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Preparation, chemical constituents and antimicrobial activity of pyroligneous acids from salix psammophila branches

WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

SHAOXIANG CAI, YULIANG GUO, AND YANJUN LI

EFFECT OF PHENOL FORMALDEHYDE RESIN IMPREGNATION ON NANODYNAMIC VISCOELASTICITY OF PINUS MASSONIANA LAMB IN WET STATE

We evaluated the effects of phenol formaldehyde (PF) resin modification on Masson pine (Pinus massoniana Lamb.) wood cell wall in wet states. The penetration degree of PF resin into wood cell was determined using confocal laser scanning microscopy (CLSM). The micromechanical properties of PF-modified wood cell walls in wet state were analyzed by quasi-static nanoindentation and dynamic modulus mapping techniques. Results showed that the PF resin significantly affected the static viscoelasticity and nanodynamic viscoelasticity of wood cell walls in oven-dried and wet states. The cell-wall mechanics increased at a PF resin concentration due to the increased bulking effects, such as decreased crystallinity of cellulose. Furthermore, the microfibrillar angle (MFA) of cell walls was lower than that of the control wood cell wall. The cell-wall mechanics of PF resin-modified sample decreased small than control sample in wet states

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WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

PATRIK MITRENGA, LINDA MAKOVICKÁ OSVALDOVÁ, MIROSLAVA VANDLÍČKOVÁ, AND MILAN KONÁRIK

OPTIMIZING THE AMOUNT OF FLAME RETARDANT USED FOR SPRUCE WOOD

The study investigated the effect of the amount of selected retardant coatings produced and used in the Slovak Republic on the fire resistance of spruce wood samples. Experiments were conducted for two different types of flame retardants: intumescent flame retardant (IFR) and inorganic salt-based flame retardant (IS). Based on different amounts of coating applied to spruce wood samples, the important parameters as mass loss, mass loss rate and fire spread rate were determined. The experiment consisted of applying a flame source to the samples at an angle of 45° and monitoring the mass of the samples during the experiment. The findings show that when IFR is used, the protection effect of the wooden samples increases linearly with the amount of coating. However, for the samples on which an IS flame retardant was applied, a higher amount of coating had no effect on increasing the fire resistance of the wood. In this case, the average total mass loss was the same regardless of the amount of coating, yet a significant retardation effect was observed compared to the untreated samples. Samples treated with IFR showed a lower total mass loss and also a significantly lower maximum mass loss rate compared to the samples with applied IS flame retardant

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WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

MERYEM KACMAZ UNVER, MUSTAFA ALTUNOK, AND SEKIP SADIYE YASAR

THE INVESTIGATION OF NATURAL AGING BEHAVIOR OF SOME WOOD SPECIES MODIFIED WITH NATURAL PRESERVATIVES

This study evaluates the effects of 12-month outdoor weathering on Scots pine (Pinus sylvestris L.) and sessile oak (Quercus petraea L.) woods modified with tannins. Wood specimens were divided into four groups: Group A (control, natural aging (NA)), Group B (NA + 100% walnut tannin (WT)), Group C_1 (NA + 50% WT and 50% pine tannin), and Group C_2 (NA + 50% WT and 50% oak tannin). Group A showed density decreases of 4.3% for Scots pine and 4.7% for sessile oak, while Group B samples exhibited density increases of 2.6% and 1.6%, respectively. Group A specimens had hardness losses of 36.3% for Scots pine and 28.7% for Sessile oak, compared to reduced losses of 8.8% and 11.2% in Group B. Bending strength and modulus of elasticity also decreased significantly in Group A but were minimally affected in Group B. These results indicate that tannin treatments, particularly walnut tannin, improve wood durability and mechanical performance, offering an eco-friendly alternative to conventional treatments

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WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

CHENYANG LI, YATING CAI, XINJIE ZHOU, RUOGU XU, HAN YU, LILI YU, HUI LI, XIAO WANG, AND SHU-GUANG LI

PREPARATION PROCESS AND INTERFACE MODIFICATION ON THE MECHANICAL PROPERTIES OF BAMBOO FIBER/POLYPROPYLENE CARBONATE COMPOSITES

