Natural weathering on coated tropical woods

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Abstract. Teak and pine are common wood species in Indonesia. The purpose of this research is to evaluate the performance of the coating layer in these wood species after six months natural weathering. The durability on natural weathering is evaluated due to microbial disfigurement (fungi or algae), checking and cracking, whereas microbial disfigurement (fungi or algae) is evaluated using ASTM D 3274-95, checking with ASTM D660-93, and cracking with ASTM D 661-93. Wood samples of 30 (l) x 15 (w) x 2 (t) cm are sanded before painted, then preservatives, water repellents, and its combinations are applied on the surface of the samples. The results showed that the coating layer of the combination of paint and preservatives and the combination of paint and water repellent could provide better protection of the surface on long rotation teak, short rotation teak, and pine boards against microbial disfigurement, checking and cracking compared to the other coating layers after 24 weeks of natural weathering. The coating layers on long rotation teak and short rotation teak gave better protection against microbial disfigurement, checking and cracking than pine wood. The coating layer on the radial section gave better protection compared to the tangential section. However, the durability of the coating layer on the radial and tangential section is not significantly different.

1. Introduction

Wood as a structural material has not been completely replaced by other materials. Not only because it is strong but also wood has an attractive appearance that cannot be found in other materials. However, wood can be degraded by environmental influences like physically (e.g. changing of water content continuously), biologically (e.g. insects, fungi, bacteria, and marine borer), also chemically (e.g. ultraviolet radiation). One of the solutions to protect the wood from degradation is finishing. Finishing is the final treatment in the woodworking process by applying a coating layer to protect and also to beautify its appearance [1].

One of the most common woods in Indonesia is teak wood (*Tectona grandis* Linn. F.). Demand for teak wood remains high due to wood characteristics that are suitable for various purposes such as materials buildings, furniture, handicrafts, and others [2]. The characteristic is related to surface properties and affect the coating where teak wood can be lacquered and polished well [3] and also affects the absorbency, adhesion, and finishing attributes of wood [4]. On the other hand, the teak wood supply continues to decline from year to year.

The limited of long rotation wood can be overcome by utilizing fast growing species like short rotation teak and pinewood [5]. Short rotation teak and pine wood are common fast growing tropical wood species in plantation forests in Indonesia and likely to be the mainstay raw materials for the wood industry. These short rotation plants are already in demand for use in the light frame structural, woodworking, and wood composite board industries as the main source of raw material and
are becoming leading wood product exports [6]. However, fast growing wood species is not recommended for exterior use because it is very susceptible to fungi [7].

Since fast growing wood species are often of inferior quality (e.g. low density, low dimensional stability, low durability, etc.), many modification techniques are used to improve wood properties such as heat treatment [8] and applying a coating layer for exterior use [9]. Exposed outdoors timber needs protection from the effects of sunlight and rain. Surface damage occurs due to oxidation on wood surfaces whose reaction is accelerated by ultraviolet (UV) light from sunlight and accelerated also by other processes such as leaching by rainwater, temperature changes, and abrasion by particles due to wind gusts.

The difference in the coating layer can produce varied quality. However, the coating layer has good quality nor does it necessarily match the structure of certain wood surfaces. The macroscopic structure of wood greatly affects the spread and penetration of the coating layer liquid. The relationship between the macroscopic structure of wood and the ability to drain fluid coating layers has been carried out by several researchers, both on hardwood and softwood [10,11].

Coating techniques with exterior paint have been studied and proven to extend the wood life. Demirci et al. [12] uses varnishes on several species of wood to see the effect of temperature and humidity and to determine the sticky strength of varnishes. The results show that varnish applications can protect the wood from changes in temperature and humidity. The main factors that influence sticking strength are moisture content and the level of roughness of wood surfaces.

The most common coating layer is finishing exterior like paints and preservatives. This coating layer can protect the wood from temperature changes. The durability of the paint on wood can decrease due to the influence of the weather. This condition occurs on the surface of all organic materials including wood. Exterior paint used in wood can also experience degradation due to photo oxidation. Exterior paint that forms a thin film can be eroded due to damage to organic polymers because of weathering. In essence, weathering can damage wood and exterior paint layers [13]. Water repelling and permeation on wood surfaces that are only coated with exterior paint are not good. This is because basically giving exterior paint aims to provide wood resistance from weather effects, but exterior paint is not able to withstand the water penetration. To overcome this, it is necessary to make a coating process with water repellents.

