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THE TREATABILITY OF LOCAL AND IMPORTED TIMBER SPECIES USING ALKALINE COPPER QUATERNARY THROUGH PRESSURE IMPREGNATION METHOD AND RELATION TO THEIR WOOD ANATOMY

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Abstract:

At present deforestation in Sri Lanka increases rapidly and therefore, extreme attention should be given to finding different alternatives to prevent the destruction of forests for timber. Treated timber is one of the best solutions for increasing the durability. Boron treatment and Copper Chrome Boron (CCB) treatment methods are usually used to treat timber in Sri Lanka. Those two treatment methods have some critical issues such as the leaching of chemicals and risk to both human beings and the environment. Therefore, Alkaline Copper Quaternary (ACQ) treatment which is used pressure impregnation method has been introduced to overcome those issues. It is important to build timber classifications according to their treatability and application method. Hence, the present study was carried out to identify the relationship between ACQ treatability with anatomical characteristics of timber and classify timber according to their treatability via pressure impregnation method at A Wood Lanka Company at Kottawa, Sri Lanka. For this study, mostly used fourteen local and six imported timber species were selected and each sample was 30cmx10cmx5.5cm in size. The solution strength of ACQ was 4% and the treatability of ACQ was measured using chemical retention which was measured by the weight difference before and after the treatment. Chemical penetration depth was observed by using Chrome Azurol S. According to the results, timber species were classified into four classes "very difficult to treat", "moderately difficult to treat", "easy to treat" and "very easy to treat". The most effective timber species for ACQ treatment was Rubber. The relationship between treatability and total ray area was positive while the relationship between treatability and total vessel area was negative. But both showed weak relationships. Timber species were also categorized into four classes "fully penetrated", "partially penetrated, "penetrated up to 5mm" and "low penetrated" according to their penetration depth.

Key words*: Alkaline Copper Quaternary, anatomical features, chemical retention, penetration, preservatives, pressure impregnation method, treatability.*

INTRODUCTION

Wood is the hard fibrous material that forms the main substance of the trunk or branches of a tree or shrub, used for fuel or timber. As a natural and renewable substance, wood is sensitive to mechanical wear, fire, rots, and degradation when exposed to harsh environmental elements (Bhaskar et al. 2021). Since ancient times, wood has been used for a variety of domestic and industrial uses: building both inside and outside, preparing furniture, railway sleepers, transmission poles etc. People do not have accurate knowledge about wood type, wood anatomy, and wood preservation (Kannenberg et al. 2019). Because of their experience, mankind has used wood for several uses according to its strength.

Softwood comes from gymnosperm trees, which are cone-bearing trees that have needles or scales instead of leaves (evergreen). They tend to grow faster and have a more open-grain structure. This makes softwood generally lighter, easier to work with, and less expensive than hardwood. Hardwood comes from angiosperm trees, which are broadleaf trees that lose their leaves seasonally (deciduous). They tend to grow

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slower and have a denser, more closed-grain structure. This makes hardwood generally stronger, more durable, and more polishable than softwood (Taqyudin et al. 2019). People have noticed that several agents, such as fungi, bacteria, and insects, can easily deteriorate wood. To maintain wood for a long period, they have explored a strategy to safeguard it. This tragic incident gave rise to the need for wood preservation and treatments (Tarmian et al. 2020). Wood preservation is the technique of enhancing a specific wood product's resistance to biological attack and making it extremely durable by adding sufficient amounts and concentrations of toxic or repelling compounds to it (Papadopoulos et al. 2019).

Proper preservative treatment can extend the life span of wood by preventing rotting, staining, and marine borers while also protecting the wood from insects (Alade et al. 2022). Understanding all the preservatives is not sufficient; application techniques must also be understood (Gauss et al. 2019). Insufficient knowledge resulted in improper wood preservation. As a result, treated wood is not widely used and not that famous in Sri Lanka. Additionally, unnecessary wood preservation practices can result in wood waste. Therefore, it is necessary to have a basic understanding of wood anatomy, wood preservation, and the type of preservatives, as well as the best preservation technique for each wood and preservative.

Wood is a green building material. Normally deterioration of wood occurs by several factors such as environmental, and climatic conditions and deterioration agents like pests and insects (Marais et al. 2022). To overcome those problems, preservatives are applied to the wood so that it helps to increase its durability. Therefore, wood has been preserved for years using substances like Creosote, Copper Chrome Arsenate (CCA), Copper Chrome Boron (CCB), and borax: boric acid (Tarmian et al. 2020). Whereas other chemicals are commonly utilized and CCA is now forbidden in most of the countries (Xing et al. 2020). With the development of countries new technologies have been used for wood preservation. So, wood can now be treated with recently introduced copper-based treatments. As an example, ACQ chemical is currently utilized in several countries (Zor and Can 2021). Many preservatives have been tried for several years such as CCA, CCB treatment, and Boron treatments. But all treatments have several problems such as risk to both environment and human beings and chemical leaching etc (Li et al. 2019). ACQ (alkaline copper quat) is a wood preservative used to protect the wood from decay and insects. It is a water-borne solution that is applied to wood products, such as decks, fences, and siding, to protect them from decay and rot caused by insects and fungus (Can et al. 2020). The active ingredients in ACQ are copper and a quaternary ammonium compound, which work together to protect the wood. To overcome these problems, ACQ has been introduced as a wood preservative in Sri Lanka. This chemical is termite-resistant, eco-friendly green building material suitable for industry and outdoor usage (Oh and Kim 2020). Other copper-based preservatives like CCA and CCB have been replaced by ACQ as a superior preservative (Kirker and Lebow 2021). Therefore, it is timely important to check ACQ treatability on the preservation of local and imported species mostly available in Sri Lanka as a solution for preservative problems. ACQ is an environmentally friendly alternative to other wood preservatives, such as chromate copper arsenate (CCA), which have been banned in many countries due to concerns about their potential health and environmental hazards. ACQ is also less toxic than CCA and is not classified as a hazardous substance (Jones et al. 2019).

