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FINGER JOINTING OF THERMALLY COMPRESSED OIL PALM WOOD

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ABSTRACT: Finger jointing performance of thermally compressed (TC) oil palm wood was explored. TC_oil palm wood was manufactured from low (TC_LD) and medium (TC_MD) density wood, and the same type of wood samples were then finger jointed with two different finger orientations; vertical and horizontal fingers. During finger profiling, fracture of finger tips was found in TC_LD specimen, and the number of fractured fingers in the vertical finger specimen was higher. Finger jointed TC_MD had higher tensile strength than finger jointed TC_LD. Vertical finger gave higher tensile strength, and the strength increase was more pronounced in TC_MD specimen due to its finger was intact. However, the finger joint's strength was found to be relatively low compared with the tensile strength of solid specimens. The loss of tensile strength of TC_LD joint was larger than that of TC_MD joint due to the presence of fractured fingers in TC_LD occurred during finger profiling stage. Characteristic value of vertically profiled finger jointed TC_LD was found to be lower than that of horizontally profiled finger jointed TC_LD, which showed the opposite trend to that of the mean values, resulting from the presence of the larger number of fractured fingers in vertically profiled finger jointed TC_LD.

KEYWORDS: Thermally compressed oil palm wood, finger joint, tensile strength, finger joint efficiency

1 – INTRODUCTION

Oil palm tree is one of the important economic crops widely planted around tropical zone for the production of oil palm fruits. A total of global planted area of oil palm tree is approximately 15 million hectares, and most of them are distributed in South East Asia [1]. After approximately 25 to 30 years of its cultivation where the yield of oil palm fruits become relatively low, oil palm tree is generally disposed either by injecting the toxic chemical substance (pesticide) into the trunk and leave the standing tree die in the plantation area or by felling the trees and burn them out. Approximately 150 cubic meter oil palm trunk biomass is estimated to be disposed each year globally [2]. This have caused a large amount of cost to plantation's owner without any economic return from this biomass, and also results in a negative impact to environment.

With abundant of oil palm trunk biomass, many attentions have considered oil palm wood as raw material for wood industry [3-6]. However, utilization of this wood material for further processing of wood products is challenging. Oil palm wood has a large variation in properties due to varying amount of fiber cells, major cell supporting the mechanical performance of oil palm wood, within a trunk. [1, 7, 8]. Basically, high density wood has more fraction of fiber cell but lower fraction of parenchyma cells, and also higher strength [1, 8]. On average, strength of oil palm wood is relatively low compared with that of typical softwood/hardwood species commonly used for structural application, as well as wood-based products (i.e., particleboard) used for furniture production [9-11]. To utilize this wood material for wood composite products either for non-structural or structural applications, its properties should therefore be firstly improved.

Recently, Tomad et al. [12] has successfully improved the properties of oil palm wood for a whole trunk using thermal compression (TC). They found that material characteristic and properties of the resulting wood was dependent on original wood density and compression ratio used in the thermal compression process. Thermally compressed wood manufactured from low density wood (191-350 kg/m^3) at a compression ratio of 40% have shown potential for non-structural application. For TC_wood manufactured from medium density wood (350-530 kg/m^3) at compression ratio of 25%, however, its strength was found to be greater than ones manufactured from low density wood, and its application for structural application has been confirmed. Thus, further research to promote the utilization of TC_oil palm wood for wood-based products is worth to be done.

Generally, wood jointing is needed to be performed in the manufacturing process of wood-based products to increase the width or the length of the final products as desired [13]. For adhesive bonded joint, end jointing (to increase the length) is more difficult than lateral jointing (to increase the width) due to poor bonding ability of wood material in longitudinal direction of wood grain [13, 14]. Thus, there are various kinds of end jointing techniques have been used to join wood pieces together such as plain scarf joint, butt joint and finger joint [13, 14]. From the joint performance and manufacturing process efficiency (i.e., loss of wood material during cutting wood for jointing and production rate)

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perspectives, finger jointing outperforms the most [14]. Thus, finger jointing of TC_oil palm wood material was focused in this work.