Water repellents ingredients can increase wood resistance to the penetration of water particles into the wood or allow the wood to refuse the water penetration. The ability to resist water can be realized through a mixture of wax applications (beeswax), oil, or similar substances that can withstand the rate of water. Bees wax is one type of candle that is composed of 71% ester wax, 15% hydrocarbons, fatty acid, and 6% other materials. The ability of water repellents to resist water allows the wood to counteract decay and discoloration. Addition of preservatives and water repellents will increase the effectiveness of coating materials or finishing especially in inhibiting fungal growth. Water repellents can also prevent the occurrence of shrinkage which can cause cracking and warping. These materials can also protect wood that has been given an exterior coat of paint from the sun which can cause the checking of the finishing material.

The information regarding the effectiveness of paint, preservatives, water repellents, and its combination are needed especially those tested for Indonesian tropical wood species that have not widely known. Therefore, this study is conducted to evaluate the effectiveness of the application of coating layer (paint, preservatives, water repellent, and their combination) on long rotation teak and fast-grown wood species (short rotation teak and pine) for exterior use.

2. Materials and Methods

2.1. Materials

Samples are prepared according to ASTM D 358-98 [14] from long rotation teak, short rotation teak, and pine. Long rotation teak 45 years old with diameter 45 cm; short rotation teak 10 years old with diameter 25 cm, and Pine 10 years old with diameter 42 cm. Logs are cut using table circular saw
machine to produce the samples measuring 30 x 15 x 2 cm. The samples then conditioned at 21°C until reaching dry air content 12 to 15%.

The paint used is an ultran lasur with a solvent based type. Ultran lasur is a deep penetrating protective wood coating specially designed for tropical climate. Water repellents made from beeswax with composition of wax ester 67%, hydrocarbon 14%, acid fat 12%, and other materials 7%. The function of water repellents is to obstructing the water absorption. The preservative used is fungicide substance/material active thiocyanomethylthio benzotiazole (TCMTB). Variations of the coating layer are shown in Table 1.

### Table 1. Variations of the coating layer.

| Codes | Treatments                                      | Composition of the coating layer                        |
|-------|------------------------------------------------|--------------------------------------------------------|
| K     | Control (uncoated)                              | -                                                      |
| F     | coated with paint                               | 100% paint                                             |
| P     | coated with preservatives                       | 100% preservatives                                     |
| W     | coated with water repellents                    | 100% water repellents                                  |
| FP    | coated with combination of paint and preservatives | 20% preservatives, and 80% paint                        |
| FW    | coated with combination of paint and water repellents | 20% water repellents, and 80% paint                    |
| FPW   | coated with combination of paint, preservatives and water repellents | 10% preservatives, 10% water repellents, and 80% paint |

2.2. Methods

Test samples sanded with sandpaper number 80, 100, and 150 to get a smooth surface. Each variation of the coating layer is applied in test samples. The coating layer is sprinkled with brush 2 times. Before the second layer, the test sample was dried and lightly sandpapered using a 400 sized paper. Then the sample was dried to form a strong coating. The samples are exposed outdoor to test their resistance against weather. This evaluation is to observe the damage that occurs in the coating layer and classify the durability of the coating layer on 11 classes (Table 2). Surface damage due to microbial disfigurement (fungi or algae) was evaluated using ASTM D 3274-95 [15], checking with ASTM D660-93 [16], and cracking with ASTM D 661-93 [17].

### Table 2. Classification of the condition of the coating layer after natural weathering [15-17]

| Rating | Percentage of blemished surfaces (%) |
|--------|-------------------------------------|
| 0      | 100                                 |
| 1      | 90                                  |
| 2      | 80                                  |
| 3      | 70                                  |
| 4      | 60                                  |
| 5      | 50                                  |
| 6      | 40                                  |
| 7      | 30                                  |
| 8      | 20                                  |
| 9      | 10                                  |
| 10     | 0                                   |

3. Results and Discussions

The durability of the coating layer is determined based on microbial disfigurement, checking and cracking that occurs in the test sample. Microbial disfigurement is a defect that occurs due to the growth of fungi and algae in the wood and coating layer, thus damaging the appearance of the wood surface (ASTM D 3274-95) [15]. Checking is a defect that occurs in the coating layer and does not penetrate the coating layer (ASTM D 660-93) [16]. Cracking are defects that occur on the surface of the layer that
penetrate the coating layer and cause cracks on the wood surface (ASTM D 661-93) [17]. The coating layer has a different level of effectiveness according to weather conditions [13].

