Quest Journals
Journal of Architecture and Civil Engineering
Volume 9 ~ Issue 9 (2024) pp: 111-124
ISSN(Online) : 2321-8193
www.questjournals.org

Research Paper

Burma Padauk Timber Column Strengthening with Typical Box Built-Up under Compression-Parallel-to-Grain Load

Phattaraphong Ponsorn
Department of Civil Engineering, Faculty of Engineering, Rajamangala University of Technology Krungthep, Bangkok 10120, Thailand
Corresponding Author

ABSTRACT: *This study investigated and presented the results of strengthening short stub columns made from Burma Padauk timber using three different timber sizes and three distinct timber types. The strengthening method employed a typical box-built-up configuration, where four equal-sized timbers were adhered to all four surfaces of the column. A total of 12 short stub columns were tested under compression-parallel-to-grain loading. Compressive strength was measured at a 0.05% strain offset, and the failure modes observed in all specimens were documented and analyzed. Interestingly, the compressive load capacity was not significantly affected by the three wood types (Burma Padauk, Tabek, and Teak) representing hardwood, medium hardwood, and softwood, when the total cross-section area remained constant. However, an increase in the total cross-sectional area of the strengthening did lead to a noticeable increase in the compressive load capacity. The observed failure modes were crushing for Burma Padauk and Tabek timbers, while the strengthened softwood timber (Teak) exhibited a combination of crushing with wedge splitting and crushing with compression and shearing parallel to the grain.*

KEYWORDS: *Burmese Padauk, Hardwood, Timber Short Column, Strengthening Built-Up, Compression-Parallel-to-Grain.*

R*eceived 13 Sep., 2024;* ***R****evised 25 Sep., 2024;* ***A****ccepted 27 Sep., 2024 © The author(s) 2024.*
P*ublished with open access at* ***www.questjournas.org***

I. INTRODUCTION

Burma Padauk, also called Mukwa or Narra, is a tree species of Pterocarpus macrocarpus [1], related to Pterocarpus indicus [2], as in a scientific genus of Pterocapus [3]. Burma Padauk is a medium to large size tree growing to 10 to 30 m tall, and mostly native in southeast Asia countries such as Thailand, Myanmar, Loas, Vietnam and Cambodia. Some species in the West Africa is also known as African rosewood, but it is confusingly not alike to Siamese rosewood [4], true rosewood nor Padauk [3]. Since it was abundant in the regions, Burma Padauk tree has long been trended to be prepared, see Figure **1**, for usage as structural members in building constructions. Not only the abundance of the tree, its mechanical properties is as well in a good approval of consideration in most timber standards to be met with the desired load requirement in buildings.

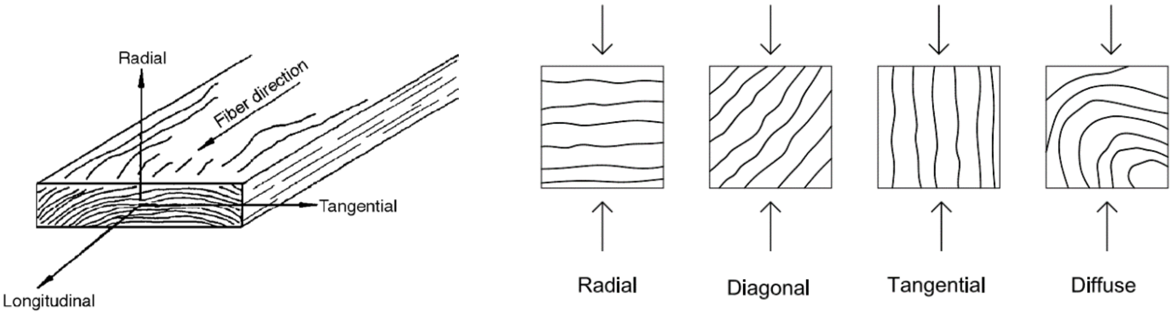
Timber design or wood design is a sub-discipline of civil engineering that relied on the strength and wood properties. It is depended on a variety of factors that correspond to moisture content, the temperature at serviceability, the number of holes, the knot number and size. The direction of wood grain, principally, makes timber an orthotopic material, which its axially engineering properties are unequalled depended on the considered axes of longitudinal, radial and tangential of wood. In civil engineering design standards, timber can be classified by species and grouped into grades of hardness, then was designed according to the methods of allowable stress design and load or resistance factor design. The physical and mechanical properties to be used in the design processes of most timber was given in the codes and standards, but not obviously covered for all wood types, nor including the effects of built-up member with different wood types. Regarding to the southeast Asia abound with the tree species, a set of 12 Burma Padauk timber specimens, provided as short stub columns, was arranged and presented corresponding to the built-up sections varying in sizes and hardness grades of the attached strengthening timbers under compression-parallel-to-grain load test.

