Experimental study on the utilization of residue from particleboard’s recycling activity

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Abstract. Both solid and liquid residues derived from activity of particleboard (PB)’s recycling were investigated. The solid was attempted to make recycle particleboard (rPB) while the liquid was tried to use as fertilizer to seedling of Acacia crassicarpa. Objective of this study was to compare quality between PB and rPB and to evaluate seedling growth of A. crassicarpa exposed to liquid disposal from PB’s recycling activity. Methods of this study were consisted of testing of physical and mechanical properties of industrial PB, manufacturing rPB, and comparing the properties between PB and rPB. Prior to manufacture rPB, liquid disposal from PB’s recycling activity was released through water immersion of industrial waste’s PB comprised of predominant trimming residues. The liquid disposal was measured its nitrogen (N) content and then it was kept in a gallon for further use as fertilizer. Observation on growth parameters (height, diameter, leaves number and seedling’s strength) of both treated and untreated seedlings was conducted weekly for 2 months. Results of this study showed: 1) rPB was feasible to be produced but their quality was slightly decreased. 2) Liquid disposal during cyclist test and water immersion of PB’s residues contained 0.69% N. 3) Growth parameters of A. crassicarpa seedling showed response positively and significant statistically between treated and untreated seedlings. These findings suggested that both residues originated from PB’s recycling can be utilized further; the solid can be used as raw material of rPB while the liquid can be utilized as fertilizer to seedlings.

1. Introduction

Particleboard (PB) is commonly considered as one of nonstructural panels, manufactured from varying sizes of ground wood with no distinct in size dimensions, and generally used less moisture-resistant of thermosetting urea-formaldehyde (UF) resins that its application limited to interior purposes. Even though wax are usually given as additives to enhance resistance to moisture ingress, but these particle based products will swell substantially under prolonged moist exposure [1]. Further, since UF resin is prone to hydrolysis, wastage of these products is overabundance [2]. In addition, PB mills generated residues during production, namely bark, screenery fines, sawdust, sander dust, and panel trim [3]. These by products can be handled directly or should be processed further for removing hazardous material first. In this context, by products originated from round wood input can be directly processed as either energy in boiler or raw material in production process. However, trimming or edge-cutting residues of
PB have been contaminated or mixed with adhesive. Therefore, in order to utilize these, treatment or handling is needed, for example by screening classification [4], steaming or hydrothermal [5], immersing in water or acid etching processes [6]. These efforts have been carried out to re-utilize renewable waste, to reduce the waste going to landfill, and to decrease pressure on the environment thus to protect the earth, forest and nature [4-6].

In this study, attempt to recycle industrial PB trims comprised of cross-cutting mat, off-cut, and rejected board wastes by soaking them in water was chosen because recycling was placed in the middle of a hierarchical pyramid for the management of waste among prevention, preparing for re-use, another recovery and disposal [7]. In addition, recycling was the most recommended choice for dealing with wood litter after incinerating and land filling disposal [8]. Direct burning will release jeopardy gases such as carbon monoxide, nitrogen oxides, sulphur oxides, polycyclic aromatic hydrocarbons, dioxins, and polychlorinated biphenyls depends on type combustion used [9] while direct disposing as mulch to prevent erosion and enhance soil condition caused some negative effects such as high energy consumption, toxic methane gas, bad smell release and slower reaction kinetics [8]. Therefore, recycling is the best way for handling PB wastages.

Here, a simulation for recycling such of materials has been presented. PB trims were immersed into water for separating between wood particle and adhesive components. It is believed that recycled particle can be utilized as raw material for remanufacturing PB into recycle PB (rPB). Some scientists have been concerned to study, discuss, and deal with rPB [2-6,10]. They concluded that rPB was promising and potential to be developed.

Related to water disposal which is used as hydrolysis agent, it can be utilized as fertilizer because of rich of nitrogen (N) content. UF resin contained leached chemical component or sol fraction which cannot participate to the bonding strength [6,11]. An excellent literature review described wood waste flows and their availability including route of residual adhesive recently[12].UF polymer chain as a predominant adhesive attached in PB can undergo a hydrolysis reaction in the presence of water leading to disintegrate and shorten polymer fragments. Since low mole UF resin (i.e. around 1.1-1.2) started to be applied in PB’s mill nowadays [13], penetration of moist was inevitable thus weaken both chemical and physical bonding between the resin and wood components. Low mole UF resin contained a mixture of partially branched polymers, a large portion of linear polymers, mono-hydroxymethylurea, and free urea [14]. The cure of this resin could be only partially cured [15] resulted in linear polymers which minor contribute in cross-linking reactions [14]. Moreover, a portion of un-reacted urea may remain in the cured resin [14], trapped in the polymer networks, and leached when expose to water. Further, this un-attached part becomes a source of N when it is used as fertilizer.

In this contribution, quality of industrial PB was compared to rPB and liquid disposal during recycling activity was utilized as fertilizer for non-food plants seedling. Thus, the objective of this study was to compare physical and mechanical properties of industrial PB versus rPB and to determine feasibility of liquid disposal as fertilizer to Acacia crassicarpa, a fast growing species most developed in South East-Asia for pulp and paper materials [16].

