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jmr&t
Journal of Materials Research and Technology
www.jmrt.com.br

Original Article

Microbial growths and checking on acrylic painted tropical woods and their static bending after three years of natural weathering

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ARTICLE INFO

Article history:
Received 12 June 2019
Accepted 17 June 2019
Available online 3 July 2019

Keywords:
Acrylic paint
Tropical woods
Outdoor exposure
Mold and decay fungi
Climate index
Cracking
Bending strength

ABSTRACT

Wood products exposed outdoor could be weathered, especially in the tropical region with high in sun light, temperature, rain intensity, and relative humidity. Water based acrylic paint was coated on surface of teak, camphor, and pine woods for natural weathering resistance. The natural weathering and wood materials affected the resistance of the acrylic paint film on fungi (blue-stain and decay fungi), cracking, and MOE/MOR bending. After 36 months of exposure, the surface of unpainted pine and camphor panels were covered by fungi over 40% and reached the growth index of 5. The acrylic painted woods provided lower growths index of fungi up to three years of exposure. Application of the acrylic paint on the wood panels was observed to minimize the index of cracking from 5 for unpainted to 3 for painted after 36 month exposure. The average adhesion scale for the acrylic paint film dropped from 4.5 before exposure to 2.3 after 36 month exposure. The percentages of MOE/MOR drop after 36 month exposure were observed. The 36 month exposure caused the loss of MOR of 10.7% and 5.1% for unpainted and acrylic painted panel, respectively, and the loss of MOE of 6.8% and 1.4% for unpainted and acrylic painted panel, respectively. The acrylic paint film can be considered to protect the pine, camphor and teak at least 36 months. However, teak wood with the greatest resistance to the natural weathering factors will provide the longest service life compared to pine and camphor.

1. Introduction

Weathering is a general term used to define a slow degradation of wood materials exposed to the weather. Wood materials have great physical, mechanical and decorative qualities. However, wood materials exposed to biotic and abiotic factors

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https://doi.org/10.1016/j.jmrt.2019.06.024

lose their original qualities because of their organic nature [1–3]. Significant variation in natural weathering of wood exists between wood species due to differences in their chemical and density properties. The weathering initially causes the color of the wood surface to change, followed by the occurrence of surface checking and increased roughness of the samples. The fine surface of wood is also transformed by the formation of cracks and split caused by the absorption and loss of moisture resulting in swelling and shrinkage [4,5].

The changes in colour are mainly due to solar radiation (ultraviolet, visible and infrared light) [6–8]. The change in colour of wood exposed to sun and rains is also influenced by the kind of extractives present in the cell wall [9]. During weathering, extractives are moved toward the surface by water where they are partially oxidized [10]. The main chemical components of wood surface shows a transformation with the affected lignin producing carbonyl and carboxyl chromophoric compounds which results in the surface colour transformation [11]. The discoloration of the surface is a direct indication of the chemical modification in the cell wall due to weathering. Most of the time, weathered wood would have a more pronounced gray color than unexposed wood as a result of the modification of lignin and hemicelluloses. Such discoloration in the cell wall is influenced by photochemical reactions leading to the degradation of wood constituents, mainly lignin. A major part of solubilized lignin during degradation is washed out by rain. However, fiber-rich cellulose with a higher resistance against ultraviolet light degradation remains in the cell wall without significant modification and results in the wood acquiring a whitish to gray color [12,13].

Surface molds and decay fungi are biological agents that highly contribute to the colour and strength changes of wood caused by weathering. Several factors affect performance and durability properties of painted wood constructions. One important factor is mold fungi and decay fungi. The critical limit for mold growth on wood is around relative humidity (RH) 75–80% (constant ambient air humidity), but mostly higher relative humidity around 90% (wood moisture content around 20%) is required for growth. The actual limit depends on temperature, exposure time, wood material and fungal species [14,15]. Unpainted champor wood after 4 months of out door exposure in Indonesia was reported to be attached by mold fungi of genera *Aureobasidium*, *Cladosporium*, and *Penicillium* [16]. In other studies surface degradations of unpainted wood due to weathering up to one year were characterized by the presence of mold fungi and blue-stain fungi on the wood samples [17–19].

Research works have investigated the application of paints to the surface of wood for possible protection of wood products against weathering, without changing their natural appearance. Assessment of these protective properties of coatings should be a great importance. The durability of a coated exterior wood surface depends on its ability to resist the degradation processes that act on the coating and the wood substrate. Several studies have reported that coating formulation and pigmentation influence fungal growth [20,21]. It was shown that brown semi-transparent coatings are less sensitive to blue stain than white paints. In another study, Ozgenc et al. [22] noted that, the acrylic clear-coated wood show better color stabilization and surfaces quality than that of the uncoated samples after exposure to artificial weathering. Most studies on assessments of the protective properties presented above had been carried out on painted wood surfaces for short weathering time (less than one year of exposure), in which decay fungi have not been in the growth yet. Therefore the protective assessments for a longer time (at least three years) of the natural weathering exposure should be performed to provide more complete indication on the quality of a paint or paint coated on wood surfaces. Detailed information on protective assessment of painted woods weathering is important to obtain a better understanding of their outdoor functioning.

