TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

Department of Materials and Environmental Technology

THE IMPACT OF PRODUCTION TECHNOLOGY TO THE PROPERTIES OF CROSS LAMINATED TIMBER AFTER REPEATED TEST CYCLE

Tootmistehnoloogiate mõju ristkihtliimpuidu õhupidavusomadustele pärast korduskatset

MASTER THESIS

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Tallinn, 2018

AUTHOR’S DECLARATION

Hereby I declare, that I have written this thesis independently.
No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

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Thesis is in accordance with terms and requirements

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Department of Materials and Environmental Technology

THESIS TASK

Student: Ricardo Miguel Lopes Horta, 156316KVEM

Study programme: KVEM - Technology of Wood and Plastic

main speciality: Wood Technology

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Thesis topic: The impact of production technology to the properties of cross laminated timber after repeated test cycle

Tootmistehnoloogiate mõju ristkihtliimpuidu õhupidavusomadustele pärast korduskatset

Thesis main objectives:

1. Conditioning specimens to equal equilibrium moisture content
2. Measurements of moisture content, cracks area and air leakage of specimens
3. Data processing and analysing
4. Completing the thesis

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Preparing and placing specimens for conditioning	01.07.2017
2.	Proceeding measurements after each conditioning	01.03.2018
3.	Collecting the data, processing into results, and making analysis	10.05.2018
4.	Writing and formalization the thesis	31.05.2018

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Foreword

The current work is the continuation of the experiments developed by Giovanni Luciani, Martin Püssa and Ricardo Horta in the CLT field during the years of 2016/2017. The CLT specimens that were produced, were submitted to a new set of conditions and re-tested.

24 CLT panels were made with different types of technologies (edge bonding, number of laminations and different relative humidity conditions of the lamellae used for production) and submitted to 3 steps of relative humidity (75%, 43%, 30%) during 3 consecutive months. Conditioning time (1 month/cycle) was estimated to achieve the equilibrium moisture content and allowing the complete conditioning of the entire thickness of the panel (30mm). Specimens were tested for air leakages according to the EN12114:2000 and crack development was recorded for each conditioning stage. Data was collected an evaluated, allowing to clarify which of the manufacturing technologies is more effective for preventing air leakages and cracks in the CLT panels.

This work is a remarkable effort of a small group of people that never gave up, even when countless hours of dark times were ahead of us.

I would like to recognize the help, guidance and all the recommendations given by my supervisor Professor Jaan Kers and co-supervisor engineer Villu Kukk, without their knowledge, perseverance, motivation, and wise words this work would not be a reality.
To my friends and fellow students Giovanni Luciani and Martin Püssa for the help and collaboration in such ambitious project.
Finally, to my mother and sister for their endless support.

Key words: cross laminated timber, conditioning, air leakage test, master thesis

Table of Contents

1. Introduction

1.1 The use of CLT

Cross Laminated Timber (CLT) is a relatively new product in construction industry. The initial development begun in Switzerland in the early 90's, but it was an Austrian partnership between industry and universities that allowed the progress of CLT into the modern panel so in use nowadays. In the beginning of the 21st century the usage of this new construction system seriously increased, to some extent due to the sustainable building politics that were trying to be implemented a bit all over the world.
The panel efficiencies and characteristics helped with the introduction into construction market but also because it started to be seen as a "non-light" system distant from light wood frame and relatively close to masonry and concrete structural systems. [1]

Energy concerns and green buildings are nowadays trends. Emissions reduction and carbon sequestration are fashionable assets and highly coveted. Public concerns with energy savings in buildings also comes into play with near-zero energy building rules applied from 2020. Air leakages account for significant overall energy losses in buildings worldwide. Leakages of air can be charged towards values ranging from 5 to 40% of the operational costs with buildings. [2]

A reduced construction time and the ease of handling in mid-height buildings make it a special attractive setup. The good performance showed in the thermal and acoustic fields, in addition to the above average behaviour under fire conditions are considered key for its fast growth in the construction industry. A study made in 2010 by FPInovations mentioned that when comparing CLT buildings versus determined concrete, masonry, and steel constructions, the first can be cost competitive even disregarding the edge given by the faster construction period and lower foundation costs (due to the lighter weight of the overall building). The same study also refers that this advantage is especially noticed in mid-rise residential and non-residential, low-rise educational, low-rise commercial and one-story industrial buildings [1].

1.2 The objective of the thesis

Crack development in cross laminated timber (CLT) have a significant impact to the air permeability properties of the panels, that may lead to unwanted energy costs [3]. Proper production technology is basis for the quality of CLT and might also affect the air tightness of the panels and quality of building envelope in general. Leakages and cracks in panels may lead to unwanted problems related with moisture entrance, thermal comfort, and energy consumption.

The main objective of this research work is to clarify which combination of production technologies is most efficient in preventing air leakages and crack formation in CLT panels, in a repeated test cycle, from more moist conditions (75% RH) to drier ones (30% RH).

It was proposed to prove the following hypothesis:

- the more layers a CLT panel has, the less air leakages it has;
- CLT panels using edge bonding technology have less air leakages than those without bonded edges;
- when CLT panels are produced from wood lamellas with lower moisture content will have less air leakages;
- CLT panels manufactured with 5 layers will have less crack development than those with 3 layers.

To evaluate the above hypothesises, the research and experiments will be conducted in the following sequence.

Three different production technologies will be used and compared (lamination edge bonding, number of laminations and pre-conditioning of raw material in different relative humidity environment) to produce enough data to allow an analysis and drawing of conclusions.
Three months conditioning experiment will be carried out to bring the panels from a relative humidity environment of 75% to one with 30%. Preparation for conditioning requires the design of a “small greenhouse chamber” as in TTÜ there is no climate chamber available for such number of specimens. To condition the chamber environment to the desired levels, two different saturated saline solutions will be produced with NaCl for 75% RH and K_2CO_3 for 43% RH. Air permeability tests will be performed in all specimens according to the EN 12144:2000.

Based on the results of the research work it is possible to analyse the production technology methods and draw the conclusion as to the need for future possible changes. The results of the research will allow the manufacturing companies to optimize technology, assuring the required quality of the product, and that the same result will be achieved at lower cost and in a shorter production cycle.

The experiment was conducted as a repeated test to re-evaluate the properties of the panels during a long period of use. The repeated test gave the opportunity to improve the measurement methodology and thus obtain more precise results for characterizing the panels properties. A longer period of testing and conditioning also allowed to get a bigger picture on how the samples behave after a full moistening/drying cycle and how this relates with the crack development and air leakages. The experiments of this work started in the point where the Masters´ thesis 2017, conducted by Martin Püssa and Giovanni Luciani ended [22, 23].

2. Cross laminated timber

2.1 CLT as a product

In the past years, different types of buildings and structures were erected using CLT, showing the world the potential this system has to offer. The tallest wood building in Europe (nine storeys) at the time of its construction was the Stadhaus, Murray Grove in London (Figure 2.1).

Figure 2.1. Stadhaus, Murray Grove Building. [4]

CLT is a multi-layer wooden panel made from lumber. Each layer of boards is placed crosswise to the adjacent layers for increased rigidity and stability. The panel can have three to seven layers, or more, normally in odd numbers, symmetrically around the mid layer [1]. This wood building system consists of ready-to-use elements which are assembled to form complete frameworks. Solid lumber pieces are used as main material, with these being assembled using an adhesive, although nails or wooden dowels can also be used. Low grade layers can be used for the interior of the panels and higher grades for the outside. While panels using softwood prevail, it is possible to use hardwood to manufacture CLT panels, like Poplar.

Cross laminated timber elements exhibit many positive characteristics: pre-assembly in factory with weather independent production allows a large-scale prefabrication of elements. This allows a quick construction time on-site. As the elements are with 12-14% MC from factory, no additional moisture is delivered into the building during construction. Weather unpredictable conditions may be taken care of with special protection structures.

The layered construction allows the assembly of decorative or also sounds and fire protection technically adapted protective layers. Through the crosswise arrangement of the board layers and the blocking effect associated with this, humidity changes in the panel layers produce controlled swelling and shrinkage. This allow for a bigger dimensional stability. Limitations of the construction component dimensions are merely the result of the manufacturer specific maximum and conveyance dimensions, giving designer freedom to develop new concepts and ideas.

Cross laminated timber, in comparison to other construction materials, has a very low thermal conductivity. The planar construction with closed surface layers achieves considerable benefits for heat, moisture, fire, and sound protection since air movements within the structure are prevented. Solid cross laminated timber construction components are not subject to any limitations regarding the loads (for example, heavy kitchen cabinets). Compared to other solid construction methods the manufacture and processing of cross laminated timber components requires very little energy. It contributes to sustainable carbon storage and thus to the minimization of the greenhouse gas effect through the fusion of CO_2. At the end of its use, cross laminated timber can be, materially or thermally, recycled. In the event of thermal recycling of reinstated cross laminated timber elements, only the CO_2 which was stored during the growth period of the timber is discharged into the atmosphere. [5]

2.2 Wood and water relation

The wood cell walls of the living tree are containing a significant percentage of water. This value fluctuates according to several factors including species, seasons, location, and age among others, while the tree is alive [6].

But this relationship does not end when the tree is cut down. Water content keeps playing a major role in wood behavior.

Wood is considered as a hygroscopic material as it can exchange vapour with the surrounding air. This means that it will keep equalizing its own moisture level with the one present in the local atmosphere. When wood reaches this point, it is called equilibrium moisture content (EMC). If the wood and surrounding air are not in equilibrium state, wood gains or loses moisture (adsorption and desorption processes, respectively) to reach this plateau. Different EMC points can be attained depending on the surrounding conditions (relative humidity and air temperature).

The hygroscopic properties of wood allow it to shrink or swollen as it loses or gains water. After losing "free water" wood will slowly begin to lose "bound water" (see Figure 2.2) from inside the cell walls. These water molecules need greater amount of energy to be released from inside of the cell, due to the existing hydrogen bonds between wood cell wall and water molecule [6].

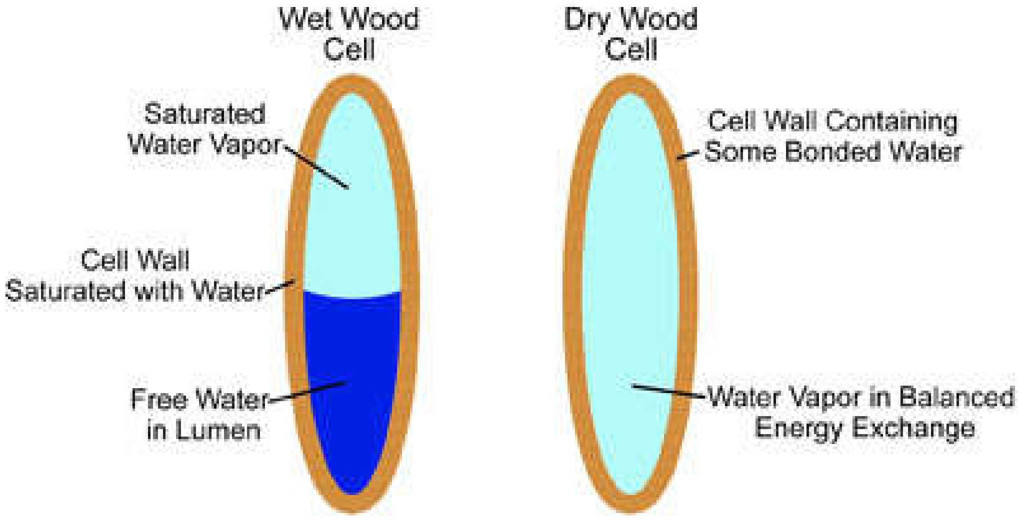


Figure 2.2. Water in green wood cell (left) and water in dry wood cell (right) [7].

During the drying period, cracks can be formed if this process is done too quickly. Different levels of drying among exterior surfaces and middle layers will produce different levels of moisture within the wood cells causing internal tension that will provoke splitting, hence the cracks at a microscopic and later on macroscopic scale.

In the next table, it can be seen the different kinds of EMC for the most usual wooden products according to different relative humidity conditions but maintaining the temperature constant. Worth of mentioning is the lower percentage of water in wood composites than in natural wood caused by the introduction of new materials (resins and coatings) and heat treatment effect during the manufacturing process.

Table 2.1. Equilibrium moisture content for different wood products at 21°C. Adapted from [6].

	Moisture Content (%)				
Relative Humidity (%)	Wood	Softwood Plywood	Particleboard	Oil-treated hardboard	High-pressure laminate
30	6.0	6.0	6.6	4.0	3.0
42	8.0	7.0	7.5	4.6	3.3
65	12.0	11.0	9.3	6.9	5.1
80	16.1	15.0	11.6	9.5	6.6
90	20.6	19.0	16.6	10.8	9.1

3. Materials and methods

To be able to accomplish the designated thesis objectives a methodology was designed, and materials were carefully chosen. In this chapter, it will be described how the experiments were driven, which materials were used and the key steps of the whole process.

3.1 Specimens

The Norway Spruce (Picea abies) as the most common material used for CLT manufacturing in Estonia was chosen for the test panel manufacturing. Four side planed, and calibrated material was bought at the Estonian company Rait Ltd. It was delivered in packs with 6 lamellas with 18mm thickness and 4.1 meters of length.

The chosen dimensions for the specimens were 1300mmx460mmx30mm. This was planned so each layer would contain the maximum number of gap interceptions in-between laminations.