In this study, bamboo fiber (BF) and polypropylene carbonate (PPC) were used to prepare BF/PPC composite materials. The single factor test combined with orthogonal experiment was used to investigate the effects of different hot pressing process conditions (hot pressing temperature, hot pressing pressure and hot pressing time) on the mechanical properties of BF/PPC composites. Based on the hot pressing process results, the filler nano-calcium carbonate (Nano-$CaCO_3$), γ-aminopropyl triethoxysilane (KH550) and maleic anhydride (MAH) were added respectively to the composites to improve the interface between BF and PPC in order to increase the mechanical properties of the composites. The results showed that the reasonable preparation conditions of BF/PPC composites with the best mechanical properties were set at 170°C, under 1.9 MPa for 10 min. Compared with PPC samples, the tensile modulus, bending modulus and impact strength of BF/PPC composites could be increased to 102%, 38.69% and 65.13%, respectively. The optimal interface modification treatments have been proved that nano-$CaCO_3$ with 10% content could increase the tensile modulus and impact strength to 70.53% and 65.84%, while the best result for the bending modulus of BF/PPC composites was modified with MAH with 2.5% content, which could increase to 28.46%

WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

HİKMET YAZICI

IMPACT OF HOLLOW CORE DIAMETER AND BFRP WRAPPING ON AXIAL COMPRESSIVE STATIC PERFORMANCE OF TIMBER

This paper presents an experimental study on the axial compressive static performance of the cylindrical timber-wrapped basalt fiber reinforced polymer (BFRP). Beech and black pine woods were used as cylindrical timber material, polyurethane (PUR) adhesive was used as the adhesive agent, and BFRP was used as fiber-reinforced polymers (FRP). The stress on compression tests was applied to 70 pieces of test samples prepared. The results showed that there was found out that the highest average stress value of 51.8 MPa was achieved inthe black pine cylindrical timber- BFRP wrapping- hollow core (Ø=70 mm)- the beech cylindrical timber blocks- BFRP wrapping samples under compression loading. The lowest average value stress value of 30.78 MPa was found in the black pine cylindrical timber- none hollow core samples. On average, the stress of the black pine cylindrical timber- BFRP wrapping- hollow core (Ø=70 mm)- the beech cylindrical timber blocks- BFRP wrapping samples were68% higher than the stress of the black pine cylindrical timber- none hollow core samples. The influence of the hollow core diameter and the BFRP wrapping type were found statistically significant

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WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

ROMAN HERDA, MILOŠ SLIVANSKÝ, JÁN BRODNIANSKY, AND TOMÁŠ KLAS

DETERMINATION OF FLEXURAL STRENGTH AND YOUNG'S MODULUS OF ELASTICITY OF ACTIVELY BENT WOOD

The article focuses on the experimental verification of wooden laths with a cross-section of 10 mm x 40 mm which were selected for active bending. The laths are made of pine wood and are 2 m in length. The research includes experimental measurements to determine the limit deformations achieved by bending the wood without chemical treatment, by applying compressive force to an originally straight beam, causing it to buckle and further deform. Ten bending tests of beams were performed, and from the same pieces, 21 tests were conducted using the four-point bending test to determine the flexural strength, and 30 tests to determine the global modulus of elasticity

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WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

THIPPAKORN UDTARANAKRON, TAWICH PULNGERN, NATTAWAT MAHASUWANCHAI, CHANNARONG SOMBATKAEW, THEERAPAT CHINNARAT, AND NARONGRIT SOMBATSOMPOP

FLEXURAL STRENGTHENING OF THERMALLY MODIFIED RUBBERWOOD GLULAM

BEAMS WITH FRP UNDER STATIC AND CYCLIC LOADS

The purpose of this research is to investigate the flexural properties and cyclic response of strengthened with fiber reinforced polymer (FRP) of glulam beam made from thermally modified rubberwood. The efficiency of three different FRP was assessed based on the bonding properties. The experimental results demonstrated that the glass fiber-reinforced polymer (GFRP) showed the strongest adhesion. Static and cyclic flexural tests were also carried out to study the behavior of glulam beams. The static test results indicated that double sides strengthened glulam beam enhanced their flexural strength. The strengthened glulam beams under static load demonstrated a reduced deformation rate due to increased modulus of rupture compared to non-strengthening glulam beam. The cyclic load test showed the strengthening effect on improving energy dissipation and ductility, while the impairment of strength did not affect