The mold rating should be a useful parameter that provides information on the protective properties of paint coatings on the surfaces of woods weathered in the tropic due to favorable climate for fungal growth. The growths of mold fungi and decay fungi in Indonesia as a tropical country with a wet, hot, humid climate the entire year, with high temperatures often in the 34 °C during the day, and the humidity between 70 and 90% would be more aggressive on the surface of wood under weather exposure. Nevertheless, little is known about growth of mold fungi and decay fungi on the surfaces of coated tropical widely used woods such as teak (*Tectona grandis*), camphor (*Dryobalanops aromatica*) and pine (*Pinus merkusii*). Since 5 years ago, a water based paint had been promoted in Indonesia as an exterior coatings for the environmental reason with less scientific research support. Therefore, investigating the growth of mold fungi and decay fungi on the surface of painted teak, camphor and pine under weather exposure will lead to making better utilization of these woods and their service life for out door uses. The objective of this study was to investigate the growth of fungi, checks on the surface of water-based acrylic paint coated on the three tropical woods under 36 months natural weathering exposure, and its effects on adhesion of the paint and bending strength of woods.

2. Materials and methods

2.1. Specimens preparation

Pine (*Pinus merkusii*) and teak (*Tectona grandis*) sample trees were supplied from plantation forest planted by the Indonesian State Forests Enterprise (Perhutani) at West and East Java. Three trees of each species were selected from the plantation sites as representative specimens. The pine and teak sample trees were in the age of 20 and 40 years, respectively. After felling, the trees were cross cut in length of 2.0 m from the bottom part of the tree stem. The sample logs were maintained in green condition, and they were transported to the wood workshop for preparation of test specimens. The sample logs were band sawed in flat cutting pattern to produce flat sawn flitches in thickness of 25 mm. Camphor (*Dryobalanops aromatica*) flat sawn flitches (25 × 300 × 400 mm) were obtained from a sawn timber shop in Bogor, Indonesia. The flitches were edged, and the boards produced were seasoned at 25 °C and relative humidity of 80% until their moisture content of about 15%. The boards were planed and cross cut to produce panels of 20 × 150 x 300 mm (tangential × radial × longitudinal) for specimens of natural weathering tests. Selection of 30 panels

Table 1 – General description of the woods used and the coating systems applied.

Characteristics	Description		
Paint:			
Paint type	Water based acrylic; pigments oxide transparent; high build		
Specific gravity	1.06 ± 0.02 g/cc		
Volume solid	40 ± 2 %		
Spreading rate	4 m^2/lt		
Coating layer	3 layer		
Wood panels:			
Species	Pine	Camphor	Teak
Density (g/cm^3)	(0.52 ± 0.06)	(0.86 ± 0.02)	(0.67 ± 0.03)
Durability	Low	Moderate	High
Moisture (%)	(10.5 ± 1.1)	(12.6 ± 1.2)	(11.0 ± 1.4)

completely heartwood of each species for test specimens was done carefully to keep the defects free panels.

2.2. *Coatings application*

An industrial water-based acrylic paint (Table 1) was used for the weathering test. For each wood species, 30 panels of wood samples (15 for unpainted panels and 15 for acrylic painted panels) were produced. The acrylic paint was professionally applied by brushing on the faces, edges and ends of the specimens. Three consecutive coats of acrylic paint were applied at the manufacturer's recommended spreading rate. Twenty-four hours drying time was allowed between coats. The spreading rate for the paint corresponded to a total application of 200 g/m^2 wet film and a dry film thickness of 60 ± 10 μm. The required weight of each coat to achieve these spread rates was calculated based on the surface area of the samples. When the third coat had dried, the painted samples were conditioned for one week in a clean room at approximately 25 °C temperature and 75% relative humidity.

2.3. *Static bending and adhesion test measurement*

Five unpainted panels with true radial and tangential surfaces were taken and sawed to produce bending test specimens ($20 \times 20 \times 300$ cm; tangential × radial × longitudinal) with straight-grained and free from any visible defects. The bending test specimens were prepared for 10 replications. Static bending tests for measurement of MOE and MOR were conducted on the Instron universal testing machine based on the ASTM D 145-14 [23] testing procedure.

Five painted panels were used for adhesion test. A cross-cut tape test method was applied to evaluate the resistance of the coating films to separation from wood surfaces according to ASTM D 3359-97 [24]. A cross-cut pattern was made through the film with a sharp cutter head. Pressure-sensitive tape was applied over the cut. Tape was smoothed into place by using a pencil eraser over the area of the incisions. Tape was removed by pulling it off rapidly back over itself close to an angle of 180°. Adhesion was assessed on a 0 to 5 scale. The scale 5 is 0% area removed, and scale 0 is greater than 65% area removed. Two cross-cut patterns per panel were made for each wood species, and ten measurements of cross-cut were obtained. The scales of the adhesion were averaged.