2. Materials and methods

2.1. Materials
Trimming panel of PB comprised of cross-cutting mat, off-cut, or cutting edge donated by PT Canang Indah, Medan, became main object observation of this research. These samples type were confirmed using UF resin as the binder but the mol ratio between formaldehyde and urea was unknown. Ready to use UF resin with solid content of 60.52% was also supplied by PT Canang Indah Medan for binding rPB. Ammonium chloride (NH₄Cl) as hardener was purchased from local distributor.

2.2. Methods
2.2.1. Evaluation physical and mechanical properties of PB. PB trims comprised of cross-cutting mat, off-cut, and rejected board wastes were cut and referred into test specimens according to Japanese Industrial Standard/ JIS [17]. The specimens were then justified to physical evaluations such as density and moisture content (MC). Gravimetric method was applied and it was carried out in room temperature around 27-31°C. Measurement of thickness swelling and water absorption was conducted in periods of 24 hours. Mechanical properties evaluations were according to JIS standard with aid of a Universal Testing Machine (UTM). One-point loading was determined on Tensilon UTM for measuring both Modulus of Elasticity (MoE) and Modulus of Rupture (MoR). An Internal Bonding (IB) test was also investigated for evaluating adhesive strength within the specimens. Each parameter test was done in 5 (five) replications without considering the specimens origin. Resulted data then were tabulated and compared to JIS standard [17].

2.2.2. Remanufacturing rPB and evaluation of their properties. All specimens used in PB’s physical and mechanical properties evaluation were then immersed in water. After the specimens swelled, a hand-stirring was run for disintegrating wood particles. A fabric screen then was used for separating between solid and liquid residue. Solid residues, hereafter recycle particles, were exposed to sunlight for drying. For reaching a target MC of ± 5%, recycle particles were oven-dried using a convection oven.

Remanufacturing rPB was conducted in a laboratory scale used a column-type hydraulic hot-press. Target size was 10 mm for thickness and 25 cm x 25 cm for dimension. Density was determined according to result measurement in physical testing of PB. Composition of the adhesive was 8% UF resin based on solid and 3% NH₄Cl as hardener. For adhesive curing, temperature of hot-press was set at 120°C for 15 minutes. Prior to evaluation its properties, each rPB was conditioned in ambient temperature for 2 weeks. Physical and mechanical properties examination was done as same procedure of evaluation the PB referring standard [17].

2.2.3. Analysis of the N content of liquid disposal. Water disposal originated from recycling activity was kept in a plastic gallon for further use as fertilizer. The N content was analyzed using titration method and carried out in Laboratory of Indonesian Oil Palm Research Institute, Medan, North Sumatra, Indonesia.

2.2.4. Treatment, observation, and data analysis of growth seedlings. Seedlings of a crassicarpa were divided into two groups, namely treated(T) and untreated (U), and for each group was consisted of five seedlings. Cultivation of the seedlings was carried out by watering in the morning every day for 2 months. Treatment was applied by giving a dosage of 75 ml liquid disposal twice a week to T group. Observation was carried out for measuring growth parameters, consisting of stem height, steam diameter, and leaves number. These measurements were conducted every two week, and the compiled data were used for statistical analysis. Paired sample t-test was applied to evaluate whether there was a significant differences between two connected variables.

3. Results and discussions

3.1. Physical and mechanical properties of PB and rPB
Table 1 showed results of measurement of physical properties both of PB and rPB with comparison to JIS standard. As aforementioned in method section, that target density of rPB followed result of measurement of PB. Therefore density of rPB was similar to PB. Even though the density of PB met the standard, its value was slightly lower comparing to general PB. This was because the origin of specimens in this study. As mentioned earlier, samples of this study derived from trimming residues such as cross-cutting mat, off-cut, and rejected board wastes.
Table 1. Physical properties of PB versus rPB.

| Physical properties          | PB       | rPB      | JIS standard |
|------------------------------|----------|----------|--------------|
| Density (g/cm³)              | 0.65 ± 0.02 | 0.64 ± 0.03 | 0.40 – 0.90  |
| Moisture content (%)         | 6.65 ± 0.31 | 9.71 ± 1.74 | 5 - 13       |
| Water absorption (%)         | 80.81 ± 2.01 | 87.43 ± 3.25 | -            |
| Thickness swelling (%)       | 13.44 ± 0.91 | 21.92 ± 1.40 | < 12         |

Value of MC was very different between industrial PB and rPB. Although the industrial PB here was classified as residues, they presumably underwent some treatments in production process such as addition of wax as water resistant agent [1]. Therefore, MC of PB was very low in contrast MC of rPB whose almost 10%. Indeed, the MC value of rPB was fulfilled the JIS criteria; in this case treatment for immersing PB residue in order to reproduce recycle wood particles can leach wax. In addition, amount of wax added during production process was very small (around 1-2%) so presumably during reproduction of rPB wax part was not on the surface again. Therefore, hygroscopic characteristic of the wood particle was inevitable.