2 – BACKGROUND

Finger joint is one of the most widely used end-jointing techniques for achieving a longer piece of lumber for non-structural and structural applications. The finger joint quality is affected by the factors categorized in two groups: material characteristics (i.e., annual ring orientation, moisture content and wood species, adhesive formulation) and manufacturing process (i.e., adhesive application method, finger profile, profiling speed, clamping pressure) [15-19]. Finger joint strength could reach approximately 90% of the solid wood's strength parallel to grain if the optimum material characteristic and manufacturing process were used [13-14].

The material characteristics of thermally compressed (TC) oil palm wood recently studied by Tomad et al. [3] were different from that of TC softwood (or hardwood). It was reported that TC-oil palm wood manufactured from medium density wood at 25% compression ratio had more uniform density profile along the thickness (i.e., vertical density profile) and higher mechanical properties than ones manufactured from low density wood at 40% compression ratio. The vertical density profile would result in wood's strength variation along the thickness, which consequently could affect the quality of finger profile as well as finger joint strength. Thus, in this work, the influence of the thermal compression on the horizontal and vertical finger jointing performance was experimentally evaluated.

3 – MATERIALS AND METHODS

3.1 PREPARATION OF FINGER JOINTED TC_OIL PALM WOOD SPECIMEN

Oil palm with low (190-350 kg/m^3) and medium (350-530 kg/m^3) density was thermally compressed at 40% and 25% compression ratios, respectively to 27 mm thick boards, denoted as TC_LD and TC_MD, respectively, using the method described in Tomad et al. [12]. After thermal compression process, these samples were kept in conditioning room at temperature and relative humidity of 20 °C and 65%, respectively for about one month. The average density of TC_LD and TC_MD at the time of finger jointing process were 369 ± 74 kg/m^3 and 551 ± 52 kg/m^3, respectively.

Two TC-oil palm wood specimens of the same type (TC_LD or TC_MD), each had dimensions of 27 mm (thick) × 100 mm (width) × 160 mm (length), was finger jointed (Finger profile was shown in Fig. 1; finger length (L) = 12 mm, tip thickness (t) =0.9 mm, finger pitch (p) =4.1 mm) with two finger orientations; vertical and horizontal fingers (Fig. 2a and 2c), using finger jointing machine (YNF-16L., Taiwan) at the Center of Excellence in Wood and Biomaterials, Walailak University. Polyurethane adhesive was applied to profiled fingers and jointed at a clamping pressure of 0.25 MPa for 30 seconds in accordance with the suggestion from the local rubberwood finger jointing industry. After finger jointing process, the finger jointed samples were kept in a conditioning room for about one week, and subsequently cut and sanded to obtain the specimen with the final dimensions of 25 mm (thick) × 100 mm (width) × 305 mm (length) as shown in Fig. 2a and 2c.

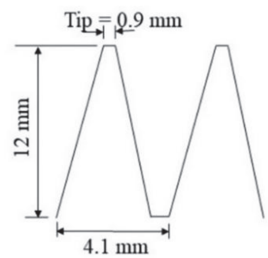

Figure 1. Finger profile used in finger jointing process.

