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ENHANCING THE QUALITY OF PALM VENEER WITH OIL PALM BARK EXTRACT-RESORCINOL-FORMALDEHYDE RESIN IMPREGNATION

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ABSTRACT

The oil palm plantations in Indonesia have prompted the need for technology to utilize non-productive oil palm trees (*Elaeis guineensis* Jacq.). This study was aimed to collect information on the quality of oil palm trunk veneer modified using SRF impregnation from oil palm bark extract. The impregnant was synthesized by copolymerizing resorcinol (R) and formaldehyde (F) on palm bark extract (S). Fourier Transform Infrared (FTIR), Pyrolysis-Gas Chromatography-Mass Spectroscopy (Py-GCMS), X-Ray Diffraction (XRD), and Differential Scanning Calorimetry (DSC) were used to characterize the oil palm resorcinol formaldehyde (SRF) resin. The SRF-impregnant material was used to improve the oil palm veneer's density, thickness, swelling, stiffness, and strength. The results of the DSC analysis showed that the SRF resin was thermoset. The SRF-impregnated palm veneer could increase the veneer density by 20%, lower thickness swelling below 25%, and increase the modulus of rupture (MOR) by over 10% and modulus of elasticity (MOE) by 50%.

Keywords: formaldehyde; impregnant; palm bark extract; resorcinol; veneer.

INTRODUCTION

Several research groups, including Nuryawan *et al.* (2022), Malik and Santoso (2021), Dungani *et al.* (2013), Rosli *et al.* (2016), and Mokhtar *et al.* (2012) have conducted studies and initiatives to improve the characteristics and possible utilization of palm tree trunks, specifically concerning composite materials. Nevertheless, the dimensional stability of the oil palm wood is categorized as significantly low, exhibiting shrinkage variations ranging from 9.2% to 74%. Additionally, the oil palm wood strength falls within the class IV with a specific gravity of 0.3-0.4, modulus of elasticity (MOE) of 35-50 MPa, and modulus of rupture (MOR) of 50-73 MPa. Furthermore, it is worth noting that the oil palm trunk is hygroscopic, as stated by Bakar *et al.* (1998). Consequently, conducting a study aimed at enhancing the quality of oil palm trunks remains an intriguing endeavour. This is the primary challenge that arises when considering the utilization of palm wood a fundamental material for furniture. To attain the intended goal, it is crucial to enact specific modifications, one of which entails employing the impregnation methods using an impregnant (Dungani *et al.*, 2013).

Impregnant refers to a substance used in the process of impregnation treatment, which can be derived from either synthetic or natural sources, or a combination of both. Because of growing concerns over environmental and health matters, it has become imperative for impregnating materials, including solvents, to exhibit compatibility with both of these aspects (Malik, 2019). According to Kislik (2012), water is regarded as the best choice for solvents. One of the readily accessible impregnants that satisfies these conditions is oil-palm bark. This material can be extracted using a water-based solvent and subsequently polymerized to form bioresin.

The results of the impregnation method by Dungani *et al.* (2013) showed that impregnating either vacuum or non-vacuum palm stalk waste improved its physical-mechanical properties as a furniture material, especially when using resins that have chemical and biological resistance and low molecular weight such as phenol-formaldehyde. Other results also show that the application of impregnant materials from biomass extraction using the impregnation technique can improve the physical and mechanical properties of wood, including increasing resistance to weather changes (Malik and Ozarska, 2019, Dungani, *et al.*, 2020a, Dungani, *et al.*, 2020b). Treatment with this resin also increases the decay and termite resistance of particle board (Kajita and Imamura, 1991) and solid wood (Malik *et al.*, 2022a, Malik *et al.*, 2022b).

The increment in characteristics does not only occur in conventional wood but also occurs in impregnated coconut and oil palm wood (Dungani *et al.*, 2020a, Malik and Santoso, 2021). The ability to improve the characteristics and quality of wood by impregnant formulated from biomass extracts due to changes in the properties of the phenolic resin copolymer from hydrophilic or highly soluble in water during the polymerization process to become hydrophobic at the end of the polymerization process has been carried out in previous studies (Malik *et al.* 2020). This will only occur in the proportion of constituent materials or in modified phenolic resins where the main constituent components are resorcinol (R) and formaldehyde (F) compounds (Dunky and Pizzi, 2002). The ratio of R to F determines the characteristics of the resin formed. Engineering or modification both at the time of manufacture and when the low-energy application is highly desirable. According to Durairaj (2003) and Detlefsen (2002) to make polymerized mixtures at room temperature (without heat treatment) made from phenol (P) and formaldehyde (F), the P/F mole ratio must be <1 or $F/P \geq 1$. This resin is classified as a resole (Detlefsen, 2002, Durairaj, 2003, Akay, 2012, Gardziella *et al.*, 2000). Characterization of bio-impregnant resin is needed to estimate the effectiveness of its use.

The synthesis, characterization and application of impregnant from palm bark extract with the aim given at improving the physical and mechanical characteristics of palm veneer so that it can be used for products in the humid environment are presented in the paper.

MATERIAL AND METHODS

Materials

Bark from a 32-year-old oil palm (Elaeis guineensis) stem from Malingping (Banten Province), tapioca flour, 37% (w/v) formaldehyde, 40% (w/v) sodium hydroxide (NaOH), technical resorcinol crystals from Cadixo Chemicals LLP, Surat, India and distilled water were used in the experiment. The log of the oil palm (*Elaeis guineensis*) was stripped of its bark (debarking process). The oil palm logs were then peeled using a rotary veneer machine with a veneer thickness of 5 mm. The veneers obtained were cut into 400 mm (length) × 80 mm (width) × 5 mm (thickness). Veneers for oil palm trunks were made using a 5-feet spindle-less rotary machine as performed by Balfas and Malik (2020).

The tools used included glassware and pycnometer (Pyrex, Glandale, US), analytical balance (Radwag AS 220.R1 Plus, Radon, Poland), VT-04E viscometer (Rion, Tokyo, Japan), oven (Memmert, Haberbosch, Germany), Universal Testing Machine (HST, Jinan, China), hot press & cold press (Becker and Van Hullen, Germany), UV-Vis spectrophotometer (Shimadzu UV-1700, Shimadzu Corporation, Japan), water bath, Digital Caliper (Mitutoyo Asia Pacific. Jakarta, Indonesia), Fourier Transform InfraRed (FTIR) Spectrometer (Alpha Platinum-ATR, Bruker), Differential Scanning Calorimetry (DSC) (Shimadzu DT-30, Japan), Py-GCMS (Shimadzu series 45 QP2010 GC/MS, Shimadzu Corporation, Japan) and X-ray Diffraction (XRD) (XRD-7000 Shimadzu).