2.4. *Weathering test and assessment*

Ten replicate panels of each species both for acrylic painted and unpainted were exposed outdoors at the research field of the Bogor Agricultural University for 3 years (October 2014–September 2017). The exposure was carried out on weathering racks inclined at an angle of 45° to the horizontal and facing East in accordance to EN 927-3 [25]. All panels were examined visually each three months for evaluating degree of checking, and degree of fungal disfigurement using the rating index developed in the EN 927-3. This rating index should be suitable to assess the weathering of coatings on tropical hardwood as it combines different features and includes specific degradation phenomena. The rating indexes have an increment of 1 allowing intermediate ratings. The photographic standards of the EN 927-3 rate the checking and fungal growth on the surfaces from 0 (no defect) up to 5 (dense defects). A rating of 0 (no defect) would indicate a surface totally absent of checking or fungal disfigurement by particulate matter. To analyze the development of surface appearance during the exposure, photographs on the surfaces of the unpainted and painted panels were made every three months. Images were also made using digital video microscope to analyze the degree of checking, and fungal disfigurement.

Both MOE/MOR and adhesion test after 3 years of exposure were also measured according the ASTM D 145-14 and ASTM D 3359-97 (1997), respectively. Unpainted and painted five panels each were taken for measurement of the MOE/MOR and the values of adhesion. The rest of the weathered panels were used for identification of fungi which have grown on the surface of the unpainted and painted woods.

The fungi that have grown on the weathered panels were taken and isolated into a prepared Potato Dextrose Agar (PDA) media in petri dish. All fungal isolations were undertaken aseptically. The isolates were incubated at room temperature (26–28 °C). The fungi that grew then were purified by being transferred to new PDA media. After 7 days, identifications of the fungi were carried out. Identifications of fungi were carried out both macroscopically and microscopically. For microscopic observations, preparations were made by putting the isolates on the object glass, dripping with distilled water and covering with a lid, then were observed under a microscope. Identifications of the isolates were done by observing and studying the morphological properties. Fungi species was determined according to Barnett and Hunter [26].