II. LITERATURE REVIEW

Wood is an isotopic material for which the mechanical properties, for instance, modulus of elasticity, Poisson's ratio, modulus of rigidity, modulus of rupture, shear, tensile and compressive strength, are unique and independent for each grain direction with respect to the three principal grain axes, as shown in Figure **2**(a), of longitudinal, radial and tangential. The load carrying capacity of a structure is thereby effective to the load direction respected to the direction of grain and the annual growth rings of the wood, as illustrated in Figure 2(b). The strength properties of wood can be different up to 10 times between the strongest and the weakest [5]. There are two methods used for grading the timber strength: visual strength grading, which was inspection by visually observing the timber specimen, for instance, the rate of growth, the knots, the slope of grain, the fissures, the fungal and insect damage, etc; machine strength grading, mostly considered by using nondestructive evaluation, for example, static bending methods, acoustic wave methods, transverse vibration, X-ray CT scanning, proof loading, near-infrared spectroscopy, etc. The wood properties in engineering are generally referred as in the state of green condition, or 12% of moisture content. The informative strength properties of some commercially important woods, respected to grain directions, were given by Forest Products Laboratory for those grown in the region of the United States [6], and Manus Anusiri for those grown in the southeastern region of Asia [7]. The typical failure mode patterns of timber, for instance of compression-parallel-to-grain loading, were normally found as crushing, wedge spitting, shearing, spitting, compression and shearing parallel to grain and brooming or end-rolling failures [8], which were described as in Figure 3. Strength quality of woods can be classified as hardness into categories of softwood to hardwood, however, depending on the standard criterion. In some criterion, a wood hardness category may be considered up to be a higher rank when shielded with wood chemical coating preservation [9]. The reduction of wood properties due to size, direction, angle and location of knots was stipulated in ASTM D245 [10]. Knots, depending to the size effect [11], may likely cause to a specific failure mode of wood specimen in which the possible corelated patterns can be generated [12]. Connection holes can affect the likelihood of brittle failure under tension parallel-to-grain load [13, 14], alter failure modes [15], and can be designed by adopting the proposed models [16-18]. Under parallel-to-grain loading, softwood was also found to be sensitive to seismic loads [19]. In 2000, a series of Southern Pine very short column of varying built-up box section sizes subjected to axial load, squash load test, was conducted to find the effect of the box sizes [20]. The study mentioned that benefit of the built-up box section can increase the squash load up to approximately 7 times. The additional found on the study was that the use of the smaller dimension timbers to make the large built-up column section was the advantage. The increase of the temperature caused the decrease of compression-parallel-to-grain load due to the change of wood fiber and the loss of the moisture content [21]. In 2012, a set of Maritime Pine specimens was adopted to the experiment to acquire the longitudinal modulus of elasticity by implementation of stereovision measurement comparing with the result from conventional attached strain gauges [22]. The comparison shown that the stereovision method gave the results similar to the strain gauge one, but with less scattering deviation. The innovative application of the high strength properties such as glass fiber reinforced polymer (GFRP) to the axial-compression-load column found that the ultimate load and stiffness can be improved [23]. As well as the use of carbon fiber reinforced polymer (CFRP) material to strengthen the long timber column, by wrapping particularly at the weak spot of the middle column length, as ear hoop, can improve the axial compression behavior of the timber column [24]. The repair and reinforcement of timber column by using fiber reinforced polymer (FRP) also shown that the mechanical properties of the element were enhanced [25]. In addition to the elevation of temperature changes, some timber kinds, for instance Paulownia wood, will affect significantly large deformation when undergone the temperature higher than 180˚C [26].

(a) (b) (c) (d)

Figure 1: Burma Padauk: (a) tree [2], (b) leaves and flowers [1], (c) Trunk [2] and (d) timber [3].



(a) (b)

Figure 2: Wood annual growth rings and grain direction: (a) Three grain principal axes [6] and (b) Load direction with respect to annual growth rings orientation [27].

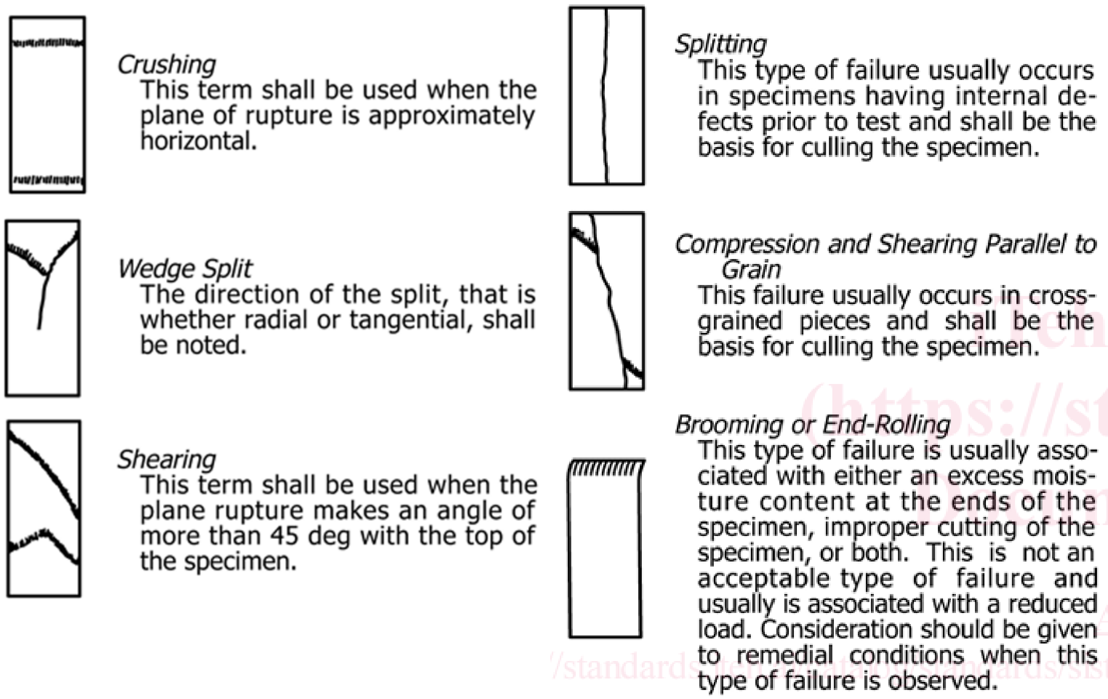
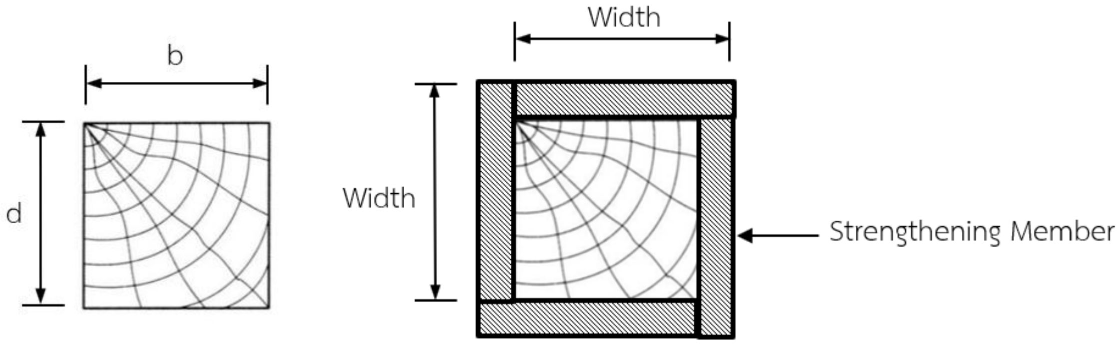


Figure 3: Description of failure mode patterns of timber caused by compression-parallel-to-grain test [8].

