Use of Organic Resins for Wood Modification

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Abstract. Several Indonesian wood species were modified with two solutions of organic resins, i.e. shellac and damar which were diluted with methanol. The resin solutions were impregnated into wood blocks of coconut, rubber, fast grown teak and jabon. Physical and mechanical properties, and durability of the treated woods were determined to evaluate effects of the treatments. Results showed that effects of the treatments varied depending on wood species and kind of treatment. Wood blocks, treated to the highest weight percent gain (WPG), attained approximately 15% anti-shrink efficiency (ASE) after ten cycles of water saturation and drying. Coconut wood has higher permeability, solution uptake, retention and WPC than those of other three wood species. The ASE increased with an increase in the WPG. The resin modifications induced significant durability and mechanical strength improvements on all wood species.

1. Introduction
Wood is an important and favorable building material because it is economical, low in processing energy, renewable, strong, and aesthetically pleasing. On the contrary, there are several wood disadvantageous properties such as biodegradability, flammability, changing dimensions with varying moisture contents, and degradability by ultraviolet (UV) light, acids, and bases. Such inferior properties of wood have long been subjects of improvement through various modification treatments.

Wood characteristic improvements can be done through physical, mechanical or chemical treatments, but the last is most intensively explored [1, 2, 3, 4, 5]. Hill [2] also explained that the modification of wood can involve active modifications, which result in a change to the chemical nature of the material, or passive modifications, where a change in properties is effected, but without an alteration of the chemistry of the material. The active modification methods investigated to date have involved the chemical reaction of a reagent with the cell wall polymer hydroxyl groups. This can result in the formation of a single chemical bond with one OH group, or cross-linking between two or more OH groups.

There have been numerous efforts undertaken to improve characteristics of Indonesian woods using imported reagents, monomers and polymers. Balfas [6] reported that furfurylation treatment significantly improve dimensional stability and strength of tusam (Pinus merkusii) and mangium (Acacia mangium). Wood modification on jabon (Anchocephalus sp.) and nyamplung (Calophyllum sp.) with acetylation markedly improved vapor arbsorption property of the two wood species [7]. Significant improvements were demonstrated through the impregnation of the synthetic monomers and polymers into jabon wood [8]. However, these imported impregnants are very expensive and hardly meet economic production requirements.

Alternative approach has to be sought to find an effective way for improving wood quality and economically feasible as well. The use of certain wood extractive and organic resins to improve other wood characteristics has been initiated by Yamamoto and Hong [9]. Extractive impregnation has significant improvements on physical and biological wood performances [10]. Pine resin impregnation could improve strength and machining properties of eight wood species [11].

It is established that wood modification with organic resin is able to influence dimensional stability, strength and durability of the treated wood [12, 13]. It can be an alternative to conventional
preservation of wood and enhances the resistance to biological destruction agents without using biocidal compounds. Treatment of wood with organic resin is classified as a passive (impregnation) modification, where the resin is deposited in the cell wall without chemically reacting with the matrix polymers [14].

This study aims at investigating the effect of organic resin solutions impregnation to enhance dimensional stability, strength and durability of the modified wood.

2. Material and methods

2.1. Wood and chemicals
Wood logs of coconut (Cocos nucifera L.), rubber (Hevea brasiliensis Mull.Arg.), fast grown teak (Tectona grandis L.f.) and jabon (Anthosepalus cadamba Roxb. Miq.) were collected from a farmer plantation in west Java and cut into planks of approximately 60×150×2000 mm³ (radial × tangential × longitudinal) or (tangential × radial × longitudinal). The planks were cut to the specific grain orientation and specimen sizes described below. The specimens were then oven-dried at 65 ± 2°C for several days to reach approximately 10% moisture content. Samples were then weighed with electric balance in order to be able to determine the solution uptake and weight percent gain (WPG) after modification. Prior to treatment with organic resins, the dried wood specimens were conditioned at 25°C and 65% relative humidity (RH) to a constant weight.