The production plan contained 24 specimens to the produced and tested. In table 3.1, it is described the type of panels that were manufactured. For each type of specimen 3 units were produced.

Table 3.1. Different kind of specimens produced for the experiment.

3-layer panels			**5-layer panels**		
Layer thickness	**Initial RH conditioning**	**Bonded edges**	**Layer thickness**	**Initial RH conditioning**	**Bonded edges**
10mm	70%	Yes	6mm	70%	Yes
10mm	70%	No	6mm	70%	No
10mm	30%	Yes	6mm	30%	Yes
10mm	30%	No	6mm	30%	No

In the results and discussion chapter, specimens will be labelled according to the manufacturing technology:

- 3L for panels with 3 laminations and 5L for panels with 5 laminations
- BE for panels with bonded edges and WBE for panels without bonded edges

Reporting to the initial RH environment conditioning labelling, when necessary the reference to it will be given in the end of the sample identification, i.e. 3L-BE (30%), meaning a 3-lamination specimen with bonded edges and which raw material was pre-conditioned in a 30% relative humidity environment.

3.2 Manufacturing technology

The specimens were produced considering the EVS-EN 16351_2015_Timber structures- Cross laminated timber- Requirements. To assemble the panels the adhesive used was the Loctite HB S509 Purbond (technical data in the appendix D).

As basic guidelines, the chosen methodology was the following one:

1. Pre-conditioning of the material
2. Planing of the lamellas with thicknessing machine
3. Gluing and assembling using cold-pressing equipment and vacuum press equipment
4. Conditioning
5. Testing

In a more detailed way, the process was initiated with the cutting of the lamellas into the needed dimensions to produce the 24 CLT panels, considering the two distinct dimensions (length 1300mm and width 460mm). Panels dimensions were chosen specifically to guarantee the following conditions:

- Permit the handling of the panels in an easy and comfortable way;
- Allow the panel to possess enough gaps crossing points where most probably the air flow would go through (approximately 56 points in each panel);

A very simple setup was prepared to allow the lamellas to be glued in an edge-to-edge assembly.

Figure 3.1 illustrates the aforementioned setup for glued edge panel manufacturing.

Figure 3.1. Setup used for gluing lamellas edge-to-edge.

Sequentially, the glued layers and the remaining lamellas cut for the non-glued edge panels had their thickness reduced from 24mm to 10mm and 6mm, accordingly to the number of layers of the panels they were used in (3 layers and 5 layers respectively). In Figure 3.23.2, the thicknessing equipment that was used is shown and it belongs to the Tallinn Ehituskool workshop.

Figure 3.2. Thicknessing machine D 630 from Tallinn Ehituskool workshop.

An illustration of the gluing process is presented in Figure 3.3.

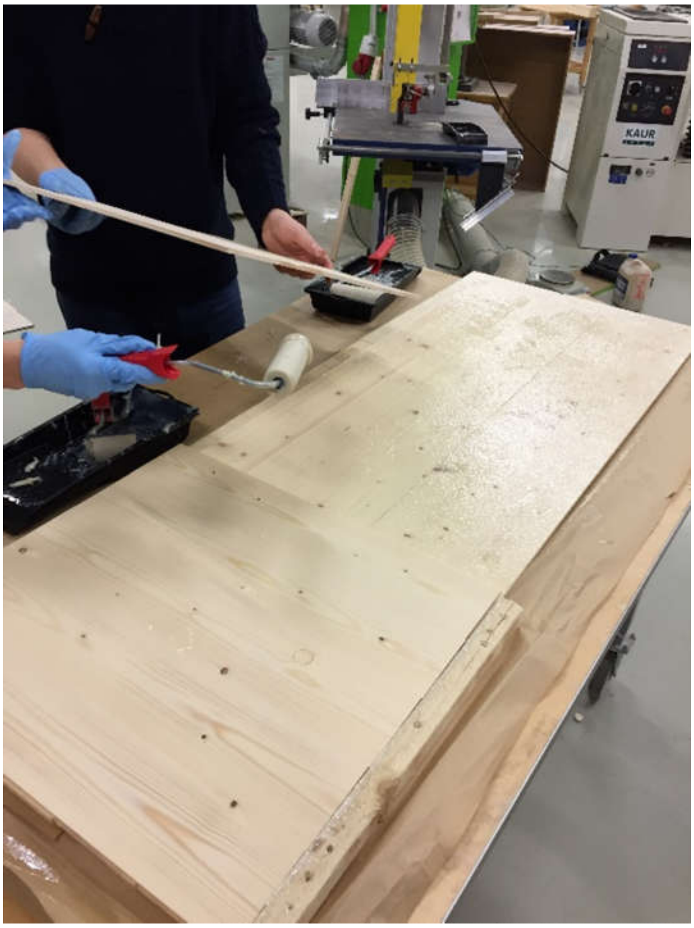


Figure 3.3. Gluing layers in a bonded edge panel.

The adhesive was chosen taking into attention the needed open and pressure time as seen in Figure 3.4. The 50 minutes of open/assembly time guaranteed that the gluing procedure could be achieve properly and adequately. Press time was not much of a concern as no human intervention was necessary after the pressing process had started. The HB S509 had a pressing time of 125 minutes. The pressure applied was the recommend (0.12 - 0.16kgf/m^2 equivalent to 1.18 – 1.57 Pa).

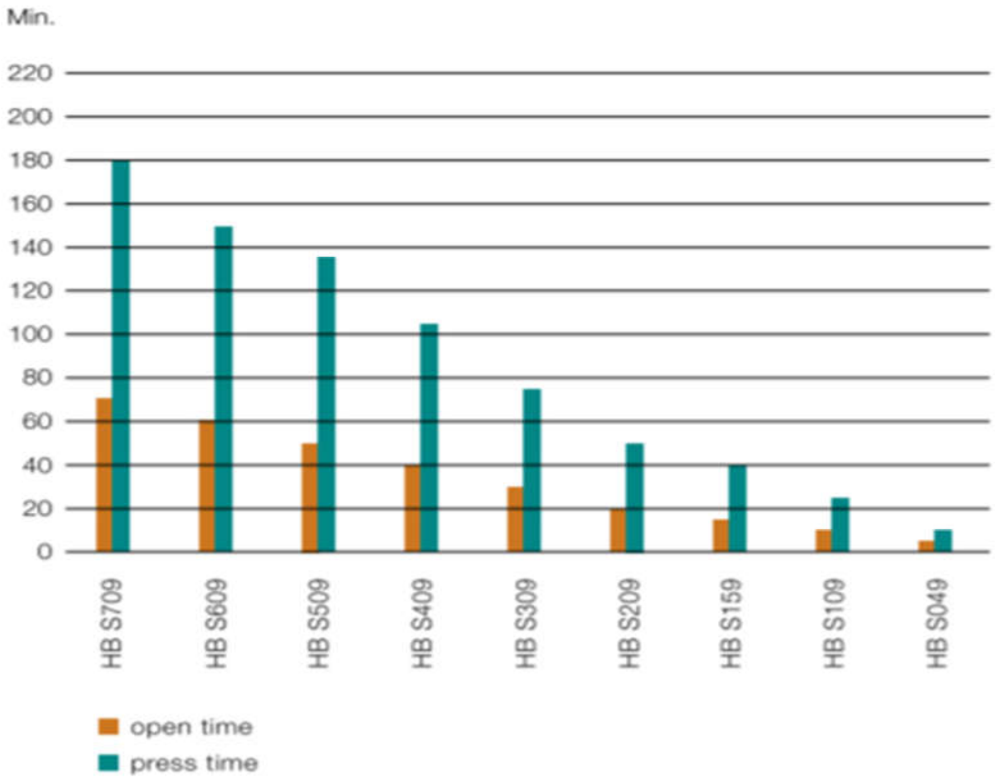


Figure 3.4. Open and press time for Loctite HB S509 Purbond. [8]

The list of known components disclosed by the manufacturer are the following ones, presented in the Table 3.2.

Table 3.2. Chemical components of the adhesive Loctite HB S509 Purbond. Adapted from product data sheet (see appendix D).

Chemical components	Proportions
Isocyanic acid, polymethylenepolyphenylene ester, polymer with 1,3-diisocyanatomethylbenzene, hydrazine and 2-methyloxirane polymer with 1,2,3-propanetriol (3:1)	60- <= 100 %
Isocyanic acid, polymethylenepolyphenylene ester	10- < 30 %
o-(p-Isocyanatobenzyl) phenyl isocyanate	< 10 %
4,4'- methylenediphenyl diisocyanate	< 10 %
Hexane, 1,6-diisocyanate-, homopolymer	< 5 %
Non-hazardous ingredients	< 10 %

The first set of 6 panels (bonded edge panels) were produced in the Tallinn Ehituskool using a cold press equipment as it shown in Figure 3.5.

Figure 3.5. Cold press equipment.

For all the remaining specimens a different option was taken, especially after the assembling of a test panel using the cold press equipment. Due to the lack of horizontal pressure the panel was not properly assembled. After that decision was made to use vacuum press equipment for panel manufacturing.

The assembly of the cross laminated timber panels with the vacuum press was done at Arcwood (Peetri Puit OÜ) facilities in Põlva. This equipment allows a different approach from the one used with the cold press and a better overall quality of the panels.

Instead of having the lamellas prepared for each individual panel 1300mm x 460mm, this time they were set for a single big panel with the dimension of 3100mm x 1100mm. After the assembly, the panels were cut to the necessary dimensions 1300mm x 460mm.

Another particularity of this process was in arrangements to avoid the penetration of glue between the lamellas during the vacuum pressing cycle. Half of the panels were planned to be manufacture without bonded edges.

As it can be seen in Figure 3.6 and Figure 3.7, stripes of paper tape were placed to cover the gaps between the wood lamellae's before applying the PUR adhesive layer. Stripes were removed before adding the next crosswise layer, preventing a direct contact of the glue with the edges of the lamellas.

Figure 3.6. Method to avoid gluing the edges.

Figure 3.7. Removing paper tape stripes.

After the production process was finished, panels had all edges painted with one layer of a liquid airtight membrane which created a continuous air and vapour-tight seal over cracks and gaps. Data sheet of the product can be found in the appendix E.
Once the liquid membrane was dry and cured, one extra layer of protection was added in the form of a PE tape as showed in Figure 3.8.

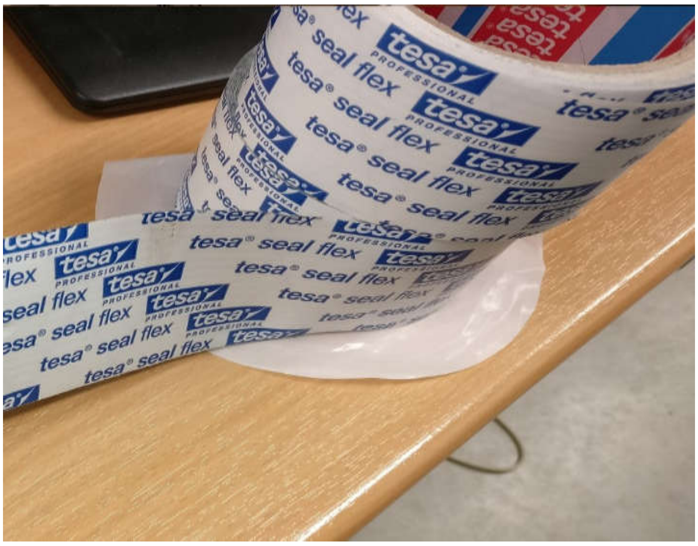


Figure 3.8. Polyethylene (PE) tape.

Finally, the panels were ready to start the conditioning stage.

3.3 Conditioning stage

The conditioning steps were scheduled for a 30 days period. To estimate the necessary period of conditioning a simulation software was used.

The mentioned software is WUFI® and it allows realistic calculation of the transient coupled one- and two-dimensional heat and moisture transport in walls and other multi-layer building components exposed to natural weather. The software is using the latest findings regarding vapor diffusion and moisture transport in building materials and has been validated by detailed comparison with measurements obtained in laboratory and on outdoor testing field. [8]

The given result (30 days) was achieved for being the amount of time that the samples would attain the equilibrium moisture content point.

Due to the large number of specimens that were needed to condition at the same time, there was no available equipment to hold the 24 samples. It was necessary to build a "small greenhouse chamber" equipment that could maintain the desired amount of relative humidity mandatory for the experiment to succeed. This equipment is illustrated on Figure 3.9 where it can be seen the specimens under conditioning.

Figure 3.9. Specimens in conditioning stage inside the chamber.

A sensor was placed inside the chamber mainly to control the relative humidity and temperature. The temperature was constant at 20°C.

To achieve the desired levels of humidity inside the chamber saturated saline solutions were prepared with the help of two different salts for the two different RH steps. According to Greenspan, L. (1977), a specific equilibrium relative humidity in air versus temperature can be obtained by adding a determined salt to water to create a saturated saline solution. [10]

The relative humidity levels that were reached inside the chamber for the first two conditioning steps were 75% with the help of sodium chloride ($NaCl$) and 43% using potassium carbonate (K_2CO_3). Concerning the last conditioning step, test samples were kept in a storage room of the Laboratory of Wood Technology which had a constant environment with relative humidity of 30%. [10]

3.4 Testing apparatus

The main equipment used for the air permeability test was the following, as illustrated in Figure 3.10. Air permeability box was custom made for this experiment. It has rectangular shape, made from steel and sturdy enough for achieving unchangeable volume (technical drawings of the box in appendix F).

