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Research Paper

Assessment of the mixed timber combination effect of finger-jointed timber species using flexural and tensile strength

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Abstract: Off-cut wood is one of the wastes dumped by sawmills, and inadequate length of sawn timber materials fail to fully utilize the wood supply. Finger joint, a method that connects two small pieces of timber, is identified as a sound technique to minimize wastage. Different timber species should be bonded at the finger joint production process for making finger-jointed mixed boards. When mixing the different timber species, timber pieces should be matched based on the mechanical strength. This study was, therefore, conducted to find the strength properties of mixed finger-jointed timber species of wood, namely, Grandis (*Eucalyptus grandis*), Jack (*Aartocarpus heterophyllus*), Kumbuk (*Terminalia arjuna*) and Pine (*Pinus caribaea*), commonly used in Sri Lanka in the manufacture of furniture. The tests were carried out on timber samples with 19 mm finger lengths made of two sections bonded with an adhesive containing polyvinyl acetate (PVAc). The tensile strength and variation of the flexural strength of the finger length of the samples were studied. BS 373: 1957 was the standard used for the flexural tests. A Universal Testing Machine (UTM 100 PC) was used for the mechanical tests. Timber combination categories are not significantly different for the MOR tests. Pine-Pine vs. Pine-Grandis combination category is significantly different for Bending tests. According to overall results, timber combination categories are significantly different for the tensile tests except for Pine and Kumbuk combinations. The findings of this study will directly benefit the finger joint manufacturers in Sri Lanka.

Keywords: Combinations, Finger joint, Mixed timber, Strength

Introduction

Timber is one of the oldest building materials in Sri Lanka and is widely used in furniture manufacturing. When using timber in the construction and furniture manufacturing industry, waste timber material and short-length sections of timber dumped by sawmills are considered a matter of concern (Muthumala *et al*., 2020). Waste-sawn timber material from Furniture factories and short lengths of sawn wood are common problems in the timber industry in Sri Lanka. The shorter section of timber dumped by sawmills is a considerable factor because of the scarcity of timber. However, some wasted wood is used to fuel the kiln-dried boiler (Muthumala *et al*., 2018a). Joining timber is another option in utilizing waste timber.

Sawmills must make full use of the timber they process as off-cuts, a type of waste, are produced when timber is processed. One major issue faced by the timber industry is the waste generated during the production of sawn timber and the short lengths of sawn timber produced during furniture manufacture. However, some of this waste timber is used as a source of fuel in the ovens used in bakeries and the boilers used in sawmills (Ofosu *et al*., 1996). This timber waste can be minimized by using the finger-jointed technique to join pieces of timber. Using this technique, timber planks, trimmings, and edgings produced as waste in sawmills can be sustainably made into finger-jointed boards and furniture.

Finger joints are interlocking end joints that can join two sections of timber; they are made by machining several similarly tapered symmetrical fingers at one end of each of the two timber sections. The two sets of fingers made with finger joint cutters are subsequently bonded together (BS EN 15497, 2014). Polyvinyl acetate (PVAc) is one of the most common adhesives used by furniture factories in their non-structural applications. The PVAc can produce strong and durable bonds on hardwood and hardwood-derived products used in furniture manufacturing. The PVAc adhesives are not generally recommended for joints under continuous loads and when used at high temperatures and/or high humidity levels (Jokerst, 1981; Sellers *et al*., 1988).

Muthumala *et al*. (2018a; 2018b) investigated the factors affecting the glue strength of finger joints in the timber of wood species commonly found in Sri Lanka. They identified PVA–SWR as the best PVA glue for non-structural finger joint products and investigated the geometric relationships among the finger length, finger pitch, fingertip thickness, and finger slope of the finger joints. The finger joint technology (Jokerst, 1981) can expand timber production in Sri Lanka. Furthermore, using this technology will ensure the maximum utilization of timber, thereby minimizing pressure on forest resources. Most customers value the uniqueness and attractiveness of finger-jointed products and are, therefore, willing to pay more for these products (Muthumala *et al*., 2019a). This study assessed the combination effect of different mixed finger-jointed timber species with flexural and tensile tests.

Materials and Methods

Wood materials:

For the experimental purposes, the samples of timber commonly used for furniture manufacturing in Sri Lanka were made from four species of wood (Table 1) collected from two provinces in the country.