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ANIF JAMALUDDIN, NIDYA CHITRANINGRUM, SUBYAKTO, BERNADETA AYU WIDYANINGRUM, ARDITA SEPTIANI, SULISTYANINGSIH, WINY DESVASARY, FAJRI DARWIS, AHMAD FUDHOLI, SUDARMANTO, NUR ADI SAPUTRA, EKO WIDODO, AND TOSHIMITSU HATA

THE X-BAND MICROWAVE ABSORPTION CHARACTERISTICS OF POROUS ACTIVATED CARBON FROM NATURAL RESOURCES

Porous activated carbon (PAC) from bamboo, sisal, and coconut coir fibres with two carbonization steps were prepared and the microwave absorbing characteristics in the frequency range of 8 GHz to 12 GHz were investigated. The PAC based on bamboo, sisal and coconut coir had BET surface areas of 354.79, 141.91, and 25.70 m2/g, respectively. The return loss of -27.3, -25.6 and -16.4 dB was achieved for PAC from bamboo, sisal, and coconut fiber at 10.46, 11.08 and 11.00 GHz, respectively. The microwave absorption of more than 99% for porous activated carbon of bamboo and sisal, and more than 90% for porous activated carbon of coconut coir fiber, is indicated by these return loss values. It is shown by these results that biomass resources can be considered a promising lightweight, cost-effective, and eco-friendly microwave absorber material

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WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

ZANBIN ZHU, CHUNMEI YANG, WENJI YU, BO XUE, JIE YAN, YUCHENG LI, AND TONGBIN LIU

FRACTURE MECHANISM ANALYSIS OF HIGH-DENSITY FIBREBOARD BASED ON DIGITAL IMAGE CORRELATION TECHNOLOGY

This paper analyses the scattering images of the bending deformation of high-density fibreboards based on the digital image correlation (DIC) technique, so as to study its mechanical deformation law. Three-point bending tests were carried out on fibreboards using a mechanical testing machine with a non-contact measuring system. The measured values of the displacements of the grid nodes in the region of interest (ROI) were combined with the Moving least squares (MLS) method to construct the strains of the high-density fibreboards at different loading forces, thus deriving the strain values of the fibreboards during the bending deformation process. To further analyze its force deformation mechanism, this paper used a portable electron microscope and scanning electron microscope to analyze the damage situation at the fracture damage, and at the same time, it verified that the constructed strain field model was accurate

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WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

RUNZHONG YU, YAN LIU, ARIF CAGLAR KONUKCU, AND WENGANG HU

A METHOD OF SIMULATING SEAT LOAD FOR NUMERICAL ANALYSIS OF WOOD CHAIR STRUCTURE

This study aimed to investigate the characteristic values of the human-seat interface in a normal sitting posture, and to numerically mode the load on the chair seat for the structural design of chairs. The stress distributions and the characteristic values of seat were measured under normal sitting posture by using a human body pressure distribution measurement system considering the effects of gender and body mass index (BMI). The stress distribution on the seat was then numerically modeled using three modeling methods. The observed results and the numerical analysisresults were compared. The results showed that an inverted U-shaped pressure distribution was observed in normal sitting posture. The stress was concentrated on the ischial tuberosity with a maximum value of 0.066 MPa. The ratio of the load on the seat to the gravity of the human body weight was about 65.3%. The numerical model established using the body pressure mapping method was superior to those of the uniform load method and the standard loading pad method in terms of stress distribution, maximum stress, and contact area

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WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