ACQ is widely used in North America and Europe in residential and commercial construction. It is also used in agricultural and marine applications (Kim et al. 2020). It's important to note that ACQ-treated wood should not be used in contact with aluminum as the copper in the treatment will react with the aluminum and cause discoloration and damage (Zelinka et al. 2019). In general, ACQ is a safe and effective wood preservative that can help to extend the life of wood products and protect them from decay and rot. It's important to follow the manufacturer's instructions when using ACQ and to always wear protective gear to avoid contact with the skin (Sandak et al. 2019).

ACQ is a water-based wood preservative containing mainly Copper (II) Carbonate and Didecyl dimethyl ammonium chloride as active ingredients. There are several different types of ACQ, including Types A, B, C, and D, which vary in the amount of CuO to quaternary compound, the specific quaternary compound employed, and the solvent system used (Liu et al. 2020). Since copper is the most common biocide for wood preservation, effectiveness against copper-tolerant fungi is a key need for any formulation of copper-based wood preservative. So ACQ functions as a fungicide, an insecticide, and a termite assault deterrent which is, useful for tropical country like Sri Lanka.

The development of Sri Lanka's treatability guidelines was based on firsthand experience. Therefore, the local community lacks the necessary information and expertise regarding how to treat wood, which species of timber should be treated, and what application techniques are appropriate for preservation. People frequently do experiments with a type of preservatives without first determining which ones are suitable and how to use them which results in time and waste of money. Therefore, it is critical to classify timber species following their treatability as well as preservation strategy and anatomical characteristics. Determining the treatability, appropriate preservatives, and technique of application for a particular timber species would be helpful.

MATERIALS AND METHODS

Samples Collection, Identification of Wood Species and Observe their Anatomical Features

The study was conducted in State Timber Cooperation, Battaramulla, Sri Lanka, and A Wood Lanka Company at Kottawa, Sri Lanka from May 2022 to September 2022. In this investigation, 14 local timber species and 6 imported timber species (Table 1 and Fig. 1) were selected which can be used for construction purposes as the ACQ treatment is only done for timber that is used in constructions. Four timber specimens were taken in the size of 30cmx10cmx5.5cm from each local and imported species. Timber species were collected from the timber complex of the State Timber Corporation, Kaldemulla, and A Wood Lanka Company, Sri Lanka.

Table 1

Selected local and imported timber species for the experiment

Local Timber Species			
No.	**Common Name**	**Botanical Name**	**Family**
01	Alastonia	*Alstonia macrophylla*	Apocynaceae
02	Domba	*Calophyllum inophyllum*	Clusiaceae
03	Grandis	*Eucalyptus grandis*	Myrtaceae
04	Halmilla	*Berrya cordifolia*	Tiliaceae
05	Hora	*Dipterocarpus zeylanicus*	Dipterocarpaceae
06	Jack	*Artocarpus heterophyllus*	Moraceae
07	Kaya	*Khaya sanegalensis*	Meliaceae
08	Kumbuk	*Terminalia arjuna*	Combretaceae
09	Mahogany	*Swietenia macrophylla*	Meliaceae
10	Palu	*Manilkara hexandra*	Sapotaceae
11	Pine	*Pinus caribaea*	Pinaceae
12	Rubber	*Heavea brasilliensis*	Euphorbiaceae
13	Satin	*Choloroxylan swietenia*	Rutaceae
14	Teak	*Tectona grandis*	Lamiaceae
Imported Timber Species			
15	Durian- Aja	*Durio zibethinus*	Bombaceae
16	Kasai	*Pometia spp.*	Sapindaceae
17	Kekatong	*Cynometra spp.*	Leguminosae
18	Kempas	*Koompassia malaccensis*	Leguminosae
19	Pauh- kijang	*Irvingia malayana*	Simaroubaceae
20	Tulang	*Koompassia excelsa*	Leguminosae

Fig. 1.

Selected local and imported timber species. 1- Alastonia; 2 – Domba; 3 – Grandis; 4 – Halmilla; 5 – Hora; 6 – Jack; 7 – Kaya; 8 – Kumbuk; 9 – Mahogany; 10 – Palu; 11 – Pine; 12 – Rubber; 13 – Satin; 14 – Teak; 15 - Durian- Aja; 16 – Kasai; 17 – Kekatong; 18 – Kempas; 19 - Pauh- kijang; 20 – Tulang.

