Master Thesis
M.Sc. Wood Technology

Strength and stiffness properties of Cross-Laminated Timber from fast-growing hardwood plantations in Indonesia

Abstract:

Cross-Laminated Timber (CLT) is manufactured commonly from softwood but nowadays hardwood is also drawing the attention of the wood industries. Indonesia's tropical hardwood plantations are growing very fast and are currently used by the local community as a lightweight and non-structural component. But a noble idea was initiated to convert the resource to a more profitable value-added product. The target of the overall project was to develop a mass-engineered timber components (GLT and CLT) from such species. This thesis concentrated on CLT panels loaded flatwise to predict and investigate the strength and stiffness properties numerically as well as experimentally. The theoretically and analytically estimated values were very close to the experimental bending and shear strength results. The conclusion was that CLT from plantation hardwood timber correspond to a strength class CL24 from softwood material.

Numerical and Experimental

Five layered CLT panels were numerically computed for symmetrical and asymmetrical layer lay-ups by varying stiffness and geometrical parameters. Comparison between layer thickness ratio variation (intermediate to the outer layer and middle to the outer layer ratio) were done to see the correlation and influence for the stress behaviour of CLT. A stress-chart model was also prepared to figure out the stresses without numerical calculations and to predict the failure modes in shear or in bending.

The destructive tensile tests were performed according to the standard EN 408: 2012 on 15 boards without finger joints and 30 boards with finger-joints. Tests on CLT panels according to EN 16351:2015 were conducted in a 4-point bending test on 10 samples each for bending and shear tests.

Results

From the numerical calculations, the main influencing geometrical and stiffness parameters of symmetrical CLT panel loaded flatwise were analyzed (see Table-1). Total thickness of CLT has strong influence on bending and shear stresses whereas span to depth ratio influences strongly to bending stress only. Stiffness variation for boards in the middle layer has very small influence on stresses and effective modulus of elasticity of CLT.

Table-1:Stiffness and geometrical parameters and their influences on bending and shear stress in summary

[MPa]	$\frac{L}{H}$	Thickness				$\frac{t_2}{t_1}$	$\frac{t_3}{t_1}$	Stiffness		
		H	t_1	t_2	t_3			E_1	E_2	E_3
σ_{max}	+ + +	(− − −)	(− −)	(−)	(−)	+ +	+	(−)	0	±
$\tau_{v,max}$	0	(− − −)	(− −)	(− −)	(−)	(− −)	±	+	0	∓

Note ➔ (≤ 5%) ± very small influence, ∓ very small negatively influence, (<10%) + small influence, (<20%) ++ medium influence, (>20%) +++ strong influence and (− − −) strong negatively influence, (− −) medium negatively influence, (−) small influence, 0 no influence

A stress model helps to estimate the stresses and to predict the failure mode. The example in figure-1 demonstrates how to find the expected shear stress for 20 MPa and 30 MPa bending stress at span to depth ratio of L/H=12 and L/H=24 respectively. From the chart a maximum load of around 52.5 KN and a shear stress of 0.560 MPa can be found for an expected 30 MPa bending stress. From these results, it can be concluded that a failure in bending will occur. Tension tests on graded boards indicate a very good correlation between density and dynamic/static MOE. A high correlation between the density and tensile strength was also achieved. Some of the boards were found to have a very high tensile strength. The highest tensile strength was recorded 97.9 MPa. The mean tensile strength of boards with finger-joints was recorded as 23.9 MPa.

