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Mechanical properties of finger jointed beams fabricated from eight Malaysian hardwood species

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HIGHLIGHTS

- Bonding properties of low-density wood species are better due to better wettability.
- Finger length exerted significant influence on strength of finger joints.
- Vertically jointed finger joints are stronger than those of jointed horizontally.
- Low-density wood exhibited better joint efficiency.

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ABSTRACT

Mechanical properties of finger joints made from eight Malaysian tropical hardwood species were investigated in this study. The wood species studied were merpauh (*Swintonia* spp.), kapur (*Dryobalanops* spp.), resak (*Cotylelobium* spp.), white meranti (*Shorea* spp.), bintangor (*Calophyllum* spp.), jelutong (*Dyera* spp.) sesendok (*Endospermum* spp.) and kelempayan (*Neolamarckia cadamba*). All of the selected wood species fell into strength group (SG) ranged from SG 4 to SG 7 as described in MS 544: Part 2. Effects of species, finger orientations (horizontal and vertical) and fingers lengths (15 mm and 25 mm) on mechanical properties of finger joints were evaluated. It was observed that bonding properties of low-density wood was better than high-density wood due to better wettability characteristics. Intimate bonding between wood and adhesive was found in low-density wood as its higher porosity promoted better resin penetration. Better joint efficiency was also observed in low-density wood. Finger joints made from longer finger (25 mm) generally exhibited better strength properties compared to shorter one. Samples that jointed vertically displayed superior properties in comparison to that of jointed horizontally. Non-destructive evaluation technique was found not suitable to estimate the static modulus of elasticity of the finger joints that fabricated in this study and further improvements is needed to obtain better result.

1. Introduction

Rapidly shrinking Malaysian forest due to inefficient logging practices give rise to insufficient supply of high quality and bigger-sized solid timber beams. Besides, low sawmill recovery rate and under-utilization of the mill residues undoubtedly aggravated the current situation. In response to this issue, approaches in making use of these residue effectively are urgently called for. Strickler [1] suggested that high performance beams can be produced by jointing short pieces of wood using finger jointing technology. Finger jointing is an economical and prevalent practice in wood industry for the production of both non-structural and structural products. Furniture and cladding are the examples of non-structural uses of finger jointed products [2]. For structural use, it will be end jointed to form glue-laminated timber [3]. Therefore, finger jointing is an ideal method in improving the efficiency and profitability of sawmills.

To produce high performance structural finger jointed products, specific processing parameters such as finger geometry and finger configurations should be taken into consideration. Wood-related factors such as species and density are also known to affect the properties of the finger jointed products [4]. Karastergiou et al. [5] examined finger length and finger orientation on bending strength of finger jointed Turkey oakwood (*Quercus cerris* L.) and found that better strength was found in the vertically jointed

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samples with longer finger length. Study on finger jointing of Black pine wood (*Pinus nigra* L.) was conducted by Mantanis et al. [6] and the results revealed that the bending strength was dependent on both finger length and orientation. Nevertheless, in comparison to the well documented and extensively studied temperate timber species, finger jointing using tropical hardwood species has yet received adequate attention [7]. Malaysia in particular, as one of the most diverse and complex ecosystems of the world, has been endowed with abundant and great varieties of timber species. However, little or no information is available on the properties of this finger jointed tropical hardwood species.

Four-point bending test is a conventional method to determine the bending strength of finger jointing samples. Unfortunately, conventional bending test are costly, destructive and difficult to carry out especially on wood with structural size. According to Ross and Pellerin [8], in comparison to conventional bending test, non-destructive evaluation (NDE) is a relatively economical and less destructive method in determining the mechanical strength of materials without influencing its end-use performance. NDE techniques are prevalently employed to assess the quality and strength properties of timber by the wood industry and research communities. In the recent years, non-destructive evaluation is not only confined to solid wood but also prevalently applied on wood composite such as particleboards and wood plastic composites as well as concrete columns [9–11]. Nevertheless, information and studies reporting on the application of NDE techniques on finger-jointed timbers are relatively scarce, especially for finger-jointed tropical hardwoods. Biechele et al. [12] and Hemmas et al. [13] employed NDE techniques in determine the elastic properties of finger jointed black spruce and oak wood but little or no information was found on the finger-jointed tropical hardwoods. On that account, feasibility of NDE techniques on finger-jointed tropical timber for stiffness measurement is still questionable.