Methods

1. Liquid extraction of oil palm bark

As much as 10 kg of pieces of palm bark measuring 5 cm long, 1–5 cm wide and 0.5–1 cm thick were air-dried and then mixed with water with a ratio of pieces of palm bark and water 1:4 (w/w), then boiled at 80 °C for 3 hours with stirring. The mixture that has reached room temperature is then filtered. The extraction process was repeated 2 times. The filtrate from the two replicates was combined into one and filtered and then 20 liters of the filtrate were taken to make impregnant materials with a condensation copolymerization reaction.

2. Synthesis of SRF resin from Liquid Extract of Oil Palm Bark

The SRF resin was made by reacting liquid palm bark extract (S) with resorcinol (R) and formaldehyde (F) with a weight ratio of S:R:F = 100 : 2.5 : 10 (Malik *et al.*, 2022a). As much as 1.0% of tapioca flour based on the total weight of the SRF was added to the mixture, and stirred until homogeneous. The reaction conditions were carried out at room temperature and alkaline pH (10 – 11) with an addition of 40% NaOH. Characterization of palm bark extract as an impregnant material and its condensation polymerization reaction products were analyzed by infrared spectroscopy (FTIR), Py-GCMS, XRD, and DSC. The measurement was undertaken once for each instrument used.

3. Characterizations of Liquid Extract and the SRF resin

a. FTIR analysis

Powder samples of liquid extract and SRF resin were prepared by drying at 130 °C for 3 h in an oven and then were ground to powder for analysis. As much as 15 mg of SRF impregnant of 0.125 mm size from selected samples was directly used in FTIR spectroscopy measurements. Powder samples were planted in potassium bromide (KBr) pellets in a 1:1 weight ratio and analyzed using the Bruker Alpha Platinum-ATR spectrometer. The material was scanned in absorption mode in the range from 4000 to 500 cm^{-1} with a resolution of 2 cm^{-1}.

b. Py-GCMS analysis

In this study, pyrolysis was performed with a control pyrolyzer Py-2020iS coupled to a Shimazu QP2010 GC/MS using an Rtx-5ms capillary-type column phase (60 mm × 0.25 mm × 0.25 mm). The inlet temperature is set at 280 °C and pyrolysis at 600 °C. The samples were identified by comparing the mass spectrum with a standard spectrum (NIST 98).

c. DSC analysis

The SRF samples, control palm veneer, and palm veneer impregnated with SRF resin, were prepared in the powder form as much as 10-15 mg. The samples were sealed in a standard DSC pan. The samples were heated from 30 °C to 550 °C, at a heating rate of 20

°C/minute, under a nitrogen flow of 20 mL/min. The DSC-60 detector (Shimadzu, Japan) is used. The heat difference between the sample and the reference is recorded as a thermogram.

d. XRD analysis

The XRD analysis was used to determine the level of crystallinity of the sample from the bio-impregnant. The tool used was the X-Ray Diffraction (XRD) Maxima-X Shimadzu® XRD-7000. The X-rays were energized from a 40 kV, 30 mA source and scans were made in the range 0 - 40 degrees at a scanning speed of two degrees per minute. The degree of crystallinity was calculated using Gaussian function curves with OriginPro 8.5.1 software (OriginLab Corporation, Northampton, MA, USA), using the following equation:

$$Crysrallinity\ (\%) = \frac{Area\ crystalline}{Total\ area\ (crystalline + amorphous)} x100 \qquad (1)$$

4. Impregnation of palm veneer

Veneers derived from palm stems were made measuring 30 cm × 8 cm × 0.5 cm (length × width × thickness). The palm veneers were dried in an oven at 100 °C for ± 3 hours to obtain a maximum moisture content of 12% prior to the impregnation thus, it is easier for the impregnant to enter during impregnation and fill the wood pores. The impregnation technique was carried out without vacuum pressure, the palm veneer was impregnated for 15 minutes and then conditioned at room temperature (± 28 °C) for 24 hours. The impregnated veneer was air-dried for three weeks to obtain a final moisture content of 20%.

5. Testing of impregnated veneers

The physical parameters of palm veneer were tested both before and after impregnation. These properties encompassed moisture content, density, and thickness swelling referring SNI-ISO 16983:2010 (BSN 2010). The mechanical properties tested are modulus of rupture (MOR) and modulus of elasticity (MOE) referring to SNI 8853:2019/ASTM D143 – 14, IDT (BSN, 2019).

The samples were oven-dried at 103 ± 2 °C until the weight was constant, then weighed in the oven-dry condition to determine the moisture content. Observation of samples for thickness swelling was carried out by cold immersion (interior test) in distilled water for 24 hours, and hot immersion (exterior test) in boiled water for 3 hours as done by Malik *et al.* (2022). The thickness dimension is measured at a predetermined point and the thickness dimension is measured again after immersion at the same point. Meanwhile, the mechanical properties of the modified oil palm veneer were observed by testing the MOR and MOE with concentrated loads using a universal testing machine (Alb. Von Tarnogrocki Essen UPH 2, German). Tests with instruments were also carried out on impregnated palm veneer, which included functional group analysis by FTIR, thermal properties by DSC, chemical components contained by Py-GCMS, and degree of crystallinity by XRD.

RESULTS AND DISCUSSION

A. Characteristics of Liquid Extract from Palm Bark

The characteristics of the liquid extract from the palm bark are presented in Table 1. The colour of the extract was dark brown with an acidity (pH) of 6.53 measured by a Digital pH meter (OrionStar A111, ThermoScientific, USA). The yield of liquid extract based on 1 kg of palm bark was 83.80%, with an average solids content of 0.54%. This indicated that 1 kg of palm bark contained around 838 grams of liquid extract. The solid extract of the 838 grams of liquid extract was around 4.5 grams and the 833.5 was water. The viscosity of the liquid extract was around 0.0125 Poise, the specific gravity was 0.997 and the index of high reactivity to formaldehyde was indicated by the Stiasny's number of 84.99% (Lee and Lan, 2006).

Tab. 1 Characteristics of liquid extract of palm bark*).