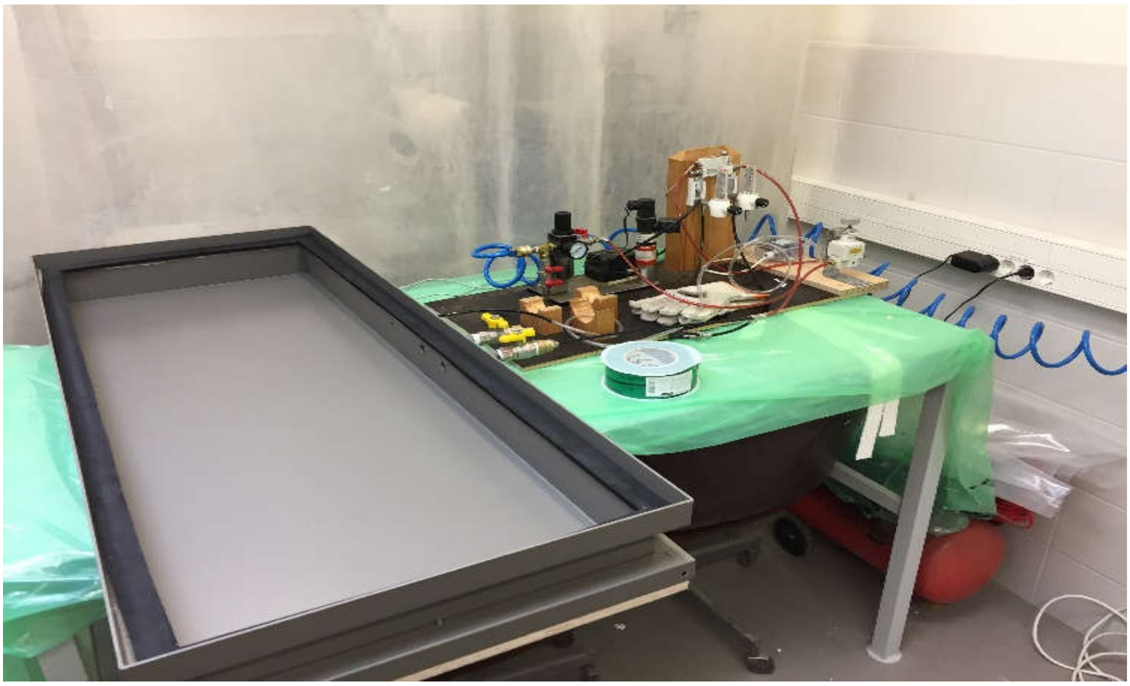


Figure 3.10. Air permeability box and remaining test apparatus.

Air permeability test apparatus consisted of following parts:

- Custom made air permeability box
- Manometer, Huba Control 699
- Air flow meter SMC PFM 710 with integrated flow adjustment valve
- Air compressor
- Several hoses connecting the different devices
- Closed cell neoprene membrane. This was used to assure a proper connection between the box and the specimen being tested, and to prevent any leakages through this link
- Clamping system

A close-up view of these smaller items is illustrated in Figure 3.11.

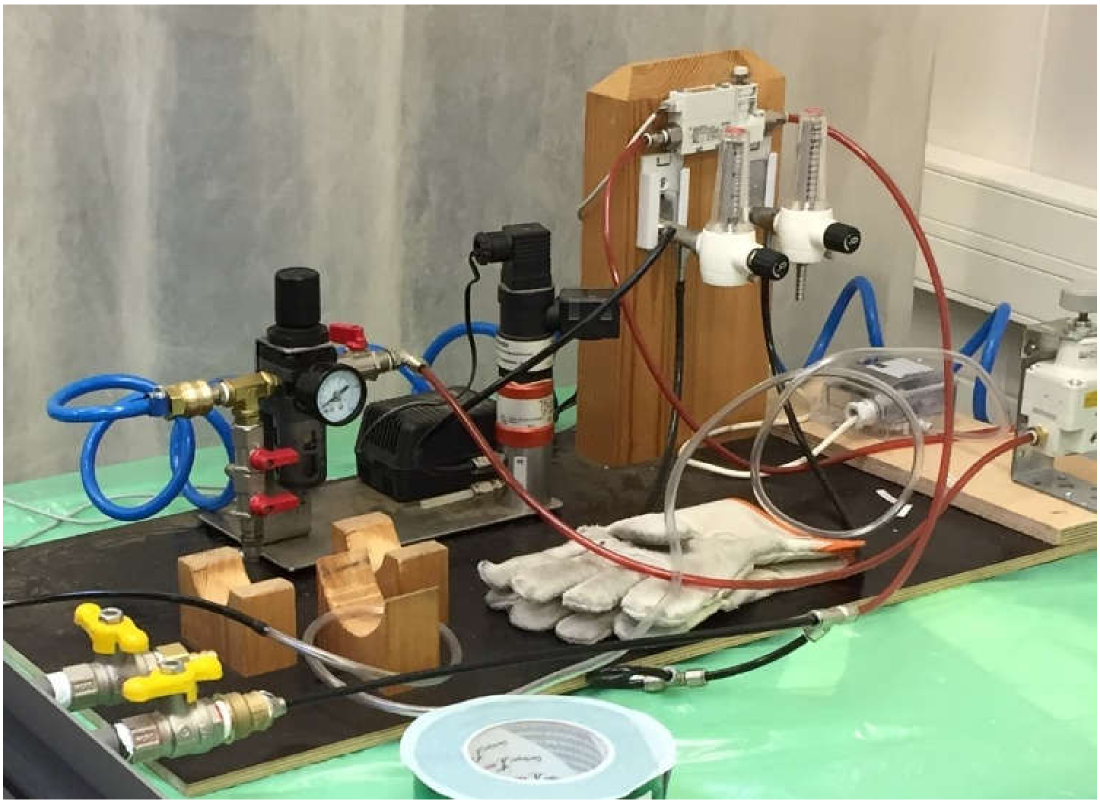


Figure 3.11. Close-up view of the smaller items completing the apparatus.

Air tightness of the system and the measurement accuracy of the equipment was initially tested with a laminated plywood board which achieved 1000Pa without any leakage in the system.

The crack measuring gauge was much simpler and easier to use. A gauge ruler was adopted to take note of the cracks dimensions. Figure 3.12 demonstrates this piece of equipment.

Figure 3.12. Measuring gauge.

On the top side, it is visible the scale of the gauge which varies between 0,1mm and 7mm.

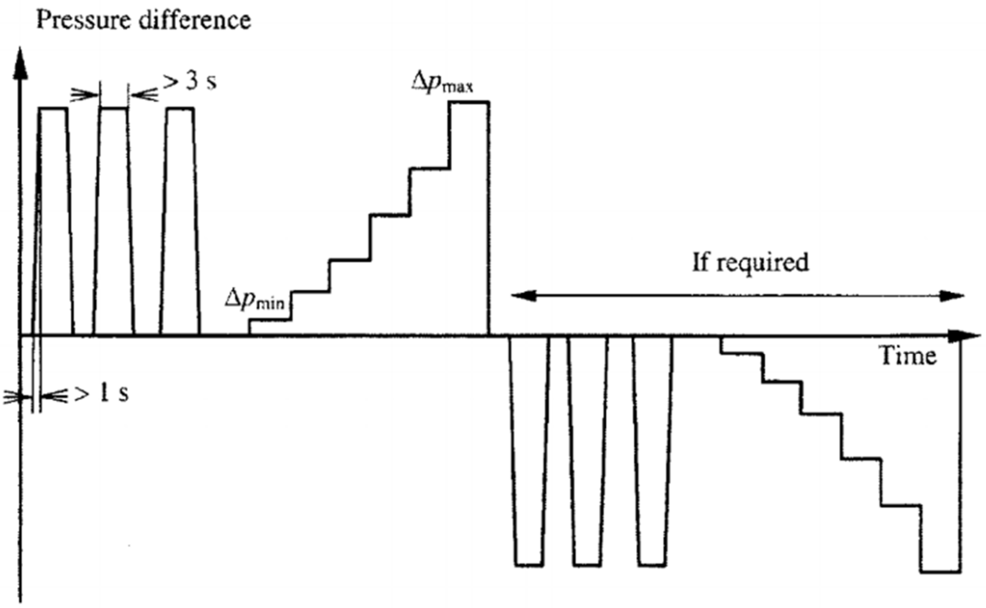
3.5 Test methodology

Each cross-laminated timber panel was tested at once after the conditioning period was terminated.

The air permeability test was performed following the EN12144:2000 standard, with the dimensions of the cracks and the gaps between laminations formed during the period also being recorded.

Only positive pressure was used during the test procedure and in accordance with an air permeability test report for CLT panels made in the Graz Technical University, the maximum pressure difference Δpmax was chosen to be 500 Pa and minimum Δpmin 50 Pa [11].

Following the EN 12114, two pressure stages need to be to the specimens in two consecutive steps. An illustration of this procedure can be seen in Figure 3.13.



Variation of pressure difference with time

Figure 3.13. Explanatory figure showing the pressure steps of the air permeability test. [12]

1) I stage. Three pulses of pressure were applied to the specimens. Each pulse maintained about two minutes. Each pulse produced about 550 Pa of pressure difference.

2) II stage. Seven steps of pressure difference (between and including maximum and minimum pressure differences) were applied to the specimens. Each pressure step maintained about one minute.

The seven steps of pressure difference in second stage of pressure application were calculated by following equation:

$$\Delta pi = 10^{i\frac{log\Delta pmax - log\Delta pmin}{N} + log\Delta pmin}$$

Where,
N- total number of pressure steps,
i- number of pressure step.

In table 3.3, it is shown the correspondent values for each pressure step that derive from the above equation.

Table 2.3. Pressure steps for the II stage air permeability test.

Number of pressure steps, i	Pressure steps values, Δpi (Pa)
0	50
1	73
2	108
3	158
4	232
5	341
6	500

Concerning the crack formation and evaluation, the method proposed by Brischke et al. in the COST Action FP 1303 – Cooperative Performance Test was followed. [13]

Cracks formed in the middle of the laminations and the gaps between laminations were recorded. The following measurements were taken:

- Crack and gap length
- Number of cracks on each face of the panel
- Mean crack width

Each crack or gap were numbered and marked with a code. Fissures formed in the middle of the laminations were names as cracks while the spaced formed between the edges of laminations were named gaps. The extremums of the cracks were also marked to allow an easier observation of the dimensions change in the following stages of the experiment. The full test setup can be seen in Figure 3.14.

Figure 3.14. Specimen being submitted to the air permeability test.

To assure that the existing leakages were coming exclusively through the panel wide side, the PE tape was also applied on top of the connections between the frame and the panel. The moisture content of each test panel was measured with the equipment Hydromette HT85T illustrated in Figure 3.15.

Figure 3.15. Hydromette HT85T.

4. Results and discussion

4.1 Moisture content of the specimens

In Figure 4.1 it is shown the equilibrium moisture content (EMC) of each specimen group and its variation according to the different conditioning stages across the experiment. It is visible that the pre-conditioning phase (RH 70% and RH 30%) did not had a major influence over the moisture content of the specimens, as no significant differences are seen.

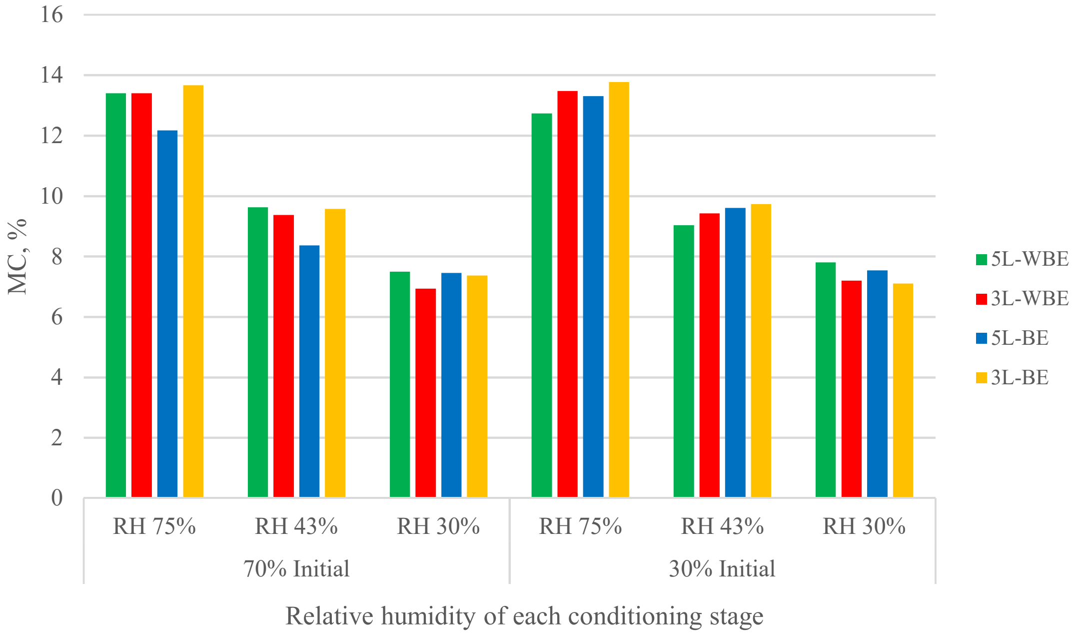


Figure 4.1. Moisture content of specimens after each conditioning stage.

