Original Article
J. Korean Wood Sci. Technol. 2024, 52(6): 555-564
https://doi.org/10.5658/WOOD.2024.52.6.555

Journal of the Korean Wood Science and Technology
pISSN: 1017-0715 eISSN: 2233-7180
http://www.woodj.org

Effect of Keruing and Meranti Wood Extracts on the Nail Corrosion Rate

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ABSTRACT

Many houses and wooden constructions in East Kalimantan Province use keruing and meranti wood. Local carpenters widely use ordinary and concrete nails to join the wood. One of the factors affecting the corrosion rate of nails in wood is the extractive compound. Unfortunately, the amounts and types of keruing and meranti wood extractives and their effects on the corrosion rates of ordinary and concrete nails have not been studied. This study aimed to determine the amount and types of keruing and meranti wood extractives and their effects on the corrosion rates of ordinary and concrete nails. Wood extractive content was determined according to TAPPI 204 cm-97. A gas chromatograph-mass spectrometer test determined the chemical compound content of wood extractives. The electrochemical test measured the corrosion rate according to modified ASTM 199-09. The study showed that keruing wood contained 3.83% extractives and was dominated by cyclic carbon compounds. Meranti wood contained 1.97% extractives, and contained sulfurous acid, cyclohexylmethyl pentadecyl ester, which is acidic and therefore accelerates the rate of nail corrosion faster than keruing wood extractives. The lowest corrosion rate was found on cocrete nails in keruing wood extractive media, 0.65104 μm/year. The highest corrosion rate was found in ordinary nail in meranti wood extractives, 3.7434 μm/year. The nail corrosion rate in the keruing wood extractive media was lower than in the meranti wood extractive media.

Keywords: keruing, meranti, wood extractives, corrosion, nails

1. INTRODUCTION

Meranti and keruing wood are two types of tropical hardwood that are widely used in construction, particularly as a raw material for the building and housing industries (Lee *et al.*, 2024; Viholainen *et al.*, 2021). Wood is a renewable resource, has great mechanical properties, is an excellent thermal insulator, and is easy to shape and join (Popovski *et al.*, 2014).

Several pieces of wood can be nailed together to form a specific structure to achieve the assembly convenience of wood (Han *et al.*, 2023). The advancement and enhancement of connectivity technologies utilizing nails will additionally expand the potential of construction methods involving wood (Pang *et al.*, 2017). Local carpenters in East Kalimantan frequently use both ordinary and "ulin nail" or concrete nails to join wood. Concrete nails are classified as "square boat nails". They

Date Received March 14, 2024; Date Revised April 12, 2024; Date Accepted July 11, 2024; Published November 25, 2024
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have a square cross-section, as opposed to the round cross-section of ordinary nails. For the same length, ordinary nails have a marginally smaller cross section than concrete nails (Cohen *et al.*, 2015). Galvanized concrete nails are more expensive than ordinary nails (Amayreh, 2022).

After the wood has been fastened, nails that are left in place for an extended period of time will begin to corrode. If left undetected, corrosion of the nails can cause the nail joints to come loose (Takanashi and Sawata, 2017), as a result of metal corrosion, there has been a decrease in weight (Suprapti *et al.*, 2020). Knowing the rate at which nails corrode will help avoid the danger of disconnecting a joint where the nails have corroded.

Each species of wood is distinguished by its anatomical structure, physical properties, mechanical properties, and chemical properties (Berglund and Burgert, 2018) such as wood extractives. Some wood extractives, such as phenolic compounds (Yeon *et al.*, 2019), inhibit corrosion (Aourabi *et al.*, 2021), while others, such as organic acid compounds such as fatty acid and resin acid in heartwood (Arisandi *et al.*, 2024), accelerate corrosion (Maraveas, 2020). Corrosion of metals embedded in wood is affected by three types of extractives: organic acids, tannins and phenols (Abo Elgat *et al.*, 2021). Unfortunately, the amount and types of extractives in keruing and meranti wood sold in lumber stores and their effect on the corrosion rates of ordinary and concrete nails, have not been investigated. The purpose of this study was to determine the amount and types of extractives in keruing and meranti wood sold in lumber stores, and their effects on the corrosion rates of ordinary and concrete nails based on electrochemical test.