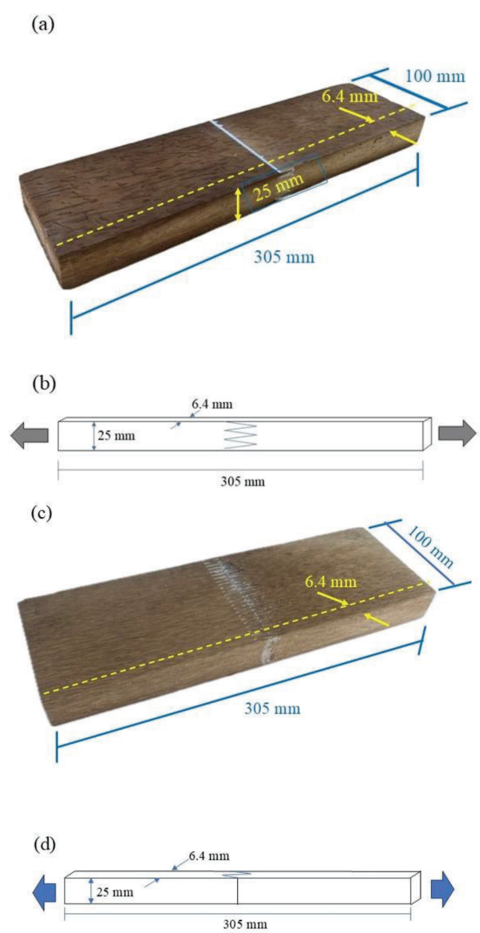

Figure 2. (a,b) Horizontally finger-jointed thermally compressed oil palm wood and the tensile test specimen and (c,d) vertically finger-jointed thermally compressed oil palm wood and the tensile test specimen.

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3.2 TENSILE TEST OF FINGER JOINTED SPECIMEN

For each finger jointed wood type, 30 tensile test specimens with dimensions of 25 mm (thick) × 6.4 mm (width) × 305 mm (length) were prepared as shown in Fig. 2b and 2d. Also, the specimens of the same size and amount from solid TC_LD and TC_MD were prepared for the test as a control. Thus, a total of 180 specimens were tested. The tensile test specimen was loaded using the constant cross head speed of 5 mm/min until fracture in accordance with ASTM D 4688 [20]. Tensile strength of finger joint (FJT) or solid wood (ST) was then calculated using the following equation.

$$\text{FJT or ST}=\frac{F_{max}}{A} \tag{1}$$

where, F_{max} is the maximum tensile force and A is cross sectional area of the test specimen. The characteristic values of TC oil palm were derived based on nonparametric 5th percentile values with 75% confidence in accordance with the ASTMD 2915 standard [21].

3.3 DETERMINATION OF FINGER JOINT EFFICIENCY

The term "Finger joint efficiency" is basically used to evaluate the performance of wood jointing by comparing its strength to that of solid wood (un-jointed specimen) [14]. For tensile strength property, finger joint efficiency (FJE) is determined from the ratio of tensile strength of finger jointed wood product (FJT) to the tensile strength of solid wood (un-jointed specimen) (ST), using the following equation:

$$\text{FJE}=\frac{\text{FJT}}{\text{ST}}\times 100 \tag{2}$$

4 – RESULTS

4.1 QUALITY OF FINGER PROFILE

The profiling quality of the horizontal and vertical fingers of TC oil palm is shown in Figs. 3 and 4, respectively. Regardless of the finger orientations, the TC_LD finger profile tips were fractured followed by tear-out, while TC_MD finger profiles were intact. These observations can be explained by the anatomical features of oil palm. As the stiffness and strength of vascular bundles are significantly larger than that of parenchyma cells in oil palm wood [1], a greater resistance capacity against knife-cutting force is expected by vascular bundles. Hence, an abrupt change in the strength and stiffness of wood cells might induce the relatively high stress concentration around the interface zone of the two cells during the knife passing through them, and have caused the fracture of the parenchyma cell, which has relatively low strength [1]. Thus, the high parenchyma cell-to-vascular bundle ratio of low-density oil palm contributed to the fracturing of the tips of the TC_LD finger profiles.