Preparation of wood for microscopic examination

Wood samples were boiled in water periodically for three days until the air space of the wood was filled with water. Each species was shaped and sized into a wood block of 2cmx2cmx3cm. The transverse, radial and tangential sections at the range of 10-15 micrometer thickness were taken using a sled microtome (model Leica SM2000 R). The piece of wood sample and the knife were flooded with 30% Ethanol during the section cutting to facilitate fine sectioning.

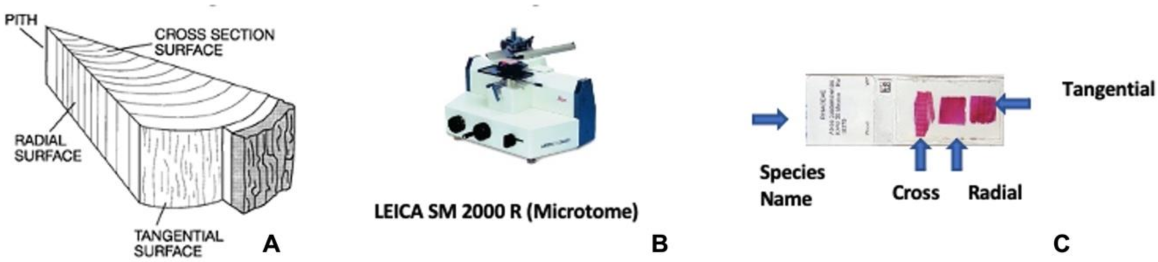

Fig. 2.
Preparation of wood for microscopic examination.
A – Wood Sample; B-Microtome; C-Preparation of Slide.

Wood samples were prepared, and a microscopic examination was done to take anatomical measurements (Fig. 2). Transverse, Radial, and Tangential sections of each wood sample were taken using the following steps and time. First 50% Alcohol dip for 5 minutes, followed by Safranin in 50% alcohol for 15 minutes. Then rinse once with 50% alcohol, followed by 70% alcohol for 5-10 minutes. In the third step 90% alcohol for 10 minutes and Absolute alcohol for 10 minutes keep covered at this stage due to the evaporation. Absolute alcohol+ Xylene mixture for 10 minutes, then Xylene treatment for 10 minutes. Finally, mount in Canada balsam and keep in a drying oven for 24 hours. Anatomical measurements were taken under a light microscope with a magnification of 4x10. Measurements were taken using anatomical photos and Micro metrics SE Premium 4 software available at the Research Division of the State Timber Corporation. Tangential vessel diameter, rays per mm^2, and vessels per mm^2 were measured in the transverse section of 20 timber species. Ray height and ray width were measured in the tangential section of timber species.

Preparing Timber Species for ACQ Treatment

Both local and imported timber species were labeled with treatment number and replicate number. Then, moisture content was measured by Moisture Meter. Timber species that were in high moisture content were seasoned at the Kaldemulla timber complex of State Timber Corporation to decrease moisture content by up to 20% Moisture content was maintained at around 20% and all timber specimens were weighed. After that, all timber specimens were taken to A Wood Lanka Company and specimens were prepared as bundles before the treatment.

ACQ Treatment Process

ACQ treatment was done through the pressure impregnation method. The initial vacuum was done to remove all the air inside the wood and the chemical was supplied under vacuum. Then Pressure pump was opened to occur the flow of chemicals and a final vacuum was done to stabilize the pressure in the wood cells (Fig. 3). The initial vacuum is done for 45 minutes at 76Hgcm, then the Pressure period for 15 minutes. The final vacuum is done for 30 minutes at - 76Hgcm and the Solution strength is made up of 4%. Those were unloaded after one day.

Data Collection

Following data were collected during the experimental period.

Fig. 3.
Preparation timber samples for microscopic observation and ACQ Treatment process.

Anatomical measurements

Mean Tangential Vessel Diameter; Average of ten measurements was taken from the anatomical photos by using Micrometrics SE Premium 4 software.

Vessels and Rays per mm^2; Anatomical photos were taken in an area of 25mm^2. They were taken into 1mm^2 and counted vessels and rays within 1mm^2.

Ray height and ray width; Average of ten measurements were taken from the anatomical photos by using Micrometrics SE Premium 4 software.

Measurements of timber parts

Average moisture content: the Moisture content of each timber specimen of 20 timber species was taken using a digital moisture meter.

Density: Both densitometer and water displacement methods were used to take accurate density for each species. After that, they were compared with actual density.

Weight of the timber parts; Weight of the timber parts before ACQ treatment and after treatment was taken by using an electronic scale.

Chemical penetration length: Wood parts were cut in the middle of them, and Chrome Azurol S (CAS) was applied on the cut surface with a width of around one inch to check whether any color change happens.

Calculation of total vessel area

By using the anatomical photos of prepared slides, the diameter of the vessels and the total number of the vessels were counted in a 25mm^2 area. Then it was calculated into the area of 1mm^2. For this, 40× magnification was used, and Micrometrics SE Premium 4 software was used to count vessels and measure the diameter of vessels.