Countries that have tropical climate such as Indonesia use Schmidt and Ferguson's classifications based on dry month ratio to wet month. A dry month is a month with total precipitation below 60 mm/month and a wet month is a month with total precipitation above 100 mm/month [18]. The climatic data during the 24 weeks of observation is described in Table 3. The results in Table 3 reveal that the intensity of rainfall in April was 206 mm/month and decrease in June and July then increase in August. This made the surface of the test sample exposed to different conditions during 24 weeks of observation.

| Parameter                          | Duration of weathering test (month) |
|------------------------------------|-------------------------------------|
| Rainfall (mm/month)                | Apr 206.1  May 201.9  Jun 90.2  Jul 1.6  Aug 112.4  Sep 79.3  Oct 180 |
| Temperature (°C)                   | Apr 25.8  May 26.3  Jun 26.2  Jul 26.1  Aug 26.2  Sep 26.2  Oct 26.8 |
| Humidity (%)                       | Apr 86  May 82  Jun 79  Jul 74  Aug 75  Sep 70  Oct 75 |
| Solar Radiation Intensity (Cal/cm²)| Apr 313  May 338  Jun 328  Jul 353  Aug 369  Sep 361  Oct 375 |

Source: Meteorology and Geophysics Agency Darmaga, Bogor

The intensity of the sun's rays and the fluctuating of the rainfall from April to October made several samples experienced cupping which causes the coating layer to peel and crack (Figure 1). The possibility of splitting and cupping can be reduced by applying the right coating layer [19]. Wood endurance for exterior use is strongly influenced by the type of coating layer used [20].

![Figure 1](image_url) Defects in the tangential section of pine (a) cupping and (b) cracking

Nejad et al. [21] report that the life service of the wood can be extended by increasing its dimensional stability. This research is focused on optimizing the application process of coating materials in the form of hot oil in some types of wood that will be used as building floors. The result of the research showed that wood with a coating layer had better resistance to color fading, abrasion, and scratches than the unapplied coating layer wood. The resistance of the coating layer is determined by the large sticking force between paints and wooden surfaces [22]. One of the constraints applying the coating layer is caused by grain raising, the condition of wood surface after sanding, and species of wood [23,24]. On some species of wood, applying exterior paint on a sanded wooden surface can cause the wooden fibers to be lifted. The amount of fiber lifted and the surface roughness are affected by the type of sandpaper [25,26] and the low density of wood [27].

Evaluation of the durability of the coating layer against microbial disfigurement, checking and cracking are presented in Figure 2. From this graph, it can be seen that the durability of the coating layer against microbial disfigurement, checking, and cracking has decreased since the 6th week of exposure. We can assume that this happened because of the high intensity of rainfall in April and May, which then
dropped dramatically in July which reached below 60 mm/month. This causes the durability of most of the protective layer to experience damage in the form of checking and cracking.

The durability of the coating layer is affected by sunlight, duration of radiation, and temperature [28-30]. The resistance of the coating layer is influenced by the type of coating layer and the species of wood used [31]. The durability of the coating layer affects the level of water absorption and changes in dimensions [32]. The highest absorption rate was indicated by uncoated wood, and wood with a coating layer with a water solvent, while the lowest absorption rate was shown by wood with a coating layer with oil solvent.

The percentage of the test sample with a coating layer F, FP, and FW have a lower defect compared to the test sample without a coating layer (Figure 2). Without the coating layer, wood can be directly affected by weather changes. Wood which is continuously exposed in the outdoor will experience discoloration and is easily overgrown with fungi [33].

Figure 2. Rating of (a) microbial disfigurement (b) checking and (c) cracking based on the type of coating layer after 24 weeks exposure; (d) Percentage of damage after 24 weeks exposure
due to photo-degradation of organic polymer components of surface protective materials, especially by ultra-violet light. Most of the surface color of the test sample which was given a coating layer became brighter and seemed yellow-brown after 24 weeks of exposure. This result is due to extractive substances that can evaporate to painted wood surfaces and when yawning will leave a stain of extractive substances that is yellow to brownish red in the paint layer. Rainwater can dissolve extractive substances in the wood so that the wood undergoes genuine color changes [36,37]. Ultra-violet rays penetrate the wood surface and can cause weathering in wood.

3.1. The durability of the coating layer based on the wood species

One of the important factors influencing the durability of the coating layer is the wood species. Wood has different characteristics and properties. Water, dust, and other materials can enter the wood pores. These cause damage to the wood to swell or shrink, checking, cracking or change color. The decrease in the coating layer is presented in Figure 3.