2. MATERIALS and METHODS

Meranti wood sample was purchased from Mustaqim Proprietorship lumber store, and keruing wood sample was purchased from Putera Harapan Ibu Proprietorship lumber store, in Samarinda City, East Kalimantan Province, Indonesia. The wood samples purchased from the lumber stores, each measuring 4 × 6 × 400 cm, consisted of two pieces per wood species. Sawdust was produced by cutting the wood at every 100 cm intervals using a circular saw.

The extractive content of the wood was evaluated according to TAPPI 204 cm-97 (Arango-Perez *et al.*, 2023). The thimble containing 2 ± 0.1 grams of 40–60 mesh sawdust was placed in the Soxhlet extractor containing 300 mL of methanol. The duration of the extraction process was four to five hours. The extracted sawdust was dried in an oven at 103 ± 2℃ to determine its extractive free weight. The extracted solution was filtered using Whatman microporous filter paper with a pore size of 0.45 μm and a diameter of 47 mm. The resulting filtrate was filtered and divided into two portions, 200 mL for electrochemical testing and 100 mL for gas chromatograph-mass spectrometer (GC-MS) testing.

The chemical compound content of the wood extractives was determined by GC-MS (Mangindaan *et al.*, 2017; Yeon *et al.*, 2019). A rotary evaporator was used to concentrate 100 mL of the Soxhlet extraction filtrate, yielding 8 g of concentrated extract, which was used for GC-MS analysis. A Shimadzu QP 2010 GC-MS was used for the measurement. The GC-MS was equipped with a Restek column, RTx-5MS capillary column (30 m × 0.25 mm I.D. and 0.25 μm). The RTx-5MS column has a working temperature range of 50℃–300℃, initial temperature 50℃ (hold 5 min) to final temperature 300℃ in increments of 5℃/min (hold 12 min); interface temperature 270℃; split ratio 1:0; and pressure 108.1 kPA; helium gas as carrier gas. GC-MS readings indicate retention time, chemical constituents, and concentrations (Guerrero-Chanivet *et al.*, 2020). The National Institute of Standards and Technology (NIST) library database version 11 was used for component identification (Vieira *et al.*, 2021). Chemical compound concentrations were determined from the peak area of the GC-MS graph (Baccolo *et al.*, 2021).

Four-inch ordinary nails and concrete nails were purchased from a hardware store in Samarinda. The ends and heads of the nails were then cut to a length of four centimeters for use in the electrochemical test. The treatment for electrochemical testing is shown in Table 1. Each treatment was tested in three replicates.

Electrochemical testing using a potentiostat/galvanostat to determine the corrosion rate was in accordance with ASTM 199-09 (Almeraya-Calderon *et al.*, 2024). The electrolyte liquid was derived from meranti and keruing wood extracts produced by Soxhlet extraction. The electrochemical test results show the corrosion currents, potentials, and rates (Nyby *et al.*, 2021). The electrochemical test results are reported as means with SDs.

3. RESULTS and DISCUSSION

Based on TAPPI 204 cm-97 test, the extractives content of keruing wood was 3.83% and meranti wood was 1.97%. Keruing wood contained 3.83% extractives and meranti wood contained 1.97% extractives. In comparison, the heartwood of the base of *Shorea retusa* had an extractive content of 4.69%–5.87%, *Shorea macrophylla* had an extractive content of 2.35%–4.27%, and *Shorea macroptera* had an extractive content of 10.62%–11.37% (Yunanta *et al.*, 2014). Meanwhile, the extractive content of *Dipterocarpus glabrigemmatus* wood was 8.8%, *Dipterocarpus stellatus* was 6.8%, and *Dipterocarpus pachyphyllus* was 7.7% (Dewi and Supartini, 2017). The study results showed that the extractive content of the wood test samples had a lower value than the reference. The reference's extractive content was measured from felled tree trunks, whereas the study’s extractive content was assessed from sawn wood sold in wood shops. Cutting wood from logs to lumber and the time the lumber is stored or stacked in the workshop may result in reduced wood extractives (Chen *et al.*, 2020). The GC-MS test results of keruing wood extractives are shown in Table 2.