Table 1. Wood species selected for the study

Common name	Scientific Name*
Grandis	*Eucalyptus grandis*[1]
Jack	*Aartocarpus heterophyllus*[2]
Kumbuk	*Terminalia arjuna*[2]
Pine	*Pinus caribaea*[1]

* 1 - Central Province, 2 - Southern Province

Adhesives:

The adhesive used in the samples was SWR containing polyvinyl acetate (PVAc). Muthumala *et al*. (2018b) found that PVAc-SWR has the highest glue strength among the adhesives used in Sri Lanka for finger joints. The PVAc is a thermoplastic polymer widely accepted in the adhesive industry as a raw material (Ayhhan and Fatih, 2007). The average weight of PVAc is 1.1 kg/L. The adhesive SWR was applied to one surface of each section of the timber samples. It was produced and supplied by PIDILITE, a firm in Mumbai, India (Pidilite Technical Data Sheet, 2018).

Determination of moisture content:

The samples, each 20 mm x 20 mm x 20 mm in size, were first weighed and then oven-dried at 103 °C until constant weight. The moisture content (r) of each sample was determined using Equation 1.

$$r = \frac{M_r - M_0}{M_0} \times 100 \quad \text{--------------------------------} \quad \text{Equation 1}$$

Where, r is the moisture content of the sample (%), M_r is the moist weight of the sample, and M_0 is the fully dried mass of the sample.

Preparation of the test samples:

Timber samples for each wood species were prepared by cutting seasoned timber planks. The samples were obtained from the heartwood portions of timber planks and had an average moisture content of 12 ± 3 %. Each sample of the same species was cross-cut into two identical pieces using a circular saw machine and joined using the adhesive. Each sample of the wood, 300 mm (length) × 20 mm (height) × 20 mm (width) in size, had a finger length of 19 mm and vertically oriented joints, while the samples of the second set, which had exact dimensions as the samples of the first set, had vertically oriented joints with two different timber species. The assembling pressure was 6 MPa (Castro and Paganini, 1997). All the samples were made at the finger jointing factory of the State Timber Corporation in Galle, Sri Lanka. Figure 1 and Table 2 show the dimensions of the finger joints. The experimental set up for the specimens with finger-joints is illustrated in Figure 2.

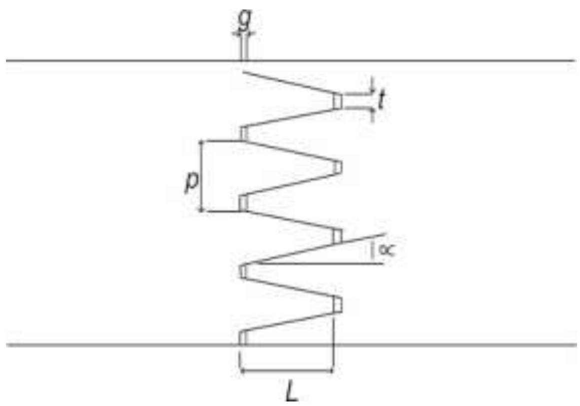

Figure 1: Geometric parameters of the finger joint: L = finger length (mm), t = tip width (mm), P = pith (mm), α = slope angle°, g = gap

Table 2. Finger profiles selected for the finger joints

Specimen type	Finger Length (L) (mm)	Tip width (t) (mm)	Pitch (P) (mm)	Slope angle° (α)	Gap (g) (mm)
1 - clear					
2 - Finger-joint	19	1	4	7	0.5

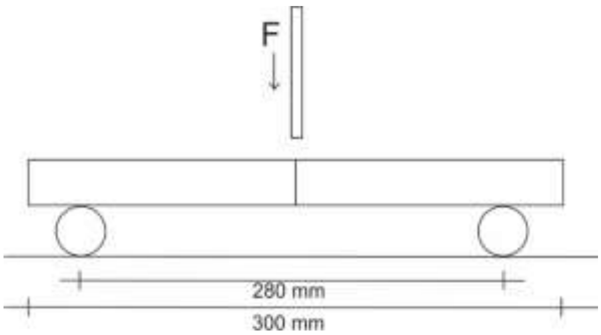

Figure 2. Experimental set up of specimens with finger joints (F)

Testing was done under laboratory and manufacturing conditions as required by British standards (BS 373:1957). The set up for the bending test is illustrated in Figure 3. The structural performance of the samples that were kept for two weeks at average room temperature (27 °C) was better than that of the dry samples (35 °C) and wet samples (16 °C) (Vivek *et al*., 2016). The tests were conducted at the Wood Science Laboratory of the State Timber Corporation, Sri Lanka. Flexural tests were conducted on the samples using a Universal Testing Machine (UTM-100), which had its loading plate moving at 2 mm/min for the flexural test and 1 mm/min for the tensile test. The average density and moisture content of each sample were obtained before the load was applied to them by the UTM. The mixed timber specimens used for the tensile test is illustrated in Figure 4.