Vessel area was calculated by using following equation:

$$\textbf{Vessel area} = \pi\ (D/2)^2$$

where: D = Vessel Diameter

Total vessels area was calculated as follows. ***Total vessels area = Vessel area × No. of vessels.***

Calculation of total ray area

By using the anatomical photos of prepared slides, the width and the height of rays and the total number of the rays were counted in a 5mm area. Then it was calculated into the area of 1mm. For this 40× magnification was used, and Micrometrics SE Premium 4 software was used to count rays and the measure width and height of the rays. Ray area was calculated by using the following equation: ***Ray area = Width of ray × Height of ray***. The total ray area was calculated as follows***. Total ray area = Ray area × No. of rays***

Determination of chemical retention

Retention is the number of chemical preservatives that are kept in a unit volume of wood which is measured in kilograms per cubic meter Weight of the timber parts before ACQ treatment and after the treatment was taken. The following equation was used to calculate the chemical retention:

$$CR = G \times C \times 10 \ /V \qquad \text{(kg/m}^3\text{)}$$

where: CR = Chemical Retention (kg/m^3); G - Amount of solution absorbed by wood (W_a- W_b); W_a - Weight of wood after impregnation (g); W_b- Weight of wood before impregnation (g); V - Volume of the wood (cm^3); C - Solution concentration (%) (Hakan et al. 2013).

Determination of chemical penetration

The depth to which a preservative has penetrated the wood is known as penetration. Before adding colorants, wood sections of 20 timber species were cut in the middle away from the end to prevent longitudinal penetration. After that, Chrome Azurol S was applied to the cut wood surface with a width around one inch (Fig. 3). The observation used to gauge ACQ penetration was a shift in color to dark purple/Blue. After that, penetration depth was measured.

Analysis of variance

All results are expressed as mean ± S.D. The significance of difference was calculated by SPSS and values <0.05 were considered to be significant.

RESULTS AND DISCUSSION

Moisture Content

Wood seasoning, also known as air-drying, is the process of removing moisture from freshly cut wood so that it can be used for construction or other purposes. The process involves stacking the wood in a well-ventilated area and allowing it to dry naturally over time. The length of time required for wood to fully season depends on several factors, including the type of wood, the thickness of the boards, and the humidity and temperature of the drying environment.

During the seasoning process, the moisture content of the wood will gradually decrease, and the wood will become more stable and less likely to warp rot or decay. The ideal moisture content for most types of wood used in construction is around 12-15% (Bartlett et al. 2019). Wood that has been properly seasoned will be less likely to shrink or expand when exposed to changing humidity levels. It's important to note that wood that has not been properly seasoned can cause problems when used in construction, such as cracking, warping, and twisting the wood. In addition, wood that still has a high moisture content can also provide a favorable environment for the growth of mold and mildew, which can cause health problems (Imken et al. 2020). Therefore, it is crucial to ensure that the wood you are using is properly seasoned and has the appropriate moisture content before starting any construction project.

Moisture content is defined as the total water content. For proper treatment, the moisture content must be reduced before the treatment through drying or seasoning. The mean moisture content of 20 timber species was varied as shown in Fig. 4A. The highest mean moisture content was recorded in *Alstonia macrophylla* (Alastonia) while the lowest mean moisture content was recorded in *Koompassia excelsa* (Tualang).

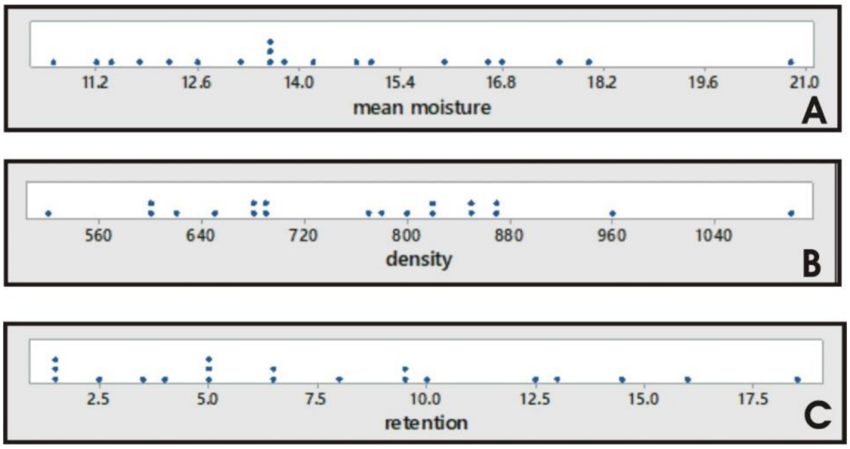

Fig. 4.
Dot plot analysis. A-Moisture content; B-Density; and C-ACQ Retention on timber.

Density

Wood density refers to the weight of wood per unit volume and is typically measured in pounds per cubic foot (PCF) or kilograms per cubic meter (kg/m3). Different species of wood can have widely varying densities, with hardwoods generally having a higher density than softwoods. Density plays an important role in the durability and preservation of wood. The combination of high density and the presence of natural preservatives in the wood makes it more resistant to decay and insects, leading to greater durability and a longer lifespan (Walsh-Korb and Avérous 2019). For example, dense hardwoods like oak and hickory are often used in flooring and furniture because of their durability and resistance to wear and tear. Density can vary depending on a tree's stage of development. Therefore, density can be thought of as a range for a given timber species. Fig. 4B showed the variation of chosen imported and local timber species. Mean densities which were determined using a densitometer and the water displacement method. The highest mean density was observed in *Manilkara hexandra* (Palu) while the lowest mean density was shown in *Pinus carebaea* (Pine) (Fig. 4B).