Parameters	Palm tannins
Appearance*	Dark brown
Yield (%)*	83.80 ± 0.20
Solids content (%)*	0.54 ± 0.03
pH (25 °C)*	6.53 ± 0.03
Viscosity (Poise)*	0.0125 ± 0.0009
Specific gravity *	0.997 ± 0.0003
Stiasny's number (%)	84.99

*Remark: *) average of 4x repetition*

The results of the functional group analysis using FTIR spectroscopy on the powdered extract of the oil palm stem bark presented in Figure 1 show the absorption of OH stretching vibrations (3280 cm^{-1}) indicating the presence of phenolic OH groups; vibration C=C (alkene) aromatic ring (1557 cm^{-1}); the C-O-H bending vibration of phenol (1408 cm^{-1}, 1226 cm^{-1}); cyclic ether C-O vibrations (1100 –1300 cm^{-1}), C-C vibrations (656 cm^{-1}), and out-of-plane C-H vibrations (614 cm^{-1}, 442 cm^{-1}, and 442 cm^{-1}).

The spectrum produced from the extract of the bark of the oil palm showed that the tannin extract from the bark of the oil palm was indicated to contain condensate tannin compounds with specific functional groups, namely phenolic and ether, in line with the research of Tondi and Petutschnigg (2015) which stated that tannin condensate has a specific wave number in the area of 1400 – 1100 cm^{-1} and there is no C=O group in the area of 1720 – 1700 cm^{-1}.

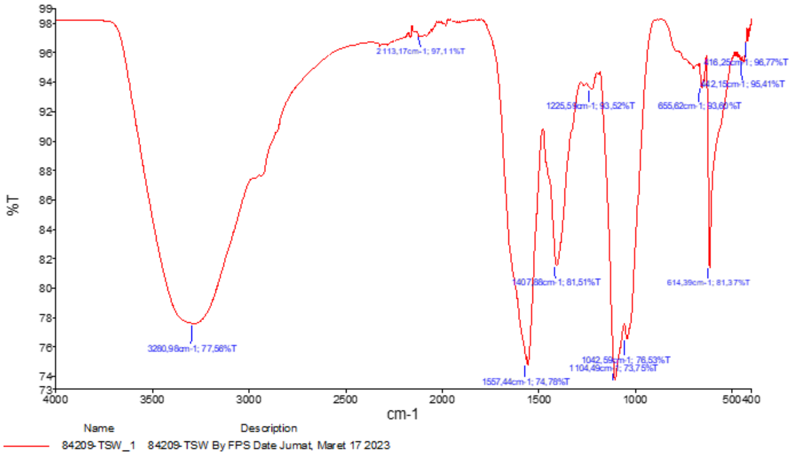

Fig. 1 Infra-red spectra of the extract from oil palm-bark.

The results obtained were similar to the functional groups of phenolic compounds identified in previous studies (Santoso and Abdurachman, 2016) in extracts of mahogany (Swietenia sp.), Okti *et al.* (2018) on mangium bark extract (*Acacia mangium*), and palm bark extract (Malik *et al.*, 2022), where these extracts predominantly contain OH groups, C=C aromatic rings, and ether groups.

The results of further analysis with Py-GCMS (Figure 2) showed that the oil palm bark extract contained 30 chemical components, which were dominated by carboxylic compounds (23.3%), thiols (14.94%), aldehydes (9.69%), ketones (9.18%), alcohol (4.62%), etc. Compounds containing hydroxyl groups (OH), such as alcohols and carboxylates, are important components as activators in bio-impregnant wood quality improvement treatments. Several studies have stated that compounds commonly used in wood modification to improve wood properties include those containing hydroxy functional groups, namely phenols contained in PF resins, capable of increasing dimensional stability (Ryu *et al.*, 1991, 1993; Sakai *et al.*, 1999; Ohmae *et al.*, 2002).

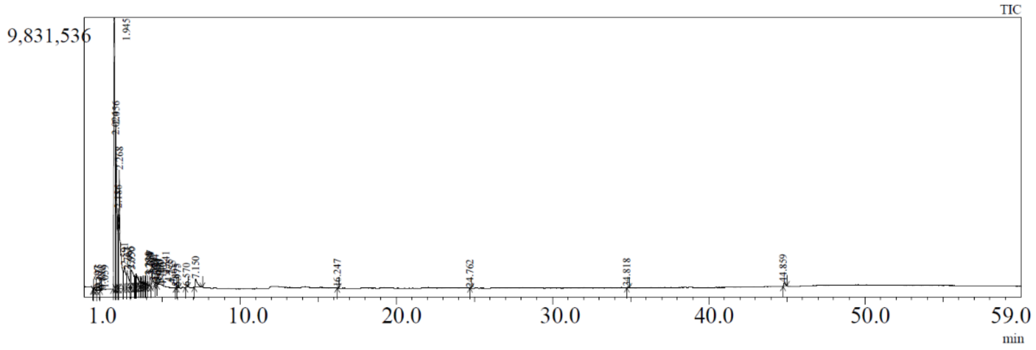

Fig. 2 Py-GCMS chromatogram of oil palm-bark extract.

Furthermore, based on the results of the analysis with X-ray diffraction, it is known that the degree of crystallinity of the compounds contained in the extract of the oil palm stem bark is 85.95% (Figure 3). This indicates that crystalline (orderly) forms dominate the structure of the compound chain. The degree of crystallinity greatly influences the properties of polymers (Cowd, 1991) so polymers with a high degree of crystallinity have higher strength and stiffness than polymers with a low degree of crystallinity. A high degree of crystallinity indicates that chains with high orderliness dominate the structure of the compound contained in the sample, and the forces between the chains are strong enough so that the chains or parts of the chains can approach each other in parallel, forming crystalline areas.

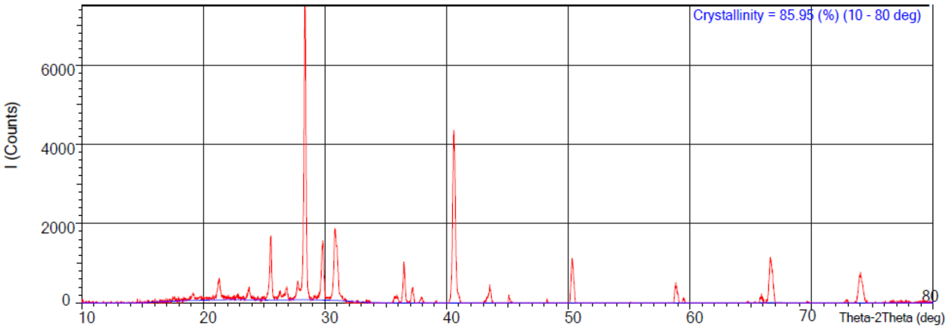

Fig. 3 The diffractogram of oil palm-bark extract.

