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Stiffness and strength of oil palm wood core sandwich panel under center point bending

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A B S T R A C T

This paper presents a study of the bending's stiffness and strength of oil palm wood (OPW) core sandwich panel overlaid with rubberwood veneer under center point bending. Parameters including density and grain orientation of OPW core, rubberwood veneer thickness and span length were investigated. An experimental evaluation of some mechanical properties of OPW and the bending stiffness and strength of the sandwich beams was performed. Linear elastic beam theory was used to predict the bending performance of the panels. Results show that the linear elastic beam theory with the uses of the power law expressions of Young's moduli and shear strength of the OPW as a function of density derived within this study, adequately predicted the stiffness and bending strength of the sandwich beams. Higher OPW core density increased stiffness and strength of the beam. Failures by face fracture and core shear were observed which the latter tended to occur at low OPW core density, relatively thick veneer face and short span length. Grain orientation of OPW core little influenced stiffness and strength of the sandwich board. Finally, the stiffness and failure load equations of the OPW sandwich board were proposed for practical uses of this product.

1. Introduction

The use of leftover oil palm (*Eaeis guineesis*) trunks, otherwise plantation waste material of palm oil industry, has been recently explored as the core of structural sandwich panels [1]. Due to its relatively low density with an average value of 235 kg/m^3 [2], the oil palm wood has great potential to be a good alternative to replace polymer foam core commonly used in the lightweight sandwich structures [3–5]. Since it is a natural material, the oil palm wood possesses a large density variation ranging from 190 kg/m^3 to 580 kg/m^3 both in the cross section and along the oil palm trunk height [6]. This density variation affects the mechanical properties of the oil palm wood and therefore the sandwich panels containing the oil palm wood core. Therefore, a method is needed to predict the bending stiffness and strength of oil palm wood core sandwich panels at various oil palm wood core densities to achieve a more practical use of this product.

Stiffness and strength are two main mechanical parameters used to evaluate the performance of a sandwich beam under bending load [7]. Both values depend on the properties of its faces, core materials and geometry [7,8]. Generally, beams have to meet a minimum required stiffness and strength for specific applications [7,8]. In practice, the optimum face and core thickness are therefore needed to achieve the required stiffness and strength. Linear elastic beam theory has been employed to predict stiffness and strength of the sandwich beam [9–17]. In addition, a failure mode map of sandwich beams consisting of various faces and core materials have also been developed [10,18,19]. However, those calculations have usually been designed for the sandwich beam containing strong and stiff faces with a much softer and weaker core in which some properties of core materials have been omitted [9–19].

The objective of the study is to evaluate theoretically and experimentally the stiffness and bending strength of an oil palm wood core sandwich panel overlaid with a rubberwood veneer face under center-point bending. Mechanical properties of the oil palm wood in relationship with density needed for the evaluation of bending stiffness and strength was examined. The effects of the oil palm wood density, core grain orientation and face thickness on the beam's stiffness and strength were considered.

2. Theoretical background

In this study, linear elastic beam theory is used to describe the sandwich beam's flexural characteristics of two differently aligned core grain orientations to the axis: the horizontal (PR) and vertical (PP) directions, respectively. Orthotropic elasticity of the wood material is not considered. Configurations of the PR and PP beams under center point bending are shown in Fig. 1. The sandwich beam consists of two face laminae of thickness t, core thickness c, beam width b, beam thickness h and span length L loaded with point load P at the midspan. It is assumed that

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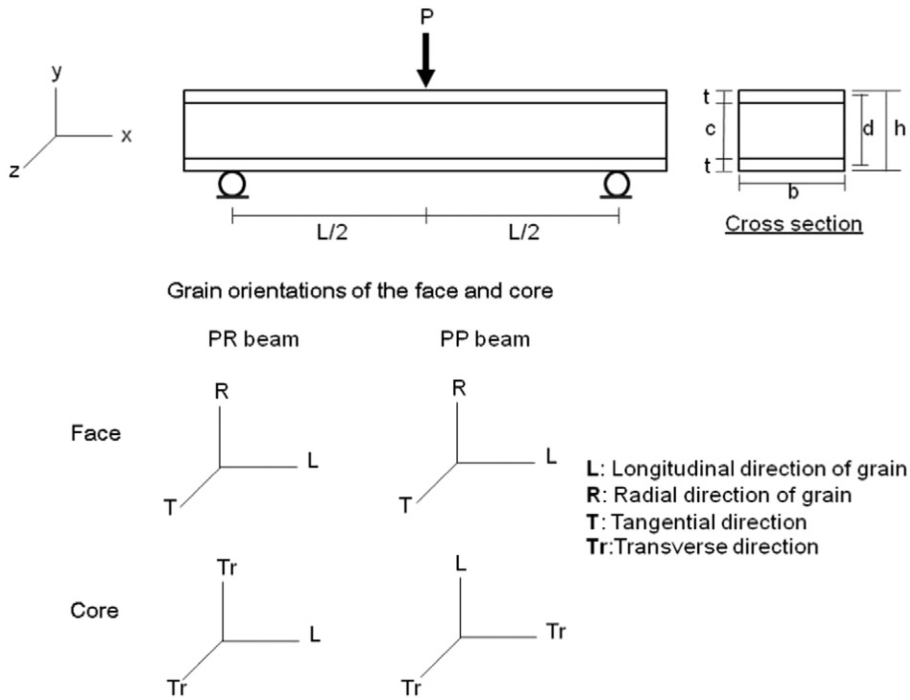