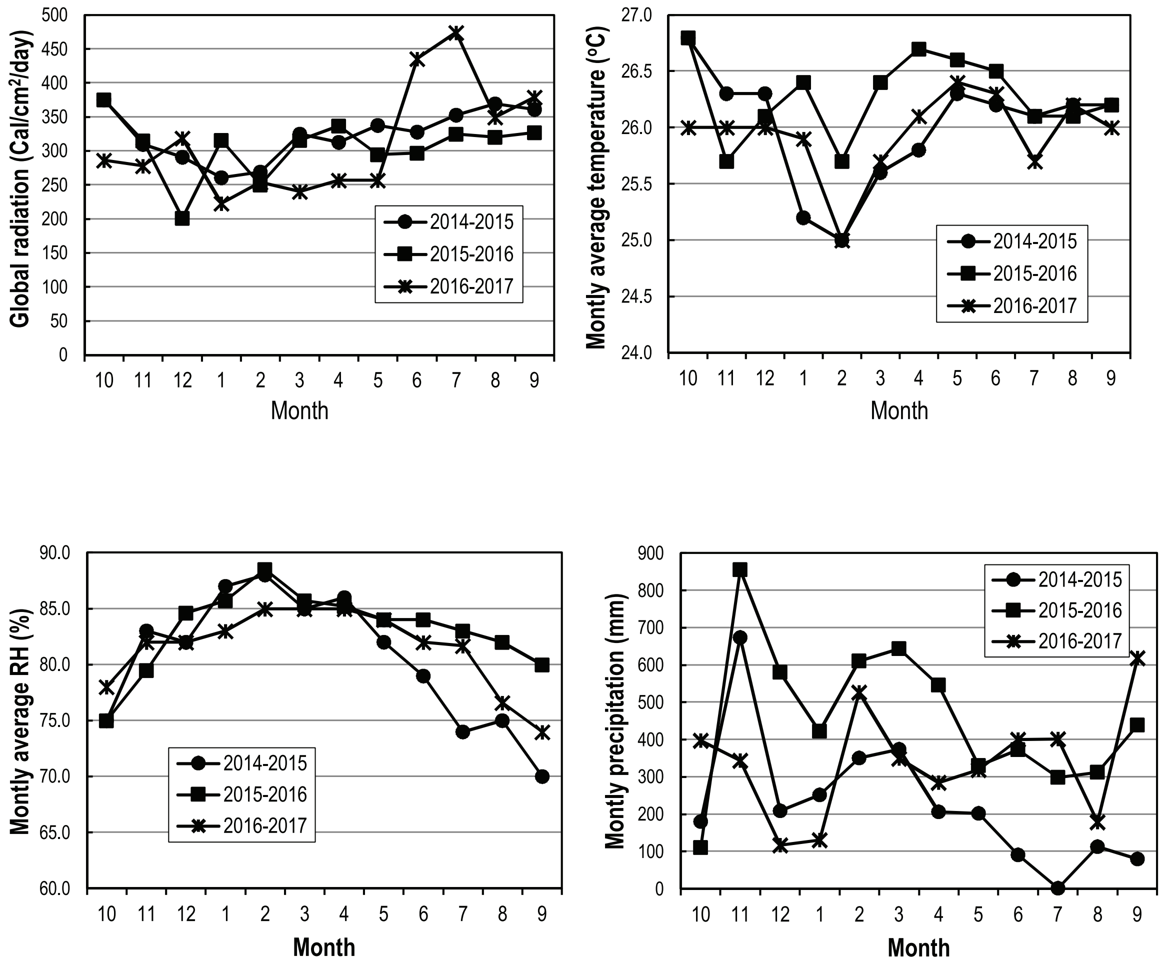

Fig. 1 – The fluctuation of global radiation, monthly average temperature, monthly average RH and monthly precipitation at Darmaga Bogor City during the three years of exposure.

2.5. *Climatic index*

Climatic data for the exposure period in Bogor was obtained from a respective local meteorological agency. Climate index (CI) were calculated according to Scheffer [27] and Creemers et al. [28] to estimate decay risk for wood exposed above ground to exterior conditions. Scheffer climate index (CIs) and Creemers climate index (CIc) are calculated by following equations.

$$\mathrm{CIs} = \sum_{\mathrm{Jan}}^{\mathrm{Dec}} [(\mathrm{T}-2)(\mathrm{D}-3)]/16.7,$$

where T is monthly average temperature (expressed in °C), D is number of days per month with 0.25 mm or more of precipitation, and $(\mathrm{T}-2) \equiv 0$ if $T < 2$.

$$\mathrm{CIc} = \frac{\mathrm{I_{global}}}{20} + \frac{\mathrm{n_r}^{*}\mathrm{R_{sum}}}{500},$$

where $\mathrm{I_{global}}$ = global radiation (kWh/m^2) on panels tilted at 45°, $\mathrm{n_r}$ = days of rainfall with more than 0.1 mm of precipitation; $\mathrm{R_{sum}}$ = total precipitation (cm).

3. Results and discussion

3.1. *Climatic conditions*

Climatic data in the three years of exposure for Bogor are described in Fig. 1. The results in Fig. 1 reveal that the average global solar radiation for the year 2014–2015, 2015–2016, 2016–2017 was 324.42, 306.17, 312.75 cal/cm^2/day, respectively. Monthly average temperatures fluctuated slightly throughout the year in between 25 and 27 °C, however annually average temperature was uniform in the value of around 26 °C. Monthly rainfalls in Bogor throughout the year except on June, July and September 2015 were very high with the values more than 100 mm, and its annual rainfalls were 2729, 5519, 4066 mm for the year the year 2014–2015, 2015–2016, respectively. It also appears from the results in Fig. 1 that the monthly average RH throughout the year was larger than 70% which was critical limit for fungi growth on wood. By using climatic values in Fig. 1, climate index values for the Bogor city were calculated and listed in Table 2. Both the CIs and CIc climate index values in the Bogor were larger than 100. It was reported in another article [29], the Scheffer climatic

Table 2 – Climate index values for the Darmaga city at Bogor Indonesia.

Period of exposure	According to	
	Scheffer	Creemers
2014/2015	201.6	122.0
2015/2016	336.7	298.0
2016/2017	323.5	215.2
Average	287.3	211.7

index (CIs) at Trabzon, Artvin, Kastamonu sites in Turkey was 79.7, 72.4, 23.2, respectively. Dawson et al. [30] found that the values of the Creemers climatic index (CIc = 113) in Rotorua New Zealand exceeded that (CIc = 73) in Braunschweig Germany, confirming that climatic condition is harsher in Rotorua than in Braunschweig. Thereby, climatic conditions in Bogor Indonesia should be harsher than those in Turkey, Germany New Zealand, which lead to the higher decay risk for woods under weather exposure.

3.2. *Fungi disfigurement and cracking*

The index of fungal disfigurement on the surfaces of unpainted and acrylic painted wood panels exposed outdoor at Bogor were shown in Fig. 2. As shown in Fig. 2, for unpainted panels, the highest fungi growth was observed in the pine panels while the lowest fungi growth was observed in teak panels. The pine wood is lower in durability compared to the teak wood [31]. After 24 months of exposure, the surface of unpainted pine and camphor panels were covered by fungi over 40% and reached the growth index of 5. The acrylic painted panels displayed marked differences with respect to their macroscopic appearances. Panels painted with acrylic suffered lower growth of fungi. During 12 months of exposure, there was not fungi growth on the surfaces of the painted acrylic for all wood species. Fungi were observed to grow on the surface of painted panels after 15 months of exposure (Fig. 2). Color changes on both the unpainted and painted panel surfaces were observed (Fig. 3). During the initial 12