DSC analysis is used to determine the temperature of a material transformation by quantizing its heat. This DSC analysis uses a temperature rise rate of 30 °C/minute up to 550 °C to determine the glass transition temperature, melting point, and crystallization point of palm bark extract. The results of testing the thermal properties of the palm bark extract are presented in Figure 4.

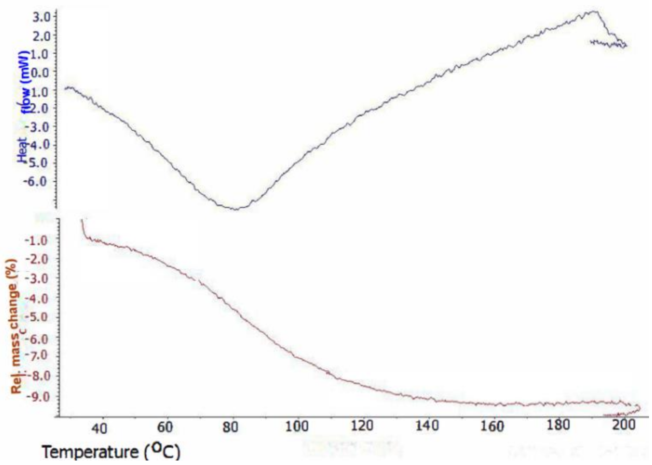

Fig. 4 The Thermogram of oil palm-bark extract.

Based on the thermogram in Figure 4, it can be seen that the oil palm bark extract changed thermal capacity at 82.2 °C, while the temperature due to decomposition/dissociation occurred gradually, namely at 120.4 °C, 165.7 °C and 188.4 °C and as the thermal rate increased it caused the extract from the palm bark to crystallize at 191.0 °C.

B. Impregnant Characteristics of Palm Bark Extract

The copolymerization product of palm bark extract with resorcinol and formaldehyde in alkaline conditions produces a resin that is visually a reddish-brown liquid, thicker than the liquid extract before copolymerization, has an acidity (pH) of 7.48 with an average solid level of 11.16%, a liquid extract viscosity of 4.0 Poise, a specific gravity of 1.054 and a gelation time of more than 180 minutes (Table 2). Furthermore, based on the results of analysis with the FTIR spectrophotometer, the resin from the palm bark extract caused the absorption band of the FTIR spectrum to change compared to the initial extract conditions (Figure 5).

Tab. 2 Specifications for bio-impregnant from Palm Bark extract.

Parameters	Impregnant
Organoleptic – Visual test* : • Form • Colour • Smell	Liquid Reddish brown Typical phenolic
Solids content (%)*	11.16 ± 0.11
pH (25ºC) *	7.48 ± 0.44
Viscosity (Poise)*	4.0 ± 0.26
Specific gravity *	1.054 ± 0.01
Gelatinated time (minutes)	more than 180 remains liquid
Resin immersion test in cold water (24 hours), then conditioned for 1 month	Not dissolved
Resin immersion test in boiling water (4 hours), then conditioned for 1 month	Not dissolved
Distribution of molecular weights (g/mol)	44 – 380
Total molecular weights (g/mol)	33.724
Number of chemical components/compounds	50
Decomposition temperature (°C)	204.6
Degree of Crystallinity (%)	13.57

Remark: *) average of 4x repetition

The shift in the OH stretching vibration occurred from previously oil palm stem bark extract to bio-impregnant in the absorption area of 3280.98 cm^{-1} to 3340.28 cm^{-1} with a decrease in intensity from 77.56% to 58.35%. Another shift occurred in the C=C aromatic group resulting in an absorption band at wave number 2923.78 cm^{-1} with an intensity of 92.46% to 2195.52 cm^{-1} with an absorption intensity of 97.57%, besides there was a new absorption band of C-H stretching vibrations of the aldehyde group which originally appeared at 1557.44 cm^{-1} with an intensity of 74.78% to 1580.46 cm^{-1} with absorption intensity of 48.74%. This absorption phenomenon occurs due to the addition of resorcinol and formaldehyde in the copolymerization process, which causes the formation of new bonds from free OH groups to ether bridges and methylene bridges in the copolymer formed (Malik *et al.*, 2022).

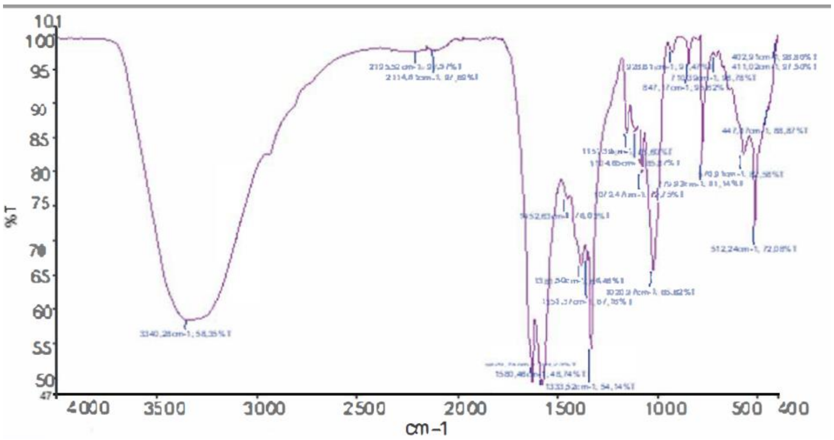

Fig. 5 Infra-red spectra of the impregnant made from oil palm-bark extract.

The absorption band at wave number 1349.01 cm^{-1} indicates the presence of a methylene bridge (CH_2) resulting from the copolymerization reaction between the phenolic extract from the bark of the oil palm stem and formaldehyde. In addition, absorption bands of C-OH bending vibrations (1210.19 cm^{-1}) formed from the phenolic group, shifted C-O stretching vibrations of the ether bridge from the condensation polymerization of phenolic compounds (1013.90 cm^{-1}), and reduced out-of-plane C-H vibrations (775.26 cm^{-1}) which are typical fingerprint regions for formaldehyde and phenol.

