Evaluation of the failure modes of the finger-jointed timber species for utilization of waste timber

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Abstract

Off-cut wood pieces are often dumped by sawmills as they are considered to be wastes in the wood industry. A certain portion of timber has to be removed also due to inadequate length of sawn timber material. Finger jointing technique is used to eliminate wood defects which weaken the strength of sawn wood plank and unused short pieces can even be used for obtaining defect free longer lengths of timber. A study was undertaken to evaluate the tensile strength performance and major failure modes of the finger-jointed productions. A finger profile of 13 mm finger length, 4 mm pitch and 1 mm tip width were used in the study. The sections were joined using PVAc adhesive. BS 373: 1957 and BS EN 15497:2014 were used as standards for tests. The test for tensile properties were performed using Universal Testing Machine (UTM 100 PC) with loading plate moving speed of 01mm/min. Load vs. displacement variation was obtained and maximum load was identified to calculate ultimate tensile strength for evaluating the major failure modes. Density and major finger joint failure modes were also investigated.

The major failure mode of the finger- jointed seven timber species subjected to a tensile test was mainly due to glue line failure (47.14%), followed by wood grain failure (24.28 %) and fiber failure(15.71%). The least failure mode was recorded as weak finger joint (12.85 %). The highest mean finger joint strength was obtained from Grandis (50.23 N/mm^2) timber species and least mean finger joint strength was recorded in Kumbuk (16.88 N/mm^2) timber species. There is no considerable relationship between Density and the failure occurrence of finger-jointed timber species. This results would be benefited for finger-jointed furniture manufacturing industry for sustainable use of wood waste.

Keywords: Finger joint, tensile strength, Failure mode, Glue line failure

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I. INTRODUCTION

Timber is an excellent material for use in roofs and other construction works, furniture, interior decorations, doors, window frames, paneling, partition boards, floorings, wood carvings and musical instruments etc [1]. Nearly 450 species of wood are found in the forests in Sri Lanka, and the timber made from this wood is used in both structural and non-structural applications.

Timber is a renewable natural resource, which can effectively reduce climate change. Timber processing generates enormous amounts of timber residues and these timber residues can be used to lessen the effects of climate change [2]. Trees sequester carbon during their life, pulling carbon dioxide (CO_2) from the atmosphere and storing it in their mass. For every kilogram of wood grown, 1.5 kg of CO_2 is removed from the atmosphere [3]. Storing CO_2 in wood could therefore be considered as an effective means of mitigating climate change, though wood also releases CO_2 when they used t as fuels [4]. Quantitative characteristics and behavior of timber are determined by its mechanical properties. These mechanical properties are important because they can significantly influence the performance and strength of the timber used in structural applications [5]. The strength of wood used for timber depends on the species of the wood and the effects of some of the growth characteristics of the wood [6].

Off-cut wood is currently one of the wastes dumped by sawmills and as they failed to fully utilize the wood supply. Waste sawn timber material of furniture factory and short length of sawn timber are also big problem in timber industry. However, some of this wasted wood is already being used as fuel wood for boilers in sawmills and also for bread baking. To further suggest ways to minimize the waste, by applying a jointing system, this utilizes the finger- jointed techniques. Using this method, waste timber planks, trimmings and edgings can be used as Finger- jointed boards and furniture in sustainable way.

Finger joint is a sustainable, eco-friendly and economically viable concept for furniture industry. It ensures the sustainable utilization of small wood cut pieces which removed as waste [7]. Engineered wood, including finger joint lumber, can meet the new demands and is recognized as providing a high quality, dependable and cost-effective alternative to traditional building products [8].

The finger joint timber manufacturing is considered to be a viable solution for minimizing the waste generation in furniture manufacturing activities. Type of glues applied for the joining process of finger joint is one of the key factors which determine the strength of the product.
This study was undertaken to determine the major failure modes of the finger- jointed timber species under tensile test. Finger length of 13 mm is commonly used finger type in Sri Lankan furniture manufacturers.

MATERIALS AND METHODS

For the experimental tests, samples made of timber that is commonly used in Sri Lanka and collected from the southern and central provinces of Sri Lanka were made from the following species of wood (Table 1).