SHUYU ZHAO, FU HU, LIFEN LI, YAN CAO, HUA GAO, XIAOHUI YANG, AND HAILONG XU

EVALUATION OF PROPERTIES OF WOOD PLASTIC COMPOSITES MADE FROM SEVEN TYPES OF LIGNOCELLULOSIC FIBERS

This article aims to investigate the characteristics of wood plastic composites (WPC) prepared from polyethylene (PE) reinforced with lignocellulosic fibers derived from the xylem and bark of Masson pine, fir, cypress, as well as from Moso bamboo. The surface polarity and elemental composition of fibers were determined through contact angle measurements and X-ray photoelectron spectroscopy (XPS). The lignocellulosic fiber/PE composites were manufactured through hot-pressing technique, and their water absorption, mechanical properties, and mildew resistance were evaluated. The results revealed that the surface free energy of xylem fibers was higher than that of bark fibers among the three conifer species. XPS analysis showed that the O/C ratio of bark was consistently lower than that of xylem fiber. Among the three conifers, the Masson pine bark had the lowest O/C ratio (22.25%), while its xylem fibers had the highest ratio of 41.64%. WPC made with bark fibers had better water resistance. Additionally, the composites reinforced with xylem fibers showed superior static bending strength, impact strength, and mildew-resistant properties as compared to the composites reinforced with bark fibers. WPC made from bamboo fibers exhibited the best water resistance, with a water absorption rate and thickness swelling rate of 1.83% and 1.42%, respectively. They also had the highest static bending strength, elastic modulus, and impact strength, at 41.31 MPa, 3.82 GPa, and 10.24 kJ/m2, respectively. The WPC made from fir xylem fibers showed the most effective mildew resistance, with the smallest damage (0.50)

WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

HILAL ULAŞAN AND CEVDET SÖĞÜTLÜ

THE EFFECT OF SUPPORT LAYER MATERIAL AND ADHESIVE TYPE ON COMPRESSIVE DYNAMIC BENDING AND SHEAR STRENGTH IN LAMINATED WOOD

In this study, strength properties of wood material reinforced with carbon fiber fabric, steel wire mesh and bamboo veneer were determined. Polyvinylacetate (PVAc) and polyurethane (PUR) glues (D4)were used for the lamellas obtained from Scotch pine (Pinus sylvestris L.) and eastern beech (Fagus orientalis L.). Compressive strength according to TS EN 408+A1; dynamic bending (shock) strength according toTS ISO 13061-10 and shear strength according to ASTM D 3110 were determined on 3 and 5-layers samples. According to the results, the highest compressive strength (62.8 N/mm2) was found in 5-layerseastern beech samples reinforced with carbon fiber fabric and bonded with PUR glue. The highest dynamic bending strength value (110.8 kJ/m2) was found in 5-layerseastern beech samples reinforced with carbon fiber fabric and bonded with PUR glue and the highest shear strength value (12.3 N/mm2) in 3-layered eastern beech samples reinforced with steel wire mesh and bonded with PUR glue

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WOOD RESEARCH VOLUME 69, NUMBER 3, 2024

SENDER ALTANGEREL, IKUMI NEZU, JYUNICHI OHSHIMA, SHINSO YOKOTA, AND FUTOSHI ISHIGURI

CHANGES IN WOOD QUALITY OF BETULA ERMANII LOGS BY HEATING TREATMENT

Logs of Betula ermaniiCham. were heated at a temperature inside the logs of 80°C for different heating durations of 0, 20, 40, and 60 h using a laboratory oven. After heating treatment, several wood qualities were examined, including residual stresses, moisture content, wood color, and physical and mechanical properties. The effects of the heating treatment duration on wood quality were analyzed using linear mixed-effect modeling. The developed models revealed that heating treatment affected residual stresses and wood color but not mechanical properties. The obtained results also suggest that a heating treatment duration of 20 h is sufficient to reduce residual stresses in B. ermaniilogs without reducing the physical and mechanical properties of wood

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CHUMIN CHEN, MING LI, SAIYIN FANG, JIALONG ZHAO, XIN ZHANG, FANGYONG LU, TINGTING DENG, AND BO ZHANG

STUDY OF STRESS WAVE PROPAGATION PATH AND DEPTH IDENTIFICATION IN CRACKED WOOD BASED ON ACOUSTIC EMISSION AND COMSOLSIMULATION