The test data in Figure 4.1 shows that for both environments the biggest loss of moisture content in the test samples occurred between the test stages RH 75% and RH 43% with an average decrease of the 3.9%. In the next conditioning cycle from RH 43% to RH 30% the average reduction in MC was 1.98%.

4.2 Cracks growth and development

Concerning crack development in the visible faces of the specimens, the results obtained throughout the experiment are expressed in Figure 4.2.

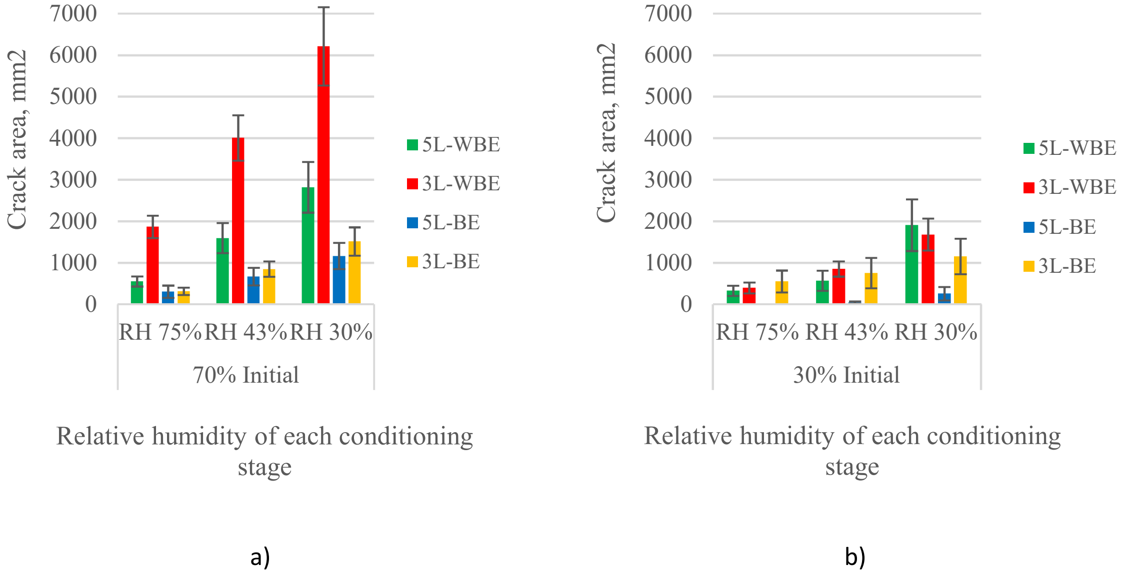


Figure 4.2. Average crack area per side of specimen. a) lamellas initially conditioned with RH of 70%. b) lamellas initially conditioned with RH of 30%.

For both groups of specimens, the crack area increased with the diminishing of the RH conditions and consequently with the lower MC % in the samples, as initially expected.

Comparing the initial RH conditioning, it is visible that the panels with lamellae conditioned under 70% had superior development of cracks from those with the laminations conditioned under 30%. Specimens without bonded edges (WBE) also developed more pronounced cracks then the samples with bonded edges (BE)

Another relevant fact is that during the experiment the 3L-WBE specimens group developed the most significant crack area growth 6214mm^2 (RH 70% initial conditioning environment of the lamellas). On the second place were the 5L-WBE specimens with crack area growth of 1907mm^2 (RH 30% % initial conditioning environment of the lamellas). On the other hand, the 5L-BE specimens group had the less crack area growth with 1165mm^2 and 257mm^2, depending on the initial environmental conditions of the lamellas (70% and 30% of RH accordingly).

In relation to the crack growth by observing the data presented in Table 4.1, it is shown that the biggest growth was achieved in the 5L-BE with 12233% in the end of the test (for the 30% of RH initial conditioning environment of lamellas).

Table 3.1. Average crack area per side of specimen and crack growth after each conditioning stage.

70% initial conditioning environment of the lamellas

Specimen	**75%**	**43%**		**30%**		
	Average crack area, (mm^2)	**Average crack area, (mm^2)**	**Growth (%) 75%->43%**	**Average crack area, (mm^2)**	**Growth (%) 43%->30%**	**Growth (%) 75%->30**
5L-WBE	551	1595	190	2819	77	412
3L-WBE	1866	4008	115	6214	55	233
5L-BE	304	669	120	1165	74	283
3L-BE	315	849	169	1514	78	381

30% initial conditioning environment of the lamellas

Specimen	**75%**	**43%**		**30%**		
	Average crack area, (mm^2)	**Average crack area, (mm^2)**	**Growth (%) 75%->43%**	**Average crack area, (mm^2)**	**Growth (%) 43%->30%**	**Growth (%) 75%->30**
5L-WBE	326	876	168	1907	118	484
3L-WBE	396	851	115	1680	97	325
5L-BE	2	47	2141	257	450	12233
3L-BE	549	752	37	1154	53	110

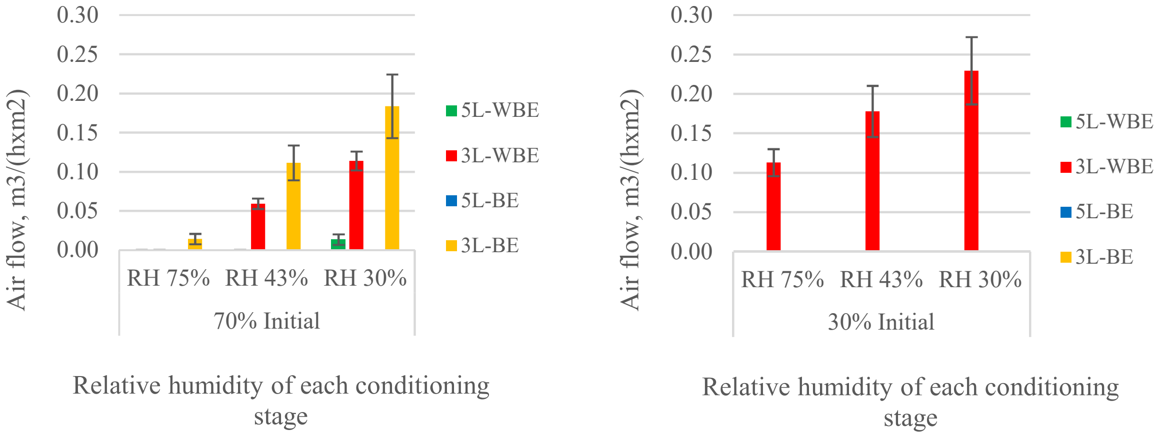
The 5L-BE specimen, despite having the lowest crack area among all the specimens possesses the biggest crack growth as well, which might seem incompatible at first sight. This huge value that outstands from all the others can be explained by the fact that this specimen had near zero crack area in the beginning of the experiment (2mm^2) and any crack growth would cause a big impact in the growth percentage, which was the case.

The specimen with lowest crack growth was the 3L-WBE and the 3L-BE for 70% and 30% initial conditioning environment, respectively.

It can also be deduced that, generally the biggest crack growth was achieved during the first conditioning step, from 75% to 43%, with the only exception being the 3L-BE specimen that developed a bigger area of cracks in the cycle 43% to 30%.

4.3 Air permeability of specimens

The air permeability tests for the step 1 of the EN 12114:2000 returned the values illustrated in Figure 4.4.3, in which it is visible that the specimens with 3 layers showed the highest values for air leakages for both initial conditioning environments 30% and 70% of RH.



a) b)

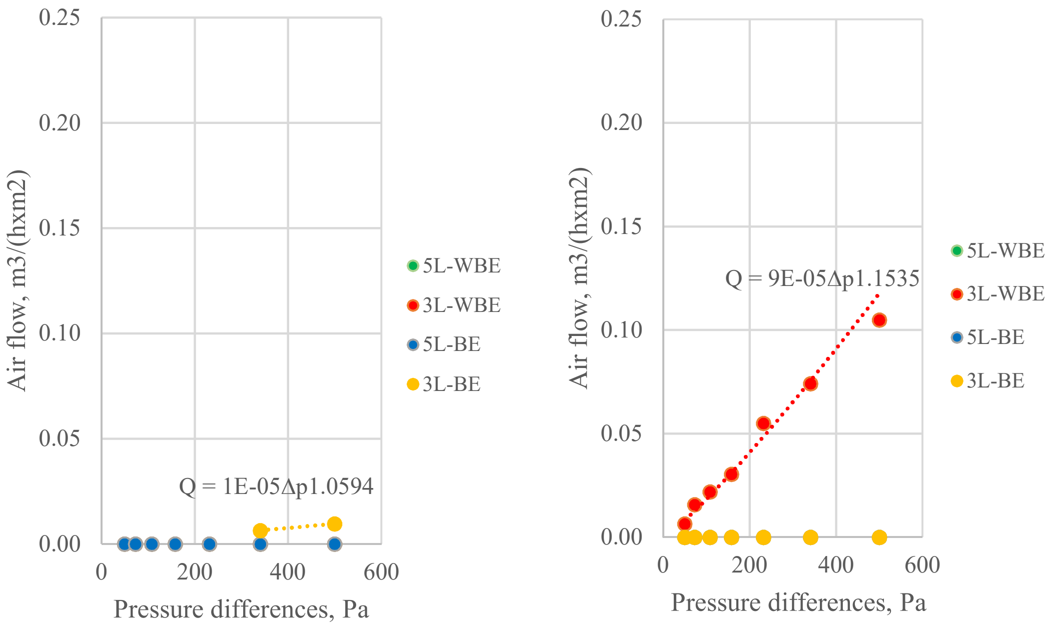
Figure 4.3. Air flow rate after each conditioning stage [step 1 of the EN 12114:2000]. a) lamellas initially conditioned with RH of 70%. b) lamellas initially conditioned with RH of 30%.

The specimen 5L-BE can be considered airtight for all stages and conditions of the experiment, when all other specimens showed some air permeability for some of the stages or conditions. Concerning the 30% relative humidity initial conditioning stage, panels had a very good behaviour, except for the 3L-WBE specimens group, which exhibit the highest values for air leakages of all. Within the 70% initial conditioning stage, samples with only 3 layers had more leakages in comparison with the ones with 5 layers.

The biggest value for air leakage was obtained for the 3L-WBE (30% initial) specimen group with 0.2294m^3/(hxm^2) and for the 3L-BE (70% initial) specimen group with 0.1835m^3/(hxm^2). Generally, panels produced with laminations with 30% RH initial conditioning had less leakages when compared to those with laminations conditioned with 70% RH initial conditioning.

The step 2 of the air permeability test was performed with increasing pressure steps in a logarithmic scale and the results are stated in Figures 4.4 - 4.6.

In Figure 4.4 are presented the air flow test measurement results after the 70% relative humidity conditioning stage. The air leakages at this moment were almost negligible, with values under 0.01m^3/(hxm^2) for the 3L-BE (initial 70% RH) and 0.11m^3/(h.m^2) for the 3L-WBE (initial 30% RH). The 3L-BE presented no leakages until the 341Pa pressure step was applied. The remaining specimens were airtight, at this time.

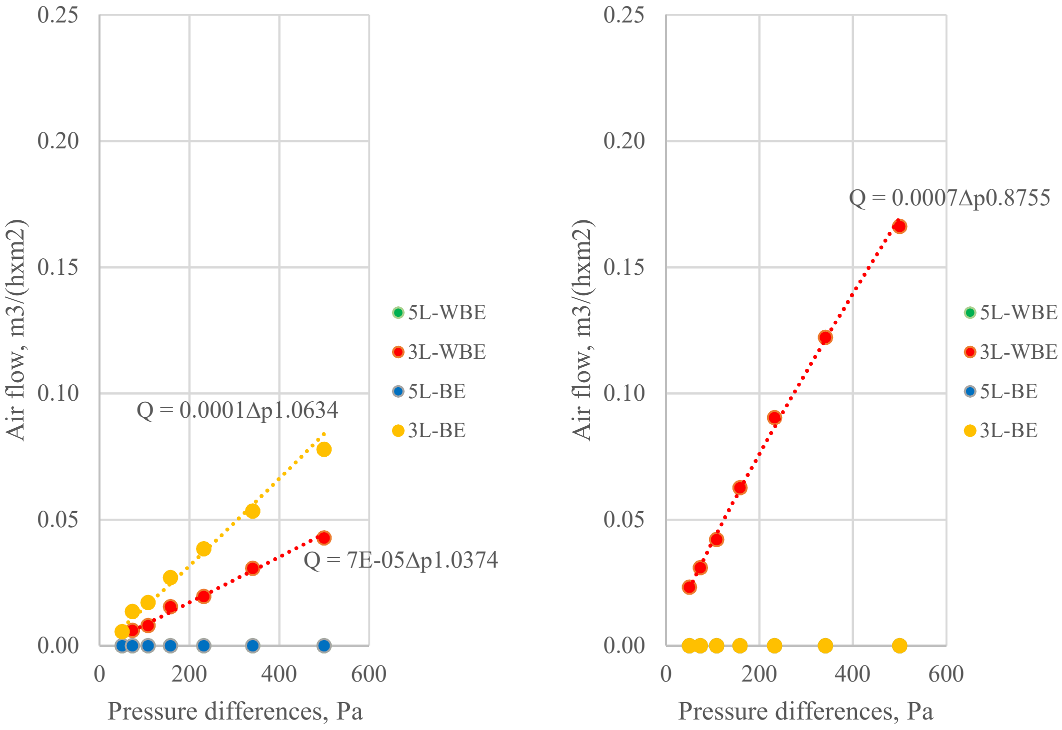


a)

b)

Figure 4.4. Air flow rate after the RH 75% conditioning stage [step 2 of the EN 12114:2000]. a) lamellas initially conditioned with RH of 70%. b) lamellas initially conditioned with RH of 30%.