Development of Classification Scale for Retention of ACQ

The American Wood Protection Association (AWPA) has established a classification scale for the retention of ACQ, which is based on the minimum retention requirements for different types of wood products (Kirker and Ibach 2019). The scale is divided into several categories, including:

- Ground contact: For wood products that will be in direct contact with the ground, such as fence posts and decks, a retention of 0.25 PCF (Pounds per Cubic Foot) is required. Above-ground: For wood products that will be used above ground, such as siding and trim, a retention of 0.15 PCF is required. Marine: For wood products that will be used in marine environments, such as docks and piers, a retention of 0.40 PCF is required. Industrial: For wood products that will be used in industrial settings, such as pallets and crates, a retention of 0.25 PCF is required. It's important to note that the retention of ACQ is only one factor that affects the level of protection provided by the preservative (Mankowski et al. 2022). Other factors, such as the type of wood, the environment, and the application method, can also affect the effectiveness of the preservative.

The highest ACQ retention was observed in *Heavea brasilliensis* (Rubber) and the lowest retention was observed in *Manilkara hexandra* (Palu) (Fig. 4C). Selected 20 species of local and imported timber species were divided into four groups based on the treatability level: very difficult, moderately difficult, easy, and very easy to treat. To the easiness of the chemical application and application method, it is better to develop a classification scale with four categories. According to the above classification, 20 species were categorized as follows.

Class 01 – Very Difficult

Calophyllum inophyllum (Domba), *Eucalyptus grandis* (Grandis), *Berrya cordifolia* (Halmilla), *Artocarpus heterophyllus* (Jack), *Manilkara hexandra* (Palu), *Choloroxylon swietenia* (Satin), *Tectona grandis* (Teak) and *Pometia pinnata* (Kasai) were showed lowest ACQ retention. So that they were categorized into class very difficult to treat.

Class 02 - Moderately difficult to treat

Khaya senegalensis (Kaya), *Mahogany macrophylla* (Mahogany) and *Koompassia excelsa* (Tulang) were categorized into class 02.

Class 03 - Easy to treat

Timber species which categorized into this class were *Terminalia arjuna* (Kubuk), *Durio zibethinus* (Durian-aja), *Cynometra ramiflora* (kekatong), *Koompassia malaccensis* (Kempas).

Class 04 – Very easy to treat

Alstonia macrophylla (Attonia), *Dipterocarpus zeylanicus* (Hora), *Pinus caribaea* (Pine), *Heavea brasilliensis* (Rubber), *Irvingia malayana* (Pauh-kijang) were categorized to class 04.

Relationship of ACQ Treatability with Total Vessel Area and Total Ray Area

ACQ (alkaline copper quat) is a wood preservative that is applied to wood products to protect them from decay and rot caused by insects and fungus. The treatability of wood with ACQ is determined by the total vessel area (TVA) and total ray area (TRA). The TVA is the total cross-sectional area of the vessels (also known as pores or xylem) in a piece of wood. The larger the TVA, the more readily the wood will absorb the ACQ preservative (Pang et al. 2021). Hardwoods generally have a larger TVA than softwoods, which makes them more treatable with ACQ. The TRA is the total cross-sectional area of the rays in a piece of wood. The rays are the cells that run perpendicular to the grain of the wood and are responsible for the radial movement of moisture. The larger the TRA, the more the wood will expand and contract with changes in moisture content, which can make it more difficult to properly treat with ACQ.

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In general, wood with a larger TVA and smaller TRA is more treatable with ACQ. This means that hardwoods with small rays and large vessels will be more treatable than softwoods with large rays and small vessels (Manga Bengono et al. 2023). The treatability of wood with ACQ can also be affected by other factors, such as the density of the wood, the type of cut (plain sawn, rift sawn, or quarter sawn), and the moisture content of the wood at the time of treatment. Various types of wood have different numbers, positions and sizes of rays and vessels. Additionally, it fluctuates according to the various stages of a tree's growth. Table 2 showed the Pearson correlation values and probability values of ACQ retention with total vessel area and total ray area.

Table 2

Relationship between ACQ retention and wood anatomy

	Total ray area	Total vessel area
Pearson correlation	0.165	-0.317
P-Value	0.488	0.173

Fig. 5 - shows a positive relationship between total ray area and ACQ retention. So that there was a poor postive relationship between total ray area and ACQ treatability. Furthermore it shows that there was a negative relationship between total vessel area and ACQ retention. So there was a negative relationship between total vessel area and ACQ treatability (Table 2).