III. PREPARATION OF SPECIMENS

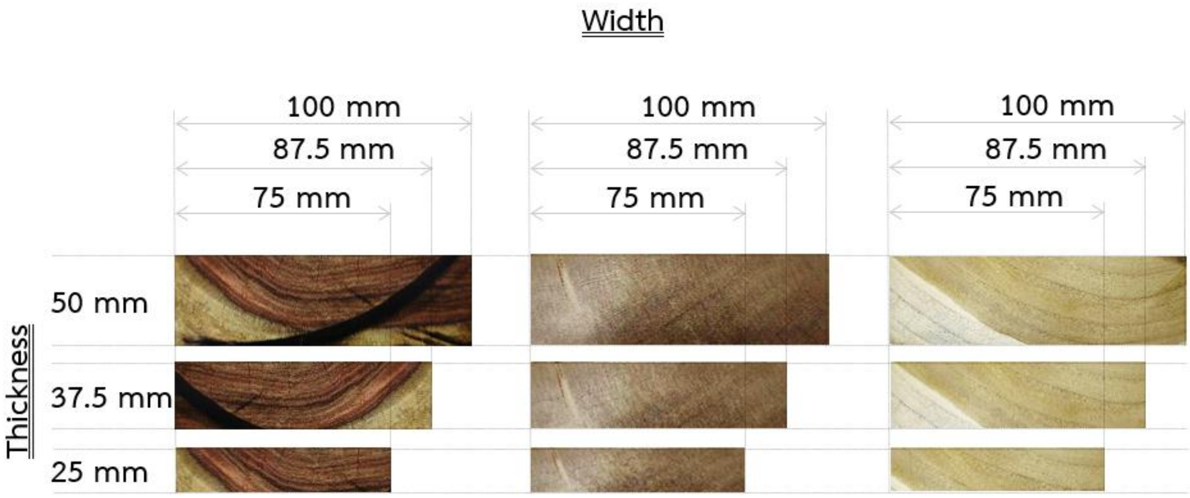
In this study, all the 15 Burma Padauk timber specimens have been prepared as two main groups of unstrengthening and strengthening, which the latter was varies with the timber hardness grades and the sizes of built-up member. The original group, the unstrengthening timber specimen, represented to the short stub column, was shown in Figure 4 with 50 mm width, 50 mm depth and 200 mm length, according to standard specification for compression-parallel-to-grain test [8]. For the strengthening group, the original unstrengthening timber specimens, 50x50x200 mm in dimensions, were strengthened by strong bond adhesion of four equally built-up members as typical box column, see Figure 5, which they were varied with three timber harness grades and three cross-section sizes. The three types of wood species, that is Burma Padauk, Tabek and Teak, and the three sizes of cross section dimensions, 25x75 mm, 37.5x87.5 mm and 100x50 mm, for the built-up members to be strengthened were shown in Figure 6. The three types of the strengthening built-up member were also listed as in Table 1, including of engineering properties [7] for Burma Padauk, Tabek and Teak, for the ranks of hardwood, medium wood and softwood, respectively. The nomenclature of the timber specimens is illustrated in Figure 7, in which the first position C represented to unstrengthen and Cs strengthen, the second position 1, 2 and 3 represented to the built-up wood types shown in Table 1, and the last three-digit position represented to the testing specimen order 001 to 012. Details and dimensions of all 12 strengthening built-up timber specimens were shown in Table 2, including the total cross-section area.

Figure 4: Burma Padauk timber specimen 50x50x200 mm: (a) top view and (b) perspective view.



(a) (b)

Figure 5: Timber specimen section: (a) original unstrengthen section and (b) strengthening section of typical box built-up.



(a) (b) (c)

Figure 6: Variation of wood types and cross-section sizes for strengthening built-up member: (a) Buma Padauk wood, (b) Tabek wood and (c) Teak wood.

Table 1: Types and engineering properties of strengthening built-up member.

Symbol Number	Timber Name	Type of Hardness [7]	G.S. [7]	Modulus of Elasticity, MPa [7]	Compression-Parallel-to-Grain, MPa [7]	Compression-Parallel-to-Grain, MPa [9]
1	Burmese Padauk	Hardwoods	0.82	12600.75	48.56	70
2	Tabek	Medium Hardwoods	0.72	11041.74	36.79	52
3	Teak	Softwoods	0.62	8002.31	32.08	49

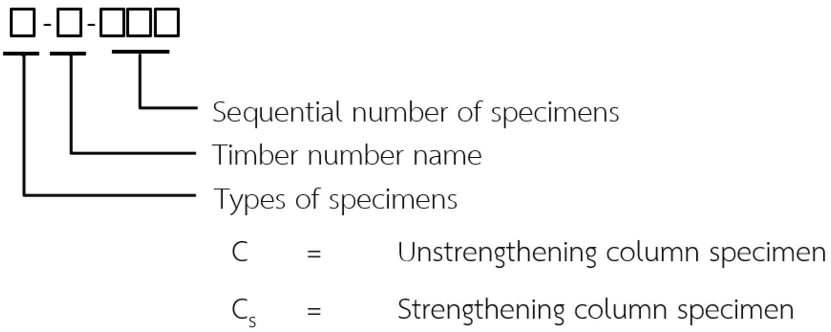


Figure 7: Nomenclature of timber specimens.

Table 2: Details and dimensions of strengthening built-up timber specimens.