The results achieved after the 43% conditioning stage are depicted in Figure 4.5. The panel with highest air leakage was at this stage 3L-WBE (initial 30% RH) with 0.1661m^3/(hxm^2) at 550Pa. Considering the initial conditioning environment of 70% RH, 2 panels showed air leakages, 3L-BE with 0.0779m^3/(hxm^2) and 3L-WBE with 0.0427m^3/(hxm^2) at 550PA. All the remaining ones were airtight throughout the test.

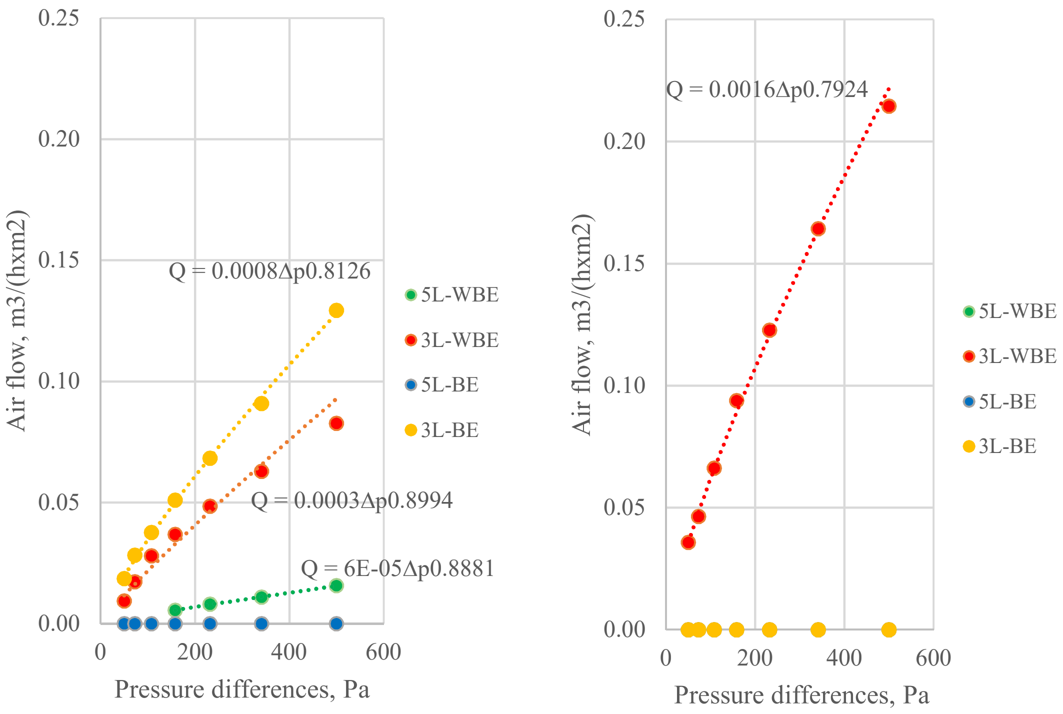


a)

b)

Figure 4.5. Air flow rate after the RH 43% conditioning stage [step 2 of the EN 12114:2000]. a) lamellas initially conditioned with RH of 70%. b) lamellas initially conditioned with RH of 30%.

Regarding the last conditioning stage of the experiment, the outcome of the air permeability test is presented in Figure 4.6. Once again, the specimen with the highest leakage was the 3L-WBE (30%) reaching 0.2144m^3/(hxm^2) at 550Pa, while the other samples initially conditioned in a 30% relative humidity environment were completely airtight.



a) b)

Figure 4.6. Air flow rate after the RH 30% conditioning stage [step 2 of the EN 12114:2000]. a) lamellas initially conditioned with RH of 70%. b) lamellas initially conditioned with RH of 30%.

A different scenario was found for the cross laminated timber panels made of lamellas kept in 70% initial relative humidity environment conditions. The exception was the 5L-BE specimen being airtight while all the remaining ones presented air leakages. In this case, the 3L-BE achieved the highest score with 0.1293m^3/(hxm^2) at pressure level of 550Pa.

Observing the test results presented in previous Figures 4.4 - 4.6, it is possible to verify that the air permeability growth rate is superior for the cross laminated timber panels with only 3 laminations and among these, the panels without bonded edges hold a superior growth rate in opposition to those with bonded edges.

Although it could be expected a straightforward correlation between air leakages and superficial crack area, results show that it is not the case. When comparing directly crack area growth results with the corresponding air leakage values there are cases where a bigger superficial area of the cracks does not implicate a bigger air leakage. If we compare the 3L-WBE and 3L-BE values for crack area are respectively 6214mm^2 and 1514mm^2, but against expectations air leakage values are 0.1137m^3/(hxm^2) and 0.1835m^3/(hxm^2).

Regarding the proposed hypotheses in the beginning of this research paper, according to the analysis and results:

- *“the more layers a CLT panels has, the less air leakages it has*” was proven correct.
- “CLT panels using edge bonding technology have less air leakages than those without bonded edges” was not proven correct but has explained before it might be related with the production place and type press used.
- “when CLT panels are produced from wood lamellas with lower moisture content will have less air leakages” was proven correct.
- “CLT panels manufactured with 5 layers will have less crack development than those with 3 layers”, can´t be proven correct since there are a few exceptions in the results that do not comply.

Conclusions

From the data analysis and results obtained along the experiment it can be concluded that panels fabricated with 5 laminations have a better behaviour concerning air tightness tests than that of produced with 3 laminations. The superior number of laminations and adhesive layers seem to help preventing air leakages even when superficial cracks are present on specimens. This way, it appears that when a bigger number of layers is present in a specimen it reduces the possibility of having a superposition of cracks favouring the airtightness of the element.

The crack development was deeply marked in some of the specimens. It was noticeable that the samples that possessed laminations which had a 70% initial conditioning environment, developed superior crack area in opposition to the ones that were submitted to the 30% initial conditioning environment. Secondly, the number of laminations had as well a positive impact on the crack formation (more laminations less cracks).

Concerning the edge bonding technology, results showed that using bonded edges avoids, to some extent, substantial air leakages across the panel. The exception for this is the 3L-BE (70%) specimen, although it is suspected that this is due to the different production place (cold press vs vacuum press).

As final comments, the most impactful and effective technology for preventing both cracks and air leakages was the pre-conditioning of the lamellae in 30% relative humidity environment followed by the number of laminations in panels. When manufacturing technologies are under consideration regarding airtightness of CLT panels, it is advised to have the moisture content of the raw material the closest possible to the equivalent relative humidity of service and to produce elements with many layers (5 or more). The use of bonded edges, although it slightly increases the quality of the specimens, its impact is not as relevant as the other two.

As a proposal for future experiments within the same scope, it would be very useful to know what is happening inside the panels regarding crack development and through where is exactly the air leakages occurring within the panel. How much of the air leakages is going through cracks formed during the drying process and how much is going through the existing gaps between lamination.

Summary

Crack development in cross laminated timber (CLT) wall panel has a significant impact to the air permeability properties of the panels, that may lead to unwanted energy costs. Proper production technology is good basis for assuring the quality of CLT panel and might also affect the air tightness of the panels and quality of building envelope in general.

The main objective of this work was to clarify which combination of production technologies is most efficient in preventing air leakages and crack formation in CLT panels, in a repeated test cycle, from more moist conditions (75% RH) to drier ones (30% RH).

This work is the continuation of the experiments developed by Giovanni Luciani, Martin Püssa and Ricardo Horta in the CLT field during the years of 2016/2017[22, 23]. The CLT specimens that were produced, were re-submitted to a new set of conditions and re-tested.

The production process of the 24 specimens of CLT panels was made with C24 strength class spruce boards. Panels were made in Laboratory of Wood Technology in TTÜ, Tallinn Ehituskool and Arcwood (Peetri Puit OÜ) factory in Põlva.

24 panels with 1300mm x 460mm were produced using different technologies (laminations amount but with the same overall thickness of 30 mm, edge bonding and different initial relative humidity conditioning of the laminations).

The specimens were submitted to a 3-step conditioning cycle that endured 3 months (one month each step, 75%, 43%, 30%) and to a constant temperature of 20°C. At the end of each step, cracks dimensions and moisture content values were taken, and an air permeability test was performed to monitor the air leakages for each specimen. All the results were registered.

The most impactful technology for preventing both cracks and air leakages was the pre-conditioning of the lamellae in 30% relative humidity environment followed by the number of laminations in panels. When manufacturing technologies are under consideration regarding airtightness of CLT panels and crack development, it is advised to have the moisture content of the raw material the closest possible to the equivalent relative humidity of service and to produce elements with many layers (5 or more). The use of bonded edges, although it slightly increases the quality of the specimens, its impact is not as relevant as the other two.

In future experiments within the same scope, it would be very useful to know what is happening inside the panels regarding crack development and through where is exactly the air leakages occurring within the panel. How much of the air leakages is going through cracks formed during the drying process and how much is going through the existing gaps between lamination.

Kokkuvõte

Pragude tekkel ristkihtliimpuidust seinapaneeli (CLT) on märkimisväärne mõju paneeli õhupidavusomadustele, mis võib viia hoone ootamatute energiakuludeni. CLT paneelide kvaliteedi aluseks on sobilik toomistehnoloogia, millel võib samuti olla mõju paneelide õhupidavusele ja hoone piirde kvaliteedile.

Antud magistritöö eesmärgiks oli välja selgitada missuguse ristkihtliimpuidu tootmistehnoloogia kombinatsioon on kõige efektiivsem vältimaks õhu leket ja pragude teket paneelis.
Töö tulemused saadi läbi korduskatse konditsioneerides paneele järk järgult niiskemast kuivema suhtelise õhuniiskusega (75-30%). See magistritöö on jätkuks uurimistööle, millega alustasid Giovanni Luciani, Martin Püssa ja Ricardo Horta CLT alal õppeaastal 2016/2017 [22, 23].

Korduskatseks kasutati eelnevalt toodetud ristkihtliimpuidust paneele, mis olid valmistatud kuuselaudadest tugevusklassiga C24. Paneelid toodeti TTÜ Puidutehnoloogia laboris, Tallinna Ehituskoolis ja Arcwoodi (Peetri Puit OÜ) tehases Põlvas.

Korduskatseks kasutatud 24 paneeli mõõtudega 30 x 460 x 1300 mm olid toodetud kolme erineva tehnoloogiaga: 1) erineva kihtide arvuga (3 ja 5 kihti) paneelid; 2) sileservseotisega (liimitud servadega) paneelid ja 3) erineva algniiskusega puidu kasutamine paneelide tootmisel. Katsekehad konditsioneeriti kolmes tsüklis ja iga tsükkel kestis ühe kuu. Tsükli vältel konditsioneeriti paneelid keskkonnas suhtelise õhuniiskusega 75%, 43% ja 30% konstantse temperatuuri juures 20 ^{o}C. Pärast igat konditsioneerimistsüklit mõõdeti paneelidel niiskussisaldust, pragude pindala ja õhulekke väärtust.

Tulemuste põhjal järeldati, et kõige efektiivseim tehnoloogia ennetamaks pragude kasvu ja õhuleket oli väiksema algniiskkusega puitmaterjalide kasutamine paneelide tootmisel. Sellele järgnes suurema puidukihtide arvu kasutamine paneeli tootmisel. Tehnoloogia valikul tootmaks võimalikult õhupidavaid paneele ilma suuremate pragude tekketa tuleks puit konditsioneerida tasakaaluniiskuseni, milleni puit jõuab hoone sisekliima madalaima suhtelise õhuniiksuse juures ja soovituslikuks paneeli kihtide arvuks on vähemalt viis kihti. Sileservseotisega paneelidel oli mõju paneelide õhupidavuse kvaliteedi tõstmisel, kuid võttes arvesse tehnoloogia keerukust ja tulemuste erinevust võrreldes teiste tehnoloogiatega, ei ole selle mõju niivõrd märkimisväärne.

Tulevastes uurimistöödes tuleks uurida täpseid õhulekke asukohti paneelides ja selle abil hinnata pragude tekke ja kasvamise mõju paneeli õhupidavusomadustele. Prao omaduste uurimisel on võimalik leida, kas peamiseks õhulekke allikaks on laudade keskele tekkinud praod ja nende kasvamine või suurenenud laudade vahed erinevate paneelikihtide ristumiskohas.