Table 1. Electrochemical test treatment

Code	Wood extractives	Nail
CK	Keruing	Ordinary nail
CM	Meranti	Ordinary nail
UK	Keruing	Concrete nail
UM	Meranti	Concrete nail

The keruing wood extractives contained a lot of oleoresin. The oleoresin in *Dipterocarpus gracilis* is dominated by caryophyllene and caryophyllene oxide (Fernandes and Maharani, 2019), in *Dipterocarpus grandiflorus* by β-bisabolene (Wahyudianto *et al.*, 2020), and in *Dipterocarpus verrucosus* by caryophyllene and α-humulene (Fernandes and Maharani, 2022). Based on Table 2, keruing wood extractives contained coumaran (27.28%), sitostenone (17.26%), methyl p-coumarate (12.11%), antiarol (9.57%), and γ-sitosterol (9.86%). Coumaran compounds can be natural inhibitors to prevent corrosion in mild steel in 0.5 M HCl solution (Yaqoob *et al.*, 2023). Methyl p-coumarate inhibits corrosion on metal surfaces by an anionic mechanism (Udabe *et al.*, 2021). Whereas, antiarol compounds can inhibit corrosion by preventing excessive oxidation (Sprang *et al.*, 2022). The γ-sitosterol compound can adhere parallel to the metal surface and is supported by the activity of heterooxygen atoms, aromatic carbon groups and the presence of double bonds, so it can effectively prevent corrosion reactions on metal surfaces (Rehioui *et al.*, 2023). Meanwhile, sitostenone is a ketone derivative of sitosterol (Szakiel *et al.*, 2022), so its corrosion inhibition mechanism is similar to that of sitosterol compounds. The results of GC-MS analysis of meranti wood extractives are shown in Table 3.

Shorea leprosula wood contains guaiacol, furfural,

Table 2. Results of GC-MS analysis of keruing wood extractives

Retention time (min)	Chemical name	Concentration (%)	Functional chemical structure	Corrosion inhibitor or accelerator
12.89	Coumaran	27.28	Cyclic structure O-structure	Corrosion inhibitor
21.10	Antiarol	9.57	Cyclic structure O-structure	Corrosion inhibitor
24.54	4-((1E)-3-Hydroxy-1-propenyl)-2-methoxyphenol	4.01	Cyclic structure O-structure Double bond	Corrosion inhibitor
24.70	Methyl p-coumarate	12.11	Cyclic structure O-structure Double bond	Corrosion inhibitor
25.55	2-Cyclohexen-1-one, 4-hydroxy-3,5,6-trimethyl-4-(3-oxo-1-butenyl)-	9.33	Cyclic structure O-structure Double bond	Corrosion inhibitor
28.47	Elaol	5.87	Cyclic structure O-structure Double bond	Very weak acid, corrosion accelerate
29.04	3-(2,5-Dimethoxyphenyl)-propionic acid	2.40	Cyclic structure O-structure Double bond	Weak acid, corrosion accelerator
36.80	Hexadecanal	2.30	Aliphatic structure O-structure Double bond	Corrosion inhibitor
49.45	γ-Sitosterol	9.86	Cyclic structure O-structure Double bond	Corrosion inhibitor
53.40	Sitostenone	17.26	Cyclic structure O-structure Double bond	Corrosion inhibitor

GC-MS: gas chromatograph-mass spectrometer.