The propagation velocity models were built using AE sensors to capture stress wave on pine specimen surface.On the different specimens, cracks were made in different numbers and the depth was gradually increased from 0 mm to 90 mm at 10 mm intervals. AE experiment was combined with COMSOL to investigate propagation path.The results show that R-squared is 0.996 when fitting tangent of angle to propagation velocity.At smaller crack depths, stress wave is diffracted around crack tip and then continues to propagate in to sensor along a straight line.However, as the crack depth increases, the reflected wave at the end face will arrive at the detection location faster with significantly weaker diffraction.The area with dimensions of20×10 mm was identified about the crack tip by crack identification method

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WOOD RESEARCH VOLUME 69, NUMBER 3, 2024
YOSAFAT AJI PRANATA AND BAMBANG SURYOATMONO

EXPERIMENTAL TESTS OF RED MERANTI (SHOREA SPP.) DOWEL BEARING STRENGTH AT AN ANGLE TO THE GRAIN

The angle to the grain has a significant influence on timber bearing strength. As the grain angle increases the bearing strength decreases. The aim of this research was to obtain the dowel bearing strength of the red meranti (Shorea spp.) timber at an angle to the grain. The scope of this research was as follows the specimens were made according to ASTM D143, the grain angle ranged from 0° to 12°, and the dowel bearing tests were displacement controlled in accordance with ASTM D5764. Results of this research was an empirical equation of dowel bearing strength (in MPa) in terms of an angle to grain θ (in degrees) namely Fe = 32.74 – 4.701θ + 0.2064θ2. The importance of studying the influence of the grain angle to the dowel bearing strength for timber connection design is because the direction of the timber grain is not perfectly 0°

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Short notes

EXPERIMENTAL TESTS OF RED MERANTI (*SHOREA SPP.*) DOWEL BEARING STRENGTH AT AN ANGLE TO THE GRAIN

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(RECEIVED JULY 2024)

ABSTRACT

The angle to the grain has a significant influence on timber bearing strength. As the grain angle increases the bearing strength decreases. The aim of this research was to obtain the dowel bearing strength of the red meranti (*Shorea spp*.) timber at an angle to the grain. The scope of this research was as follows the specimens were made according to ASTM D143, the grain angle ranged from 0° to 12°, and the dowel bearing tests were displacement controlled in accordance with ASTM D5764. Results of this research was an empirical equation of dowel bearing strength (in MPa) in terms of an angle to grain θ (in degrees) namely $F_e = 32.74 - 4.701\theta + 0.2064\theta^2$. The importance of studying the influence of the grain angle to the dowel bearing strength for timber connection design is because the direction of the timber grain is not perfectly 0°.

KEYWORDS: Dowel bearing strength, grain angle, red meranti, orthotropic.

INTRODUCTION

The dowel bearing strength is the value that can be reached before a timber hole fails due to compression from dowel, when a timber connection is laterally loaded with axial tension internal load. Bearing strength is an important parameter used in timber design, for example in design of timber truss bridge and timber truss roof. The angle to the grain or the angle between the grain direction and the compressive bearing stress has a significant influence on timber bearing strength, since timber is an orthotropic material and have three main direction which are longitudinal, radial, and tangential. As the grain angle increases the bearing strength of the timber decreases.

The aim of this research was to determine the dowel bearing strength of the red meranti (*Shorea spp*.) timber at an angle to the grain experimentally. Red meranti is a species that is easily found in Indonesia and is commonly used as a construction material and as a nonstructural for example door and window. The importance of studying the influence of the grain angle to the dowel bearing strength is because the direction of the timber grain is frequently not perfectly 0°. The scope of this research was as follows the specimens were made according to ASTM D143, tests were provided on 169 specimens, the grain angle ranged from 0° to 12°, and the dowel bearing tests were displacement controlled in accordance with ASTM D5764.

Previous studies

Since the dowel bearing strength is an important parameter for design of wood connections, for example a tension member subjected to axial tension force, the past research were also carried out to tests the round timber bolted connections with slotted in steel plates subjected to axial tension (Lokaj and Klajmonova 2014).