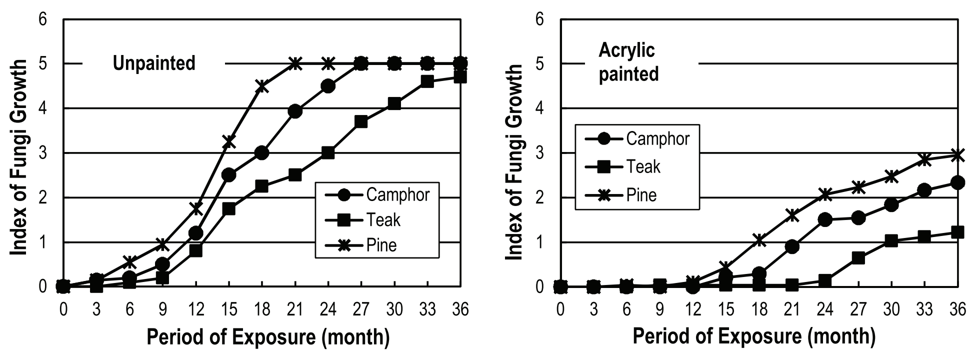

Fig. 2 – The changes in the index of fungi growth with the time period of exposure.

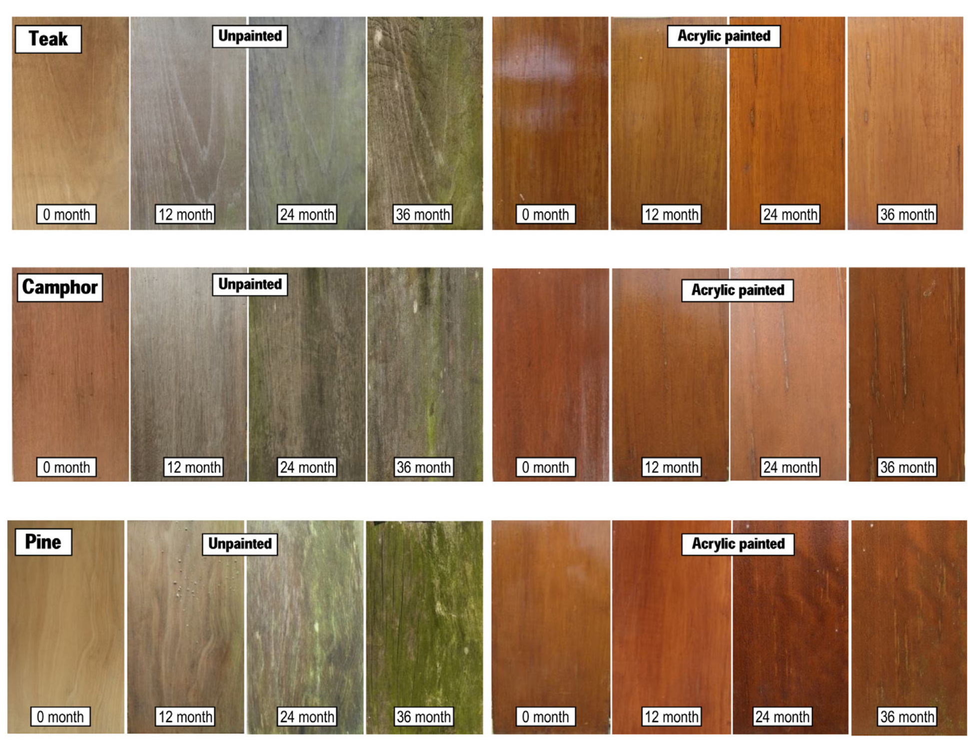

Fig. 3 – The surface conditions for the unpainted and acrylic painted panels before and after 12, 24, 36 month of exposure.

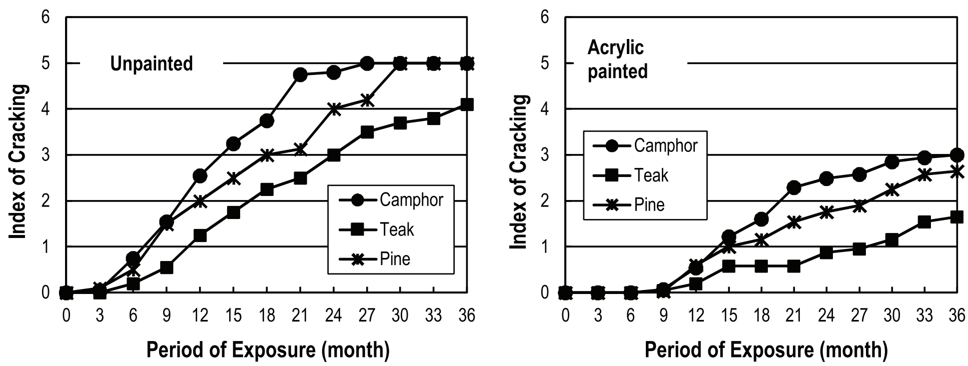

Fig. 4 – The behaviors of the cracking for the unpainted and acrylic painted panels with the time period of exposure.