2.2. Organic resins treatment
Resin solution formulations were prepared with 4 and 8% weight of shellac and damar, respectively, by diluting with technical grade methanol. The conditioned wood specimens were impregnated at 25°C in a vacuum-pressure vessel using a full cell process which included an initial vacuum phase of 5 kPa (15 minutes) and a pressure phase of 1200 kPa (1 hour). After the impregnation, the excess solution at the surface of the samples was removed with a paper towel and the samples were weighed. Then they were exposed to the temperature of 65°C in a drying oven for 48 hours. Solution uptakes (SU) after treatment and the weight percent gain (WPG) after drying were related to the dry mass of the untreated wood samples.

2.3. Anti-shrink efficiency and maximum swelling determination
Anti-shrink efficiency (ASE) was determined after cyclic water soaking and drying as described by Xiao et al. [15]. Five specimens (25 mm × 25 mm × 10 mm, r × t × l) per treatment and 5 untreated specimens were subjected to 10 cycles of water saturation (1 h with distilled water at 8 kPa, 24 h stored under water at atmospheric pressure) subsequently oven drying (40°C, 80°C, 103°C; 24 h each). After each cycle, the dimensions at oven dry state and water saturation were determined.

2.4. Durability
Wood durability testing against subterranean termites (Coptotermes cyanocephalus) was conducted by the procedure of an Indonesian standard [16]. Five specimens (25 mm × 25 mm × 5 mm, r × t × l) for each treatment were placed in glass containers with 200 g of sterilized river sand, 50 mL of water and 200 healthy and active workers of C. cyanocephalus termites from a laboratory colony. The containers were put in a dark room at temperature of 25–30°C and 80–90% relative humidity for 4 weeks and weighed each week. If the moisture content of the sand decreased by 2% or more, water was added to maintain the 25% moisture content. At the end of the fourth week, wood specimens were oven dried to determine weight loss, termite mortality and termite feeding rate, using the following formula.
Weight loss = \((W_1 - W_2) / W_1 \times 100\%\)  

where \(W_1\) = weight of the oven-dried sample before the test (g)  
\(W_2\) = weight of the oven-dried sample after the test (g).

Termite mortality = \((T_1 - T_2) / T_1 \times 100\%\)  

where \(T_1\) = number of live termites before the test and  
\(T_2\) = number of live termites after the test.

The calculated results were then classified into durability class according to the following table.

| Resistance | Classification  | Mass loss (%) |
|------------|----------------|---------------|
| I          | Very resistant | < 3.52        |
| II         | Resistant      | 3.52–7.50     |
| III        | Moderate       | 7.50–10.96    |
| IV         | Poor           | 10.96–18.94   |
| V          | Very poor      | > 18.94       |

2.5. Mechanical properties
Parallel and perpendicular compression strengths of the treated and untreated samples were determined according to the modified ASTM standard [17]. Parallel compression strength specimens (20 mm × 20 mm × 90 mm, \(r \times t \times l\)) and perpendicular compression strength specimens (20 mm × 20 mm × 60 mm, \(r \times t \times l\)) were conditioned at 25°C and 65% relative humidity (RH) to a constant weight prior to mechanical testing.

3. Results and discussion

3.1. Weight percent gain and solution uptake.
Solution uptake (SU), retention, and weight percent gain (WPG) demonstrated that four wood species were easily treatable with two organic resin formulations (Table 2). Both parameters linearly increased with the solid content in the treating solution. As observed previously [12], the weight-based solution uptake (SU) tended to slightly increase with the solid content as the density of the treating solution increases with the solid content. Table 2 showed that coconut wood samples have higher SU, retention and WPG than those of the other species. This may be due to the more porous structure of coconut wood with abundant parenchymatous tissue and metaxylem. The fast grown teak (FGT) samples indicated lower values of SU, retention and WPG. The least permeability of fast grown teak (FGT) may be related to its smaller pith perforation and vessel size compared with the other treated wood samples [13]. Table 2 also showed that the samples treated with damar had higher SU, retention and WPG than those treated with shellac resin. This difference may be caused by the higher particulate content per unit volume of the damar solutions, as damar resin is known to possess higher specific gravity of about 1.4 [18] than 1.1 of shellac resin [19].
Table 2. Solution uptake, retention and WPG of the treated wood

| Treatment | Solution uptake (%) | Retention (kg.m⁻³) | WPG (%) |
|-----------|---------------------|--------------------|---------|
|           | Co Rw FGTJb         | Co Rw FGTJb        | Co Rw FGTJb |
| 4% Shellac | 107 88 81 92        | 134 112 108 116   | 57 23 18 30 |
| 8% Shellac | 118 93 87 101       | 157 121 114 130   | 62 26 22 36 |
| 4% Damar   | 136 105 93 108      | 196 154 137 162   | 68 34 26 42 |
| 8% Damar   | 154 119 102 124     | 216 160 148 175   | 76 36 31 48 |