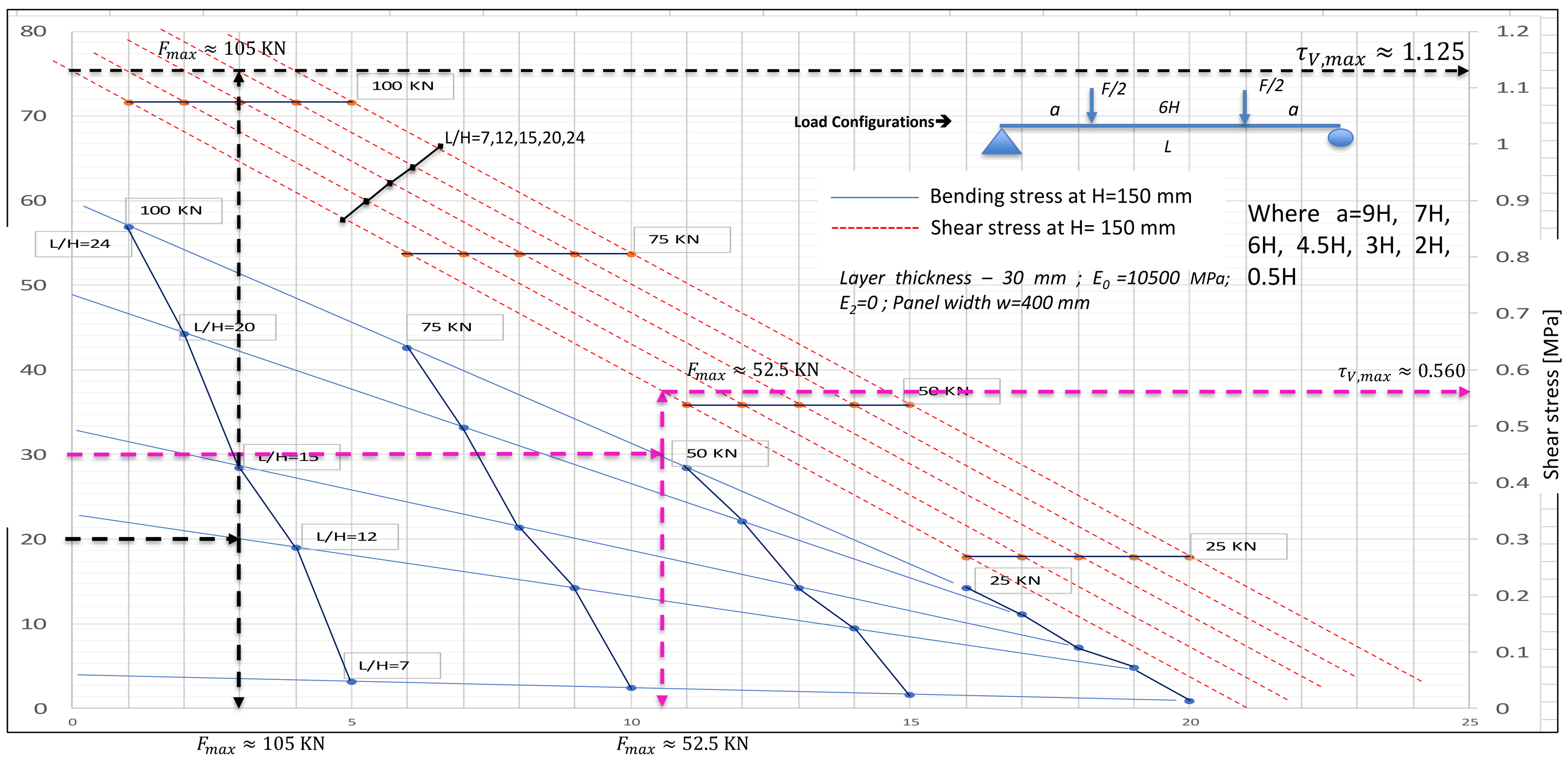

Figure-1:Stress-Chart of 5 layer CLT based on Timoshenko beam theory

Tests on finger-joints showed very low strength compared to the boards without finger-joints.

The bending strength of CLT panels loaded flatwise was attained within the expected strength capacity. The 5%-fractile of bending and shear strength was found $f_{m,clt,05}$=24.55 MPa and $f_{v,clt,05}$=1.57 MPa respectively. The 5%-fractile of the bending strength through the analytical method was also estimated to 24.78 MPa. For CLT from C24 strength class softwood boards, the characteristic bending and shear strength is stated 24 MPa and 1.50 MPa respectively. Therefore, the tropical hardwood species can then be classified to be at least equivalent to C24 to obtain a CLT strength class of CL24.

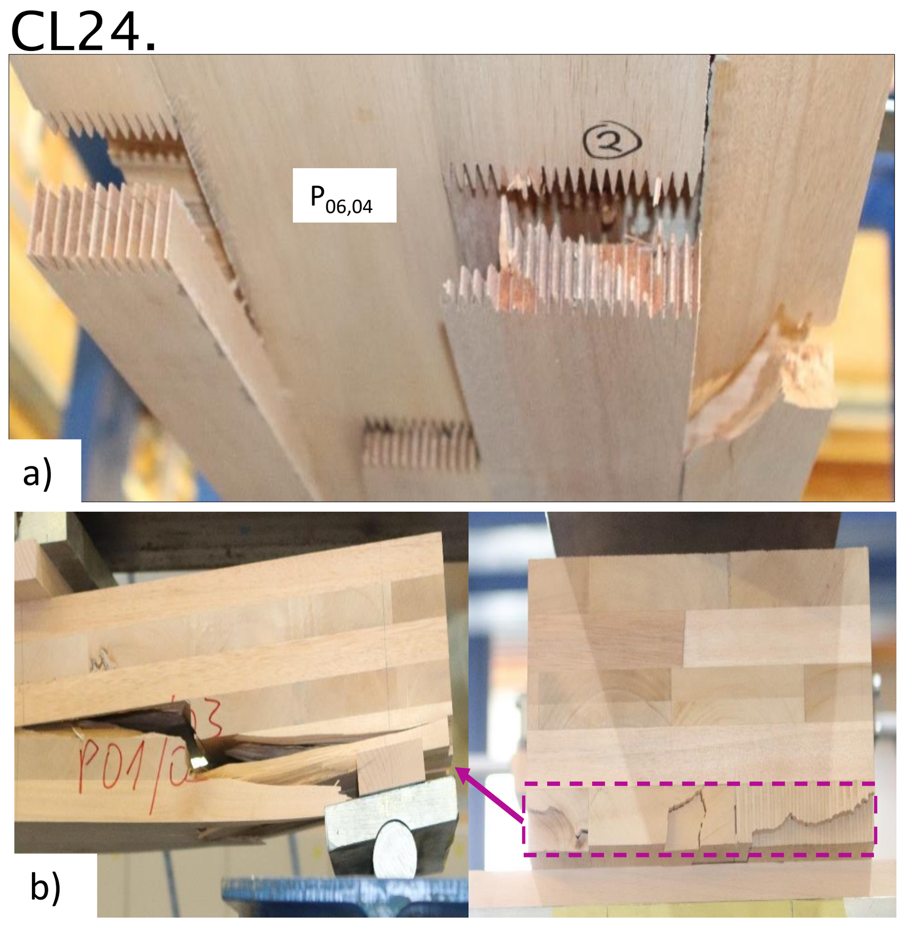

Figure-2: Failure modes a) bending failure in the finger-joint for a bending test and b) shear failure for a shear test configurations.

Conclusion

The failure modes of CLT tested in bending flat was mainly found at the finger-joints and therefore, optimizing the geometry of finger joints and developing appropriate grading measures for boards could substantially improve the strength capacity of the panels. High potential can be seen from the tests and using hardwood from tropical fast-growing plantations may boom the area economically.

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