7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient Buildings and Urban Environments

ibpc2018.org | #ibpc2018

The effects of production technologies on the air permeability properties of cross laminated timber

Villu Kukk[1,*], Targo Kalamees[1] and Jaan Kers[2]

[1]Tallinn University of Technology, Tallinn. Department of Civil Engineering and Architecture
[2]Tallinn University of Technology, Tallinn. Department of Materials and Environmental Technology

[*]*Corresponding email: villu.kukk@ttu.ee*

ABSTRACT
In building envelope, the cross laminated timber (CLT) is often used as air barrier layer. The objective of this study was to evaluate the impact of production technologies such as edge bonding, different initial moisture content (MC) of lamination, and number of lamination layers (3 and 5) on the air-permeability properties of cross laminated timber. Air leakage and crack growth in CLT panels were measured after the panels were conditioned in environments with different relative humidity (RH) in progressive steps from humid to dry environments (RH 70%→ RH 50%→ RH 30%→ RH 10%). The test results showed that the most effective technologies for avoiding large crack growth and air leakages through panels were to use 5 layers of laminations with bonded edges. Overall, it can be recommended that for the production of CLT panels it is advisable to use primarily a larger number of layers, at least 5, for smaller growth of cracks on panel surfaces and thereby avoid air leakages during the time of use. The use of bonded edge technology helps to ensure the avoidance of possible air leakage threats, but in the long-term, this beneficial effect might decrease as bond layers may rupture or cracks may form in the middle of laminations.

KEYWORDS
Cross laminated timber, production technology, crack growth, air permeability

INTRODUCTION
Airtightness of building envelope has become an important property of building envelope. The more airtight envelope and more efficient heat recovery with reduced thickness of thermal insulation has a lower construction cost and lower energy consumption, making it financially viable (Saari, et al., 2012). The building envelope is locally sensitive to exfiltration airflow, as moisture convection could cause a remarkable increase in the moisture accumulation rate on the inner surface of the sheathing (Kalamees & Kurnitski, 2010). Kayello et al. (2017) showed that frost accumulation and condensation can happen very easily due to air leakage and pose a significant risk to the integrity of the envelope. In building envelope, the CLT is often used as air barrier layer. Crack formation in CLT influences it's water vapour resistance and air permeability (Kukk et al. 2017) as well fire resistance, acoustic properties, and lower the quality (Brander, 2013).
Moisture movement in wood has a major role in crack formation. The important benchmark for the wood properties affected by moisture is the fibre saturation point (FSP). FSP is defined as the point where wood cell lumen does not contain free water but the cell wall is still saturated. Properties of wood, such as volume and mass, change if the MC changes below FSP point. A decrease or increase of MC results, respectively, in shrinkage or swelling of wood.

The unequal decrease of MC in different wood directions (tangential, radial and longitudinal) results in unequal shrinking of wood which causes internal stresses inside the wood. This, in turn, results in the formation of checks and cracks in the wood surface. Changes of MC in the laminations of a CLT panel result in shrinking and swelling of the wooden board's volume, which may cause cracks in board surfaces and also gaps between the edges of the boards.
This study is focused on analysing the effects of productions technologies on the air permeability properties of CLT panel. The objective is to study the effects of the number of layers in the panel, bonded edges and initial MC in lumber to crack growth in CLT panels' lamination surfaces and air permeability.

METHODS

Test specimens

Specimens were produced using three different technologies whose parameters are given in Table 1. Three specimens were made for each technology combination. According to this, 24 specimens of rectangle-shaped cross-laminated timber panels with dimensions of 1300x460mm, a thickness of 30mm and constructed from spruce wood (Picea abies) were designed and produced for the air permeability and crack evaluation test.