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Appendix A

Crack measurement data

Table 0.A1

Specimen	Conditioning steps	Face											
		A						B					
		id	**length**	**a**	**b**	**c**	**area (mm2)**	**id**	**length**	**a**	**b**	**c**	**area (mm2)**
A5,WBE,5L	RH 70%	1	105	0.20	0.20	0.20	21.00	1	1300	0.10	0.40	0.10	260.00
		2	154	0.20	0.20	0.20	30.80	2	285	0.10	0.15	0.10	33.25
							51.80	3	140	0.10	0.10	0.10	14.00
													307.25
	RH 50%	1	105	0.25	0.25	0.25	26.25	1	1300	0.45	0.60	0.40	628.33
		2	154	0.30	0.30	0.30	46.20	2	1300	0.20	0.35	0.30	368.33
		3	730	0.10	0.15	0.10	85.17	3	1300	0.10	0.25	0.10	195.00
							157.62	4	1300	0.10	0.35	0.10	238.33
								5	1300	0.10	0.30	0.10	216.67
								6	352	0.10	0.15	0.10	41.07
													1687.73
	RH 30%	1	105	0.35	0.40	0.30	36.75	1	1300	0.95	1.00	0.60	1105.00
		2	150	0.40	0.35	0.35	55.00	2	1300	0.50	0.75	0.70	845.00
		3	753	0.10	0.50	0.30	225.90	3	1300	0.70	0.45	0.50	715.00
		4	520	0.10	0.15	0.10	60.67	4	35	0.10	0.35	0.50	11.08
		5	73	0.15	0.15	0.15	10.95	5	1300	0.70	0.50	0.40	693.33
							389.27	6	363	0.10	0.45	0.10	78.65
								7	160	0.10	0.30	0.10	26.67
								8	154	0.10	0.20	0.10	20.53
								9	100	0.10	0.25	0.10	15.00
													3510.27

Table 0.A2

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
B5,WBE,5L	RH 70%	1	1300	0.10	0.25	0.10	195.00	1	438	0.10	0.10	0.10	43.80
		2	147	0.10	0.25	0.10	22.05	2	47	0.10	0.10	0.10	4.70
		3	46	0.10	0.15	0.10	5.37	3	33	0.15	0.15	0.15	4.95
							222.42	4	63	0.15	0.15	0.15	9.45
								5	57	0.15	0.15	0.15	8.55
								6	480	0.10	0.25	0.10	72.00
								7	191	0.10	0.10	0.10	19.10
								8	161	0.10	0.10	0.10	16.10
								9	80	0.10	0.10	0.10	8.00
								10	597	0.10	0.10	0.10	59.70
													246.35
	RH 50%	1	1300	0.45	0.40	0.15	433.33	1	438	0.20	0.20	0.20	87.60
		2	1300	0.10	0.35	0.10	238.33	2	47	0.15	0.15	0.15	7.05
		3	1300	0.10	0.20	0.10	173.33	3	33	0.20	0.20	0.20	6.60
		4	1300	0.10	0.15	0.10	151.67	4	63	0.20	0.20	0.20	12.60
							996.67	5	57	0.20	0.20	0.20	11.40
								6	480	0.25	0.25	0.25	120.00
								7	191	0.15	0.15	0.15	28.65
								8	161	0.15	0.15	0.15	24.15
								9	80	0.15	0.15	0.15	12.00
								10	597	0.15	0.15	0.15	89.55
													399.60
	RH 30%	1	1300	0.60	0.60	0.50	736.67	1	192	0.20	0.20	0.20	38.40
		2	1300	0.50	0.50	0.20	520.00	2	166	0.30	0.20	0.30	44.27
		3	1300	0.60	0.65	0.25	650.00	3	80	0.20	0.15	0.15	13.33
		4	1300	1.00	0.90	0.25	931.67	4	6	0.25	0.25	0.25	1.50
							2838.33	5	200	0.25	0.20	0.20	43.33
								6	480	0.50	0.40	0.45	216.00
								7	57	0.35	0.30	0.30	18.05
								8	64	0.35	0.45	0.35	24.53
								9	33	0.30	0.30	0.30	9.90
								10	47	0.20	0.20	0.20	9.40
								11	19	0.20	0.20	0.20	3.80
								12	219	0.15	0.15	0.15	32.85
								13	190	0.20	0.20	0.20	38.00
								14	45	0.10	0.10	0.10	4.50
								15	42	0.10	0.10	0.10	4.20
								16	38	0.10	0.10	0.10	3.80
								17	33	0.10	0.10	0.10	3.30
								18	40	0.10	0.10	0.10	4.00
								19	112	0.10	0.10	0.10	11.20
								20	46	0.10	0.10	0.10	4.60
													528.97

Table 0.A3

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b	c	area (mm2)	id	length	a	b	c	area (mm2)
C5,WBE,5L	RH 70%	1	15	0.10	0.10	0.10	1.50	1	360	0.10	0.25	0.10	54.00
		2	23	0.10	0.10	0.10	2.30	2	1300	0.30	0.65	0.60	671.67
		3	14	0.15	0.15	0.15	2.10	3	664	0.10	0.15	0.10	77.47
		4	51	0.10	0.15	0.10	5.95	4	154	0.10	0.15	0.10	17.97
		5	35	0.10	0.15	0.10	4.08	5	798	0.10	0.35	0.10	146.30
		6	92	0.15	0.25	0.15	16.87	6	119	0.10	0.10	0.10	11.90
		7	22	0.30	0.30	0.30	6.60	7	27	0.10	0.10	0.10	2.70
		8	51	0.10	0.25	0.10	7.65						**982.00**
		9	204	0.10	0.10	0.10	20.40						
		10	62	0.30	0.30	0.30	18.60						
		11	10	0.10	0.10	0.10	1.00						
		12	48	0.10	0.10	0.10	4.80						
		13	39	0.10	0.10	0.10	3.90						
		14	169	0.10	0.15	0.10	19.72						
		15	126	0.10	0.15	0.10	14.70						
		16	144	0.10	0.10	0.10	14.40						
		17	42	0.10	0.10	0.10	4.20						
							148.77						
	RH 50%	1	15	0.10	0.10	0.10	1.50	1	1300	0.10	0.25	0.10	195.00
		2	23	0.10	0.10	0.10	2.30	2	1300	0.40	0.60	0.80	780.00
		3	14	0.15	0.15	0.15	2.10	3	1.3	0.15	0.30	0.30	0.33
		4	51	0.10	0.15	0.10	5.95	4	1300	0.10	0.40	0.40	390.00
		5	35	0.15	0.15	0.15	5.25	5	781	0.10	0.25	0.10	117.15
		6	92	0.25	0.25	0.25	23.00	6	320	0.10	0.15	0.10	37.33
		7	22	0.30	0.30	0.30	6.60						**1519.81**
		8	51	0.25	0.25	0.25	12.75						
		9	204	0.10	0.15	0.10	23.80						
		10	62	0.30	0.30	0.30	18.60						
		11	10	0.10	0.10	0.10	1.00						
		12	48	0.10	0.10	0.10	4.80						
		13	39	0.10	0.10	0.10	3.90						
		14	169	0.10	0.20	0.10	22.53						
		15	126	0.15	0.15	0.15	18.90						
		16	144	0.10	0.10	0.10	14.40						
		17	42	0.10	0.10	0.10	4.20						
							171.58						
	RH 30%	1	15	0.20	0.20	0.20	3.00	1	1300	0.35	0.40	0.45	520.00
		2	22	0.25	0.25	0.25	5.50	2	1300	0.85	1.00	1.00	1235.00
		3	27	0.20	0.20	0.20	5.40	3	1300	0.55	0.70	0.55	780.00
		4	180	0.10	0.10	0.10	18.00	4	1300	0.70	0.85	0.35	823.33
		5	14	0.35	0.35	0.35	4.90	5	1300	0.25	0.45	0.40	476.67
		6	62	0.25	0.25	0.25	15.50	6	112	0.10	0.20	0.10	14.93
		7	31	0.30	0.30	0.30	9.30						**3849.93**
		8	95	0.35	0.35	0.35	33.25						
		9	25	0.40	0.40	0.40	10.00						
		10	52	0.35	0.35	0.35	18.20						
		11	205	0.20	0.25	0.25	47.83						
		12	62	0.30	0.35	0.35	20.67						
		13	10	0.15	0.15	0.15	1.50						
		14	50	0.20	0.20	0.20	10.00						
		15	39	0.15	0.15	0.20	6.50						
		16	171	0.30	0.30	0.30	51.30						
		17	127	0.25	0.25	0.25	31.75						
		18	145	0.10	0.20	0.20	24.17						
		19	42	0.10	0.15	0.15	5.60						
							322.37						

Table 0.A4

Specimen	Conditioning	Face											
		A						B					
	steps	id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P1,WBE,5L	RH 70%	1	127	0.10	0.20	0.10	16.93	1	225	0.10	0.10	0.10	22.50
		2	456	0.10	0.10	0.10	45.60	2	810	0.10	0.15	0.10	94.50
		3	266	0.10	0.20	0.10	35.47	3	110	0.10	0.15	0.10	12.83
		4	30	0.10	0.15	0.10	3.50	4	35	0.10	0.20	0.10	4.67
		5	120	0.10	0.10	0.10	12.00	5	83	0.10	0.10	0.10	8.30
		6	360	0.10	0.10	0.10	36.00	6	55	0.10	0.10	0.10	5.50
		7	140	0.10	0.20	0.10	18.67	7	15	0.10	0.15	0.10	1.75
		8	500	0.10	0.25	0.10	75.00	8	160	0.10	0.10	0.10	16.00
		9	36	0.10	0.20	0.10	4.80	9	125	0.10	0.20	0.10	16.67
		10	1300	0.10	0.25	0.10	195.00	10	227	0.10	0.10	0.10	22.70
		11	1300	0.10	0.20	0.10	173.33	11	350	0.10	0.10	0.10	35.00
		12	35	0.10	0.25	0.10	5.25						**240.42**
							621.55						
	RH 50%	1	1300	0.55	0.35	0.30	520.00	1	225	0.10	0.25	0.25	45.00
		2	51	0.10	0.25	0.25	10.20	2	861	0.10	0.35	0.10	157.85
		3	212	0.10	0.25	0.10	31.80	3	110	0.10	0.30	0.30	25.67
		4	396	0.10	0.30	0.10	66.00	4	56	0.10	0.20	0.10	7.47
		5	268	0.10	0.30	0.10	44.67	5	107	0.10	0.35	0.10	19.62
		6	332	0.10	0.25	0.10	49.80	6	59	0.30	0.30	0.30	17.70
		7	146	0.10	0.25	0.10	21.90	7	15	0.40	0.40	0.40	6.00
		8	986	0.10	0.20	0.10	131.47	8	161	0.35	0.35	0.35	56.35
		9	1300	0.50	0.45	0.55	650.00	9	126	0.30	0.30	0.30	37.80
		10	1300	0.65	0.40	0.65	736.67	10	217	0.25	0.25	0.25	54.25
		11	1300	0.50	0.55	0.45	650.00	11	350	0.15	0.15	0.15	52.50
		12	35	0.10	0.25	0.10	5.25	12	51	0.20	0.20	0.20	10.20
		13	37	0.10	0.30	0.10	6.17	13	30	0.20	0.20	0.20	6.00
		14	150	0.10	0.20	0.10	20.00	14	356	0.10	0.20	0.10	47.47
		15	175	0.10	0.10	0.10	17.50	15	470	0.10	0.30	0.10	78.33
		16	161	0.10	0.15	0.10	18.78	16	387	0.10	0.20	0.10	51.60
		17	91	0.10	0.15	0.10	10.62	17	517	0.10	0.15	0.10	60.32
							2990.82	18	107	0.10	0.15	0.10	12.48
													746.60
	RH 30%	1	1300	1.00	0.85	0.60	1061.67	1	225	0.10	0.25	0.40	56.25
		2	52	0.10	0.55	0.70	23.40	2	1000	0.25	0.50	0.35	366.67
		3	214	0.10	0.55	0.10	53.50	3	57	0.10	0.30	0.35	14.25
		4	400	0.10	0.70	0.10	120.00	4	157	0.10	0.45	0.10	34.02
		5	273	0.10	0.60	0.10	72.80	5	240	0.10	0.45	0.10	52.00
		6	332	0.10	0.65	0.10	94.07	6	130	0.10	0.30	0.10	21.67
		7	155	0.10	0.50	0.40	51.67	7	260	0.35	0.45	0.55	117.00
		8	990	0.10	0.35	0.10	181.50	8	119	0.10	0.25	0.10	17.85
		9	1300	0.65	0.65	0.95	975.00	9	184	0.50	0.50	0.50	92.00
		10	1300	1.00	0.75	1.00	1191.67	10	220	0.40	0.35	0.35	80.67
		11	1300	0.70	0.75	0.65	910.00	11	354	0.10	0.30	0.20	70.80
		12	35	0.10	0.60	0.10	9.33	12	53	0.35	0.35	0.35	18.55
		13	37	0.10	0.40	0.40	11.10	13	32	0.30	0.30	0.30	9.60
		14	156	0.10	0.40	0.10	31.20	14	355	0.10	0.35	0.40	100.58
		15	185	0.10	0.20	0.10	24.67	15	504	0.10	0.50	0.10	117.60
		16	175	0.10	0.40	0.10	35.00	16	284	0.10	0.40	0.10	56.80
		17	93	0.10	0.20	0.10	12.40	17	121	0.10	0.45	0.50	42.35
		18	35	0.10	0.30	0.35	8.75	18	517	0.10	0.20	0.10	68.93
		19	160	0.10	0.30	0.10	26.67	19	47	0.10	0.35	0.10	8.62
		20	115	0.10	0.30	0.10	19.17	20	111	0.10	0.35	0.10	20.35
		21	65	0.10	0.20	0.10	8.67	21	122	0.10	0.20	0.10	16.27
							4922.22	22	33	0.10	0.20	0.10	4.40
													1387.22