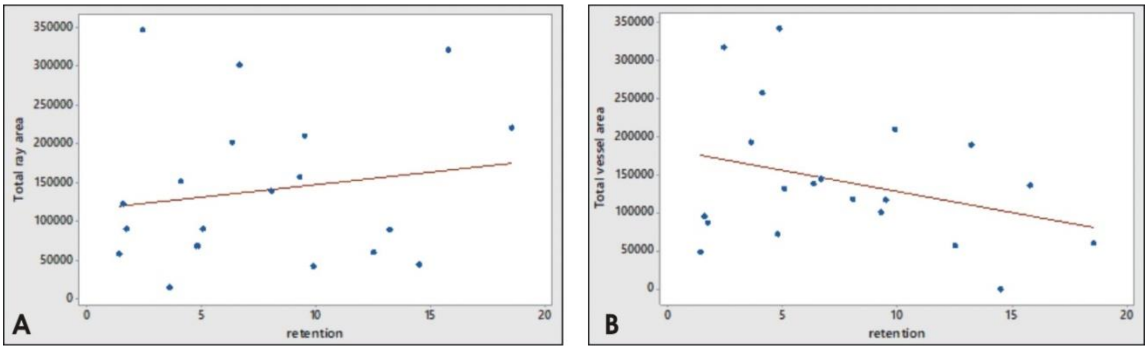

Fig. 5.
Relationship between ACQ retention: A - total ray area; B - total vessel area.

Table 3

Anatomy measurements of local and imported timber species

Local name	Botanical Name	Vessels			Rays			
		Mean tangential vessels diameter (µm)	No. of vessel per mm^2	Total vessel area (Per mm^2)	Mean ray height (µm)	Mean ray width (µm)	No. of rays per mm^2	Total ray area (per mm^2)
local timber species								
Attonia / Alastonia	*Alstonia macrophylla*	78.63	39	189330.96	489.41	23.09	8	90403.82
Domba	*Calophyllum inophyllum*	123.90	16	192811.20	117.27	13.81	10	16194.99
Grandis	*Eucalyptus grandis*	198.95	11	341782.87	204.17	30.73	11	69015.59
Halmilla	*Berrya cordifolia*	122.43	27	317745.99	482.55	55.44	13	347790.64
Hora	*Dipterocarpus zeylanicus*	186.28	5	136198.45	636.49	72.25	7	321909.88
Jack	*Artocarpus heterophyllus*	202.03	3	96131.49	466.08	53.05	5	123630.37
Kaya	*Khaya sanegalensis*	151.87	8	144864.08	526.87	63.93	9	303145.19
Kumbuk	*Terminalia arjuna*	231.041	5	209514.45	148.11	24.71	12	43917.58
Mahogany	*Swietenia macrophylla*	145.17	8	132365.04	294.74	51.45	6	90986.24

Palu	*Manilkara hexandra*	87.97	8	48599.20	270.07	27.25	8	58877.44
Pine	*Pinus caribaea*	0	0	0	220.11	29.79	7	45899.54
Rubber	*Heavea brasilliensis*	196.84	2	60831.20	393.64	47	12	222012.96
Satin	*Choloroxylan swietenia*	74.70	20	87607.40	336.64	38.56	7	90868.57
Teak	*Tectona grandis*	216.67	7	257991.44	370.12	68.64	6	152430.22
imported timber species								
Durian – aja	Durio zibethinus	151.52	4	116961.88	873.52	60.43	4	211147.25
Kasai	Pometia pinnata	193.99	4	72498.84	322.04	24.15	9	69995.39
Kekatong	Cynometra ramiflora	253.36	4	118177.04	438.63	39.89	8	139975.61
Kempas	Koompassia malaccensis	135.00	2	100780.32	511.94	43.98	7	157605.85
Pauh – Kijang	Irvingia malayana	209.59	4	57226.52	353.03	29.09	6	61617.86
Tulang	Koompassia excelsa	193.95	4	137933.80	485.78	59.7	7	203007.46

Anatomical measurements of local and imported timber species taken by micrometrics premium 4 software were depicted in Table 3.

Photographic Representations

Cross section (transverse section), tangential section and radial section of selected wood species, respectively shown in Fig. 6 (Magnification × 40). This shows a greater variation among the samples were observed.

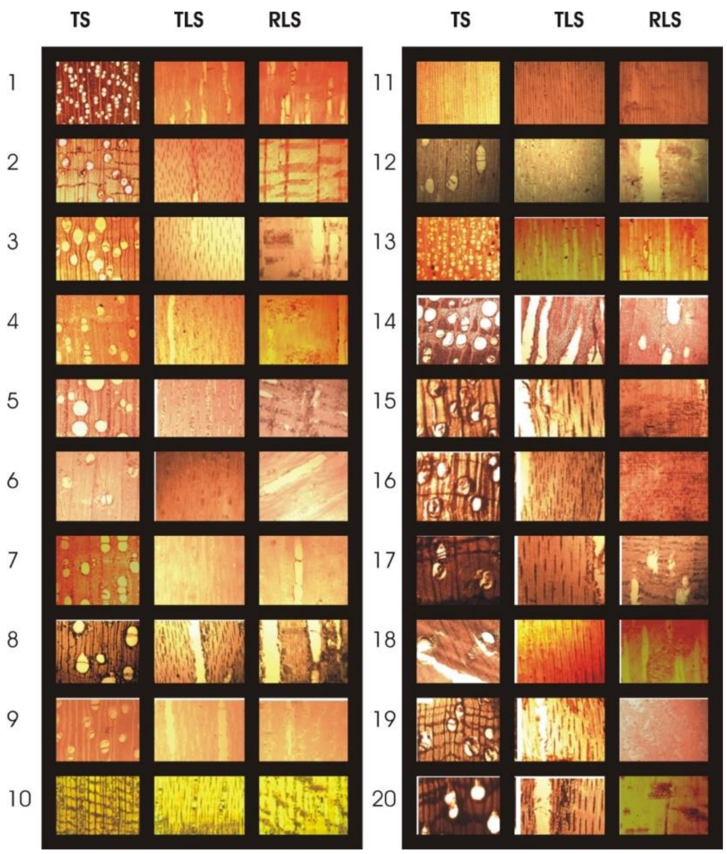

Fig. 6.
Microscopic photos of local and imported timber species; TS = transverse section; TLS = tangential longitudinal section; RLS = radial longitudinal section.