months, the surfaces of the unpainted panels were dark gray, panels painted with acrylic exhibited reduced lightness. This fact confirms that during early stage of weathering the color changes of wood surfaces is mainly caused by UV light decomposition of lignin. The reduction in discoloration of wood coated with acrylic paint can be attributed to a lesser extent to the photo-degradation of cell wall polymers resulting in less fungal staining. The color changes of the unpainted pine, camphor and teak during the initial 12 months of exposure could be also determined by the presence of mold and fungi growth in their surfaces. Mechanism of surface graying of weathered wood with fungal-action usually predominates particularly in the presence of moisture [12]. Microorganisms may also produce dark colored spores and mycelia, which can produce the dark gray, blotchy and unsightly appearance of some weathered wood. All wood surfaces will eventually turn gray when exposed to sun and rain [32].

After 3 months and 9 months of exposure, the unpainted and acrylic painted wood panels respectively showed formation of cracking which basically ran in the direction of wood fibers (Fig. 4). The presence of the cracking indicated a lack sufficient flexibility to accommodate the surface strains due to swellings and shrinkages of the woods. It was noted that exposure of lumber to ultraviolet and visible light increases the tendency of surface cracking caused by photo degradation [33]. There is a link between changes in cell microstructure caused by photo degradation of lignin and the formation of surface checks in wood exposed outdoor. Application of the acrylic paint on the wood panels was observed to minimize the cracking. The acrylic coating films coatings blocked solar radiation and prevented water penetration. Cracking on the surface of unpainted woods and on acrylic film led to higher fluctuations of wood moisture content due to high rain fall and temperature during the exposure (Fig. 1), which encouraged the growth of mold, blue stain and decay fungi.

After 9 months of exposure, the blue stain fungus *Trichoderma sp* became dominant for the unpainted panels. The visual assessments of fungal growth (Fig. 2) showed a marked increase in the area and the intensity of blue stain after 9 months of exposure, however there was not any fungal growth observed on the surface of the acrylic painted panels. The mold growth was first observed at unpainted pine panels after the three month of weathering (Fig. 3). Blue-stain fungi growth was observed in unpainted pine, camphor and teak panels, especially after the six month of exposure. The fungi successfully isolated from the panels were identified to analyze their existence and diversity on the panel surfaces after 12, 24 and 36 months of exposure. The results are shown in Table 2. The results indicate that the growths of stain fungi *Trichoderma sp* followed by decay fungi *Drechslera sp* and *Bispora sp* (Table 3) on the painted panels after 12 month were due to the visible cracking started on the 9 month of exposure (Fig. 4). It was reported that mold and stain fungi can grow on wood at lower moisture contents, more than decay and soft-rot fungi, because they probably access moisture which wood surfaces had absorbed from humid environments [34]. Moisture contents of the panels after exposure were not determined. Thus, it is possible that the panels had different moisture levels which had an effect on the blue stain and decay fungi growth. The results on the fungal growth and cracking were different among the wood species. Lower fungal growth was observed on the painted teak compared with the painted camphor and pine. The pine wood has low durability lead to more susceptible to blue stain and decay fungi than the camphor and teak woods. The teak wood, with lower degree of cracking and higher durability than pine and camphor, had a fungi growth rating of 1.2 after 36 month of exposure, reflecting less fruitful conditions for fungi growth. The lower growth of fungi index for the painted panels suggests that the acrylic paint was effective against the growths of blue stain and decay fungi up to three years of exposure.

3.3. *Adhesion and MOE/MOR bending*

The results on adhesion test before exposure and after 36 month exposure are presented in Fig. 5. Adhesion of the acrylic paint on woods surfaces was reduced after the painted woods were weathered for 36 months. The adhesion scales were in between 4–5 before exposure, and were below 3 after 36 month exposure for all wood substrates. For panels before exposure, the panels failed at the paint-wood interface and failed cohesively in the wood substrate. However, for panels after exposure 36 months, failure occurred almost exclusively at the paint-wood interface.

Reduced acrylic paint adhesion and increased paint-wood interface failure after exposure might result in poor long-term protection. The change in adhesion scale with weathering was less for the teak wood compared to the camphor and pine

Table 3 – The main fungal species identified after 12, 24, and 36 months of exposure on the wood panels. Species/Genus in bold were predominantly identified.