The results of further analysis with Py-GCMS (Figure 6) show that the impregnant of this copolymerization product consists of 50 chemical components. The results of the analysis with Py-GCMS (Figure 6) show that the impregnant of the palm bark extract was dominated by alkanes (18.6%), phenols (18.07%), ketones (12.6%), aldehydes (1.8%), and so on. This phenomenon occurred due to the addition of resorcinol and formaldehyde in the copolymerization process which causes the formation of new bonds from free OH groups to ether bridges and methylene bridges in the copolymer formed.

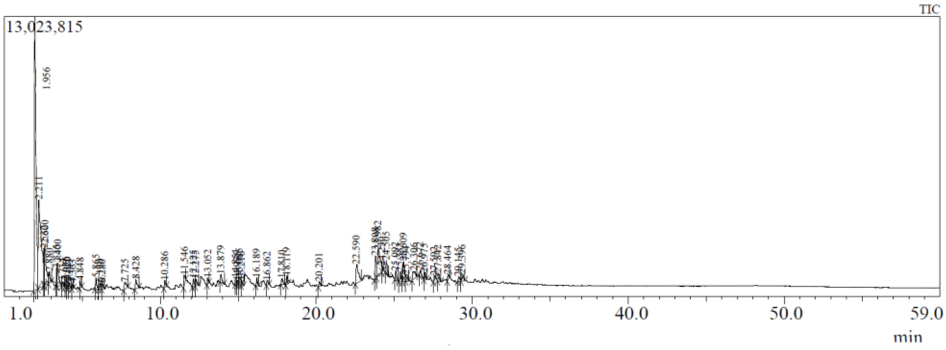

Fig. 6 Chromatogram of the SRF resin made from oil palm-bark extract.

The results of the analysis with Py-GCMS show that the impregnant of the palm bark extract was dominated by alkanes (18.6%), phenols (18.07%), ketones (12.6%), aldehydes (1.8%), and so on. This phenomenon occurs due to the addition of resorcinol and formaldehyde in the copolymerization process, which causes the formation of new bonds from free OH groups to ether bridges and methylene bridges in the copolymer formed.

Furthermore, using the X-ray diffraction method, the results of which are presented in Figure 7, it can be seen that there is a change in the degree of crystallinity which indicates the formation of an impregnant copolymer with a degree of crystallinity of 13.57% which is much more amorphous than the oil palm stem bark extract (85.95%).

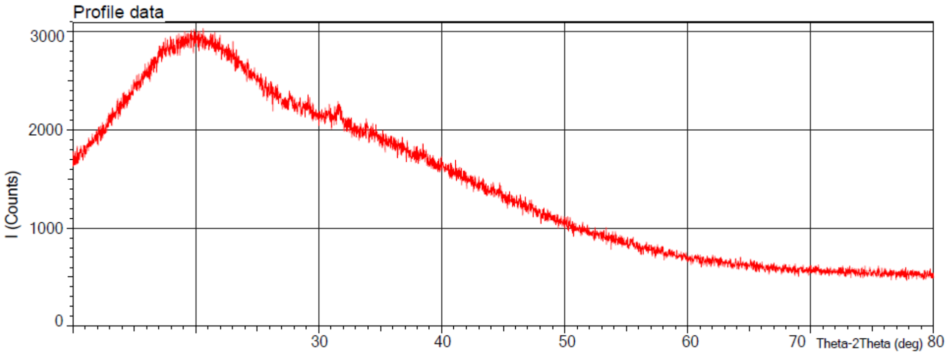

Fig. 7 Diffractogram of the impregnant made from oil palm-bark extract.

As stated above, the degree of crystallinity greatly affects the properties of polymers (Cowd, 1991), polymers with a high degree of crystallization have higher strength and stiffness than polymers with low crystallinity. A decrease in the degree of crystallization is an indication of an increase in the polymer chain structure with high disorder. Cowd (1991) suggested that very few polymers crystallize perfectly because the length and disorder of the molecules of each polymer are different. Irregularities in the chain structure, such as branching, will prevent the chains from approaching each other so that crystallization becomes limited (Cowd, 1991).

However, this does not mean that polymers with a lower degree of crystallinity are unprofitable, in the case of copolymers from palm bark extract which are included in the category of amorphous polymers which are thought to be relatively slower in "maturation" compared to copolymers with a higher degree of crystallinity, so that in application they will have a longer pot life (Cowd, 1991), in its use as a wood impregnant, what is more needed is its springiness (stretch) not just its strength/stiffness, in this case, a chain of branches is needed to inhibit or limit the movement of the chain, so it is hoped that after "ripening" it will not become firm/brittle.

Furthermore, the results of testing the thermal properties of the impregnant from the palm bark extract showed the glass transition, melting point, and crystallization point of the SRF copolymer (Figure 8).

Based on the thermogram obtained, the impregnant melting phase transition temperature can be determined – 97.9 °C (Figure 8). It is different from the initial condition (82.2 °C) (Figure 4), while the temperature due to decomposition/ dissociation along with an increase in thermal rate causes the impregnant from the palm bark to crystallize at a temperature of 204.6°C (Figure 8), which is also different from the initial conditions (Figure 4). A change in the heat capacity of the material accompanies the transition phase.

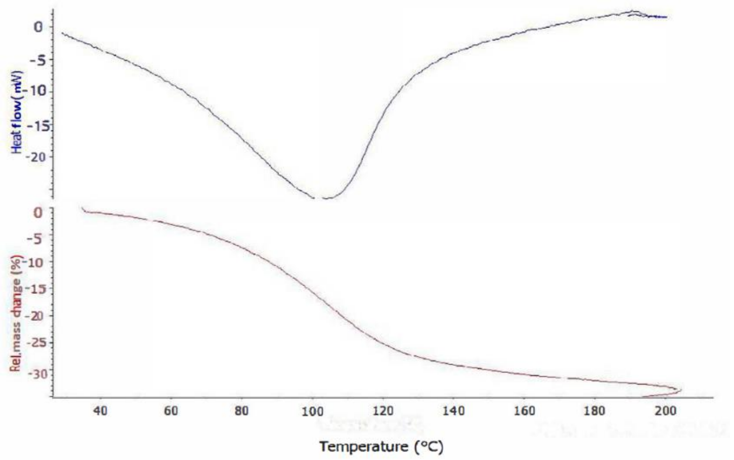

Fig. 8 Thermogram of the impregnant made from oil palm-bark extract.