Relationship of ACQ Treatability with Moisture Content and Density

ACQ (Alkaline Copper Quaternary) treatability is related to the moisture content and density of the wood. ACQ is a water-based preservative that is used to protect the wood from decay and insect damaged (Fredriksson 2019). Moisture content refers to the amount of water present in the wood. The higher the moisture content, the greater the ability of the preservative to penetrate the wood. However, if the moisture content is too high, the preservative may not effectively penetrate the wood and the treatment may be less effective.

Density refers to the weight of the wood per unit volume. The denser the wood, the more difficult it is for the preservative to penetrate. Therefore, denser woods may require more ACQ to achieve the same level of protection as less dense woods.

Moisture should be reduced before the treatments for a better application of chemicals. The Pearson correlation of ACQ retention and mean moisture was 0.457 while the Probability value is 0.043 (Fig. 7A and Table 2). Density was attained using two techniques as water displacement method and the densitometer. Density can vary depending on the stage of the tree's growth. Additionally, chemical retention of any kind of preservative was connected to density. The Pearson correlation of ACQ retention and density was -0.200 and the probability value was 0.397 (Fig. 7B).

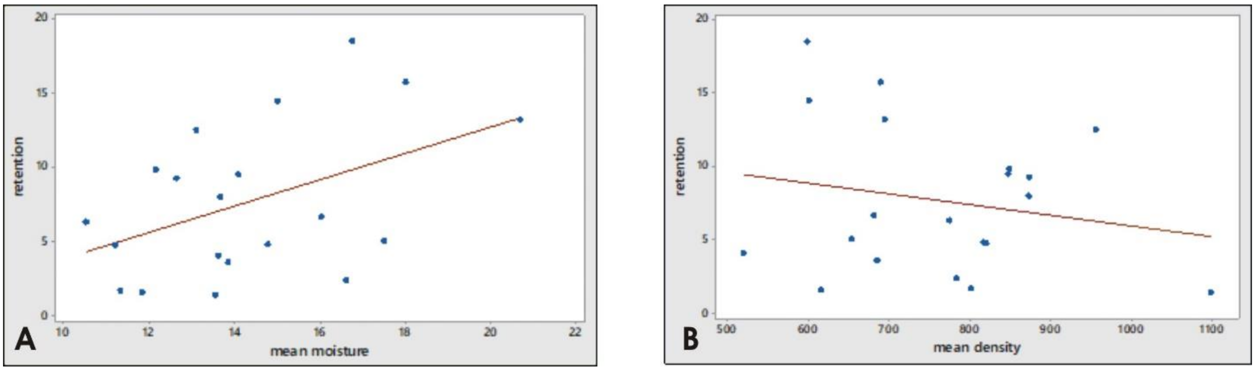

Fig. 7.
Scatterplot of ACQ retention; A – with respect to Moisture Content; B with respect to Density.

Penetration of ACQ Chemical

The penetration of the ACQ (Alkaline Copper Quaternary) chemical into the wood is a key factor in the effectiveness of the treatment. The chemical must be able to penetrate deeply into the wood to provide long-term protection against decay and insect damage (Stirling et al. 2022). The penetration of the ACQ chemical into the wood is influenced by several factors, including the Moisture content of the wood: The higher the moisture content of the wood, the greater the ability of the ACQ chemical to penetrate. However, if the moisture content is too high, the chemical may not effectively penetrate the wood. The density of the wood: The denser the wood, the more difficult it is for the ACQ chemical to penetrate (Kumar 2022). Therefore, denser woods may require more ACQ to achieve the same level of protection as less dense woods. Temperature and humidity: The temperature and humidity of the environment in which the wood is treated can also affect the penetration of the ACQ chemical. Optimal conditions for treatment are between 20-30°C and 60-80% relative humidity. Application method: The method of application, such as pressure treatment or dip-treatment, can also affect the penetration of the ACQ chemical into the wood. In summary, the penetration of the ACQ chemical into the wood is a critical factor in the effectiveness of the treatment and is influenced by several factors including moisture content, density, temperature, humidity, and application method (Meouch 2019).

Penetration of ACQ Chemical was checked by using Chromo Azurol S. This substance can detect the presence of copper. Since the ACQ chemical contains a copper component, it can be used to measure the depth of penetration. The color shift that resulted in a dark purple/blue after application allowed for the observation of the chemical penetration level (Fig. 7). Both local and imported timber species were categorized into four groups by observing their color change. Those are fully penetrated, partially penetrated, penetrated up to 5mm, and not penetrated (Fig. 8). Penetrating groups and timber species are shown in Table 4.