Remarks: Co=Coconut wood; Rw=Rubber wood; FGT=Fast grown teak; Jb=Jabon

3.2. Anti-shrink efficiency (ASE) and maximum swelling (SW_max)

ASE and SW_max show a dimensional stability of the modified wood samples. Depending on the resin concentration and wood species as shown in Table 2, the modification with organic resins induced high bulking in the range of weight gains 22-76%. These high bulking values are attributed to the relatively light weight of the resin solutions (specific gravity below 0.85). In addition, drying prior to the modification might have reduced the diameter of cell wall pores as compared to the never dried wood [20].

Maximum swelling of coconut, rubber, FGT and jabon during ten saturation and drying cycles was respectively plotted in Figures 1-4. As a consequence of resin bulking, the modifications imparted a reduced SW_max and moderate ASE, which was continuously decreased by increasing the number of cycle as shown in Figures 5-8. Resin bulking and ASE increased with increasing WPG. With respect to the high WPG attained at high treatment concentration, however, bulking and ASE were relatively low compared to the active modifications such as acetylation. This indicated that major proportion of the organic resin was not accommodated in the cell wall.

![Figure 1. Maximum swelling of coconut wood over 10 cycles saturation and drying](image-url)
Figure 2. Maximum swelling of rubber wood over 10 cycles saturation and drying

Figure 3. Maximum swelling of FGT over 10 cycles saturation and drying

Figure 4. Maximum swelling of jabon over 10 cycles saturation and drying

The SWmax of the modified specimens (Figures 1-4) increased with an increase in the number of saturation and drying cycles. This is particularly attributed to leaching of hydrophilic extractives
and to hornification of the cell wall due to high temperature drying [21]. The phenomena can be explained by bulking reduction due to leaching during cyclic wetting and drying and rearrangement of the resins in the cell wall. The decreasing ASE with increasing number of wetting and drying cycles is due to the effect of a slight increase in the SWmax values of the resin-modified specimens. This steady minor loss in the ASE indicates that the long-term outdoor dimensional stability of the organic resin-treated wood must be called into question.

Figure 5. ASE of coconut wood over 10 cycles saturation and drying

Figure 6. ASE of rubber wood over 10 cycles saturation and drying
3.3. Durability
The weight loss of wood sample, termite mortality and termite feeding rate after 4-week subterranean termite test are shown in Table 3. Values of each parameter are significantly different from treatments and wood species.
Table 3. Weight loss, mortality and feeding rate on termite test

| Treatment   | Weight loss (%) | Mortality (%) | Feeding rate (mg termite⁻¹ week⁻¹) |
|-------------|-----------------|---------------|-----------------------------------|
|             | Co Rw FGTJb Co Rw FGTJb Co Rw FGTJb |               |
| Untreated   | 32. 28.3 28.5 30.8 | 42 48 46 45   | 65 61 60 63                        |
| 4% Shellac  | 7.5 7.8 7.1 7.5  | 96 98 98 96   | 18.9 17.2 17.1 18.2               |
| 8% Shellac  | 6.8 7.3 6.7 7.3  | 98 98 99 99   | 18.5 16.8 16.0 17.6               |
| 4% Damar    | 5.8 6.5 6.3 6.8  | 99 99 99 99   | 18.3 16.2 15.2 16.3               |
| 8% Damar    | 5.7 5.9 5.1 6.4  | 99 99 99 98   | 16.2 14.1 13.8 16.0               |

Remarks: Co=Coconut wood; Rw=Rubber wood; FGT=Fast grown teak; Jb=Jabon

The weight loss of untreated wood samples varied from 28.3 to 32.6%, while the resin treated wood samples had weight loss range from 5.1 to 7.8%. The weight loss of all specimen was affected by wood species, resin concentration and the interaction of these factors. Impregnation FGT with 8% damar had the lowest weight loss compared with those of other wood species and resin treatment. The highest weight loss was encountered in rubber wood samples impregnated with 4% shellac resin. Table 3 clearly indicates that treatment with higher resin content resulted in lower wood weight loss. Table 3 also demonstrates that impregnation using damar resin consistently had lower weight losses than those treated with shellac resin. Results of this study are in line with those of Basri and Balfas [13] who stated that resin loading is proportionally increased with increasing resin content.