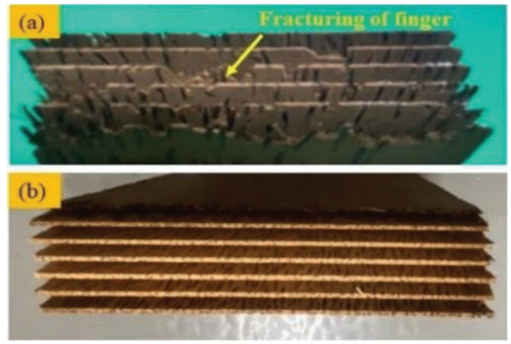

Figure 3. Appearance of fingers after horizontal finger profile cutting: (a) thermally compressed oil palm wood manufactured from low-density wood (TC_LD) and (b) thermally compressed oil palm wood manufactured from medium-density wood (TC_MD).

Figure 4. Appearance of fingers after vertical finger profile cutting: (a) thermally compressed oil palm wood manufactured from low-density wood (TC_LD) and (b) thermally compressed oil palm wood manufactured from medium-density wood (TC_MD).

4.2 FAILURE MODE OF FINGER JOINTED SPECIMEN AFTER TENSILE TEST

Examination of the tensile test specimen revealed that the horizontally profiled finger specimen failed by three main types of failure modes; i) failure initiated at the joint and progressively away from the joint (Figure 5a), ii) failure occured mostly along the joint profile but with some failure at the finger roots (Figure 5b), and iii) failure occurred at the finger roots, which were a result of tensile and shear forces (Fig. 5c). It was also observed that the shear failure of the fingers was observed from the inner region of the specimen, where its density was lower than the outer region [12].

For vertically profiled finger specimen, two types of failure modes were observed; i) failure occurred at the finger joint roots and with high overall wood failure (Fig. 6a), and ii) failure occurred mostly along the joint profile but with some failure at the finger roots, especially the outermost layer finger roots (Figure 6b). The first failure mode type was observed only in TC_LD specimen. The lower number of intact fingers of TC_LD specimen might promote this type of failure mode due to lower tensile resistance capability. For the second type failure modes, it was observed only in TC_MD specimen.

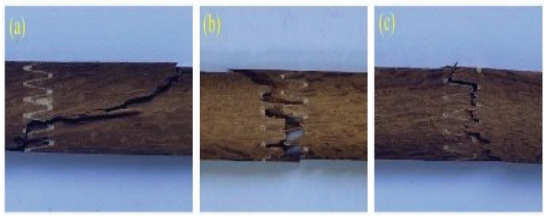

Figure 5. Failure modes of horizontal finger specimen after tensile test.

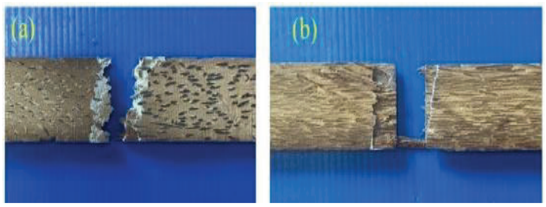

Figure 6. Failure modes of vertical finger specimen after tensile test.

4.3 TENSILE STRENGTH OF FINGER JOINT

The calculated average tensile strengths (TS) of finger jointed TC_LD and TC_MD were 4.8 ± 1.1 MPa and 11.2 ± 1.7 MPa, respectively for horizontally profiled finger specimens and 5.8 ± 2.4 MPa and 19.5 ± 4.1 MPa, respectively for vertically profiled finger specimens (See Fig. 7). The TS of finger jointed TC_MD was higher for both finger orientations due to higher tensile and shear strengths of TC_MD sample [12]. In addition, it was also noticed that finger orientation seemed to notably affect the tensile strength of finger jointed specimen as well. As can be seen in Fig. 7, tensile strength of vertically profiled finger specimen appeared to be higher for both types of specimens. This result was correspondent with the result of Ahmad et al. [22], who found that bending strength of vertically profiled finger hardwood specimens was higher than that of the horizontally profiled finger specimen. This observation might be due to the different failure modes observed in both types of specimens (horizontal or vertical fingers) as well as the differences of the surface properties of finger gluing area. For horizontal finger specimen, when the first crack was initiated around some fingers (with less side surface area of finger compared with that of the vertical finger), the crack propagated to some extent which caused the other fingers to lose the load carrying capacity. For vertical finger specimen, wood failure was observed over the whole glued surface area of the finger after the test (See Fig. 6b). More effective shear resistance along the finger joint bond lines of the vertically profiled specimens resulted in achieving higher tensile strength than the horizontal finger specimens.