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Table 4

Penetrating groups

Penetration Category	Timber species
1. Fully penetrated	Pine (*Pinus caribaea*), Attonia/ Alastonia (*Alstonia macrophylla*)
2. Partially penetrated	Rubber (*Heavea brasilliensis)*, Kempas (*Koompassia malaccensis*), Hora (*Dipterocarpus zeylanicus*), Teak (*Tectona grandis*), Durian-Aja (*Durio zibethinus*), Pauh-kijang (*Irvingia malayana*)
3. Penetrated up to 5mm	Grandis (*Eucalyptus grandis*) Kaya (*Khaya sanegalensis*), Mahogany (*Swietenia macrophylla*), Tulang (*Koompassia excels*), Domba (*Calophyllum inophyllum*)
4. low penetrated	Satin (*Choloroxylan swietenia*), Halmilla (*Berrya cordifolia*), Kumbuk (*Terminalia arjuna*), Jack (*Artocarpus heterophyllus*), Kasai (*Pometia spp.*), Palu (*Manilkara hexandra*), Kekatong (*Cynometra spp.*)

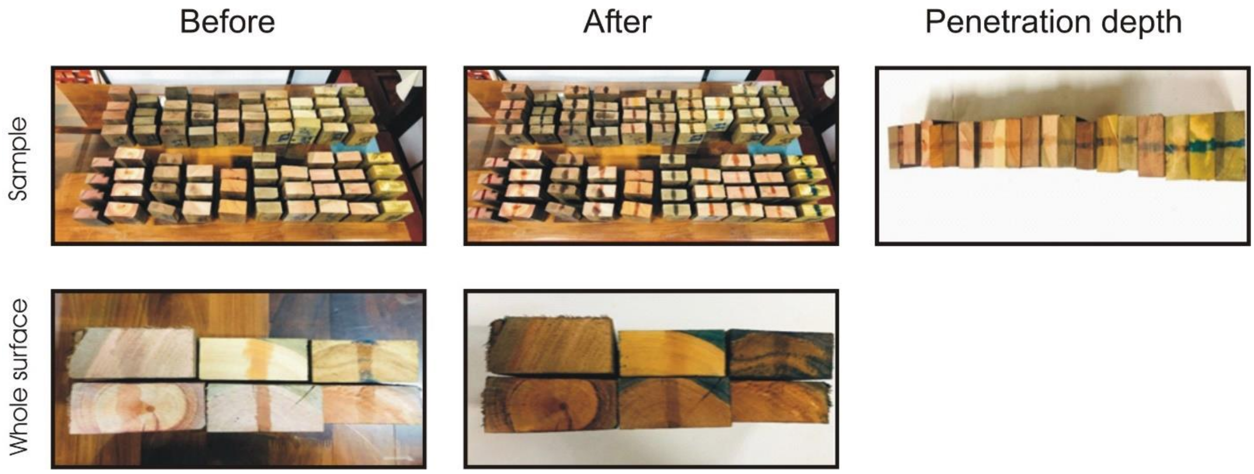

Fig. 8.
Chrome Azurol S before and after application for sample and whole surface with respect to penetration depth.

After checking the depth of penetration, a second test was performed to see if chemicals had reached the hardwood, choosing some timber like Grandis, Satin, Teak, Mahogany, Halmilla, and Domba. Chrome Azurol S was applied on the cut surface including sapwood and hardwood. Color change eventually only became visible up to the sapwood. No chemicals were introduced to hardwood in those timber species. The external appearance before and after applying Chrome Azurol S is shown in Fig. 8. ACQ chemicals successfully penetrated the sapwood portion of the timber samples as shown in Fig. 8.

CONCLUSIONS

The classification scale of retention was developed using the results of this study and previous studies. Local and Imported timber species were categorized into four groups for treatability on ACQ chemical as follows: Class 01 - Very difficult to treat (Equal and Less than 5); Class 02 - Moderately difficult to treat (Above 5 Equal and less than 8); Class 03 - Easy to treat (Above 8 Equal and Less than 10); Class 04 - Very easy to treat (Equal or Higher than 10). The relationship between treatability and total ray area is positive while the relationship between treatability and total vessel area is negative. Both relationships are weak. Therefore, these experiments should be further improved with the information on ACQ retention, vessels, and ray area according to tree age and the position of the trunk from where the wood sample is gained. Timber species were categorized into four groups according to penetration level as well. Those can be classified as fully penetrated, partially penetrated, penetrated up to 5mm, and low penetrated. According to the results of this study, the most effective timber specie for ACQ treatment was Rubber (*Heavea brasilliensis*). Furthermore, it is better to increase the accuracy of ACQ retention, experiment should be developed with more replicates. Also, research should be conducted further with more local and imported timber species for developing treatability scale and penetration level. Wood samples with different growth stages and positions of the trunk should be used to observe anatomical features. Finally, research should be done to identify the factors affecting treatability and penetration. The EN 350 standard is not directly related to wood preservation treatments themselves, but it provides a method to classify the durability of wood and wood-based products against biological agents like decay fungi and termites. This study did develop a classification scale for ACQ treatability based on the amount of ACQ retention in the wood. Here's a summary of the findings from the study with respect to EN 350: While the study doesn't directly address EN 350, it provides valuable insights into factors affecting the treatability of wood with ACQ preservative, which can be helpful for selecting appropriate wood types for applications requiring preservation.

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