Hankinson's formula (Bodig and Jayne 1993) is widely known as the analytical equation to predict the mechanical properties and the strengths of timber at an angle to the grain. In terms of experimental tests, there is no previous study for effect of grain angle to the timber dowel bearing strength. Experimental test, analytical research, and numerical analyses on the distortion energy criterion for timber that have been done previously were the compression at an angle and the tension at an angle.

The previous study on the effect of grain angle was the compression strength and the tension strength. The experimental tests and numerical analyses were done to study the compression strength of red meranti (*Shorea spp*.) timbers at an angle to the grain (Pranata and Suryoatmono 2012, Pranata and Suryoatmono 2013). Suryatmono and Pranata (2014) were also carried out to study the tensile strength of 8 species of timber at an angle to the grain. They used pete, red meranti, keruing, *Acacia mangium,* durian, mahoni, nangka, and sengon. Pranata and Surono (2015) were performed to study the tensile strength of yellow meranti timber at an angle to the grain. Agarana et.al. (2021) investigated the compressive strength of wood using Hankinson's criterion was also done for 5 species of wood.

The specimen dimension for dowel bearing test is 50 mm by 50 mm by 30 mm with a half of hole for placing the dowel. The applied load and the support of the specimen are on end-grain surfaces. The compression tool includes an adjustable crossbar to align the specimen and support the back surface at the base plate (ASTM D143-22 2022).

Calculation of the bearing load

The compression load for calculation of the bearing load is the 5% offset load that cause the failure of specimen in terms of bearing plane *t* mm (Fig. 2a) by bolt or dowel diameter in accordance with Munoz et.al. (2010). Proportional limit load is a load that is calculated as a yield point that shows the stress and strain in terms of plastic region. Method to determining the bearing load or proportional limit load used in this research is 5% offset diameter method. What is meant by diameter in this case is the diameter of the dowel. In this method, the first straight line that connects the origin and the point in the experimental curve with $0.4P_{max}$ is developed. The second straight line developed is the line that is parallel to the first line that starts from displacement of 5% diameter. The intersection of the second straight line with the experimental curve is the yield point P_y and Δ_y. Both lines and the yield point are shown in Fig. 1. In the following, the terms $P_{u5\%}$ is used as a replacement of the yield point.

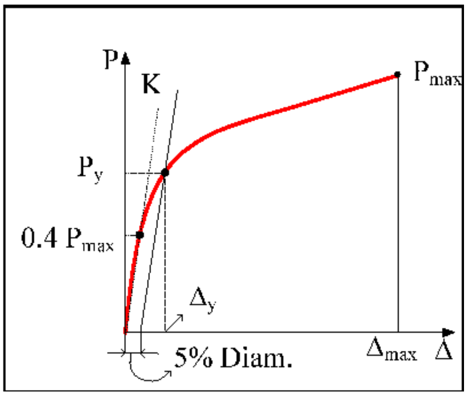


Fig. 1: The 5-% offset diameter method (Munoz et al. 2010).

In order to compute the dowel bearing strength $F_{e//}$, bearing are needs to be calculated according to Eq. 1, and the dowel bearing strength can be computed using Eq. 2, which is 5%-offset diameter load divided by the bearing area. The strain can also be calculated using Eqs. 3 and 4. Visualization of p, t, and L_o is shown in Fig. 2a.

$$A = t \times d \quad (1)$$

$$F_{e//} = \frac{P_{u5\%}}{A} \quad (2)$$

$$Lo = p - \frac{d}{2} \quad (3)$$

$$\varepsilon_{//} = \frac{D_{u5\%}}{L_o} \quad (4)$$

where: A is the bearing area of the specimen, t is the thickness of the specimen, d is dowel hole diameter, $F_{e//}$ is dowel bearing strength, $P_{u5\%}$ is 5% offset diameter load, L_o is the initial length of bearing line, p is total height of specimen, $\varepsilon_{//}$ is the dowel bearing strain, and $D_{U5\%}$ is the displacement at 5%-offset diameter load.