Table 0.A5

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P2,WBE,5L	RH 70%	1	480	0.10	0.20	0.10	64.00	1	404	0.10	0.15	0.10	47.13
		2	445	0.10	0.15	0.10	51.92	2	308	0.10	0.10	0.10	30.80
		3	180	0.10	0.15	0.10	21.00	3	77	0.10	0.10	0.10	7.70
		4	271	0.10	0.40	0.35	76.78	4	67	0.10	0.15	0.10	7.82
		5	301	0.10	0.20	0.10	40.13	5	50	0.10	0.15	0.15	6.67
		6	511	0.10	0.20	0.10	68.13	6	92	0.10	0.10	0.10	9.20
		7	1300	0.10	0.20	0.10	173.33	7	40	0.10	0.10	0.10	4.00
		8	850	0.10	0.25	0.10	127.50	8	417	0.10	0.15	0.10	48.65
		9	356	0.10	0.15	0.10	41.53						**161.97**
		10	1143	0.10	0.25	0.10	171.45						
		11	100	0.10	0.15	0.10	11.67						
							847.45						
	RH 50%	1	1300	0.20	0.40	0.30	390.00	1	395	0.25	0.25	0.25	98.75
		2	369	0.50	0.50	0.50	184.50	2	472	0.10	0.20	0.10	62.93
		3	841	0.50	0.50	0.50	420.50	3	77	0.20	0.20	0.20	15.40
		4	1300	0.10	0.35	0.40	368.33	4	67	0.20	0.20	0.20	13.40
		5	343	0.10	0.20	0.10	45.73	5	50	0.15	0.15	0.15	7.50
		6	550	0.10	0.30	0.10	91.67	6	92	0.10	0.15	0.10	10.73
		7	400	0.10	0.25	0.10	60.00	7	40	0.10	0.15	0.10	4.67
		8	125	0.10	0.35	0.10	22.92	8	417	0.10	0.20	0.10	55.60
		9	1300	0.30	0.55	0.40	541.67	9	70	0.10	0.20	0.10	9.33
		10	1300	0.20	0.50	0.40	476.67	10	120	0.10	0.15	0.10	14.00
							2601.98	11	382	0.10	0.20	0.10	50.93
								12	760	0.10	0.25	0.10	114.00
													457.25
	RH 30%	1	1300	0.45	0.75	0.50	736.67	1	432	0.10	0.45	0.30	122.40
		2	375	0.90	1.00	0.90	350.00	2	475	0.10	0.40	0.30	126.67
		3	845	0.70	0.75	0.50	549.25	3	83	0.10	0.40	0.10	16.60
		4	1300	0.15	1.00	0.65	780.00	4	67	0.10	0.35	0.10	12.28
		5	357	0.10	0.55	0.60	148.75	5	50	0.10	0.30	0.10	8.33
		6	515	0.10	0.65	0.10	145.92	6	92	0.10	0.35	0.10	16.87
		7	400	0.10	0.55	0.10	100.00	7	40	0.20	0.30	0.20	9.33
		8	127	0.10	0.45	0.55	46.57	8	447	0.10	0.35	0.35	119.20
		9	1300	0.50	0.85	0.60	845.00	9	75	0.10	0.45	0.10	16.25
		10	1300	0.45	0.90	0.65	866.67	10	187	0.10	0.30	0.10	31.17
							4568.82	11	413	0.10	0.35	0.10	75.72
								12	763	0.10	0.70	0.10	228.90
								13	58	0.10	0.15	0.10	6.77
								14	40	0.10	0.25	0.10	6.00
								15	70	0.10	0.45	0.10	15.17
								16	65	0.10	0.40	0.10	13.00
								17	333	0.10	0.35	0.10	61.05
								18	50	0.10	0.30	0.40	13.33
													899.03

Table 0.A6

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P3,WBE,5L	RH 70%	1	339	0.10	0.15	0.15	45.20	1	1300	0.10	0.20	0.15	195.00
		2	116	0.15	0.15	0.10	15.47	2	447	0.20	0.20	0.15	81.95
		3	234	0.10	0.15	0.20	35.10	3	247	0.10	0.20	0.10	32.93
		4	294	0.10	0.20	0.20	49.00	4	323	0.10	0.10	0.10	32.30
		5	667	0.10	0.15	0.10	77.82	5	1300	0.20	0.25	0.20	281.67
		6	123	0.10	0.10	0.10	12.30	6	1300	0.15	0.20	0.15	216.67
		7	92	0.10	0.10	0.10	9.20	7	17	0.50	0.50	0.50	8.50
		8	137	0.10	0.15	0.10	15.98	8	18	0.40	0.40	0.40	7.20
		9	46	1.00	3.00	1.00	76.67	9	21	0.55	0.55	0.55	11.55
		10	172	0.10	0.10	0.10	17.20	10	1300	0.15	0.20	0.15	216.67
		11	116	0.10	0.10	0.10	11.60						
							365.53						**1084.43**
	RH 50%	1	339	0.10	0.25	0.10	50.85	1	1300	0.25	0.30	0.25	357.50
		2	192	0.10	0.25	0.10	28.80	2	98	0.15	0.15	0.15	0.00
		3	292	0.10	0.35	0.10	53.53	3	1132	0.10	0.30	0.10	188.67
		4	296	0.10	0.35	0.10	54.27	4	1300	0.35	0.40	0.40	498.33
		5	833	0.10	0.20	0.10	111.07	5	1300	0.30	0.30	0.45	455.00
		6	155	0.10	0.25	0.10	23.25	6	17	0.10	0.50	0.10	3.97
		7	169	0.10	0.25	0.10	25.35	7	20	0.10	0.70	0.10	6.00
		8	130	0.10	0.25	0.10	19.50	8	22	0.10	0.90	0.10	8.07
		9	137	0.10	0.25	0.10	20.55	9	1300	0.45	0.40	0.30	498.33
		10	46	0.10	3.00	0.10	49.07	10	117	0.10	0.10	0.10	11.70
		11	172	0.10	0.20	0.10	22.93						**2027.57**
		12	133	0.10	0.20	0.10	17.73						
		13	80	0.10	0.25	0.10	12.00						
		14	150	0.10	0.20	0.10	20.00						
		15	427	0.10	0.25	0.10	64.05						
		16	216	0.10	0.35	0.10	39.60						
		17	421	0.10	0.25	0.10	63.15						
		18	195	0.10	0.15	0.10	22.75						
		19	130	0.10	0.10	0.10	13.00						
		20	310	0.10	0.25	0.10	46.50						
		21	211	0.10	0.15	0.10	24.62						
		22	125	0.10	0.15	0.10	14.58						
							797.15						
	RH 30%	1	346	0.10	0.35	0.30	112.45	1	1300	0.40	0.50	0.50	650.00
		2	205	0.10	0.40	0.10	51.25	2	103	0.20	0.25	0.25	0.00
		3	305	0.10	0.45	0.35	91.50	3	1134	0.45	0.40	0.30	434.70
		4	305	0.30	0.45	0.40	116.92	4	1300	0.55	0.80	0.60	845.00
		5	934	0.15	0.30	0.20	202.37	5	1300	0.60	0.80	0.80	953.33
		6	165	0.10	0.45	0.10	35.75	6	257	0.10	0.30	0.10	42.83
		7	182	0.10	0.40	0.10	0.00	7	132	0.10	0.50	0.10	30.80
		8	131	0.10	0.40	0.50	43.67	8	23	0.10	0.70	0.10	6.90
		9	152	0.10	0.35	0.10	27.87	9	1300	0.80	0.55	0.55	823.33
		10	44	0.10	3.00	0.10	46.93	10	131	0.10	0.45	0.10	28.38
		11	174	0.10	0.35	0.10	31.90	11	196	0.10	0.30	0.10	32.67
		12	143	0.10	0.25	0.10	21.45	12	97	0.10	0.25	0.10	14.55
		13	79	0.10	0.40	0.25	19.75						**3862.50**
		14	167	0.10	0.35	0.10	30.62						
		15	428	0.10	0.40	0.35	121.27						
		16	220	0.10	0.55	0.55	88.00						
		17	425	0.10	0.50	0.10	99.17						
		18	200	0.10	0.45	0.10	43.33						
		19	136	0.10	0.30	0.10	22.67						
		20	121	0.10	0.25	0.25	24.20						
		21	50	0.10	0.25	0.10	7.50						
		22	93	0.10	0.30	0.10	15.50						
							1254.05						

Table 0.A7

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
A3, WBE, 3L	RH 70%	1	23	0.40	0.40	0.40	9.20	1.00	36.00	0.30	0.30	0.30	10.80
		2	30	0.10	0.35	0.10	5.50	2.00	99.00	0.10	0.30	0.10	16.50
		3	168	0.10	0.30	0.10	28.00	3.00	16.00	0.65	0.65	0.65	10.40
		4	52	0.10	0.20	0.10	6.93	4.00	219.00	0.20	0.45	0.20	62.05
		5	96	0.10	0.20	0.10	12.80	5.00	38.00	0.10	0.25	0.10	5.70
		6	60	0.10	0.20	0.10	8.00	6.00	5.00	0.15	0.15	0.15	0.75
		7	40	0.10	3.00	0.10	42.67						**106.20**
		8	39	0.10	0.15	0.10	4.55						
		9	94	0.10	0.20	0.10	12.53						
		10	26	0.10	0.20	0.10	3.47						
		11	81	0.10	0.25	0.10	12.15						
		12	222	0.10	0.15	0.10	25.90						
		13	134	0.10	0.10	0.10	13.40						
							185.10						
	RH 50%	1	23	0.45	0.45	0.45	10.35	1	36	0.30	0.30	0.30	10.80
		2	561	0.10	0.25	0.10	84.15	2	99	0.30	0.30	0.30	29.70
		3	235	0.10	0.50	0.10	54.83	3	16	0.70	0.70	0.70	11.20
		4	974	0.10	0.15	0.10	113.63	4	219	0.40	0.40	0.40	87.60
		5	470	0.10	0.20	0.10	62.67	5	38	0.30	0.30	0.30	11.40
		6	425	0.10	0.35	0.10	0.00	6	30	0.10	0.10	0.10	3.00
		7	510	0.10	0.15	0.10	59.50	7	5	0.15	0.15	0.15	0.75
		8	280	0.10	0.10	0.10	28.00						**154.45**
		9	45	0.10	2.50	0.10	40.50						
							453.63						
	RH 30%	1	23	0.50	0.50	0.50	11.50	1	50.00	0.50	0.50	0.25	20.83
		2	145	0.40	0.25	0.40	50.75	2	115.00	0.50	0.55	0.35	53.67
		3	292	0.45	0.35	0.10	87.60	3	12.00	0.70	0.70	0.70	8.40
		4	90	0.25	0.30	0.25	24.00	4	220.00	0.55	0.55	0.55	121.00
		5	269	0.10	0.20	0.10	35.87	5	29.00	0.45	0.45	0.25	11.12
		6	470	0.35	0.50	0.35	0.00	6	76.00	0.10	0.15	0.20	11.40
		7	670	0.65	0.50	0.10	279.17	7	5.00	0.20	0.20	0.20	1.00
		8	253	0.10	0.15	0.15	33.73	8	234.00	0.10	0.20	0.10	31.20
		9	414	0.10	0.25	0.10	62.10	9	50.00	0.15	0.15	0.15	7.50
		10	126	0.10	0.15	0.10	14.70	10	153.00	0.10	0.15	0.10	17.85
		11	510	0.35	0.40	0.35	187.00						**283.97**
		12	589	0.45	0.30	0.30	206.15						
		13	356	0.10	0.45	0.10	77.13						
		14	119	0.10	0.25	0.10	17.85						
		15	53	0.10	0.20	0.10	7.07						
		16	700	0.10	0.25	0.10	105.00						
							1199.62						

Table 0.A8

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
B3,WBE,3L	RH 70%	1	106	0.10	0.15	0.10	12.37	1	94	0.35	0.35	0.35	32.90
		2	461	0.1	0.50	0.10	107.57	2	149	0.1	0.20	0.10	19.87
		3	168	0.1	0.15	0.10	19.60	3	194	0.35	0.35	0.35	67.90
		4	140	0.1	0.30	0.10	23.33	4	142	0.2	0.20	0.20	28.40
		5	97	0.1	0.10	0.10	9.70	5	91	0.2	0.20	0.20	18.20
							172.57	6	1300	0.1	1.50	0.10	736.67
								7	125	0.2	0.20	0.20	25.00
													928.93
	RH 50%	1	651	0.10	0.55	0.10	162.75	1	94	0.45	0.45	0.45	42.30
		2	595	0.10	0.85	0.10	208.25	2	149	0.25	0.25	0.25	37.25
		3	912	0.10	0.20	0.10	121.60	3	194	0.35	0.35	0.35	67.90
		4	845	0.10	0.25	0.10	126.75	4	142	0.25	0.25	0.25	35.50
		5	1300	0.10	0.50	0.10	303.33	5	91	0.20	0.20	0.20	18.20
		6	1300	1.00	0.40	0.15	671.67	6	1300	0.10	1.50	0.10	736.67
		7	320	0.10	0.25	0.10	48.00	7	125	0.20	0.20	0.20	25.00
		8	170	0.10	0.20	0.10	22.67						**962.82**
							1665.02						
	RH 30%	1	1300	0.50	1.50	0.60	1126.67	1	1300	0.20	2.00	0.20	1040.00
		2	370	0.10	0.15	0.10	43.17	2	172	0.30	0.80	0.30	80.27
		3	1300	0.20	0.45	0.40	455.00	3	91	0.10	0.35	0.10	16.68
		4	390	0.10	0.55	0.10	97.50	4	192	0.30	0.60	0.30	76.80
		5	835	0.10	0.55	0.30	264.42	5	143	0.40	0.20	0.35	45.28
		6	182	0.10	0.20	0.10	24.27	6	95	0.60	0.60	0.60	57.00
		7	1300	0.55	0.85	0.55	845.00	7	112	0.10	0.20	0.40	26.13
		8	1300	0.40	0.90	0.30	693.33	8	149	0.35	0.30	0.50	57.12
							3549.35	9	73	0.10	0.10	0.10	7.30
													1406.58