These results indicate that changing the phase of the palm bark extract requires a fairly low enthalpy. According to Liu *et al.* (2015), when a low enthalpy occurs in polymers, this means that polymers are more easily formed at low temperatures. This polymerization process occurs in bio-impregnant.

Cowd (1991) suggested that polymer properties can be affected by the melting transition temperature. This temperature is closely related to the amorphous region of the polymer and causes the polymer to change from a hard and crumbly substance like glass to soft and rubbery like rubber with increasing temperature. In amorphous polymers, at temperatures below the melt transition phase, the amorphous chains "freeze" at a certain point, and the polymer is vitreous or brittle. As the temperature rises to near the melting phase transition, the chain parts can move. The polymer becomes more elastic above this temperature.

C. Chemical Characteristics of Impregnated Palm Veneer

Impregnation treatment of veneer with bio-impregnant synthesized from palm bark extract showed some increase or improvement in the characteristics of the veneer. The spectrum produced from untreated palm veneer (Figure 9) shows OH stretching vibration absorption (3280.15 cm^{-1}), indicating the presence of OH groups which bind to –H with high intensity; vibration C=C (alkene) aromatic ring (2924.46 cm^{-1}); the C-O-H bending vibration of phenol (1418.91 cm^{-1}, 1242.06 cm^{-1}); C-O stretching vibrations (1018.92 cm^{-1}), C-C vibrations (770.56 cm^{-1}) and out-of-plane C-H vibrations (574.76 cm^{-1}, 527.44 cm^{-1}, and 442.94 cm^{-1}).

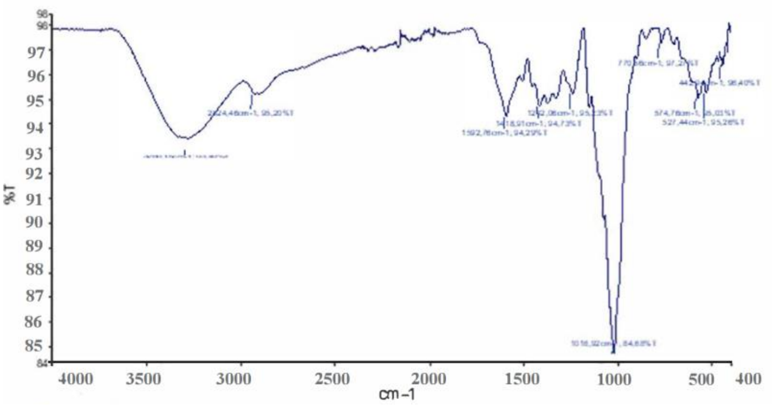

Fig. 9 Infra-red spectra of oil palm veneer without impregnant.

The spectrum of the impregnated palm veneer (Figure 10) shows the absorption of OH stretching vibrations (3313.74 cm^{-1}) with an intensity of 94.63%, indicating the presence of phenolic compounds in the presence of OH groups that bind to –H with high intensity; vibration C=C (alkene) aromatic ring (2926.32 cm^{-1}, intensity 97.03%).

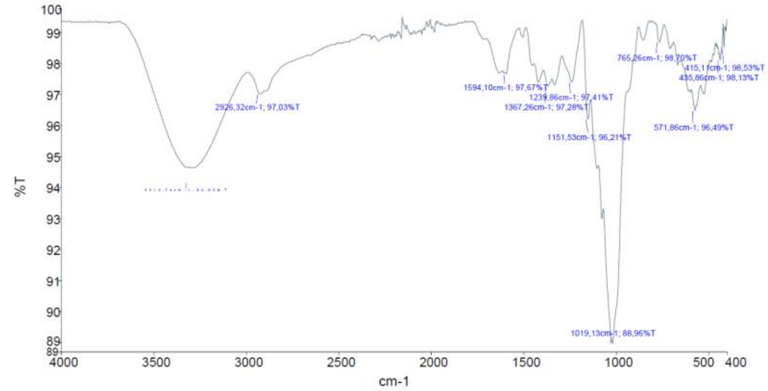

Fig. 10 Infra-red spectra of impregnated oil palm veneer.

The C-O-H bending vibrations of phenol (1367.26 cm^{-1} and 1239.86 cm^{-1} with intensities of 97.28 % and 97.41 %, respectively); C-O stretching vibrations (1151.53 cm^{-1}, 1019.13 cm^{-1}) with an intensity of 96.21% and 88.96%, respectively, C-C vibrations (765.26 cm^{-1}, with an intensity of 98.70%) and out-of-plane C-H vibrations (571.86 cm^{-1}, 435.86 cm^{-1} and 415.11 cm^{-1} with 96.49%, 98.13% and 98.53% intensity respectively) and carbonyl functional groups (1594.10 cm^{-1} with 97.67% intensity). This change in wave number and absorption intensity is an indication of the occurrence of chemical bonds between the chemical components of the impregnant and the chemical components of palm veneer.

The results of further analysis with Py-GCMS (Figure 11) show that in this palm veneer, there are 50 chemical components with a molecular distribution of 32 – 278 g/mol and a total molecular weight of 30.595 g/mol, which are dominated by phenol compounds (21.67%), carboxylates (15.41%), aldehydes (7.65%), ketones (5.40%), alcohol (4.89%), and so on, which confirms the results of the analysis by FTIR (Figure 9).

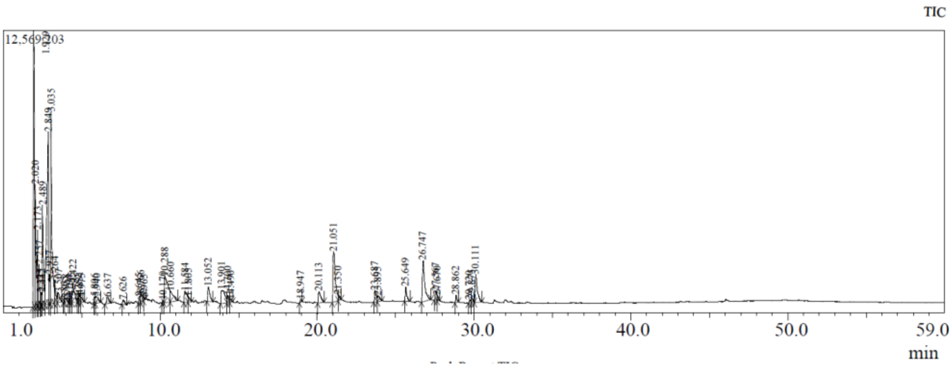

Fig. 11 Chromatogram of oil palm veneer without impregnant.