Moreover, to match the wood to its end-use categories, visual grading is traditionally employed to inspect and assess the wood quality based on the distribution of defects on the wood surface. Nevertheless, visual grading is a subjective method where some of the visually indiscernible defects might be overlooked. To improve the grading accuracy, two complementary techniques are necessary. Therefore, it is important to evaluate the dynamic modulus of elasticity (MOE_D) of the finger-jointed beams non-destructively and examine its relationship with static modulus elasticity (MOE_S) for possible extensive application of NDE techniques in wood industries in the future. Precision of the prediction of wood strength provided by visual grading could be enhanced by the employment of NDT and as validation of visual information in the meantime. Non-destructive evaluation was carried out in this study using ultrasonic technique to examine the relationship between MOE_D and MOE_S.

This study aims to evaluate the mechanical properties of finger jointed beams made with eight Malaysian timber species from different strength group (SG), which are merpauh (*Swintonia* spp.), kapur (*Dryobalanops* spp.), resak (*Cotylelobium* spp.), white meranti (*Shorea* spp.), bintangor (*Calophyllum* spp.), jelutong (*Dyera* spp.), sesendok (*Endospermum* spp.) and kelempayan (*Neolamarckia cadamba*). These timber species were chosen according to their availability and grouping of strengths. Malaysian standard (MS) 544: Part 2 [14] had divided Malaysian timber species into seven strength group, SG 1 to SG 7, in the order of decreasing strength. SG 1 is considered strong and suitable for structural applications while SG 7 is the weakest. Therefore, in the spirit of upgrading timber with superior properties, timber species ranging from SG 4 to SG 7 were used in this study. The effects of finger joint length (15 mm & 25 mm) and orientation (vertical and horizontal) on the properties of finger-jointed beams were investigated. Prior to fabrication of finger joints, bondability and wetting properties of the proposed timber species were evaluated and were later related with the joint efficiency of the finger jointed timbers. The relationships between dynamic modulus of elasticity (MOE_D) and static modulus elasticity (MOE_S) for finger jointed Malaysian timbers were also investigated to assess the feasibility of using NDE as a grading tool for finger joints.

2. Materials and method

2.1. Materials preparation

Eight timbers species that fall in the strength group (SG) of SG4 to SG7 as described in the MS 544: Part 2 [14] were selected in this study. The selected timber species including merpauh, kapur, resak (SG4), white meranti, bintangor (SG5), jelutong (SG6), sesenduk and kelempayan (SG7) were obtained from reserved forest in UiTM Jengka. Radially sawn timber with horizontal annual rings were prepared and planed into required dimensions and kiln dried to 8 ± 2% moisture content. The kiln dried timber samples were graded using visual grading by a grader from Malaysian Timber Council to identify defects such as knots, wane, distortion etc in accordance with MS 1714:2003 [15]. Timber samples that are visually free of knots and fissures (Select Structural Grade) were chose and used for the fabrication of finger joints in this study. Densities, strength class and dimensions of member used for preparing the samples are listed in Table 1. Fast curing phenol-resorcinol-formaldehyde (PRF) adhesive was supplied by Dynea Nz Ltd for the jointing of finger joint samples.

2.2. Bonding and wetting properties of adhesive and timber prior to finger joints fabrication

Bondability between the resin with timber are important prior to fabrication of finger joints. Thick Adherend Shear Test (TAST) was conducted to evaluate the bondability between the PRF and timber adherends. TAST has a simple joint geometry, and therefore is easy to manufacture and economical. The TAST was conducted according to the procedure stated in BS EN 14869-2 [16]. Two pieces of timber planks having dimensions of 110 mm × 25 mm and 2.5 mm were prepared. PRF resin was spread on the top of one of the plank. 2 mm-thick spacers placed at the end of the plank as shown in Fig. 1a in order to obtain consistent thickness of the resin. The other plank was placed on top of the resin and clamped to secure the bonded member. Then two grooves were milled on the bonded specimen as shown in Fig. 1b.

Five specimens were prepared for each species. To determine the shear strength of the bonded member, the TAST specimen was subjected to a tensile force using a tensile testing machine (SHIMADZU) equipped with 50 kN load cell. The shear stress (τ) was determined using the following equation:

$$\text{Shear stress } (\tau) = P/bL \quad (1)$$

where P = applied force (N), L = overlap length (mm), b = width of the sample.

In order to obtain a good bonding, an intimate contact between the adhesive and the timber surface must be reached. Therefore, the wettability was determined by means of measuring the contact angle of an adhesive sessile drop on the timber surfaces. Contact angles were measured using a Contact Angle Analyser. Small blocks of 20 mm thick × 50 mm width and 150 mm length were cut from timber specimen for each species. The surface was cleaned by using a dry cloth. Droplets of 5 μL resin was delivered onto the surface of timber specimen. The droplets were