Specimens	Strengthening Timber Types	Strengthening Member Size		Total Section Size		Total Section Area, mm^2
		Width, mm	Thickness, mm	Width, mm	Depth, mm	
C - 1 - 001	-	-	-	50	50	2500
C - 1 - 002	-	-	-	50	50	2500
C - 1 - 003	-	-	-	50	50	2500
Cs - 1 - 004	Burmese Padauk	75	25	100	100	10000
Cs - 1 - 005	Burmese Padauk	87.5	37.5	125	125	15625
Cs - 1 - 006	Burmese Padauk	100	50	150	150	22500
Cs - 2 - 007	Tabek	75	25	100	100	10000
Cs - 2 - 008	Tabek	87.5	37.5	125	125	15625
Cs - 2 - 009	Tabek	100	50	150	150	22500
Cs - 3 - 010	Teak	75	25	100	100	10000
Cs - 3 - 011	Teak	87.5	37.5	125	125	15625
Cs - 3 - 012	Teak	100	50	150	150	22500

IV. TESTING OF COMPRESSION-PARALLEL-TO-GRAIN

As of the timber specimens were prepared in accordance with the testing standards [8, 28] mentioned in the preceding section, the testing procedure was as well manipulated. The testing speed was set up to apply at flat end grain surface of the specimen, continuously throughout the test at the rate of 0.003 of specimen length per minute. The load-compression curve was obtained and observed until the proportional curve was well passed. The yield strength of timber was attained by offsetting the elastic linear line which paralleled to the initial elastic line off at 0.05% strain. To be obtained the satisfactory results, the position of failure that developed in the body of the specimen was methodologically observed and recorded. The compression failure at the facture surface was described and analysis in accordance with classification of the failure modes stipulated by the standard. The moisture content was kept at room temperature for all timber specimen.

V. RESULT AND DISCUSSION

A series of 12 Burma Padauk timber strengthening specimens functioned as short column was carried out with compression-parallel-to-grain test in order to report the strength, behavior and modes of failure for the objectives of effectively desired application in building construction. Of all the tested result, the data of total cross-section area, modulus of elasticity, compressive stress, compressive load and modes of failure was shown in Table 3; The 0.05% offset load yielding capacity was plotted as bar chart in Figure 8; The behavior of stress-strain relationship was also plotted in Figure 9. The result and discussion can be stated categorically as in the following sections.

Table 3: Results of Burma Padauk timber specimens strengthening with box built-up under compression parallel-to-grain test.

Specimen	Total Area, mm^2	Modulus of Elasticity, MPa	Compression Parallel-to-Grain, MPa	Compression Load, kN	Observed Failure Modes
C - 1 - 001	2500	6145.33	46.09	115.23	Crushing + Kinking
C - 1 - 002	2500	6004.00	45.03	112.58	Crushing
C - 1 - 003	2500	6204.00	46.53	116.33	Crushing
Cs - 1 - 004	10000	7471.93	42.59	425.90	N.A.
Cs - 1 - 005	15625	6279.37	39.56	618.13	Shearing
Cs - 1 - 006	22500	4635.20	57.94	1303.65	Shearing
Cs - 2 - 007	10000	7185.48	44.55	445.50	Crushing
Cs - 2 - 008	15625	4615.85	37.85	591.41	Crushing + Debonding
Cs - 2 - 009	22500	5407.23	44.88	1009.80	Crushing + Debonding
Cs - 3 - 010	10000	5263.16	50.00	500.00	Crushing
Cs - 3 - 011	15625	5054.74	48.02	750.31	Crushing + Wedge Sprit
Cs - 3 - 012	22500	3407.20	42.59	958.28	Crushing + Wedge Sprit + Compression and Shear

Parallel-to-Grain

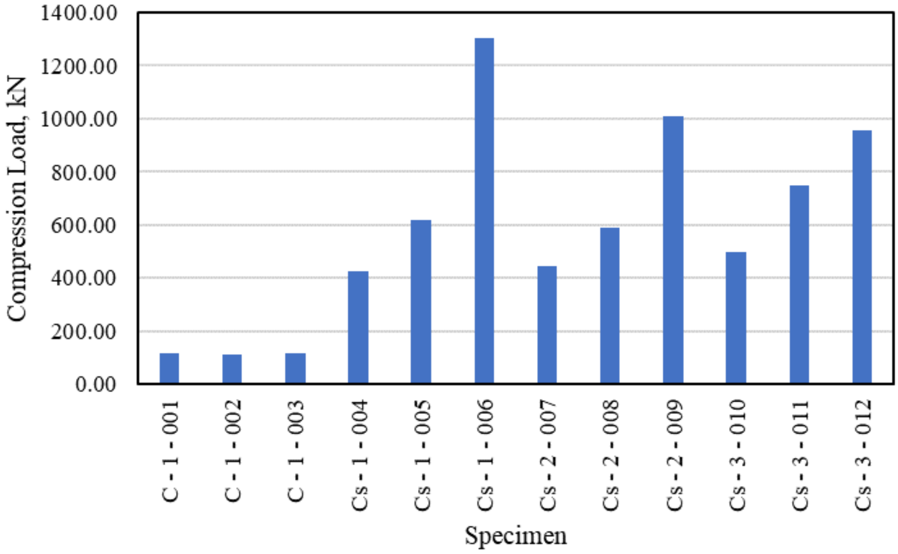


Figure 8: Compression load capacity at 0.05% strain offset under compression-parallel-to-grain test.