MATERIAL AND METHODS

Specimens for the dowel bearing tests were made from raw timber logs, which have been visually sorted to obtain defect-free parts. The number of test specimens in this study was

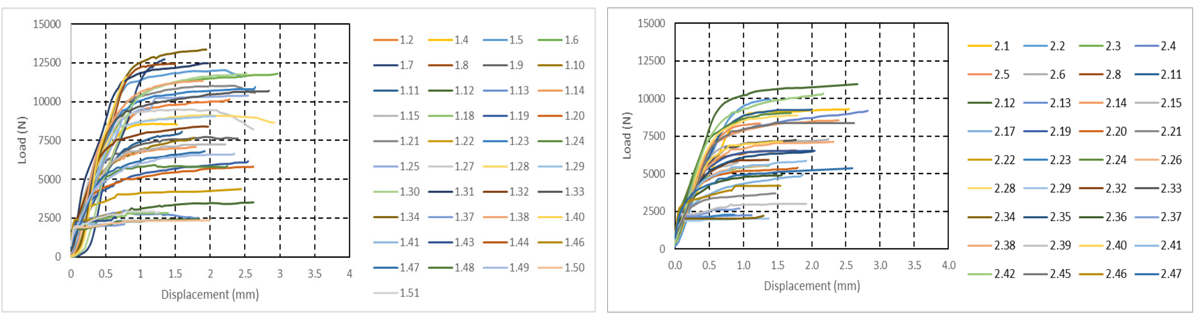
169 test specimens with grain angle variations ranging from 0° to 12° (Fig. 2b). The method of making the test specimens and the test methods are in accordance with ASTM D143-22 (2022). Fig. 2c shows setup of the experiment on the universal testing machine, set as bearing test mode with displacement controlled (crosshead speed) of 0.6 mm per minute according to ASTM D5764 (2018).

(a) (b) (c)

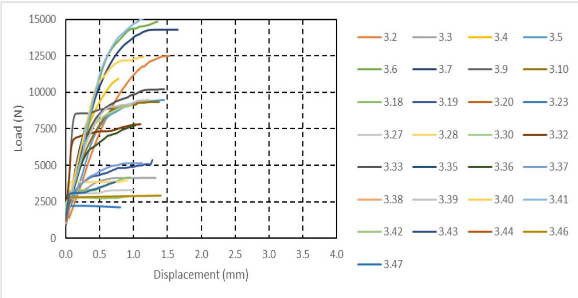
Fig. 2. a) The dowel bearing test specimen according to ASTM D143, b) samples, c) setup of the experiment on the universal testing machine.

RESULTS AND DISCUSSION

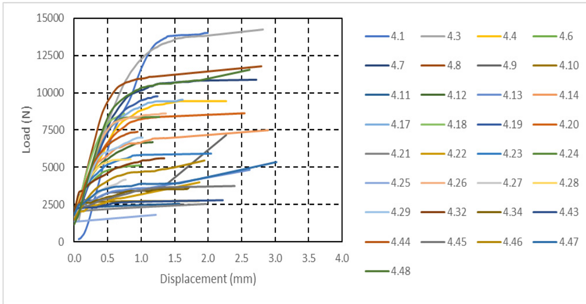
Five raw timber logs were used to make specimens for the dowel bearing tests in this research. 41 specimens using notation 1.xx were made from first timber log, 36 specimens using notation 2.xx were made from second timber log, 29 specimens using notation 3.xx were made from third timber log, 33 specimens using notation 4.xx were made from fourth timber log, and 30 specimens using notation 5.xx were made from the last fifth timber log. Fig. 3 shows the results of the experimental tests in terms of load versus displacement curves with various grain angle for all of 169 specimens. Fig. 4 shows an example of Specimen 1.23 on how proportional limit load P_y (= 5% offset diameter loads $P_{u5\%}$) is obtained.