levoglucosan and 4-vinylguaiacol (Sulistyo *et al.*, 2017). Based on Table 3, the investigated meranti wood was dominated by 1,8-nonadyine 76.15%. Compound 1,8-nonadiyne, can form a thin layer on metal surfaces to inhibit corrosion (Yoshinobu *et al.*, 2018). Another extractive compound in meranti wood that acts as another inhibitor is 1-(4-Acetamidoanilino)-3,7-dimethylbenzo (4,5) imidazo (1,2-a) pyridine-4-carbonitrile. Derivatives of imidazo (1,2-a) pyridine effectively inhibit corrosion because metal surfaces readily absorb the proton transfer (Salim *et al.*, 2019). The effect of wood extractives on the corrosion rate of ordinary nails and concrete nails is shown in the following Tafel plot in Fig. 1.

According to the Tafel plot, concrete nails corroded slower than ordinary nails. Ordinary nails are an industrial product with a low iron content and a high susceptibility to corrosion (Santoso *et al.*, 2022). Concrete nails, on the other hand, are high-quality industrial

Table 3. Results of GC-MS analysis of meranti wood extractives

Retention time (min)	Chemical name	Concentration (%)	Fungtional chemical structure	Corrosion inhibitor or accelerator
4.02	1-(4-Acetamidoanilino)-3,7-dimethylbenzo[4,5]imidazo[1,2-a]pyridine-4-carbonitrile	4.75	Cyclic structure O-structure N-structure Double bond	Corrosion inhibitor
4.15	1,8-Nonadiyne	76.15	Aliphatic structure Triple bond	Corrosion inhibitor
24.53	4-((1E)-3-Hydroxy-1-propenyl)-2-methoxyphenol	0.80	Cyclic structure O-structure Double bond	Corrosion inhibitor
28.37	Elaol	2.77	Cyclic structure O-structure Double bond	Very weak acid, corrosion accelerator
28.45	Elaol	2.89	Cyclic structure O-structure Double bond	Very weak acid, corrosion accelerator
38.70	7-(3,4-Methylenedioxy)-tetrahydrobenzofuranone	0.68	Cyclic structure O-structure Double bond	Corrosion inhibitor
38.99	Sulfurous acid, cyclohexylmethyl pentadecyl ester	0.73	Cyclic structure O-structure S-structure	Acid, corrosion accelerator
41.77	Methyl hexacosanoate	0.74	Aliphatic structure O-structure Double bond	Corrosion inhibitor
44.78	3-β,17-β-Dihydroxyandrost-5(10)-ene 17-propionate	0.68	Cyclic structure O-structure Double bond	Corrosion inhibitor
49.51	γ-Sitosterol	9.80	Cyclic structure O-structure Double bond	Corrosion inhibitor

GC-MS: gas chromatograph-mass spectrometer.

nails manufactured from stainless steel with a surface coating (Du *et al.*, 2015). The coating layer consists of corrosion-resistant substances, such as (Pb) lead, (Zn) zinc, (Cd) cadmium and (Sb) antimony (Bram *et al.*, 2020). The corrosion rate of low-quality nails ranges from 0.12 to 0.06 mm/year (Li *et al.*, 2011). The corrosion rate of steel nails is 90 μm/year and that of aluminum is 60 μm/year (Zelinka and Rammer, 2009).