The results of the analysis with Py-GCMS (Figure 11) showed that the palm veneer was dominated by ketones (26.08%), carboxylates (22.94%), phenols (20.13%), alcohol (8.60%), aldehydes (2.76%), etc., which confirmed the results of the analysis with FTIR (Figure 9).

Furthermore, the chromatogram of the impregnated palm veneer (Figure 12) shows that although the impregnated veneer both consists of 50 chemical components, it is different from the control and impregnant chromatograms. The 50 chemical components of impregnated veneer with a molecular distribution of 32 – 278 g/mol and a total molecular weight of 30,702 g/mol, were dominated by ketones (24.09%), carboxylates (20.60%), phenols (19.64%), aldehydes (9.34%), alcohols (8.07%), and so on, which confirmed the results of the FTIR analysis (Figure 9).

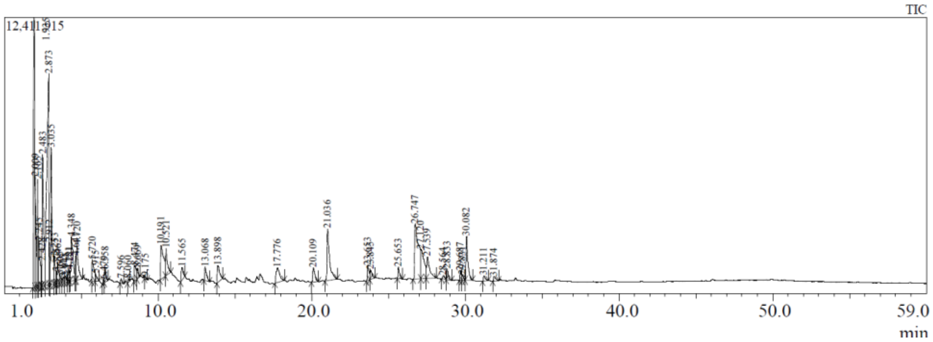

Fig. 12 Chromatogram of impregnated oil palm veneer.

Furthermore, using the X-ray diffraction method (Figure 13), it can be seen that the degree of crystallinity of palm veneer was 24.09 which after impregnated for 15 minutes experienced an increase in the degree of crystallinity reaching 24.18% (Figure 14). This indicates the formation of chemical bonds between the impregnant copolymer (15.20% degree of crystallinity; Figure 7) and the molecules in the palm veneer.

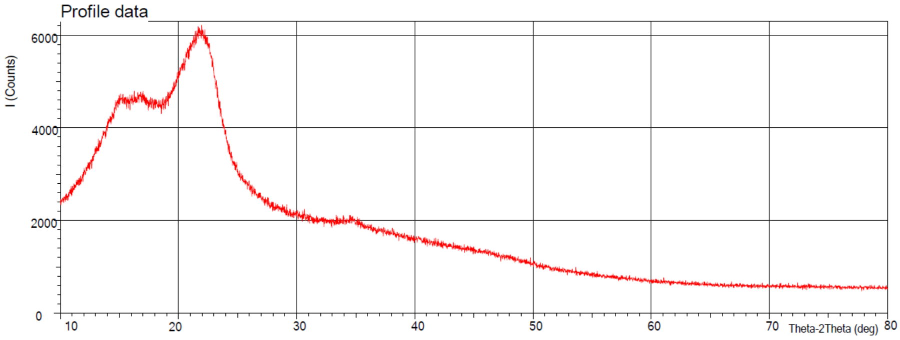

Fig. 13 Diffractogram of oil palm veneer without impregnant.

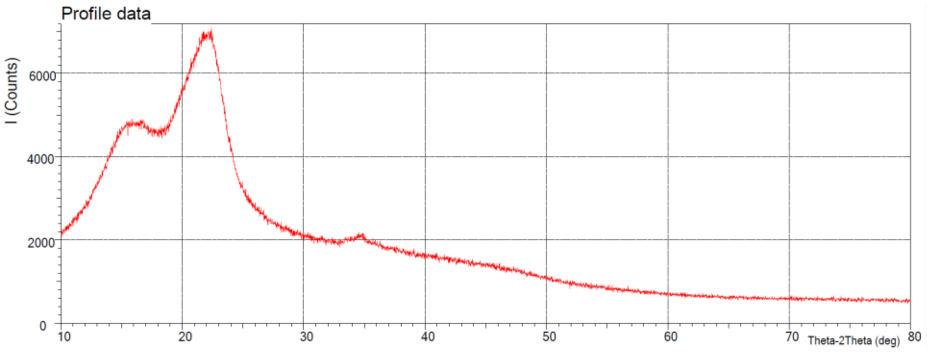

Fig. 14 Diffractogram of impregnated oil palm veneer.

Further analysis showed that the thermal properties of the glass transition impregnated palm veneer and the crystallization point (Figure 16) were 185.5 °C and 205.2 °C, respectively. On the other hand, the control palm veneer produced a glass transition (Tg) at 80.1 °C and decomposed at 204.4 °C (Figure 15).

An increase in the glass transition temperature in impregnated palm stems compared to the control indicates the formation of a more rigid and branched polymer due to cross-linking that occurs between components in the impregnant or impregnant with cellulose from palm veneer so that the structure of the palm stems becomes harder.

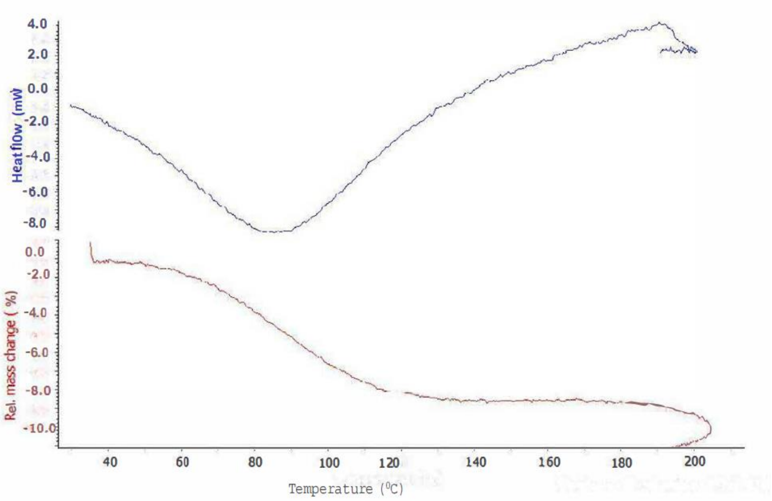

Fig. 15 Thermogram of oil palm veneer without impregnant.

