive [22], combustion of such materials will induce environment harmful. Forest as source of wood will degrade because of continuing exploitation of the wood for raw materials of FBs and PBs. In addition, burning of resin will raise poison smoke like dioxin. Therefore, combination between land-filling disposal and recycling is good choice for handling FBs and PBs wastages.

Here, environmentally friendly efforts for treating such of materials have been presented. Either FBs or PBs was immersing into water in order to leach adhesive components. It is believed that UF resin adhesive component contained leached chemical cluster or sol fraction [7]. Grigbsy et al. [23] investigated residue and water disposal of FBs bonded UF resin after water soaking. They found that nitrogen existed in both fibre and water. Further Lubis et al. [24] stated that water is potential agent for hydrolysis of FBs for recycling practice. Related to PBs, Czarnecki et al. [25] used recycle PBs as core board of PBs. Varga et al. [26] carried out recycling on décor paper to be part of raw material of PBs. Recently, Nuryawan et al. [19] reported that percentage of nitrogen (N) on wood particle was decrease after hydrolysis assessed using SEM along with Kjeldahl. From this point, activity of recycling either FBs or PBs is feasible. Solid wood residue can be utilized as raw material of recycle FBs/PBs and water disposal can be land-filled safely. Recent report of our work [27] was that liquid disposal of recycling activity can be used as fertilizer for Anthocephalus cadamba seedlings, one of types of fast growing species.

In this contribution, water disposal of recycling activity, hereafter cyclist test, will be utilized as fertilizer for Swietenia mahagoni seedling. We choose this kind of seedling because S. mahagoni is classified as medium growing species, non edible plants, and commercial wood.

2. Materials and Method

2.1. Materials

PBs bonded by three low F/U mole ratios of UF resins namely 0.95; 1.05; and 1.15; high F/U mole ratio of 2.00; and commercial one were used as object to cyclist test, as a mimic of recycling activity. Water disposal resulted in PBs recycling then used as source of treatment in this experiment because of rich of N content. Soil originated from USU arboretum having both low pH and nutrients were used as media for seedlings planting in polybag. Properties of the aforementioned water and soil have been published recently [27]. Thirty mature and healthy seedling of S. mahagoni purchased from a nursery in Binjai, North Sumatra, Indonesia become research observation in this study.

2.2. Methods

2.2.1. Cyclist test

PBs were classified according to their type resin used then cut into 5 cm x 5 cm in size. Each group was consisted of five specimens thus totally there were 25 samples of PBs. Cyclist test was comprised of cycles of five treatment steps, i.e., first: measurement of initial thickness dimension, second:
immersion in 1000 ml water at ambient temperature for 24 h, third: measurement of thickness swelling dimension, fourth: drying in convection oven at (103±2)°C for 24 h, and fifth: measurement of oven-dry thickness dimension [28]. Thickness measurement was conducted using a digital caliper. Resulted data were presented, tabulated and compared among the groups. This cycle was applied until the specimens were not possible to be measured their thickness because of sample damage, such as cleavage, broken, or crack. This test involved water for immersing the specimens in order to apply hydrolysis principle [19]. Prior to utilizing, the water disposal was dissolved in 9000 ml, measured the N content, and kept in plastic gallon for further use.

2.2.2. Media and seedling preparation
In order to prevent bias against treatment, poor nutrients soil originated from USU arboretum having both low acidity and mineral content as published in previous report [27] was used as planting media. Prior to applying in polybag, the soil was prepared by sieving at 2 mm and air-drying for 48 hours. Each polybag was filled by base fertilizer consisted of 3 g SP 36 and 2 g KCl on the bottom, a seedling of S.mahagoni and 3 kg of prepared soil. Thirty seedlings in polybag were labeled and classified into 5 groups, namely control; 0.95; 1.05; 1.15; 2.00; and commercial. Each group was consisted of 5 seedlings which mean the treatment used 5 replications.