Based on weight losses, we can determine the wood resistance class according to the Indonesian standard [16]. The untreated wood samples, having the weight loss of 28.3 to 32.6% (Table 3), were all categorised into class V (Table 1), which is very poor resistance against subterranean termite attack. And most of the resin treated wood samples were classified into class II, i.e. resistant. This indicates that organic resin treatment is very effective in increasing wood resistance against termites. The efficacy of organic resins in improving durability of jabon wood is comparable to the durability improvement made on the same wood using methyl methacrylate [8].

Termite mortality is significantly varied according to wood species, the resin treatment, and interaction of the two factors. The average termite mortality in the resin treated wood samples (Table 3) varied from 96 to 99%, meaning that most all termites were dead. These values are about double of the untreated samples (mortality of 42 to 48%). The organic resins were not toxic to termites, but they formed a barrier in the wood structure, preventing termites to reach the wood tissues directly. Higher resin deposition would result in stronger barrier and greater resistance. Resin treated wood samples are markedly more resistant than the untreated samples against C. cynocephalus subterranean termites.

Termite feeding rate on the untreated wood samples varied between 60 to 65 mg termite⁻¹ week⁻¹. These values are lower than the standard feeding rate of pine (Pinus merkusii), i.e. 79 mg termite⁻¹ week⁻¹ [22]. The resin treated wood had much lower feeding rates of 14 to 19 mg termite⁻¹ week⁻¹, which are about 30% of the untreated wood termite feeding rate. Wood species, impregnation treatment, and interaction of the two factors significantly affected values of the termite feeding rate. The lowest feeding rate was encountered in treatment fast grown teak with 8% damar.
3.4. Mechanical strength
Coconut, rubber, fast-grown teak and jabon wood samples treated with organic resins showed significant improvement in mechanical properties (Table 4). The effect varied depending on wood species, modification treatment, and combination of the two factors. Coconut wood samples treated with organic resins possess approximately 20 to 60% higher compression strength compared to those of the untreated samples (Table 4). The strength improvement of coconut wood is recorded significantly higher than those of the other three wood species, which increased of 10–30% compared to their untreated samples. The difference may be related to the higher solution uptake, retention and WPG of coconut wood compared with the other wood species (Table 2). Effective resin retention in the structure of wood samples may have caused wood structure to bulk and fibre bonding to increase to contribute to mechanical improvement [2]. Table 4 also shows that the modification treatment with damar resin improved mechanical properties of wood samples better than those treated with shellac resin.

| Treatment  | Compress // grain | Compress ⊥ grain |
|------------|-------------------|-----------------|
|            | Co    | Rw    | FGT  | Jb | Co   | Rw   | FGT  | Jb |
| Untreated  | 232.20 | 442.20 | 236.21 | 142.40 | 74.05 | 186.80 | 74.63 | 34.52 |
| 4% Shellac | 266.31 | 458.90 | 252.08 | 152.51 | 96.24 | 242.51 | 75.92 | 42.38 |
| 8% Shellac | 282.37 | 488.40 | 264.38 | 160.22 | 100.22 | 260.59 | 78.37 | 44.40 |
| 4% Damar  | 290.63 | 503.26 | 270.30 | 170.35 | 113.70 | 282.40 | 92.64 | 48.61 |
| 8% Damar  | 312.26 | 542.05 | 288.26 | 184.68 | 128.06 | 296.26 | 98.63 | 62.48 |

Remarks: Co=Coconut wood; Rw=Rubber wood; FGT=Fast grown teak; Jb=Jabon

4. Conclusions
Treatments of four wood species with two resin solutions of shellac and damar has resulted in various solution uptake, retention, weight percent gain, durability and mechanical strength between the wood species. Coconut wood has higher permeability, solution uptake, retention and weight percent gain than the other wood species. The anti-shrink efficiency (ASE) increased with an increase in the WPG. The resin modifications induced significant durability and mechanical strength improvements on all wood species.

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