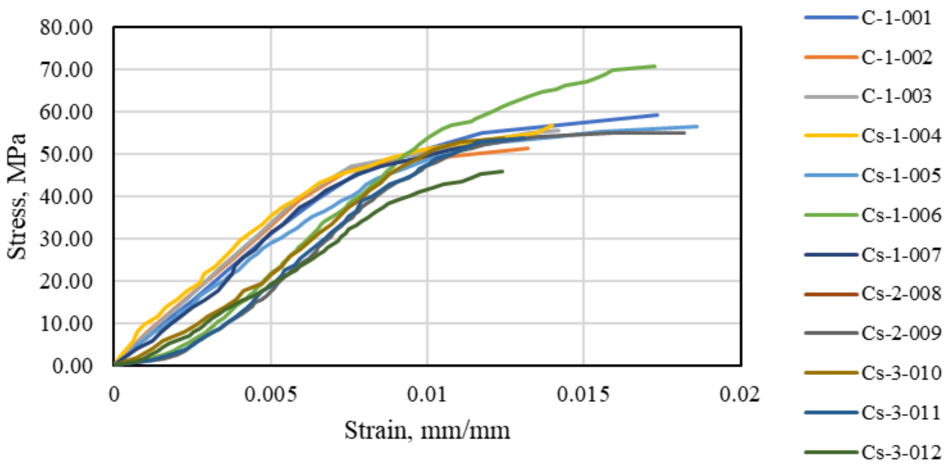
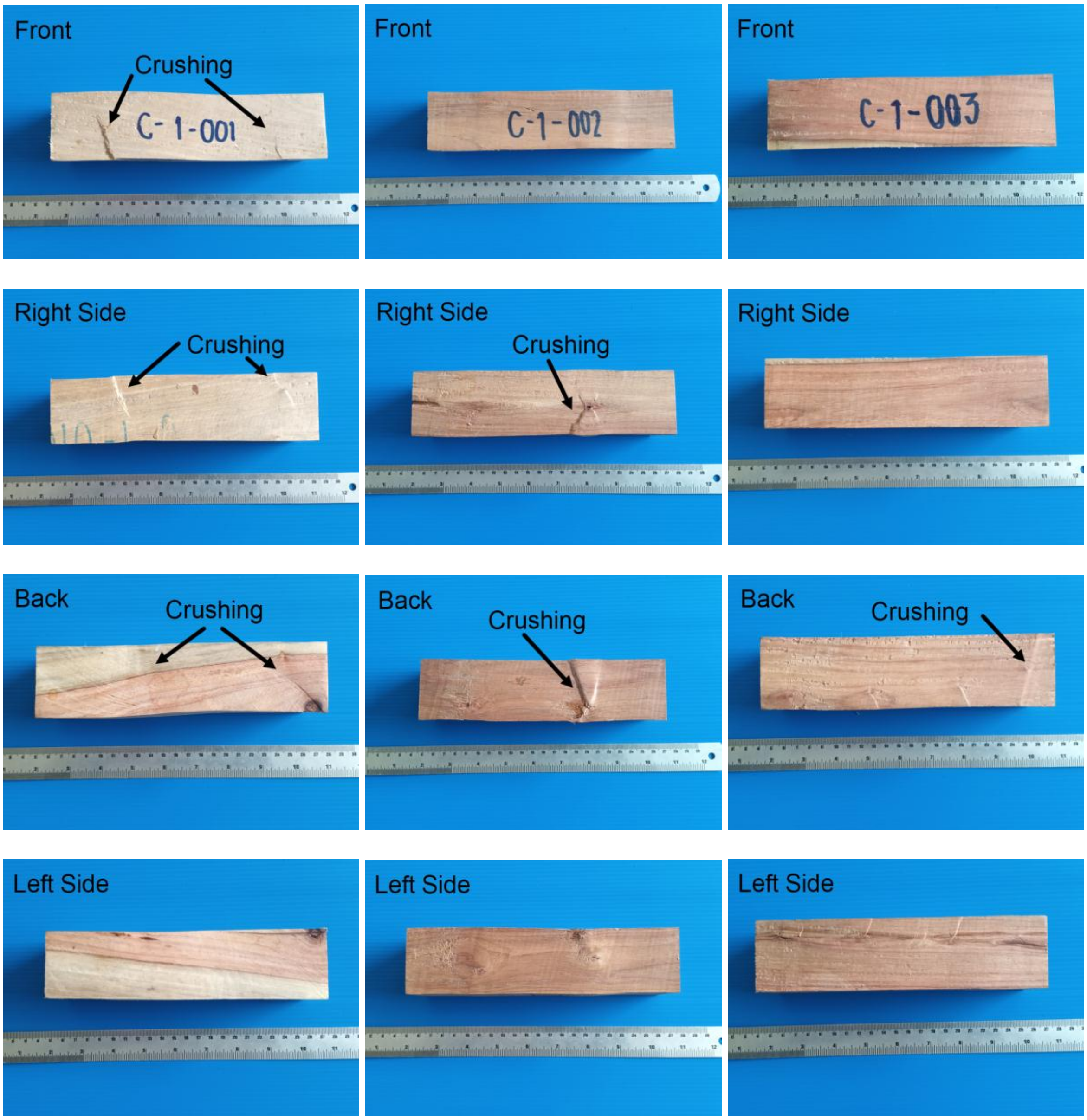
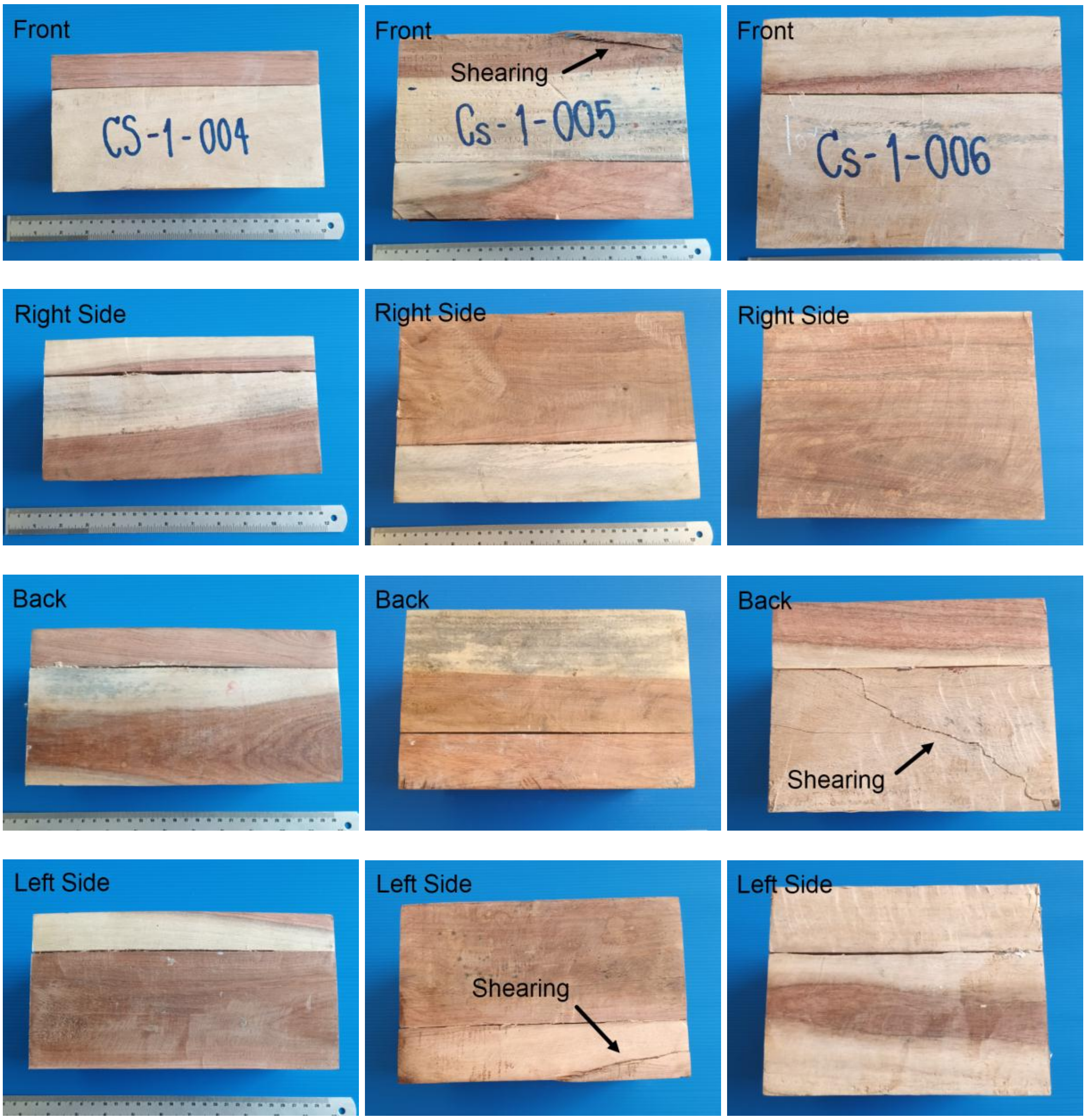