2.2.3. Cultivation, treatment and observation
All labeled seedlings were placed in a greenhouse belongs to Faculty of Agriculture, USU. They underwent watering every morning for 12 weeks. A dosage of 75 ml water disposal originated from cyclist test from each group of PBs in the plastic gallon was given weekly to the seedlings, except for control. Observation on growth parameters were conducted every week, comprising of stem height and diameter of the seedlings. Even though measurement the growth parameter was carried out every week, only the data of 9th, 10th, 11th, and 12th weeks after planted were used for statistical analysis. Biomass parameters were determined by destructive technique after harvesting when the seedlings were 12 weeks old. Each seedling then was cleaned from the soil and washed using water to remove remaining soil. The seedling then was partitioned into top parts and root. Top parts are consisted of shoot, leaves, and stem. Determination of the weight ratio between top and root was conducted in oven-dry condition. Drying using convection oven was conducted at 70°C for 48 h.

2.2.4. Statistical analysis
Resulted data from measurement of growth parameters on week of 9th, 10th, 11th, and 12th after planted were analyzed statistically using probability plot with 95% interval confidence. One-way analysis of variance (ANOVA) was applied to determine the significant parameters. Tukey test at \( \alpha=0.05 \) was continued to verify whether difference between means was statistically significant.

3. Results and Discussion

3.1. Cyclist test
Figures 1-3 showed graph of cyclist test for PBs with low F/U mole ratio UF resins while Figure 2 and 3 showed graph of cyclist test for PBs bonded with high F/U mole ratio and commercial, respectively. Cyclist tests were occurred 2.5 cycles on PBs bonded with F/U mole UF resin of 0.95, 1.5 cycles on PBs bonded with F/U mole UF resin of 1.05 and 2 cycles on PBs bonded with F/U mole UF resin of 1.15. These cycles were faster compare to those of cycles within high F/U mole ratio UF resin of 2.00 and commercial one. The first performed 10 cycles while the latter showed 8 cycles. Differences on PBs cycles were because of the type resin used. UF resin with different F/U mole ratio showed distinct characteristics.
Figure 1. Cyclist test on PBs bonded low F/U mole ratio UF resin of 0.95

Figure 2. Cyclist test on PBs bonded low F/U mole ratio UF resin of 1.05

Figure 3. Cyclist test on PBs bonded low F/U mole ratio UF resin of 1.15
Since F/U mole ratio of UF resin was equal or close to one, the properties showed peculiarity [29], such as crystallinity content of the resin [30], linear or branched of the network of resin structure [31], penetration into wood tissue [9], etc thus all of these influenced the final strength of this adhesive. Adhesion performance using this kind of resins was poor [32] resulted in lower mechanical properties [33] and dimensional instability [5,19], leading to susceptible to breakage.

**Figure 4.** Cyclist test on PBs bonded high F/U mole ratio UF resin of 2.00

**Figure 5.** Cyclist test on PBs bonded by commercial UF resin
On the contrary, PBs bonded UF resins with high F/U mole ratio of 2.0 and that of commercial one showed better dimensional stability compared to those of low F/U mole ratios. UF resins with high formaldehyde content lead to an increase the proportion of hydroxymethyl group particularly –NH\text{-CH}_2\text{OH}. An increased methylol groups proportion in a UF resin induces a lower flexibility of the UF resin in the molecular network form [34] thus rigidity of the PBs bonded with this resin was greater. In other words, UF resins with high formaldehyde content have a positive relationship with dimensional stability of PBs [35]. Commercial or industrial PBs usually used UF resin around F/U mole ratio of 1.1-1.2 [27] thus dimensional stability of the PBs bonded with this resin was better than those of PBs bonded with low F/U mole ratio of UF resins.