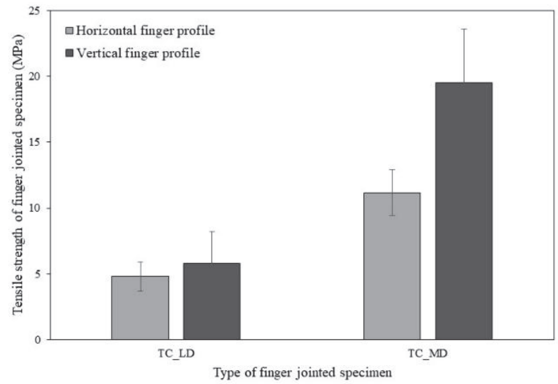

Figure 7. Tensile strength of horizontally and vertically profiled finger jointed TC_LD and TC_MD specimens.

Fig. 8 shows the characteristic value of horizontally and vertically profiled finger specimens' tensile strength for both type of specimens (TC_LD or TC_MD). The characteristic values of horizontally and vertically profiled finger specimens' tensile strength were 2.9 MPa and 1.8 MPa, respectively for TC_LD and were 8.0 MPa and 13.6 MPa, respectively for TC_MD. Notably, the characteristic value of vertically profiled finger TC_LD specimen was lower than that of horizontally profiled finger TC_LD specimen, which was in contrast to the trend of the mean tensile strength (See Fig. 7). The higher number of the fractured fingers in vertically profiled finger might have caused a huge reduction in tensile strength of this type of specimen. However, the characteristic value of TC_MD specimen showed the similar trend to that of the mean tensile strength; it was higher for vertically profiled fingers.

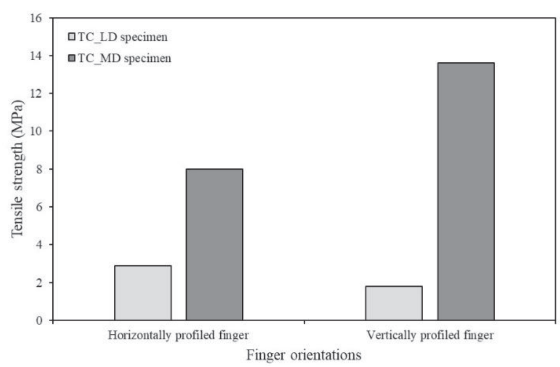

Figure 8. Characteristic value of horizontally and vertically profiled finger specimens' tensile strength.

4.4 FINGER JOINT EFFICIENCY

Fig. 9 shows finger joint efficiency (FJE) calculated using equation 2 of all specimens examined. It was found that the vertically profiled finger specimen manufactured from medium density wood (TC_MD) showed higher FJE due to its higher tensile strength (See Fig. 7). The FJE of the vertically profiled finger jointed specimens were 40% for TC_LD and 44% for TC_MD, and the FJE of the horizontally profiled finger specimens were 48%

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for TC_LD and 76% for TC_MD (See Fig. 9). This indicates that the tensile strength of all finger jointed specimens was lower than that of the corresponding solid TC specimen. In other words, finger jointing has caused the loss of tensile strength with respect to the original wood. As the wood's shear strength is much lower than its tensile strength [12], the shear failure can reduce the tensile strength of finger jointed wood if the effective glue-joint area is not large enough to provide the required shear resistance for reaching the tensile strength of solid wood [23]. Based on the works reported in literature, the effective glue-joint area (EGJ) could be calculated from the finger length (L) and the finger pitch (p) using the following equation [14]

$$EGJ=\frac{2L}{p} \tag{3}$$

By substituting the finger length (L = 12 mm) and the finger pitch (p = 4.1 mm) of the finger profile used in this work (see Fig. 1) the calculated effective glue joint area was found to be 5.9, which was lower than that of the recommended value (8 to 10) for typical wood species [14]. Thus, the effective glue-joint area of the finger profile used in this work might be not sufficient to withstand the shear force to achieve the tensile strength of the solid wood.