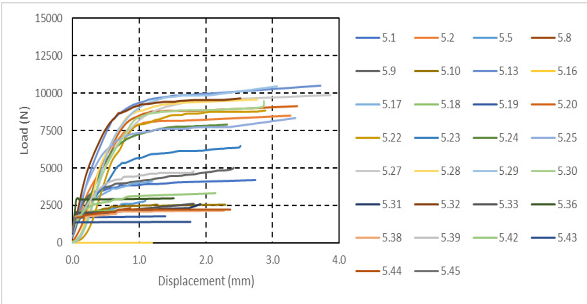
(a) (b)



(c)



(d)



(e)

Fig. 3: Bearing load versus deflection curves obtained from experimental tests. a) specimens 1.xx, b) specimens 2.xx, c) specimens 3.xx, d) specimens 4.xx, e) specimens 5.xx

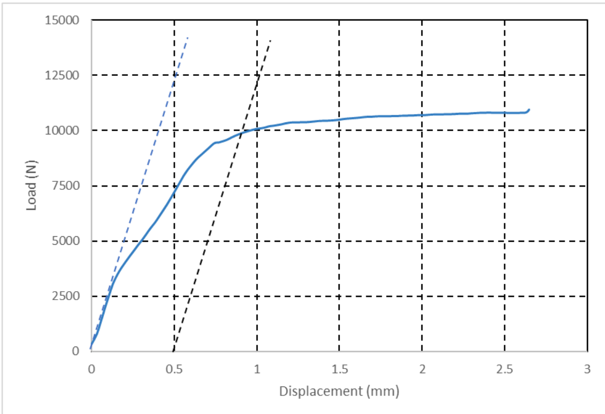


Fig. 4: Calculation of 5-% offset diameter or proportional limit load of specimen 1.23.

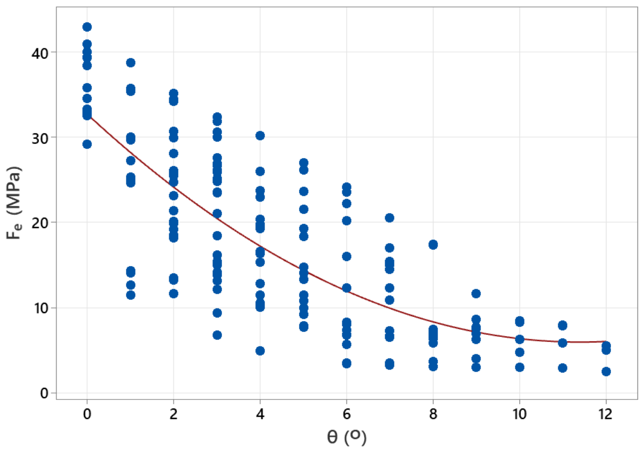


Fig. 5: Results obtained from polynomial regression analysis.

Fig. 5 shows the data points obtained experimentally and the curve obtained from the polynomial regression analysis that shows the relationship between the dowel bearing strength F_e (in MPa) and the grain angle θ (in degrees). The regression equation for the curve in Fig. 5 is shown in Eq. 5:

$$F_e = 32.74 - 4.701\theta + 0.2064\theta^2 \tag{5}$$

With the coefficient of determination of R^2 = 60.3%. Although the coefficient is generally not convincing because it is relatively far from 100%, for wood this is considered normal because wood is a material that comes from nature and far from homogeneity. Using the regression equation (Eq. 5) it can easily be seen that grain angle of just 4^o reduces the dowel bearing strength by approximately 50%, while grain angle of 10^o reduces dowel bearing strength by 80%. It is, therefore, important to design and construct connection in timber structure using zero or as small as possible grain angle.

CONCLUSIONS

An empirical regression equation to predict the dowel bearing strength of red meranti (*Shorea spp*.) The dowel bearing strength (in MPa) as a function of the grain angle (in degrees), namely $F_e = 32.74 - 4.701\text{x}\theta + 0.2064\text{x}\theta^2$ with coefficient of determination R^2 of 60.3%. This result shows that the dowel bearing strength decreases significantly with the increasing grain angle. Therefore, it is important to consider the grain angle (the angle between the grain and the direction of the bearing stress), if any, in the design and construction of timber connection using dowel fastener. The equation of F_e (at an angle to the grain) can be alternative solving to calculate the dowel bearing strength, one of main parameter in analysis or design of axial tension timber connection, that widely used for design of timber truss bridge or timber truss roof, especially for famous structural timber in Indonesia such as red meranti (*Shorea spp*.).

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