Table 1. Wood species selected for the study

Common name	Botanical name
Grandis	*Eucalyptus grandis*[1]
Jack	*Aartocarpus heterphyllus*[2]
Kumbuk	*Terminalia arjuna*[2]
Mahogany	*Swietenia macrophylla*
Pine	*Pinus caribaea*[1]
Satin	*Chloroxylon swietenia*[2]
Teak	*Tectona grandis*[2]

1-Central Province, 2-Southern Province

Finger- jointed samples were prepared from defects free sawn wood timber to calculate tensile strength properties. Finger joint specimens were made at finger joint factory at Boossa in the State Timber Corporation (STC). Finger-jointed timber specimens were made with constant finger geometry as 13 mm Finger Length, 1 mm Tip width, Tp gap 0.5 mm and 4 mm finger pitch. Finger joint geometry is shown in Figure 1.

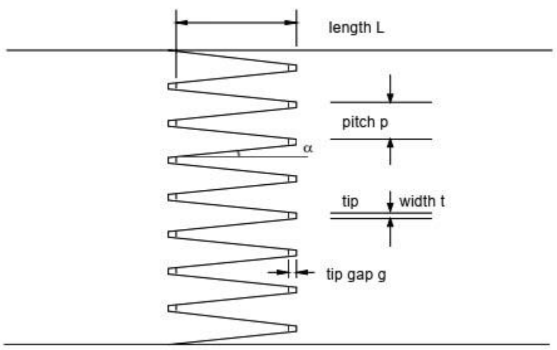

Figure 1. Geometric parameters of finger joint

(L is the finger length, B is the tip thickness, S is the tip gap, P is the pitch, α is the slope, and H is the finger depth).

The highest mean tensile strength was obtained from PVAc-SWR glue type used in finger joint production in Sri Lanka. [9,10]. Glue was applied in one face of joint. Thus, polyvinyl acetate (PVA) adhesive was used as bonding agent (Glue type) for finger- jointed samples. Assembling pressure of 6 MPa was used in this study according to recent finger joint study by Min-ChyuanYeh et al.(2011) and Juvonen [11,12].

The specimens were prepared defects free heart wood sawn woods and dimensions of the sample prepared for tensile tests shown in Figure2.

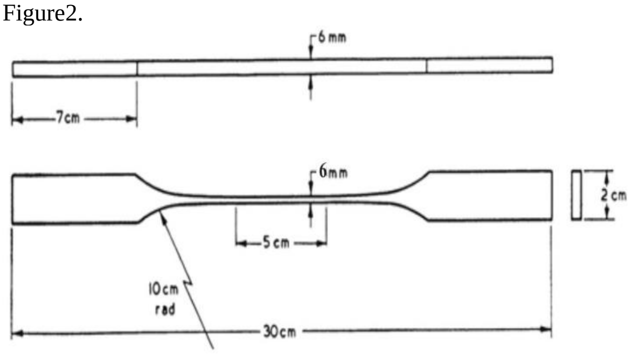

Figure 2. The dimensions of the samples prepared for tension test.

The density values were calculated for seven timber species using following equation (Eq. 01). Dry weight of the timber samples was taken by placing in 105^{0}C at the electric oven for period of 48 hours [13].

$$\text{Density} = \frac{\text{Weight of oven dry wood (kg)}}{\text{Volume of wood (m}^3\text{)}} \qquad \text{(Eq – 01)}$$

Determination of basic density was done based on the green volume and oven-dry weight using a water displacement method. Moisture contents were measured using moisture meter.

Ten replicates were made for each timber species. Samples which were placed in normal room temperature conditioned showed good structural performance compared to hot and wet conditioned [14]. BS 373: 1957 and BS EN 15497:2014 were used as standards for tests. [13,15]. The test for tensile strength were performed by Universal Testing Machine (UTM 100 PC) Experimental setup was shown in Figure 3.

Figure 3. Experimental set-up of tensile test

Determination of the Tensile strength

Maximum load act in timber section was taken into calculation. Equation 2 was used to calculate the Tensile strength.

Tensile strength of timber

$$= \frac{\text{Maximum Load}}{\text{Average cross section area of specimen}} \text{N/mm}^2$$

(Eq – 02)

RESULTS AND DISCUSSION

Table 2 presents the Density values of seven timber species at 12 % moisture content level.

Table 2. Dry density values of timber species

Timber species	Density (kg/m^3)
Grandis	570 ± 5
Jack	645 ± 3
Kumbuk	750 ± 4
Mahogany	570 ± 3
Pine	460 ± 2
Satin	975 ± 5
Teak	720 ± 5

The average densities of the seven species of wood in their descending order were 975 kg/m^3 for Satin; 750 kg/m^3 for Kumbuk ; 720 kg/m^3 for Teak ;645 kg/m^3 for Jack, 570 kg/m^3 for Grandis ; 570 kg/m^3 for Mahogany and 460kg/m^3 for Pine.