Based on Table 2, chemical compounds with cyclic carboxylic groups, i.e., coumaran, antiarol, methyl p-coumarate, 2-cyclohexen-1-one, 4-hydroxy-3,5,6-trimethyl-4-(3-oxo-1-butenyl), γ-sitosterol, sitostenone, and only one compound with an aliphatic or straight-chain carbon structure, namely hexadecanal (2.30%), dominated the extractives of keruing wood. Whereas, based on Table 3, the meranti wood extractives were dominated

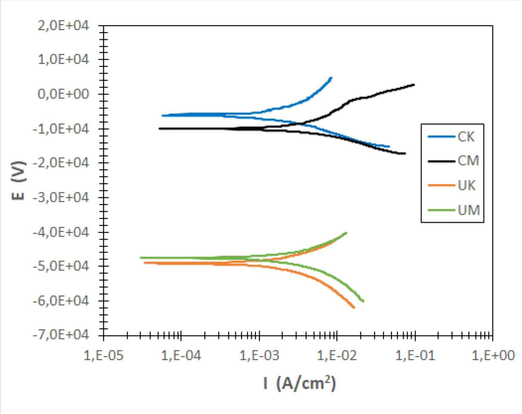

Fig. 1. Tafel plot corrosion test of wood extractives effect on the corrosion rate of ordinary nails and concrete nails.

by compounds with aliphatic or straight-chain carbon groups, i.e., 1,8-nonadiyne with 76.15% and methyl hexacosanoate with 0.74%. As corrosion inhibitors, compounds with a cyclic carbon structure have tremendous potential (Verma and Quraishi, 2021) as they inhibit corrosion more effectively than aliphatic or straight-chain carbon structures (Alamiery *et al.*, 2021).

According to Table 2, the keruing wood extractives contained 5.87% elaol and 2.40% 3-(2,5-dimethoxyphenyl) propionic acid. Elaol is slightly soluble in water and is weakly acidic when dissolved in water. On the other hand, 3-(2,5-dimethoxyphenyl) propionic acid is a weak acid that dissolves in water based on an equilibrium reaction. From Table 3, it can be seen that meranti wood extractives contained 5.66% elaol and 0.73% sulfurous acid, cyclohexylmethyl pentadecyl ester, which is acidic and accelerates the corrosion rate. Therefore, the fastest corrosion rate occurred in ordinary nails on meranti wood extractive media than keruing wood as shown in Fig. 1.

According to Table 4, corrosion potential is the potential at which the anodic and cathodic reaction rates are equal, meaning that the measured current changes sign at this potential when the potential is scanned as in potentiodynamic polarisation. Current density is the current density on the metal surface describing the general corrosion rate of metals (Nyby *et al.*, 2021). Lower corrosion current density shows that the metal corrodes faster (Sohail *et al.*, 2020).

4. CONCLUSIONS

Keruing wood contained 3.83% extractives, dominated by cyclic carbon structure, such as coumaran. Meranti wood contained 1.97% extractives, dominated by aliphatic carbon structure such as 1,8-nonadiyne. The presence of organic acids, sulfurous acid, cyclohexylmethyl pentadecyl ester, in meranti wood extractives accelerates the corrosion rate faster than keruing wood extractives. The lowest corrosion rate based on electrochemical tests was on concrete nail in keruing wood extractive media, which was 0.65 μm/year, and the highest corrosion rate was on ordinary nail in meranti wood extractive media, 3,74 μm/year. The nail corrosion rate in keruing wood extractive media is lower than that in meranti wood extractive media.

In general, wood containing acidic extractives causes

Table 4. The corrosion test of ordinary nails and conrete nails in wood extractive media

Code	Corrosion currents density (μA/cm^2)	Corrosion potentials (μV)	Corrosion rate (μpy)
CM	55.00 ± 2.03	31.93 ± 1.37	3.74 ± 0.15
CK	73.26 ± 3.74	61.18 ± 1.77	0.72 ± 0.02
UM	473.85 ± 1.94	14.28 ± 0.51	1.96 ± 0.07
UK	467.65 ± 2.43	47.53 ± 1.85	0.65 ± 0.02

faster nail corrosion rates. Therefore, it is recommended to use steel nails with an anti-rust coating. Future studies should include testing wood nailing in outside circumstances.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENT

All the authors have contributed equally to this paper. The study was conducted in collaboration between Research Center for Biomass and Bioproducts, Faculty of Forestry, Mulawarman University and State Polytechnic of Samarinda.

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