Also, since the parenchyma cell's strength is relatively low, it might be possible that there might have some micro-cracks generated along the cells during finger profiling, and manufacturing process of the finger jointed products, which resulted in reducing the tensile strength of the joint. For TC_LD specimen, the machining parameters should be optimized to avoid fracturing of fingers, as fractures hinder the fingers' capability of transferring tensile stress between the jointed pieces.

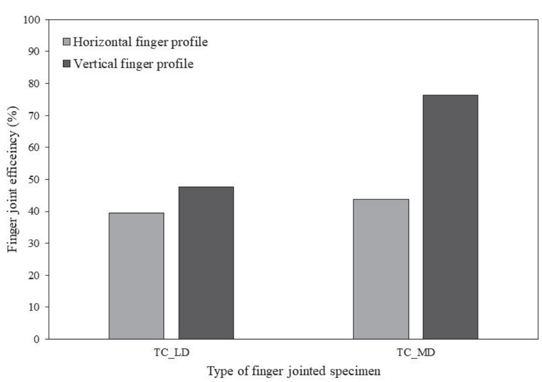

Figure 9. Finger joint efficiency of horizontally and vertically profiled finger specimens.

5 – CONCLUSION

The conclusion can be drawn as follow:

- Thermal compression affected the quality of finger of TC_LD specimen only, which might be due to the strength gradient of the wood cells have caused the relatively high stress concentration around the interface of wood cells, causing the fracture of the relatively low strength parenchyma cell.
- Tensile strengths of finger jointed TC_oil palm wood was affected by its original density and finger orientation. Higher density TC-oil palm wood and vertically profiled finger specimen gave higher the joint's tensile strength.
- The tensile strengths of finger jointed products were lower than that of the un-jointed ones. The loss of the tensile strength due to finger joint of TC_LD was larger than that of TC_MD, which might be due to the fractured fingers observed in TC_LD hindered its capability in transferring tensile stress.
- The characteristic value of vertically profiled finger joints of TC_LD was lower than that of the horizontally profiled finger joints, which might be due to the presence of the larger portion of the fractured fingers.

Based on the overall result, it is suggested that finger jointing performance of TC-oil palm wood should be improved. Investigating the optimum manufacturing parameters is recommended for the future research.

6 – ACKNOWLEDGEMENT

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7 – REFERENCES

[1] L. Fathi. "Structural and mechanical properties of the wood from coconut palms, oil palms and date palms." Doctoral dissertation. University of Hamburg, 2014.
[2] V. Kurz. "Drying of oil palm lumber: State of the art and potential for improvements." Master thesis. University of Hamburg, 2013.
[3] N. A. Nordin, O. Sulaiman, R. Hashim, N. Salim, M. Sato and S. Hiziroglu. "Properties of laminated panels made from compressed oil palm trunk." In: Composites Part B: Engineering 52 (2013), pp. 100 – 105.
[4] S. Srivaro, N. Matan and F. Lam. "Performance of cross laminated timber made of oil palm trunk waste for building construction: a pilot study." In: European Journal of Wood and Wood Products 77 (2019), pp. 353 – 365.
[5] A. Nuryawan, J. Sutiawan, Rahmawaty, N. Masruchin and P. Bekhta. "Panel products made of oil palm trunk: a review of potency, environmental aspect, and comparison with wood-based composites." In: Polymers 14.9 (2022).
[6] S. Jantawee, H. Lim, M. Li, J.K. Oh, Z. Pasztory, H. Cho and S. Srivaro. "Developing structural sandwich panels for energy-efficient wall applications using laminated oil palm wood and rubberwood-based plywood/oriented strand board." In: Journal of Wood Science 69.35 (2023).
[7] V. Erwinsyah. "Improvement of Oil Palm Wood Properties using Bioresin" PhD thesis. Technische Universitat Dresden, 2008.