Activity of cyclist test as a mimic of PBs recycling resulted in water disposal. It is believed that the water disposal was containing N derived from urea or urea-derive species. It was reported that FBs bonded UF resin have had high extractability of urea [23]. Further, our group has been published that UF resin containing sol fractions [7], the unlinked polymer chain within the UF resin network, which can be extracted because of un-attached in the network entanglement. As the mole ratio of the UF resin decreased, the sol fraction increased [7]. Recently, we published that sol fraction within UF resins with low F/U mole ratios have had de-branched polymers, linear polymer and free urea. After exposed to hot, hereafter hot pressing in manufacturing PBs, UF resins within PBs system underwent partially cured. This condition leads incomplete cross-linked network, linear polymers/ crystals as well as free urea. Involving UF resin PBs as adhesive, sol fraction existed as a rich fraction containing N as recently published report [27]. In this regard, sol fraction within water disposal of PBs recycling can be used as fertilizer for non-food seedlings. Previous work on this has been published [27] and presented [37,38]. In this study, application of water disposal for liquid fertilizer was performed and their results were described here.

3.2. Seedling observation

Figure 6.a. showed S. mahagoni seedlings used as object of this experiment in the first week after planted. After certain time exposed to watering daily and applying liquid fertilizer weekly derived from water disposal from PBs recycling, the seedlings showed growth of leaves and diameter as shown in Figure 6.b.

![Figure 6.a](image1)

![Figure 6.b](image2)

**Figure 6.** S. mahagoni seedlings was at early stage planting in polybag (a) S. mahagoni seedling after watering daily and exposing water disposal of PBs recycling weekly was at 6 weeks after planting

In order to observe the height and diameter of the S. mahagoni seedlings, measurement of the both growth parameters was recorded weekly and the data were presented in Figure 7 and 8, respectively.
Figure 7. Growth of height of S. mahagoni weekly for 12 weeks

Figure 8. Growth of diameter of S. mahagoni weekly for 12 weeks
Data of growth of both height and diameter after 9th up to 12th week after planted were chosen for statistical analysis in order to evaluate the influence of application of liquid fertilizer derived from PBs recycling. We picked these data to consider our previous study on A. cadamba seedlings [27] with similar treatment. Here is the detail of the results of statistical analysis to seedlings height, diameter, and their biomass.

3.3. Influence of water disposal of PBs recycling as liquid fertilizer to the seedlings height
Table 1 showed result of measurement of seedling height from 9th to 12th week after planted. Height of seedlings increased weekly however influence of treatment was not appearing. Among the seedlings demonstrated growth rapidly but statistically were not different. This response was different from previous study on A.cadamba seedlings [27] presumably because A.cadamba was classified as fast growing species while S.mahagoni was grouped as moderate fast growing species [39]. Each plant has different rate of photosynthesis as well as necessity of nutrient depended on the species, for example conifers only need 50% N comparing with deciduous plants [40].

| Treatment       | Week  | 9th       | 10th      | 11th      | 12th      |
|-----------------|-------|-----------|-----------|-----------|-----------|
| Control         |       | (15.40±5.33)a | (20.72±3.37)a | (25.02±2.81)a | (27.44±3.95)a |
| 0.95            |       | (19.44±3.30)a | (22.98±3.85)a | (29.38±3.99)a | (33.36±3.70)a |
| 1.05            |       | (16.24±4.84)a | (19.36±6.30)a | (23.98±6.62)a | (27.16±6.34)a |
| 1.15            |       | (19.38±2.92)a | (22.20±3.41)a | (26.10±5.08)a | (29.46±5.99)a |
| 2.00            |       | (20.98±9.06)a | (25.22±10.83)a | (32.30±11.71)a | (35.82±12.64)a |
| Commercial      |       | (20.10±4.63)a | (25.86±5.67)a | (29.38±6.17)a | (30.94±5.61)a |

Remarks: Means with same letters are not significantly different according to Tukey test at α=0.05

3.4. Influence of water disposal of PBs recycling as liquid fertilizer to the seedlings diameter
Table 2 showed results of observation of seedling stem diameter after 9th to 12th weeks old. The diameter markedly rose weekly, unfortunately similar with height measurement, showed no effect of treatment application. This response also was different from previous study on A.cadamba seedlings [27]. Study of Sarjono et al. [41] showed A.cadamba or white jabon as fast growing species has had significant performance on early growth of cultivation. S.mahagoni as moderate growing species presumably will show significant growth performance after cultivation with longer periods. It is recommended to investigate such of this treatment to other species of moderate-slow growing species in order to see the influence of this treatment.