Figure 9: Stress-strain relationship under compression-parallel-to-grain test of 12 specimens.



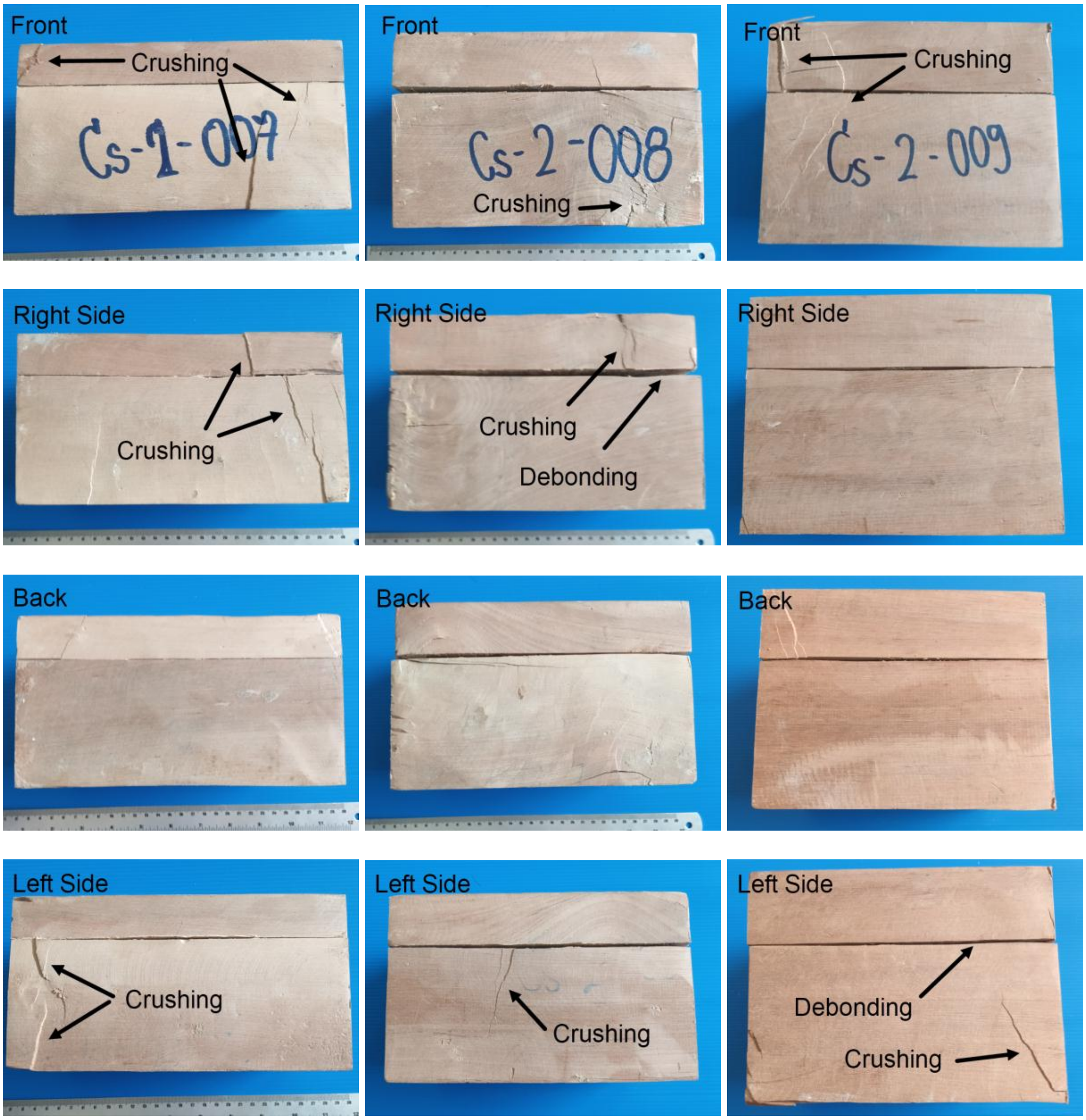
(a) (b) (c)