![Figure 3](image_url)

**Figure 3.** Rating of (a) microbial disfigurement (b) checking and (c) cracking based on the type of wood after 24 weeks exposure; (d) Percentage of damage after 24 weeks exposure.

The results in Figure 3 showed that the coating layer on long rotation teak, short rotation teak, and pine begins to degrade due to microbial attack, checking, and cracking after 24 weeks of natural weathering. The results also showed that the durability of the coating layer on pine wood is lower than the coating layer on long rotation teak and short rotation teak. This indicates that long rotation teak and short rotation teak can be used for exterior applications with long life service. Damage to the coating layer due to microbial disfigurement, checking and cracking begins to appear after one month of exposure and develops very quickly so that the class reaches an average Rating 7.

The ability of the adhesion of exterior paint on wood is influenced by the wood species, the direction of the fiber, and the surface texture [34,38-40]. The quality of the finishing results is also influenced by the direction of the fiber, the existence of the knots, and the moisture content of the wood. Meanwhile, the exterior paint resistance can be optimal if the factors that influence the finishing result are fully considered. These factors include wood as a substrate, types of exterior paint, methods for applying exterior paint, and environmental conditions.
Checking and cracking can cause the fungus to enter the coating layer to grow and spread under the coating layer. The result of this study showed that the highest microbial disfigurement occurs was in pine wood. This is because pine wood is less durable and has a greater rate of swelling and shrinking than the other samples. This can be due to pinewood contains extractive substances that slowly disappear when the wood is exposed. This cause water to easily penetrate into the wood and attacked by fungi and other microorganisms [41]. Besides, pinewood contains hydrophobic resin channels [42]. These properties cause the coating layer to bind less strongly to wood. Weather changes can cause degradation in all organic materials including coating layer material consisting of organic polymers, which is caused by changes in humidity and ultraviolet radiation on the wood surface [13].

The percentage of damage after 24 weeks of exposure based on the wood species is presented in Figure 3(d). The results showed that the percentage of checking in long rotation teak and short rotation teak is larger than in pinewood. Differences in anatomical characteristics of both hardwood and softwood affected the difference in the durability of the coating layer against the effects of weather [43]. Wood that has a smoother surface has lower durability than a rough surface. This figure also indicated that the percentage of microbial disfigurement that occur in teak wood is smaller than in pine wood. Based on the results of laboratory experiments and grave experiments on soil fungi and termites, these woods are reported to be resistant to fungal attacks, including Schizophyllum commune [3].

3.2. The durability of the coating layer based on the wood section

Wood has anisotropic properties which means that there are differences in properties especially the difference in shrinkage which can affect the durability of the coating layer. The durability of the coating layer against microbial disfigurement, checking, and cracking based on the wood section is presented in Figure 4. The decrease of the coating layer quality begins to occur in the first week because of the high intensity of radiation. This causes the surface of the coating layer is unable to withstand checking and cracking damage. The results in Figure 4 show that the durability of the coating layer against microbial disfigurement, checking, and cracking in the radial section is slightly better than that of the tangential section.

After 14 weeks, the coating layer on the tangential section experienced more checking and cracking compared to the radial section. This is considered because wood with radial section has a lower shrinkage value than a tangential section. The radial section has a lower chance of cracking because of the radial section has lower possibility for swelling and shrinkage than the tangential section in exterior applications [13,44]. The radial section of the same type (camphor) and the same growth level is better in its ability to withstand paint compared to the tangential section [45]. However, the durability of the coating layer to the radial and tangential sections is not significantly different. This can be caused by the radial section and the tangential section of long rotation teak, short rotation teak and pinewood having relatively similar wettability properties. Similar result are also shown in sengon (Paraserianthes falcataria (L.) IC Nielsen), jabon (Anthocephalus cadamba (Roxb.) Miq), acacia (Acacia mangium Willd.) and rajumas wood [8,46].
However, the durability of the coating layer in the radial section is slightly better than that of the tangential section. It can be concluded that the durability of the coating layer on long rotation teak and short rotation teak is different. Further research needs to be conducted to find out the best concentration of water repellents in a combination of coating layer.

4. Conclusions
The results of this study indicated that the best coating layers for exterior use are the combination of paint and preservatives and the combination of paint and water repellents. Based on the wood species, it can be concluded that the durability of the coating layer on long rotation teak and short rotation teak are better than the durability of the coating layer on pine wood. The results also showed that the durability of the coating layer in the radial section is slightly better than that of the tangential section. However, the durability of the coating layer on the radial and tangential sections is not significantly different. Further research needs to be conducted to find out the best concentration of water repellents in a combination of coating layer.

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