[8] S. Srivaro, J. Rattanarat and P. Noothong. "Comparison of the anatomical characteristics and physical and mechanical properties of oil palm and bamboo trunks." In: Journal of Wood Science 64 (2018), pp. 186 – 192.
[9] A.N. Haslett. "Suitability of oil palm trunk for timber uses." In: Journal of Tropical Forest Science (1990), pp. 243 – 251.
[10] S. Srivaro, N. Matan, and F. Lam. "Property gradients in oil palm trunk (Elaeis guineensis)" In: Journal of Wood Science 64 (2018), pp. 709 – 719.
[11] C.A Senalik, and B. Farber. "Mechanical properties of wood: In: Wood handbook—wood as an engineering material. General Technical Report FPL-GTR-282. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 2021.
[12] J.Tomad, S. Srivaro, H. Lim, M. Li, M, and J.K. Oh. "Characteristic properties of thermally compressed oil palm wood and its potential for glued laminated timber products." In: Industrial Crops and Products 216 (2024).
[13] C.R. Frihart, and C.G. Hunt. "Wood adhesives: Bond formation and performance" In: Wood handbook—wood as an engineering material. General Technical Report FPL-GTR-282. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 2021.
[14] R.W. Jokerst "Finger-jointed wood products" US Department of Agriculture, Forest Service, Forest Products Laboratory (1981)
[15] Z. Ahmad, W.C. Lum, S.H. Lee, M.A. Razlan, and W.H.W. Mohamad. "Mechanical properties of finger jointed beams fabricated from eight Malaysian hardwood species." In: Construction and Building Materials 145 (2017), pp. 464-473.
[16] R. Shuzhan, G. Meng, Y. H. Chui, and M. Mohammad. "Effect of end pressure on performance of structural finger-joined lumber fabricated using a short joint profile" In: European Journal of Wood and Wood Products 72.1 (2014), pp. 143-145.
[17] D. Tsalagkas, Z. Börcsök, and Z. Pásztory. "The effect of finger length and adhesive type on the curing time of finger-jointed black pine (Pinus nigra L.) lumber" In: Wood Material Science & Engineering 16.5 (2021), pp. 312-320.
[18] M. Sciomenta, J.L. Vihmann, E. Tuhkanen, A. Just, and M. Fragiacomo. "The effects of timber species and adhesive type on the behavior of finger joints in tension under fire conditions." In: Construction and Building Materials 448 (2024).
[19] H. Stolze, and H. Militz. "Tensile and Bending Strength of Birch and Beech Lamellas Finger Jointed with Conventional and Newly Developed Finger-Joint Profiles." In: Materials 17.20 (2024).
[20] ASTM D 4688 "Standard Test Method for Evaluating Structural Adhesives for Finger Jointing Lumber". ASTM Annual Book of Standboards. ASTM International, West Conshohoken, 2021.
[21] ASTM D 2915 "Standard practice for sampling and data-analysis for structural wood and wood-based products" ASTM Annual Book of Standboards. ASTM International, West Conshohoken, 2021.
[22] Z. Ahmad, W.C. Lum, S.H. Lee, M.A. Razlan, and W.H.W. Mohamad. "Mechanical properties of finger jointed beams fabricated from eight Malaysian hardwood species." In: Construction and Building Materials 145 (2017), pp. 464 – 473.
[23] S. Rao, M. Gong, Y.H. Chui, and M. Mohammad. " Effect of geometric parameters of finger joint profile on ultimate tensile strength of single finger-joined boards." In: Wood and Fiber Science (2012), pp. 263 – 270.

 https://doi.org/10.52202/080513-0097