| Treatment       | Week  | 9th       | 10th      | 11th      | 12th      |
|-----------------|-------|-----------|-----------|-----------|-----------|
| Control         |       | (0.28±0.09)a | (0.31±0.08)a | (0.36±0.09)a | (0.41±0.10)a |
| 0.95            |       | (0.30±0.13)a | (0.32±0.07)a | (0.38±0.08)a | (0.42±0.09)a |
| 1.05            |       | (0.25±0.04)a | (0.30±0.04)a | (0.38±0.06)a | (0.42±0.07)a |
| 1.15            |       | (0.28±0.05)a | (0.32±0.07)a | (0.38±0.07)a | (0.43±0.07)a |
| 2.00            |       | (0.26±0.08)a | (0.30±0.08)a | (0.38±0.10)a | (0.42±0.10)a |
| Commercial      |       | (0.24±0.04)a | (0.28±0.04)a | (0.34±0.05)a | (0.40±0.05)a |

Remarks: Means with same letters are not significantly different according to Tukey test at α=0.05
3.5. Influence of water disposal of PBs recycling as liquid fertilizer to the seedlings biomass of top parts, root part, and the ratio

Table 3 showed average of oven-dry weight of top, root and its ratio, respectively of S.mahagony seedling in the final observation or 12th week after planted.

| Treatment    | Week  | Top     | Root    | Ratio of Top/Root |
|--------------|-------|---------|---------|-------------------|
| Control      |       | (11.23 ± 0.38)a | (1.82 ± 0.26)a | (6.28 ± 0.96)a |
| 0.95         |       | (15.83 ± 2.65)a | (1.86 ± 0.33)a | (8.61 ± 1.16)a |
| 1.05         |       | (14.42 ± 2.41)a | (2.39 ± 0.89)a | (6.68 ± 2.18)a |
| 1.15         |       | (13.15 ± 3.97)a | (1.92 ± 0.41)a | (6.84 ± 1.41)a |
| 2.00         |       | (15.80 ± 4.39)a | (2.26 ± 0.83)a | (7.38 ± 1.47)a |
| Commercial   |       | (12.60 ± 1.16)a | (2.11 ± 0.58)a | (6.23 ± 0.96)a |

Remarks: Means with same letters are not significantly different according to Tukey test at α=0.05

Application of fertilizer derived from PBs recycling to S.mahagony seedling which was rich of N content should affect the partitioning of biomass between roots and shoots on top parts [40]. However this was not the case in this study because many factors influenced them, for instances the amount/level/dosage and timing of N application from external factor and stages of growth and root condition (length and surface area of the root) from internal factor [40]. Previous study on A.cadamba showed top part of biomass consisted of shoot, leaves and stem was influenced by this treatment [27]. Study of Wang et al. [42] mentioned that biomass growth of seedlings was dependent upon N availability. Low and medium N deposition could promote seedling growth but excessive input of N made less optimum for the seedling growth [42]. In other words application of fertilizer particularly rich N content should be conducted wisely. This study may represent a first step for utilizing water disposal derived from PBs recycling activity as a liquid fertilizer for seedlings in forestry sector. Further study may develop a tool for PBs recycling such as automatic stirring [43] thus cyclist test on PBs was only for predicting the degradation periods of PBs bonded by UF resins.

4. Conclusions

This study presented a cyclist test on PBs bonded UF resin as a simulation of recycling process of PBs. Water disposal of this activity contained N and it can be utilized as liquid fertilizer for seedlings in forestry sector. This study then investigated influence on application of this fertilizer to S.mahagony seedlings. Even though effect of this treatment was not appearing but growth parameters such as height, diameter and biomass increased up to 12 weeks observation presumably because S.mahagony seedlings belongs to moderate-fast growing species. Further research is needed in term of duration of observation, type species used, and dosage of application of the liquid fertilizer. Equipment unit for producing liquid fertilizer derived from PBs recycling was also recommended to develop thus cyclist test only used to predict degradation of PBs.

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