Figure 3. The set up for the bending test

The Modulus of Rupture (MOR) and Bending Strength (BS) of each of the samples were calculated using Equations (2) and (3). The tensile test was carried out using the Equation 4. The statistical analysis was done using the SPSS computer software at p=0.05.

$$\text{Modulus of Rupture (MOR)} = \frac{3FL}{2bd^2} \quad \text{……….} \quad \text{Equation 2}$$

Where, F= Maximum Force (N), L = Length of the span (mm), b = Width of the specimen (mm) and d = Depth/Thickness of the specimen (mm)

$$\text{Bending Strength (BS)} = \frac{FL^3}{4\delta bd^3} \quad \text{……….} \quad \text{Equation 3}$$

Where, F= Maximum load at proportionate stage (N), L= Length of the beam between supports (mm), b = width of the specimen (mm), d= Depth/ Thickness of the specimen (mm) and δ= Maximum deflection (mm).

$$\text{Tensile Test (TT)} = \frac{\text{Maximum force}}{\text{Average cross section area of specimen}} \quad \text{……….} \quad \text{Equation 4}$$

(a) (b)

Figure 5. Mixed timber specimens for tensile test (a) mixed panel (b) same spp. panel

Results and Discussion

Regarding the strength values of timber specimens, the MOR values varied from18.04 to 27.3 N/mm^2, bending values varied from 10.89 to 14.56 N/mm^2 and the tensile values are varied from 10.01 to 18.61 N/mm^2 (Table 3). According to statistical analysis, timber combination categories are not significantly different for the MOR tests (P>0.05). Only Pine-Pine vs. Pine-Grandis combination showed a significant difference for the Bending test (P=0.010). For the Tension test, Pine-Pine vs. Pine-Grandis, Pine-Pine vs. Pine-Jack, Grandis-Grandis vs. Pine-Grandis and Jack-Jack vs. Pine-Jack showed significant differences (P = 0.043, 0.024, 0.029 and 0.000, respectively) (Table 4). Strength-based timber classification system has been introduced by several researchers to assist finger-joint timber manufacturing (Muthumala *et al.*, 2019b).

Table 3. Average means strength values with timber combinations (N/mm^2)

Test	Combination of timber species	Strength/Stiffness of combination 1 x 2*	Combination Timber piece 1 x 1 (same spp)	Combination Timber piece 2 x 2 (same spp)
Modus of Rupture (MOR)	Pinus[1] - Kumbuk[2]	20.47	21.52	27.30
	Pinus[1] - Grandis[2]	22.03	21.52	25.78
	Pinus[1] - Jack[2]	18.04	21.52	20.32
Bending Strength (BS)	Pinus[1] - Kumbuk[2]	13.95	10.89	12.52
	Pinus[1] - Grandis[2]	14.56	10.89	12.71
	Pinus[1] - Jack[2]	12.74	10.89	10.71
Tension Test (TT)	Pinus[1] - Kumbuk[2]	13.96	12.96	13.88
	Pinus[1]-Grandis[2]	10.49	12.96	18.39
	Pinus[1]-Jack[2]	10.01	12.96	18.61

* 1 x 1 = combination of the same timber species combined; 1 x 2 = combination of two timber species

Table 4. Probability levels of statistical analysis of different finger-jointed timber combinations

Different timber combinations	Modus of Rupture (MOR)	Bending Strength (BS)	Tension Test (TT)
Pine-Pine vs. Pine-Kumbuk	0.619	0.358	0.625
Pine-Pine vs. Pine-Grandis	0.948	0.01	0.043
Pine-Pine vs. Pine-Jack	0.183	0.086	0.024
Kumbuk-Kumbuk vs. Pine-Kumbuk	0.206	0.696	0.755
Grandis-Grandis vs. Pine-Grandis	0.10	0.152	0.029
Jack-Jack vs. Pine-Jack	0.212	0.132	0.00

Different timber combination categories used in this study did not show significant differences for the MOR tests that compared the strength values of finger-jointed specimens with same species. Pine-Pine *vs* Pine-Grandis combination category showed a significant difference for the Bending tests. The overall results showed that the timber combination categories used were significantly different for the tensile tests except for Pine and Kumbuk combination with respect to finger joint.

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