Table 1. Parameters of specimens produced with different technologies

	Number of layers	
Edge bonding	**3 layer panel, thickness of one layer 10 mm**	**5 layer panel, thickness of one layer 6 mm**
Edge bonded panels	Initial MC of laminations ≈**13.1%** (conditioned with RH of 70%)	Initial MC of laminations ≈**13.1%** (conditioned with RH of 70%)
	Initial MC of laminations ≈**6.2%** (conditioned with RH of 30%)	Initial MC of laminations ≈**6.2%** (conditioned with RH of 30%)
Panels without edge bonding	Initial MC of laminations ≈**13.1%** (conditioned with RH of 70%)	Initial MC of laminations ≈**13.1%** (conditioned with RH of 70%)
	Initial MC of laminations ≈**6.2%** (conditioned with RH of 30%)	Initial MC of laminations ≈**6.2%** (conditioned with RH of 30%)

Specimens were marked as follows: P30/70 W/BE 3/5L, where P30/70 defines panels initially conditioned in an environment with RH of 30% or 70%; W/BE- without or with bonded edges panels; 3/5L- panels with 3 or 5 layers.

Measurements

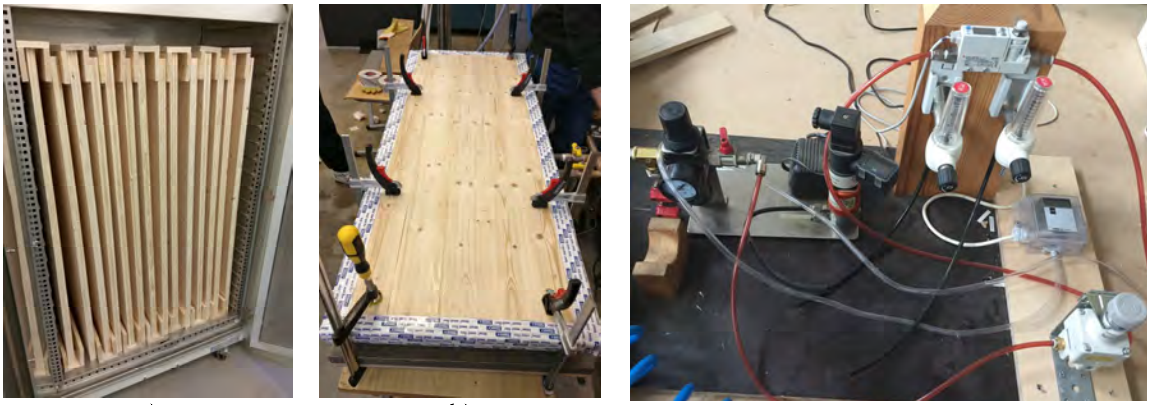
Three following parameters were measured during laboratory test: MC of panels, crack area on panels top surfaces and air permeability. Cracks area results were gained by measuring crack width and length using a crack width gauge and methodology developed by Brischke and Humar (Brischke *et al.* 2014). Air permeability was measured using a hermetic test rig and equipment for regulating and measuring air pressure differences and air flow (EN 12114, 2000), accuracy <5%, see Figure 1(b), (c). Airflow was measured by applying three overpressure impulses at a pressure difference of 550 Pa. To avoid any air leakages from the connection of the test rig and panels, all panels edges were sealed with vapour and air tight tape. Therefore the measurement area of each specimen for air permeability test was considered as 0.56 m^2 (1.25x0.45). The laboratory test process consisted of panel conditioning steps in environments with different RH supplied by a climate chamber, see Figure 1(a).
Conditioning steps for panels initially conditioned in an environment with RH 70% were as follows:

- I step: RH 50% → II step: RH 30% → III step: RH 10%;

And for panels initially conditioned in an environment with RH 30%:

- I step: RH 10%

Before and after each conditioning step all parameters were measured and recorded and corrected with an estimated error.



a) b) c)

Figure 1.(a) Climate chamber Climacell 707 for panel conditioning, (b) hermetic test rig for air permeability tests, (c) equipment for measuring air pressure differences and air flow.

RESULTS

EMC of specimens

All specimens were conditioned equally and the equilibrium moisture content (EMC) after each conditioning step was almost the same in all panels, see Figure 2. Specimens conditioned initially in an environment with RH of 70% had an overall moisture loss after each conditioning step of RH of 10% of about 8%. Specimens P70WBE5L had a moisture loss of 12.2% due to a higher initial EMC. Specimens conditioned initially in a RH of 30% had an overall moisture loss after each conditioning step of RH of 10% of about 2.5%.