Figure 10: Results of Burma Padauk timber specimens strengthening with box built-up after compression parallel-to-grain test: (a) C-1-001, (b) C-1-002, (c) C-1-003, (d) Cs-1-004, (e) Cs-1-005, (f) Cs-1-006, (g) Cs-2-007, (h) Cs-2-008, (i) Cs-2-009, (j) Cs-3-010, (k) Cs-3-011 and (l) Cs-3-012.



(d) (e) (f)

Figure 10: Con't



(g) (h) (i)

Figure 10: Con't

(j) (k) (l)

Figure 10: Con't

5.1 Unstrengthening Specimen

The result shows that the three unstrengthening specimens, C-1-001, C-1-002 and C-1-003, the core with the total area solely of 2500 mm2, have modulus of elasticity and 0.05% offset yielding strength in compression-parallel-to-grain averagely at 45.88 MPa and 6117.78 MPa, which were lower than the informative strength properties given in specifications at 48.56 MPa [7] (70 MPa [9]) and 12600.75 MPa [7], respectively. According to typical failure patterns given by standards [8, 28], the failure modes were noticeably observed as a combination of crushing failure and slightly kinking at both upper and lower parts of the first specimen, C-1-001, evidently at front side, right side and back side as shown in Figure 10(a). The failure of second specimen, C-1-002, was occurred as crushing at the know of the wood located at two-fourth length from the top end, see Figure 10(b). The third specimen, C-1-003, was found the failure mode remained as crushing failure occurred at the top end region of the timber specimen, as can be seen in Figure 10(c). The failure mode of the Burma Padauk timber specimens in this study was found mainly on crushing failure when subjected to compression-parallel-to-grain load.

5.2 Strengthening Specimen with Hardwood

Although the stress was as good as the unstrengthen specimen, timber short stub column with the same timber strengthening was found the load bearing capacity at 0.05% offset increased depending on the total section area of the specimen. The strengthening as typical box built-up with four equal timbers around the core, the total area 10000, 15625 and 22500 mm2, for specimens Cs-1-004, Cs-1-005 and Cs-1-006, shown that the 0.05% offset load bearing capacities were increased from the average core of 114.71 kN to 425.90, 618.13 and 1303.65 kN, respectively, depending on the total cross-section area. The failure mode was observed as shearing failure at the strengthening timbers, as can be seen in Figure 10(e) and (f).

5.3 Strengthening Specimen with Medium Hardwood

In strengthening with medium hardwood, Tabek wood, the results found that the 0.05% offset load bearing capacity was, for the distinct cases, reduced respected to the wood grading of hardwood to medium hardwood. The specimen case Cs-2-009 shown that the load capacity reduced by 22.54% from the case of Cs-1-006, 1303.65 to 1009.8 kN, when the total cross-section area was equaled to 22500 mm2. However, in the group of the medium hardwood, the load bearing capacities were larger depending on the total cross-section area. Specimens Cs-2-007, Cs-2-008 and Cs-2-009 had the load bearing capacities at 445.50, 591.41 and 1009.80 kN, for the total cross-section area after strengthening with typical box built-up of 10000, 15625 and 22500 mm2, respectively. Although it was found the debonding failure of the adhesive at specimens Cs-2-008 and Cs-2-009, see Figure 10(g), (h) and (i), crushing failure mode of the three specimen was still in the main pattern for specimen strengthen with Tabek timber.

5.4 Strengthening Specimen with Softwood

The softwood adopted in this group was Teak wood in which the ultimate compression-parallel-to-grain strength was, according to given information [7, 9], lower than Burma Padauk wood by 33.94% to 30%. Due to the lower strength itself, in the case of largest total cross-section area of 22500 mm2, Cs-1-006, Cs-2-009 and Cs-3-012, the 0.05% offset load yielding capacities were found gradually decreasing as 1303.65, 1009.80 and 958.28 kN, respectively; As of percentage, the strength of specimens strengthening with this Teak timbers were reduced down by 22.54% and 5.10%, comparing to the same cross-section area but with Burma Padauk and Tabek timbers. The modulus of elasticity for the specimens Cs-3-010, Cs-3-011 and Cs-3-012 shown slight differences within the group at 5407.23, 5263.16 and 5054.74 MPa, respectively. The failure modes, notably, was observed for specimen Cs-3-010 as crushing failure at two strengthening timbers at which the crushing lines were inconsistent, as can be seen in Figure 10(j). In particular for the specimens Cs-3-011 and Cs-3-012, although the main failure was still crushing, it was also found that there is combinations with wedge spitting and compression and shearing parallel to grain. For instance, the combination of crushing and wedge spitting was found the crushing occurred at the top end of the specimen Cs-3-011 at one of the four strengthening timbers, see Figure 10(k), while the combination with wedge spitting was found at the bottom end at the other one of the strengthening timber; For specimen Cs-3-012, the crushing was found all around the height of strengthening timber along with the development of spitting line and compression and shearing parallel to grain, as shown in Figure 10(l).

VI. CONCLUSION

A study of 12 Burma Padauk timber short columns strengthening in a variation of sizes and wood types was carried out under compression-parallel-to-grain load test. The unstrengthening specimens, sole core timber, shown that the modulus of elasticity, compression-parallel-to-grain stress and load capacity measured at 0.05% strain offset were averagely at 6117.78 MPa, 45.88 MPa and 114.71 MPa, respectively. The results of specimens strengthening as in the configuration of typical box built-up section by four equaled timbers shown that the modulus of elasticity and 0.05% strain offset compressive stress were in some fluctuation but not much different. When the timber specimen was strengthened, the load bearing capacity can be improved depending on the total cross-section area. The Burma Padauk and Tabek timbers represented to hardwood and medium hardwood were found the failure mode was mainly occurred in crushing of the strengthening timbers. While the specimen strengthening with softwood as Teak timber was found that the failure mode was observed as well as occurred at the strengthening timbers but in a combination with crushing, wedge spitting, compression and shearing parallel to grain.