Fig. 1. Configurations of two types of sandwich beam (PR and PP) consisting of two sheets of rubberwood veneer and oil palm wood core having different grain orientations parallel and perpendicular, respectively, to the panel's surface under center point bending.

the bond of the face and the core was perfect and that there was no curvature in the *yz* plane.

The beam's stiffness can be determined from its total deflection in the elastic range. Total deflection is composed of the deflection produced by both bending moment (δ_b) and transverse shear force (δ_s) [9]. By assuming that shear deflection in the face is relatively small and total shear deflection is only due to the lower shear rigidity of the oil palm wood core, the beam's stiffness can be expressed as follows:

$$\delta = \delta_{\mathrm{b}} + \delta_{\mathrm{cs}} \tag{1}$$

where

$$\delta_b = \frac{PL^3}{48(EI)_{eq}} \tag{2}$$

$$\delta_{\mathrm{cs}} = \frac{\mathrm{PL}}{4(\mathrm{AG})_{\mathrm{eq}}} \tag{3}$$

where δ_{cs} is deflection produced by transverse shear force in the core, $(EI)_{eq}$ is the equivalent flexural rigidity and $(AG)_{eq}$ is the equivalent shear rigidity. In the case that the face thickness is much smaller than the board thickness so that the distance between the midplane of the upper and bottom faces (d) to the face thickness (t) ratio is more than 5.77 ($d/t > 5.77$), the $(EI)_{eq}$ and $(AG)_{eq}$ of the sandwich beam can be expressed as presented in Eqs. (4) and (5), respectively [9,10].

$$(EI)_{eq} = E_{fx}\frac{btd^2}{2} + E_{cx}\frac{bc^3}{12} \tag{4}$$

$$(AG)_{eq} = 4bdG_{cxy} \tag{5}$$

where E_{fx} is the in plane Young's modulus of face materials for loading in the *x* direction, E_{cx} is the in plane Young's modulus of core materials for loading in the *x* direction and G_{cxy} is the shear modulus of the core in the *xy* plane.

Bending strength depends on the strength of the face and core materials [9]. Generally, a sandwich beam under a bending load can fail either in the face or in the core by five failure modes: face fracture, face wrinkling, face indentation, core failure and delamination of the interfacial bond [9]. Two failure modes observed in this study, face fracture and core shear, are discussed in details below.

– Face fracture
Face fracture occurs when the maximum normal tensile stress in the face layer exceeds the fracture strength of the face sheet materials (σ_{yfx}). In the case of the low core density, the effect of shear deflection should not be neglected in the calculation of the maximum tensile stress at the bottom face because it is significant when compared to the total deflection of the beam [7]. To include the effect of shear deflection in the core for the calculation of the maximum tensile stress in the face, Allen's suggestion was used as presented in Eq. (6)

$$\sigma_{yfx} = \frac{PL}{4}\left(\frac{c+2t}{2\left(\frac{bt^3}{6}+\frac{btd^2}{2}\right)} + \frac{t}{\theta\frac{bt^3}{3}}\right) \tag{6}$$

where

$$\theta = \frac{L}{c}\left[\frac{G_{cxy}}{2E_{fx}}\frac{c}{t}\left(1+\frac{3d^2}{t^2}\right)\right]^{1/2}.$$

– Core shear
Core failure occurs when the maximum shear stress in the core (τ_c) exceeds the shear strength of the core material ($\tau_c{}^*$). The maximum shear stress in the core can be determined by using Eq. (7) suggested by [9]

$$\tau_c = \frac{P}{2(EI)_{eq}}\left[\frac{E_{fx}t(c+t)}{2} + \frac{E_{cx}c^2}{8}\right]. \tag{7}$$