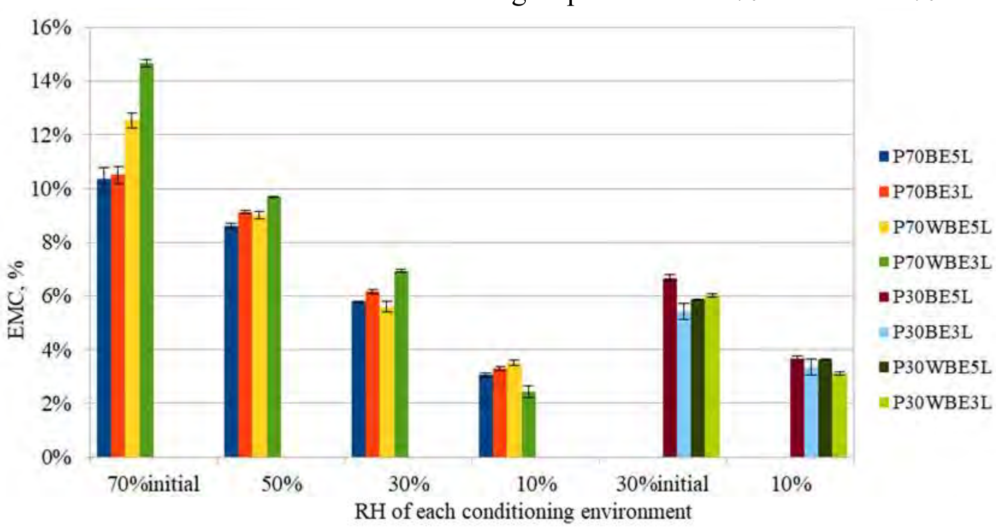


Figure 2. EMC of specimens after each conditioning step

Growth of crack area

A big difference in crack area growth between specimens P70 and P30 was expected due to the different number of conditioning steps, see Table 2. While a total crack growth in specimens P30 was from 16% to 55%, in specimens P70 it was from 516% to 22160%. The total crack growth of 22160% appeared in specimens P70WBE3L, which was about 10 times higher than rest of the specimens. Specimens P70WBE3L also had the biggest average crack area of 15456 mm^2 after conditioning steps of RH of 10%.

The smallest average crack area of 193 mm2 after conditioning steps of RH of 10% was in specimen P30BE5L, and specimen P30BE3L had the smallest total crack growth of 16%. Overall, the greatest effect on smaller crack growth was in specimens with bonded edges and initially conditioned in an environment with RH of 30%.

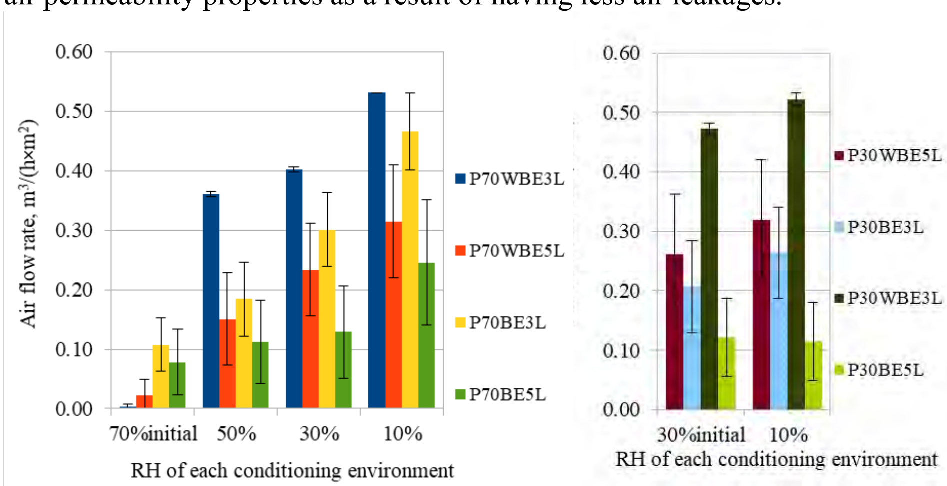
Table 2. Average crack area and growth of specimens after each conditioning step