Related to the hygroscopicity, both water absorption and thickness swelling of rPB were higher than PB. Beside this condition, work at laboratory scale with standard equipment 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. Similar case was occurred in previous study [18] when producing recycle’s fibreboard.

Table 2 presented data of mechanical properties of testing between PB and rPB. Interestingly, value of MoE of rPB was higher comparing to PB’s even though the values were under the standard requirement. Indeed, both PB and rPB were originated from waste therefore the values did not meet the standard. Waste was classified as an unserviceable remainder of any production process and it was considered as useless and unsalable [19]. Values of rPB was better than PB in term of MoE were still needed clarifications, for example on microscopy work which will be explained in next publication.

Table 2. Mechanical properties of PB versus rPB.

| Mechanical properties | PB       | rPB      | JIS standard |
|-----------------------|----------|----------|--------------|
| MoE (kgf/cm²)         | 12305±1080 | 19878±3223 | Min 20394 for type 8 |
| MoR (kgf/cm²)         | 134.14±5.55 | 46.12±7.88 | Min 132.56 for type 13 |
| IB (kgf/cm²)          | 1.31± 0.24 | 0.72±0.27 | Min 1.53 for type 8 |

MoR value of PB can be grouped into class type 13 of PB because result of MoR testing has been exceeded more than 132.6 kgf/cm². Unfortunately, when the PB was converted into rPB, the MoR was drop dramatically. This condition presumably because associated with lower bonding strength [6]. Properties of board were determined by many factors, one of them was type adhesive used. In this experiment, both MoE and MoR were not linear presumably because of the origin of specimens testing. Samples could be derived from cross-cutting mat, off-cut, or cutting edge therefore they were not uniform in term of the strength.

3.2. N content and result of growth observation

N content within the liquid disposal was 0.69%. This result was higher with previous study [18] on recycling fibreboard. Earlier study on the possibility of liquid disposal from recycling wood products bonded by UF resins showed that N content was derived from sol fraction and the values was vary depended on mol ratio of UF resins [20].

Table 3-5 showed observation on A.crassicarpa seedlings on height, diameter, and leaves number, respectively. All the growth parameters investigated here showed positively responses. In addition, after tested statistically using t-test one tail, there were significantly difference between T and UT for all parameters (height, diameter, and leaves number). Therefore treatment to give fertilizer originated from
liquid disposal from PB recycling was recommended. *A. crassicarpa* is classified as fast growing species; treatment with duration of 8 weeks was adequate for growth parameters observation. As aforementioned in earlier report [21], response of seedling growth was influenced by type seedlings used (fast, moderate, or slow growing species), duration of growth observation, and dosage of liquid disposal including the frequency as the treatment. The latter was also depended on N content as source of seedling nutrient. N was involved in all vegetative growth, comprised of root, stem, and leaves. N was also participated in chlorophylls forming, which were important in photosynthesis process.

**Table 3.** Mean height of *A. crassicarpa* for 8 weeks and t-test result.

| Variable 1 | Variable 2 | Mean | Variance | Observations | Pearson Correlation | Hypothesized Mean Difference | df | t Stat | P(T<=t) one-tail | t Critical one-tail |
|------------|------------|------|----------|--------------|---------------------|-----------------------------|----|--------|-----------------|---------------------|
| Mean       |            | 27.235 | 4.0001875 | 5             | 0.483182827         | 0                           | 4  | -2.462645514 | 0.034746771        | 2.131846786         |
| Variance   |            | 31.075 | 15.8521875 | 5             |                     |                             |    |         |                 |                     |

**Table 4.** Mean diameter of *A. crassicarpa* for 8 weeks and t-test result.

| Variable 1 | Variable 2 | Mean | Variance | Observations | Pearson Correlation | Hypothesized Mean Difference | df | t Stat | P(T<=t) one-tail | t Critical one-tail |
|------------|------------|------|----------|--------------|---------------------|-----------------------------|----|--------|-----------------|---------------------|
| Mean       |            | 0.317 | 0.0026325 | 5             | 0.047351057         | 0                           | 4  | -2.826746039 | 0.023750809        | 2.131846786         |
| Variance   |            | 0.399 | 0.00178  | 5             |                     |                             |    |         |                 |                     |

**Table 5.** Mean leaves number of *A. crassicarpa* for 8 weeks and t-test result.

| Variable 1 | Variable 2 | Mean | Variance | Observations | Pearson Correlation | Hypothesized Mean Difference | df | t Stat | P(T<=t) one-tail | t Critical one-tail |
|------------|------------|------|----------|--------------|---------------------|-----------------------------|----|--------|-----------------|---------------------|
| Mean       |            | 8.65 | 0.8625   | 5             | 0.970663638         | 0                           | 4  | -2.752988806 |                 |                     |
4. Conclusions

rPB could be reproduced using material recycling of PB wastes although its properties less satisfaction. This finding indicated that rPB was feasible to produce and recycling of PB waste was promising to be developed. Liquid disposal derived from recycling activity of PB bonded by UF resin containing N content from sol fraction origin can be utilized as fertilizer particularly for non-food seedlings fast growing species such as *A. crassicarpa*.

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