The failure modes of the finger-jointed timber species subjected to the tensile test were placed into 4 categories in this study; Finger broken, Glue line failure, wood grain failure and fiber failure.

Table 3. Failure occurrence of finger-jointed timber species

Timber species	Finger broken %	Glue line failure %	Wood grain failure %	Fiber failure %	Mean Strength (N/mm^2)
Grandis	10	40	50	-	50.23
Jack	20	30	20	30	36.06
Kumbuk	30	-	60	10	16.88
Mahogany	-	50	10	40	35.77
Pine	20	70	-	10	17.04
Satin	10	80	10	-	21.13
Teak	-	60	20	20	36.48
Total %	12.85	47.14	24.28	15.71	

The highest mean tension strength was Grandis, significantly lower than all other species. Grandis finger joint specimen shows the highest average tensile strength followed by Teak, Jack, Mahogany, Satin, Pine, while the lowest was the Kumbuk. It was also noted that finger-jointed Kumbuk samples failed in tension not due to in glue line failure but also other failure modes: 60 % wood grain failure, 30 % finger broken failure and 10 % fiber failure. The major reasons for failure of Satin finger-jointed samples were glue line failure (80 %). Singh et al (2016) was conducted research, to assess the tensile strength of finger jointed sections of *Eucalyptus spp*. and average value of maximum tensile stress of finger jointed samples is 23.5 N/mm^2 [16]. But present study shows average value of maximum tensile stress of finger jointed Grandis is 50.23 N/mm^2. Similar trends was reported by Awan et al.(2012) as maximum tensile stress value for *E. camaldulensis* was 59.93 N/mm^2 [17].

According to Table 3, finger-jointed timber specimens failed in tension with different modes depending on the wood species. There were 47.14 % of finger-jointed specimens that failed due to glue line failures (Figure 4) followed by 24. 28 % of wood grain failure and 15.71 % of fiber failure and 12.85 % of finger broken failure. The major reasons for failure of finger-jointed timber species were glue line failure except, Kumbuk.

Figure. 4. Glue line failure of the finger-jointed specimen under tensile test

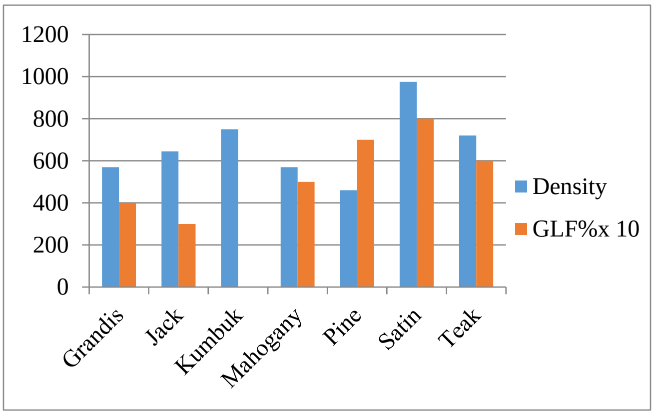

Figure. 5. Relationship between Density and the Glue line failure (GLF) %

Relationship between density and the glue line failure is shows in Figure 5. According to the Fig. 4, there is no considerable relationship between Density and the failure occurrence of finger-jointed timber species. A previous research study revealed that denser woods have more fibers per unit area, but the influence of other natural or anatomical characteristics of the wood can interfere, in order it's not possible to say that relationship between density of the piece influences on tensile strength is a rule for all wood species [18]. The another previous research study was done by Min-Chyuan Yeh et al. (2011) based on the broken-finger failure mode, emphasized that there was no difference between horizontal and vertical joint formation of finger-jointed lumber [11]. To minimize glue line failure, usage of sharp saw blades and remove dust from joint surfaces can be used, because precise and clear finger cuts are very important for finger joint production.

CONCLUSIONS

According to the results following conclusion can be drawn from this study.

The major failure mode of the finger- jointed seven timber species subjected to a tensile test was mainly due to glue line failure (47.14%), followed by wood grain failure (24.28 %) and fiber failure (15.71 %). The least failure mode was weak finger joint (12.85 %).

The highest mean finger joint strength was obtained from Grandis (50.23 N/mm^2) timber species and least mean finger joint strength was recorded in Kumbuk (16.88 N/mm^2) timber species. This results will find of this study useful for industrial application and help to produce high quality finger joint production using waste timber planks.

It is suggested that usage of sharp saw blades and remove dust from joint surfaces is necessary to improve the structural performance of the finger-jointed lumber, because precise and clear finger cuts are very important for high strength and quality finger joint production.

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