Length of weather exposure	Mold/Fungal colony	Species/Genus	Attacked wood panels
12 month	Mold	*Rhizoctonia sp*	Unpainted pine
	Blue stain	*Botryodiplodia sp*	Unpainted pine, camphor
	Blue stain	*Trichoderma sp*	Unpainted pine, camphor and teak
24 month	Blue stain	*Botryodiplodia sp*	Unpainted pine, camphor
	Blue stain	*Trichoderma sp*	Unpainted pine, camphor and teak
	White rot fungi	*Mycellia sterilia*	Unpainted pine, camphor and teak
	White rot fungi	*Drechslera sp*	Painted pine, camphor, and teak
	Brown rot fungi	*Bispora sp*	Painted pine and camphor
36 month	Blue stain	*Botryodiplodia sp*	Unpainted pine, camphor
	Blue stain	*Trichoderma sp*	Unpainted pine, camphor and teak
	White rot fungi	*Mycellia sterilia*	Unpainted pine, camphor and teak
	White rot fungi	*Drechslera sp*	Painted pine, camphor, and teak
	Brown rot fungi	*Bispora sp*	Painted pine and camphor
	White rot fungi	*Irpex lacteus*	Unpainted pine

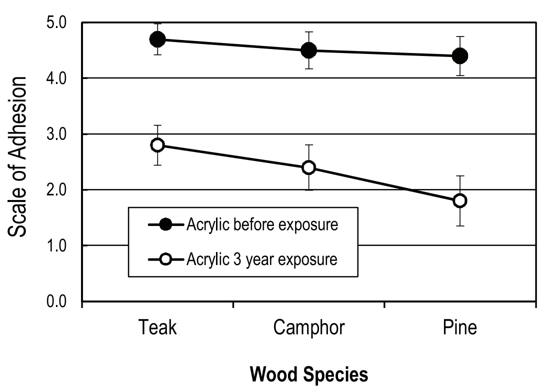

Fig. 5 – The adhesion between the acrylic film and panel substrates before and after 36 month exposure.

woods. This may be caused by the lower degree of cracking of the acrylic film on the surface of teak wood (Fig. 4).

The changes in MOE/MOR of bending strength of the unpainted and acrylic painted due to 36 months exposure are presented in Fig. 6. The results in Fig. 6 show the same trend in the MOE and MOR for all wood species. It appears that the acrylic paint coated on the surface of woods could retain a drop on the MOE/MOR of the woods. The percentages of MOE/MOR drop after 36 month exposure are depicted in Table 4. It was observed that unpainted and painted pine panels showed the largest change in MOR and MOE. The 36 month exposure caused the loss of MOR of 13.5% (from an initial value of 87.5 MPa to the final 75.7 MPa) for unpainted panel, and of 6.2% (from an initial value of 87.5 MPa to the final 82.1 MPa) for the acrylic painted panel. Camphor also showed large changes in the MOR. The decreases in MOR after 36 month exposure were 11.2% (from an initial value of 119.4 MPa to the final 106.1 MPa) for the unpainted panel, and were 5.9% (from an initial value of 119.4 MPa to the final 112.3 MPa) for the acrylic painted panel. Teak panels showed the greatest resistance to weathering stated by the smallest changes in MOR and MOE. The MOR of teak panels changed 7.4% (from an initial value of 102.9 MPa to the final 95.3 MPa) for unpainted panel, and 3.1% (from an initial value of 102.9 MPa to the final 99.8 MPa) for the acrylic painted panel. It was also observed that the pine and camphor panels suffered slightly larger decrease in MOE values compared to teak panels after the 36 months exposure. However, the decreases in the MOE values were largely smaller compared to the MOR values. The MOE of the acrylic painted panels decreased only in the average of 1.4% after the 36 month exposure (Table 4). These results suggest that the weather exposure could provide a more significant influence on MOR rather than on MOE. It can be considered that due to the weather exposure, the loss of MOR and MOE bending of the unpainted and acrylic painted wood was caused by changes in wood structure. The harshest climatic indexes (Table 2) with cyclical changes in humidity, rainfall, solar radiation intensity and temperature caused strong stress and strain which resulted in surface checks and cracks on the woods. There could be also a mass loss due to deterioration of cell walls attacked by the decay fungi. Disintegration of some long-chain tissue constituents of woods in subsurface layers led to the wood cracks, which were reflected in changes of their MOE and MOR. Falk [35] performed bending tests in 90 timber beams of 55 years old with 30 timbers containing heart checks and 60 without checks. It was found that the bending strength of checked beams is 15% lower than the beams without checks. Rammer [36] investigated the effect of split and checks on both the shear and bending strength. It was reported that the bending strength decreases significantly and that shear strength is negatively affected by the presence of split and checks.

By considering that mold, blue stain and decay fungi can cause severe problems in woods used for exterior purposes (furniture, building construction, siding etc), application of coatings on the surface of wood should be a good solution. The behaviors of fungi growth, cracks development, adhesion, and bending strength of acrylic painted pine, camphor and teak wood obtained in this study are expected to provide practical information for user, leading to a more appropriate usage of the coating and woods. The acrylic paint used in this research work minimizes UV absorption, retards penetration of moisture, and thereby reduces paint discoloration by wood extractives, paint check and cracking of the wood.