Specimen	70%$_{initial}$	50%		30%		10%		
	Av. existing crack area, mm^2	Av. crack area, mm^2	Growth, %	Av. crack area, mm^2	Growth, %	Av. crack area, mm^2	Growth, %	Total growth (RH70-10 %), %
P70BE5L	436	655	50%	1162	77%	2686	131%	516%
P70BE3L	194	246	27%	871	254%	2969	241%	1434%
P70WBE5L	202	1982	881%	3151	59%	5382	71%	2564%
P70WBE3L	69	1430	1959%	9064	534%	15456	71%	22160%
	30%$_{initial}$	**10%**	**Total growth (RH 30-10 %), %**					
P30BE5L	100	193	48%					
P30BE3L	1300	1551	16%					
P30WBE5L	1306	2918	55%					
P30WBE3L	1457	2677	46%					

Air permeability of specimens

The largest air leakages were in all specimens with three layers, when taking into account initial EMC in production and bonded and without bonded edge technology, see Figure 3. The greatest average air leakage of 0.53 m3/(h×m2) after conditioning steps of RH of 10% were in specimens P70WBE3L. The second greatest leakage of 0.52 m3/(h×m2) showed in specimens P30WBE3L after conditioning steps of RH of 10%.

Specimens with 5 layers and bonded edges and initially conditioned in an environment with RH of 30% were the most airtight which matched with pre-testing assumptions. Specimen P30BE5L showed an air leakage of 0.11 m3/(h×m2) and P70BE5L showed 0.25 m3/(h×m2) after conditioning steps of RH of 10%. Overall, 5 layer specimens had the most considerable effect on air permeability properties as a result of having less air leakages.



b)

Figure 3. Air flow rate after each conditioning step of specimens a) initially conditioned in an environment with RH of 70%, b) with RH of 30%

The large estimated error of air flow rate results was probably a result of the small number of specimens for each type, quality variation of lumber and manufacturing defects on panels (such as existing gaps between laminations and some degree of uneven distribution of adhesive). Air flow rate of specimens P70WBE3L were measured maximum what used equipment could read and therefore no estimated error is shown in Figure 3.

DISCUSSIONS

The most effective technologies for avoiding large crack growth were using laminations with bonded edges and lumber initially conditioned in an environment with RH of 30%. Specimens initially conditioned in an environment with RH of 70% had a considerable resistance to crack growth when panels had 5 layers.

Using initially drier lumber together with edge bonded laminations seems to keep wood shrinkage lower and therefore keeps crack growth on the panels surface at a low percentage during the first stages of drying (conditioning steps from RH 30% to 10%). In the longer drying process (conditioning steps from RH 70% to 10%), 5 layer panels considerable resistance to crack growth was probably due to a larger number of bond layers and thinner lamination layer thickness. Bond layers and thin laminations seemed to keep the wood steadier and controlled the formation of internal stresses during the drying process better. Specimens with bonded edges that underwent the longer drying process showed, in the first conditioning steps, a lower crack growth compared to specimens without bonded edges, but during the last step, the growth percentage was higher. This shows that bonded edges can hold the formation of internal stresses due to shrinkage for a short period and later, when bonding connections might have been ruptured or cracks might have developed in the middle of laminations, crack growth can increase over time.

5 layer specimens combined with edge bonding had the most considerable effect on avoiding air leakages through the panel. The greater number of layers helps to avoid any overlapping of gaps between laminations which are possible sources of air leakages (Kukk, et al., 2017). The same argument was confirmed in this study as 3 layer specimens had considerably bigger air leakages, especially the specimens with laminations initially conditioned in an environment with RH of 70%. The reason for better airtightness in panels with a larger number of layers can be the same as it was for low crack growth which was a larger number of bond layers and thinner laminations. The use of bonded edge technology has been also previously recommended for avoiding overlapping of gaps and cracks and it was again confirmed with the results of this study, except specimen P70BE3L, which showed a quite high air flow rate (Brander, 2013) (Skogstad, Gullbrekken, & Nore, 2011).