The crystal point of the control thermogram at a lower temperature than the impregnated palm veneer thermogram showed that the impregnation treatment on the palm veneer increased the hardness of the palm veneer. An increase in thermal properties compared to veneer without impregnation emphasizes the indication of the formation of chemical bonds between the impregnant copolymer and the molecules in the palm veneer.

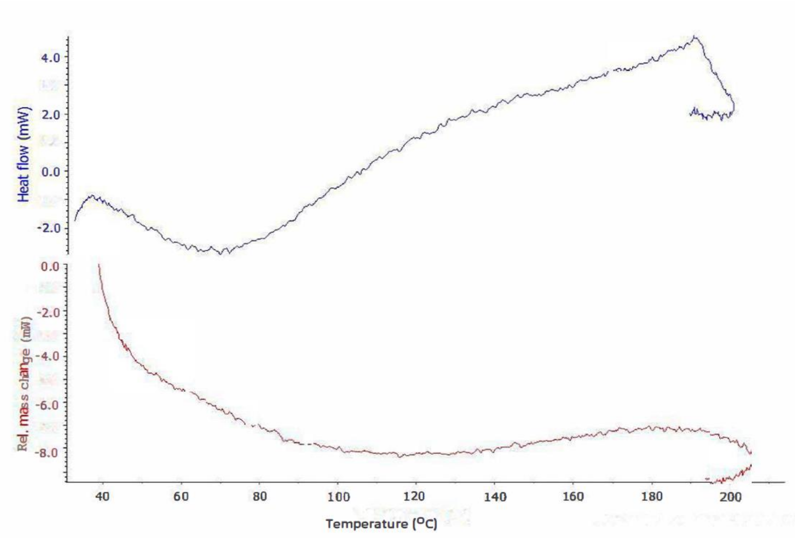

Fig. 16 Thermogram of impregnated oil palm veneer.

D. Physical-Mechanical Characteristics of Impregnated Palm Veneer

The results of physical-mechanical characterization tests of impregnated palm veneer including density, thickness swelling after soaking in cold water for 24 hours and thickness swelling after soaking in boiling water for 3 hours, and MOE and MOR are presented in Table 3.

Table 3. Veneer quality enhancement after impregnation treatment.

Parameters	Test sample	
	Control	Treated
Density, g/cm^3	0.50 ± 0.02	0.60 ± 0.02
Thickness swelling in normal water for 24 hours, %	6.18 ± 1.98	3.68 ± 0.83
Thickness swelling in boiling water for 3 hours,	9.17 ± 0.73	5.31 ± 0.58
Modulus of rupture, MPa	18.74 ± 0.25	20.84 ± 4.88
Modulus of elasticity, MPa	637.08 ± 70.66	973.28 ± 30.21

In Table 3 it can be seen that over all there was an increase in the quality of all test parameters after treatment on the palm veneer:

1. Density

Density is used to describe the mass of a material per unit volume. Impregnation treatment increased the density of palm veneer by up to 20% compared to untreated (control) palm veneer. This shows the filling of empty cavities in the veneer and the replacement of water with impregnant that can penetrate the cell walls. An increase in density also indicates that the impregnant forms polymers with palm veneer cellulose molecules so that it become compressed and solid (Malik *et al.*, 2022).

2. Thickness swelling

One of the applications for improving the quality of palm veneer is in composite products that will interact directly with a high-humidity environment so that composite products from palm veneer will experience thickness swelling due to a cold environment or shrinkage due to a hot environment. Therefore, a thickness swelling test was carried out as a benchmark for the quality of palm veneer, which was carried out by soaking in cold water for 24 hours and in boiling water for 3 hours. The lower the thickness swelling value, the better, because the palm veneer is more stable after soaking, and vice versa if the thick swelling value shows that the palm veneer has increased in thickness quite a lot when placed in a very humid environment.

The results of the thickness swelling test of impregnated and non-impregnated veneers met the standard requirements of SNI-06-4567-1998 (1998) because the thickness swelling was <25% of the original thickness. The sample of impregnated veneer after soaking in cold water for 24 hours decreased by 40% compared to the control palm veneer, while the swelling of veneer thickness in boiling water for 3 hours decreased by 42.09%. This phenomenon is in line with the results of Malik *et al*. (2022), where palm stems impregnated with Palm Resorcinol Formaldehyde resin experienced a decrease in thickness swelling after being tested in the same way. This indicates that the impregnation effect causes significant impregnant penetration and the formation of a strong specific bond between the impregnant and the palm veneer so that it becomes more stable. This increase in dimensional stability appears to be due both to the filling of the cell wall and the bonds that link the hydroxy resin components within the cell wall (Hill, 2006). Regarding the thickness swelling in boiling water, the value is greater than in cold water due to the swelling of the bonds in the veneer cellulose or the stretching of the bond of the palm veneer-cellulose adhesive thus allowing more water to enter (Malik *et al.*, 2022).

3. Modulus of Rupture and Modulus of Elasticity

The mean modulus of rupture (MOR) of this impregnated product was 20.84 MPa (Table 3), an increase of >10% compared to the control (18.74 MPa). On the other hand, the average modulus of elasticity (MOE) of impregnated veneer was 973.28 MPa , an increase of 52.77% compared to that without impregnation (637.08 MPa). This indicates that the impregnant can penetrate and form a strong specific bond between the impregnant and the palm veneer so that the MOR and MOE increase.

CONCLUSION

The extract derived from the bark of palm stems contains a chemical component that exhibits a high concentration of hydroxy groups (OH). This compound demonstrates a pronounced affinity towards resorcinol and formaldehyde when combined with an alkaline catalyst (40% NaOH). Consequently, the resulting copolymers formed through this reaction can be effectively utilized as impregnant. The specifications of the bio-impregnant as a whole are different from the characteristics of the palm bark extract as a raw material.

The utilization of copolymers derived from palm bark extract as a bio-impregnant has the potential to enhance the quality of palm veneer with a thickness of 5 mm following the 15-minute impregnation process. The observed changes in density, with a 20% rise, and the lowering thickness swelling when subjected to cold and boiling water immersion, were found to meet the specified requirements of being less than 25%. Furthermore, the MOR exhibited an increase of more than 10%, while the MOE showed an increase of over 50%.

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