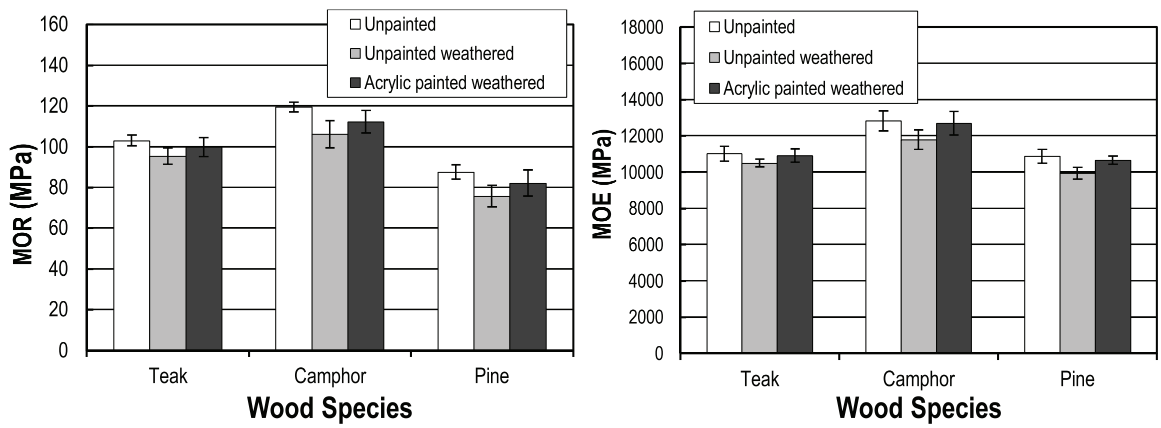

Fig. 6 – The values of MOR and MOE of the unpainted panels before exposure, unpainted and acrylic painted panels after 36 month of exposure.

Table 4 – Percentage of the decrease in MOE and MOR for the unpainted, and acrylic painted after 36 months of exposure.

Wood species	MOR decrease (%) for		MOE decrease (%) for	
	Unpainted	Acrylic painted	Unpainted	Acrylic painted
Teak	(7.4 ± 2.0)	(3.1 ± 1.1)	(4.7 ± 1.3)	(1.0 ± 0.2)
Camphor	(11.2 ± 2.6)	(5.9 ± 1.4)	(8.1 ± 2.2)	(1.1 ± 0.2)
Pine	(13.5 ± 3.3)	(6.2 ± 1.5)	(8.6 ± 1.5)	(2.0 ± 0.6)
Average	(10.7 ± 2.6)	(5.1 ± 1.3)	(7.1 ± 1.7)	(1.4 ± 0.3)

Pine is not remarkably inferior in shrinkage, and strength compared to other wood species, although it is less durable [31]. The lower decay resistance of the pine wood will restrict its utilization to interior purposes. The future for camphor wood utilization looks less promising, because of the Indonesian Government regulation to restrict the use of wood from natural forest. The greatest resistance to the natural weathering factors of the teak wood as expressed through the smallest growth in blue stain and decay fungi and less drops in the MOE and MOR bending is very promising for the exterior uses. Several studies completed on teak wood have provided a better understanding on how its good stability, high durability, high bending strength, and easy machining are important for the wood industry and government [37,38].

4. Conclusion

Aesthetical changes occur during the first 12 months of outdoor exposure for the unpainted panels. Loss of gloss and discoloration were the first visible signs of degradation. After 36 months weathering, the exposed surfaces of all unpainted wood samples are attacked heavily by blue-stain and decay fungi. No growths of blue-stain fungi are found on the surface of the samples which are coated by acrylic paint, however, decay fungi are partly found on the acrylic painted woods. Unpainted wood samples (mostly pine and camphor woods) showed formation of numerous cracks which basically ran in the direction of wood fibers. Application of the acrylic paint on the surfaces of wood panels is observed to minimize the cracking. Adhesion of acrylic paint on wood is dropped after the acrylic painted woods have been weathered for 36 months. Reduced paint adhesion and increased wood-paint interface failure will undoubtedly result in poor long-term paint protection on wood specimens against photo degradation and water damage. Outdoor exposure for 36 months causes a reduction of the MOR and MOE bending of all unpainted wood species. However, the decreases in the MOE values are largely smaller compared to the MOR values. The loss of the MOR and MOE bending gets greatly smaller as the wood surfaces are coated by the acrylic paint. Pine, camphor and teak woods show a substantially good substrate for the acrylic paint in protecting their surfaces subjected to high humidity, temperature, rain fall and solar radiation. The acrylic paint film can be considered to protect the pine, camphor and teak at least 36 months. However, teak wood with the greatest resistance to the natural weathering factors would provide the longest service life compared to pine and camphor.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgement

The authors thank the Directorate for Research and Community Service of the Ministry of RISTEK-DIKTI of the Republic of Indonesia for the research grant.

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