Current research only covered the first cycle of the drying process and specimens with laminations initially conditioned in an environment with RH of 70% and 30% had different cycle durations. In other words, the results obtained in this experiment have given information about the behavior of the panels at the beginning of their service life. For a better understanding of the air-permeability properties of the panel in long-term of use the repeated test with several cycles is necessary to carry out.

In overall, it can be recommended that for the production of CLT panels one should primarily use a larger number of layers, at least 5, for the smaller growth of cracks on panel surfaces, thereby avoiding air leakages during the time of use. The use of bonded edge technology helps to ensure the avoidance of possible air leakage threats, but in the long-term, the effect might decrease as bond layers may rupture or cracks may form in the middle of laminations. Specimens with initially drier laminations did not show a significant resistance to air leakages but had considerable effect for avoiding large crack growth.

CONCLUSIONS

In this study, three production technologies of CLT panels were analysed to determine the influence of number of layers in the panel, bonded edges and initial MC in lumber. The main findings of this study were that the most effective technologies for avoiding large crack growth were using edge bonded and initially drier laminations and 5 layer specimens combined with edge bonding had the most considerable effect on avoiding air leakages through the panel. Based on the results it is recommended to primarily use a larger number of layers, at least 5, which helps to minimise the growth of cracks on panel surfaces, therefore, avoiding air leakages during the time of use. The use of bonded edge technology helps to ensure the avoidance of possible air leakage threats, but in the long-term, the effect might decrease as bond layers may rupture or cracks may form in the middle of laminations. Using initially drier lumber helps to avoid crack growth on panel surfaces, but does not have a significant effect on avoiding air leakages.

ACKNOWLEDGEMENT

This research was supported by the Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, grant TK146 funded by the European Regional Development Fund, and by the Estonian Research Council with Institutional research funding grant IUT1-15.

Participation in the conference was supported by the Estonian Ministry of Education and Research. EU Structural Fund (Cohesion Policy Funds) period 2014-2020, TUT Development Program for the period 2016-2022, Doctoral School of Civil and Environmental Engineering project code 2014-2020.4.01.16-0032 has made publishing of this article possible.

The author wishes to thank Estonian glulam producer Peetri Puit OÜ for helping to produce CLT specimens.

REFERENCES

Brander, R. (2013). *Production and Technology of Cross Laminated Timber (CLT): A state-of-the-art report.* Graz, Austria.

Brischke, C., Humar, M., Meyer, L., Bardage, S., & Bulcke, J. V. (2014). *COST Action FP 1303-Cooperative Performance Test.* COST Action FP 1303.

EN 12114 (2000) Thermal performance of buildings - Air permeability of building components and building elements - Laboratory test method. Brussels: European Committee for Standardization.

Kalamees, T., & Kurnitski, J. (2010). Moisture convection performance of external walls and roofs. *Journal of Building Physics*, 225-247.

Kayello, A., Ge, H., Athienitis, A., Rao, J. (2017). Experimental study of thermal and airtightness performance of structural insulated panel joints in cold climates. Building and Environment, 115, 345-357.

Kukk, V., Horta, R., Püssa , M., Luciani, G., Kallakas, H., Kalamees, T., & Kers, J. (2017). Impact of cracks to the hygrothermal properties of CLT water vapour resistance and air permeability. *Energy Procedia, 132*, 741-746.

Saari, A., Kalamees, T., Jokisalu, J., Michelsson, R., Alanne, K., & Kurnitski, J. (2012). Financial viability of energy-efficiency measures in a new detached house design in Finland. *Applied Energy*, 76-83.

Skogstad, H. B., Gullbrekken, L., & Nore, K. (2011). Air leakages through cross laminated timber (CLT) constructions. *9th Nordic Symposium on Building Physics*, (p. 8). Tampere.