Acknowledgements

The author gratefully acknowledges Mr.Kitti Potiyok and Mr.Jatupong Seehangaw for their valuable contribution to the data and experimental work.

Conflict of interest
The author declares that they have no known competing financial interests of personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution Statement
The author proposed the research problem, conceptualized the experiment, and analyzed the results. The author also discussed the findings and contributed to the final manuscript.

Data Availability
The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

[1] Wikipedia. Pterocarpus macrocarpus. Wikipedia The Free Encyclopedia: Wikimedia Foundation, Inc.,; 2024.
[2] Wikipedia. Pterocarpus indicus. Wikipedia The Free Encyclopedia: Wikimedia Foundation, Inc.,; 2024.
[3] Wikipedia. Pterocarpus. Wikipedia The Free Encyclopedia: Wikimedia Foundation, Inc.,; 2024.
[4] Seemakram W, Suebrasri T, Khaekhum S, Ekprasert J, Aimi T, Boonlue S. Growth enhancement of the highly prized tropical trees siamese rosewood and burma padauk. Rhizosphere. 2021;19:100363.
[5] Arriaga F, Wang X, Íñiguez-González G, Llana DF, Esteban M, Niemz P. Mechanical Properties of Wood: A Review. Forests. 2023;14:1202.
[6] Laboratory FP. Wood handbook: wood as an engineering material: The Laboratory; 1987.
[7] Anusiri M. Theory and Practice of Material Testing in Civil Engineering. V Print (1991) Co Ltd, 23-71-72, Khwang Samae Dum, Khet Bang Khun Thian, Bangkok 10150: SE-EDUCATION Public Company Limited.; 2011.
[8] ASTM. ASTM D143-94 (Reapproved 2000) Standard Test Methods for Small Clear Specimens of Timber. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States: ASTM International; 2000. p. 31.
[9] DPT. 1104-64 Standard for Timber. 218/1 Rama VI Road, Samsennai, Phrayathai Bangkok 10400: Department of Public Works and Town & Country Planning; 2023. p. 15.
[10] ASTM. ASTM D245-00 (Reapproved 2002) Standard Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States: ASTM International; 2002. p. 16.
[11] Totsuka M, Jockwer R, Aoki K, Inayama M. Experimental study on partial compression parallel to grain of solid timber. Journal of Wood Science. 2021;67:39.
[12] ASTM. ASTM D4761-02 Standard Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States: ASTM International; 2002. p. 10.
[13] Yurrita M, Cabrero JM, Quenneville P. Brittle failure in the parallel-to-grain direction of multiple shear softwood timber connections with slotted-in steel plates and dowel-type fasteners. Construction and Building Materials. 2019;216:296-313.
[14] Pavković K, Stepinac M, Rajčić V. Brittle failure modes in reinforced and non-reinforced timber joint with large diameter fastener loaded parallel to grain. Engineering Structures. 2020;222:111104.
[15] Chen G, Jiang H, Yu Y-f, Zhou T, Wu J, Li X. Experimental analysis of nailed LBL-to-LBL connections loaded parallel to grain. Materials and Structures. 2020;53:81.
[16] Yurrita M, Cabrero JM. New design model for brittle failure in the parallel-to-grain direction of timber connections with large diameter fasteners. Engineering Structures. 2020;217:110557.
[17] Yurrita M, Cabrero JM. New design model for splitting in timber connections with one row of fasteners loaded in the parallel-to-grain direction. Engineering Structures. 2020;223:111155.
[18] Tang J-y, Song X-b, Lu Y. An elastic-plastic kinking layer model for parallel-to-grain wood embedment behavior considering wood drilling damage. Engineering Structures. 2023;280:115656.
[19] Xie Q, Zhang L, Zhang B, Yang G, Yao J. Dynamic parallel-to-grain compressive properties of three softwoods under seismic strain rates: tests and constitutive modeling. Holzforschung. 2020;74:927-37.
[20] Harries KA, Petrou MF, Brooks GD. Structural Characterization of Built-Up Timber Columns. Journal of Architectural Engineering. 2000;6:58-65.
[21] Manríquez MJ, Moraes PD. Influence of the temperature on the compression strength parallel to grain of paricá. Construction and Building Materials. 2010;24:99-104.
[22] Xavier J, de Jesus AMP, Morais JJL, Pinto JMT. Stereovision measurements on evaluating the modulus of elasticity of wood by compression tests parallel to the grain. Construction and Building Materials. 2012;26:207-15.
[23] Wang L, Liu W, Hui D. Compression strength of hollow sandwich columns with GFRP skins and a paulownia wood core. Composites Part B: Engineering. 2014;60:495-506.
[24] Li H, Qiu H, Zhao Z, Lu Y. Axial compression behaviour of retrofitted long timber columns. Advances in Structural Engineering. 2018;21:445-59.
[25] Chang W-S. Repair and reinforcement of timber columns and shear walls – A review. Construction and Building Materials. 2015;97:14-24.
[26] Zhang L, Chen K, Xu B, Liu Y, Guo K. Parallel-to-Grain Compressive and Tensile Behavior of Paulownia Wood at Elevated Temperatures. Applied Sciences. 2022;12:12118.

[27] Lourenço PB, Feio AO, Machado JS. Chestnut wood in compression perpendicular to the grain: Non-destructive correlations for test results in new and old wood. Construction and Building Materials. 2007;21:1617-27.
[28] DPT. 1221-1227 Standard Test Methods for Specimens of Timber. 218/1 Rama VI Road, Samsennai, Phrayathai Bangkok 10400: Department of Public Works and Town & Country Planning; 2008.