Table 0.A9

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
C3,WBE,3L	RH 70%	1	76	0.15	0.15	0.15	11.40	1	467	0.10	0.35	0.10	85.62
		2	294	0.35	0.35	0.35	102.90	2	293	0.10	0.20	0.10	39.07
		3	71	0.25	0.25	0.25	17.75	3	431	0.10	0.35	0.10	79.02
							132.05	4	140	0.10	0.10	0.10	14.00
								5	875	0.10	0.50	0.10	204.17
								6	196	0.10	0.35	0.10	35.93
													457.80
	RH 50%	1	76	0.25	0.25	0.25	19.00	1	1056	0.10	0.45	0.10	228.80
		2	294	0.40	0.40	0.40	117.60	2	1300	0.10	0.30	0.10	216.67
		3	71	0.35	0.35	0.35	24.85	3	681	0.10	0.40	0.10	136.20
		4	16	0.40	0.40	0.40	6.40	4	140	0.10	0.20	0.10	18.67
							167.85	5	160	0.10	0.20	0.10	21.33
								6	1077	0.10	0.70	0.10	323.10
								7	62	0.10	0.25	0.10	9.30
													954.07
	RH 30%	1	153	0.10	0.10	0.10	15.30	1	54	0.25	0.25	0.30	14.40
		2	151	0.10	0.20	0.10	20.13	2	865	0.65	0.55	0.10	374.83
		3	144	0.10	0.10	0.10	14.40	3	353	0.30	0.50	0.40	141.20
		4	70	0.10	0.15	0.10	8.17	4	690	0.10	0.20	0.10	92.00
		5	32	0.10	0.10	0.10	3.20	5	350	0.10	0.25	0.10	52.50
		6	52	0.10	0.10	0.10	5.20	6	165	0.10	0.10	0.10	16.50
		7	81	0.10	0.15	0.10	9.45	7	975	0.10	0.55	0.40	341.25
		8	15	0.35	0.35	0.35	5.25	8	70	0.15	0.15	0.10	9.33
		9	275	0.55	0.55	0.55	151.25	9	69	0.20	0.20	0.20	13.80
		10	67	0.45	0.45	0.45	30.15	10	52	0.25	0.25	0.25	13.00
		11	74	0.35	0.35	0.35	25.90	11	154	0.30	0.25	0.10	33.37
		12	25	0.60	0.60	0.60	15.00	12	310	0.65	0.65	0.10	144.67
		13	25	0.85	0.85	0.85	21.25	13	688	0.25	0.60	0.55	321.07
							324.65						**1567.92**

Table 0.A10

Specimen	**Conditioning steps**	**Face**											
		A						**B**					
		id	**length**	**a**	**b (max)**	**c**	**area (mm2)**	**id**	**length**	**a**	**b**	**c**	**area (mm2)**
D3,WBE,3L	RH 70%	1	61	0.10	0.10	0.10	6.10	1	30	0.10	0.15	0.10	3.50
		2	262	0.10	0.35	0.10	48.03	2	136	0.10	0.20	0.10	18.13
		3	311	0.10	0.10	0.10	31.10	3	556	0.30	0.30	0.30	166.80
		4	35	0.10	0.10	0.10	3.50	4	157	0.25	0.25	0.25	39.25
		5	70	0.10	0.10	0.10	7.00	5	1300	0.35	0.50	0.70	671.67
							95.73	6	90	0.50	0.50	0.50	45.00
								7	574	0.10	0.55	0.10	143.50
													1087.85
	RH 50%	1	1300	0.30	0.20	0.35	368.33	1	361	0.25	0.25	0.25	90.25
		2	126	0.10	0.25	0.10	18.90	2	555	0.30	0.30	0.30	166.50
		3	485	0.10	0.30	0.10	80.83	3	160	0.35	0.35	0.35	56.00
		4	368	0.10	0.30	0.10	61.33	4	574	0.10	0.55	0.10	143.50
		5	315	0.10	0.10	0.10	31.50	5	90	0.50	0.50	0.50	45.00
		6	450	0.10	0.15	0.10	52.50	6	1300	0.95	0.55	0.60	910.00
		7	375	0.10	0.30	0.10	62.50						**1411.25**
		8	535	0.10	0.20	0.10	71.33						
		9	88	0.10	0.20	0.10	11.73						
		10	1300	0.25	0.10	0.30	281.67						
							1040.63						
	RH 30%	1	1300	0.65	0.60	0.70	845.00	1	360	0.50	0.50	0.50	180.00
		2	684	0.10	0.20	0.50	182.40	2	600	0.35	0.45	0.15	190.00
		3	551	0.10	0.55	0.60	229.58	3	252	0.10	0.60	0.10	67.20
		4	772	0.10	0.40	0.65	295.93	4	824	0.60	0.95	0.10	453.20
		5	451	0.10	0.35	0.65	165.37	5	1300	1.00	0.85	0.50	1018.33
		6	396	0.10	0.70	0.60	184.80	6	255	0.10	0.50	0.80	119.00
		7	545	0.10	0.45	0.10	118.08	7	308	0.10	0.40	0.10	61.60
		8	152	0.10	0.35	0.10	27.87	8	190	0.10	0.15	0.10	22.17
		9	96	0.10	0.45	0.60	36.80	9	84	0.10	0.40	0.60	30.80
		10	1300	0.70	0.35	0.80	801.67						**2142.30**
		11	528	0.10	0.25	0.10	79.20						
							2966.70						

Table 0.A11

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P1,WBE,3L	RH 70%	1	1300	0.50	0.65	0.50	715.00	1	680	0.10	0.45	0.45	226.67
		2	1300	0.40	0.65	0.35	606.67	2	487	0.10	0.40	0.10	97.40
		3	285	0.10	0.35	0.10	52.25	3	100	0.10	0.25	0.10	15.00
		4	1300	0.15	0.35	0.15	281.67	4	285	0.10	0.10	0.10	28.50
		5	1300	0.10	0.30	0.20	260.00	5	207	0.10	0.10	0.10	20.70
		6	395	0.10	0.35	0.10	72.42	6	181	0.10	0.10	0.10	18.10
		7	825	0.10	0.25	0.10	123.75	7	341	0.10	0.10	0.10	34.10
		8	412	0.10	0.10	0.10	41.20	8	152	0.10	0.10	0.10	15.20
							2152.95	9	151	0.10	0.30	0.10	25.17
								10	90	0.10	0.20	0.10	12.00
								11	63	0.10	0.15	0.10	7.35
								12	35	0.10	0.10	0.10	3.50
								13	46	0.10	0.10	0.10	4.60
								14	487	0.10	0.40	0.10	97.40
								15	18	0.10	0.25	0.10	2.70
								16	285	0.10	0.30	0.10	47.50
								17	726	0.10	0.35	0.10	133.10
								18	536	0.10	0.35	0.10	98.27
								19	22	0.10	0.10	0.10	2.20
								20	747	0.10	0.25	0.10	112.05
								21	103	0.10	0.15	0.10	12.02
								22	281	0.10	0.15	0.10	32.78
								23	171	0.10	0.10	0.10	17.10
								24	401	0.10	0.10	0.10	40.10
								25	306	0.10	0.10	0.10	30.60
								26	165	0.10	0.10	0.10	16.50
								27	1300	0.20	0.30	0.25	325.00
													1475.60
	RH 50%	1	1300	1.00	1.50	1.00	1516.67	1	1300	0.85	0.45	0.40	736.67
		2	1300	1.00	1.00	1.00	1300.00	2	845	0.20	0.55	0.50	352.08
		3	285	0.10	0.40	0.10	57.00	3	360	0.10	0.55	0.10	90.00
		4	1300	0.70	0.50	0.50	736.67	4	1300	0.75	0.55	0.40	736.67
		5	1300	0.55	0.55	0.35	628.33	5	292	0.15	0.25	0.25	0.00
		6	180	0.10	0.30	0.10	30.00	6	910	0.10	0.40	0.10	182.00
		7	410	0.10	0.35	0.35	109.33	7	208	0.10	0.30	0.10	34.67
		8	1300	0.30	0.50	0.55	585.00	8	426	0.10	0.40	0.10	85.20
							4963.00	9	321	0.10	0.35	0.10	58.85
								10	200	0.10	0.20	0.10	26.67
								11	170	0.10	0.25	0.10	25.50
								12	71	0.10	0.25	0.10	10.65
								13	18	0.10	0.25	0.10	2.70
								14	290	0.10	0.45	0.10	62.83
								15	200	0.10	0.25	0.10	30.00
								16	212	0.10	0.25	0.10	31.80
								17	196	0.10	0.25	0.10	29.40
													2495.68
	RH 30%	1	1300	0.40	0.70	0.70	780.00	1	1300	0.45	0.50	0.45	606.67
		2	185	0.10	0.45	0.50	64.75	2	210	0.10	0.45	0.30	59.50
		3	1300	0.70	0.80	0.50	866.67	3	425	0.10	0.75	0.10	134.58
		4	40	0.10	0.10	0.10	4.00	4	320	0.10	0.65	0.10	90.67
		5	435	0.65	0.60	0.10	195.75	5	210	0.10	0.35	0.10	38.50
		6	1300	0.85	0.85	0.85	1105.00	6	170	0.10	0.35	0.40	48.17
		7	1300	1.50	1.50	1.50	1950.00	7	290	0.10	0.35	0.25	67.67
		8	283	0.10	0.50	0.30	84.90	8	140	0.10	0.30	0.30	32.67
		9	1300	1.50	2.00	2.00	2383.33	9	754	0.10	0.75	0.25	276.47
		10	133	0.10	0.10	0.10	13.30	10	27	0.15	0.15	0.15	4.05
		11	41	0.10	0.10	0.10	4.10	11	1300	0.70	0.70	0.65	888.33
							7451.80	12	70	0.10	0.40	0.40	21.00
								13	314	0.10	0.60	0.50	125.60
								14	39	0.10	0.20	0.10	5.20
								15	840	0.10	0.70	0.55	378.00
								16	1300	0.85	0.80	0.80	1061.67
								17	290	0.10	0.60	0.35	101.50
								18	210	0.10	0.35	0.10	38.50
								19	220	0.10	0.50	0.10	51.33
								20	195	0.10	0.50	0.25	55.25
								21	73	0.10	0.40	0.10	14.60
								22	151	0.20	0.35	0.10	32.72
								23	382	0.10	0.70	0.15	120.97
													4253.60

Table 0.A12

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P2,WBE,3L	RH 70%	1	1300	0.65	0.80	0.75	1007.50	1	59	0.10	0.15	0.10	6.88
		2	1300	0.45	0.70	0.65	877.50	2	265	0.10	0.25	0.10	39.75
		3	372	0.10	0.30	0.10	62.00	3	868	0.10	0.35	0.10	159.13
		4	242	0.10	0.10	0.10	24.20	4	1300	0.10	0.35	0.20	281.67
		5	1300	0.55	0.50	0.35	606.67	5	182	0.10	0.20	0.10	24.27
		6	91	0.10	0.10	0.10	9.10	6	42	0.10	0.10	0.10	4.20
		7	113	0.40	0.40	0.10	33.90	7	86	0.10	0.15	0.10	10.03
		8	1300	0.10	0.30	0.10	216.67	8	179	0.10	0.15	0.10	20.88
		9	1300	0.10	0.20	0.10	173.33	9	130	0.10	0.15	0.10	15.17
							3010.87	10	502	0.10	0.15	0.10	58.57
								11	35	0.10	0.10	0.10	3.50
								12	50	0.20	0.20	0.20	10.00
								13	33	0.25	0.25	0.25	8.25
								14	54	0.10	0.30	0.10	9.00
								15	52	0.30	0.30	0.30	15.60
								16	291	0.25	0.25	0.25	72.75
								17	27	0.15	0.15	0.15	4.05
								18	334	0.10	0.25	0.10	50.10
								19	10	0.15	0.15	0.15	1.50
								20	62	0.20	0.20	0.20	12.40
								21	61	0.10	0.20	0.10	8.13
								22	1300	0.25	0.25	0.15	281.67
								23	96	0.10	0.10	0.10	9.60
								24	84	0.10	0.10	0.10	8.40
								25	369	0.10	0.20	0.10	49.20
								26	212	0.10	0.10	0.10	21.20
								27	242	0.10	0.10	0.10	24.20
													1210.10
	RH 50%	1	1300	1.50	1.50	1.50	1950.00	1	62	0.1	0.30	0.40	16.53
		2	1300	1.00	1.00	1.00	1300.00	2	1150	0.10	0.55	0.20	325.83
		3	429	0.10	0.50	0.10	100.10	3	1300	0.55	0.70	0.70	845.00
		4	396	0.10	0.45	0.10	85.80	4	1300	0.10	0.30	0.10	216.67
		5	1300	0.85	1.00	1.50	1451.67	5	91	0.10	0.40	0.50	30.33
		6	100	0.10	0.20	0.10	13.33	6	400	0.10	0.40	0.10	80.00
		7	113	0.10	0.45	0.10	24.48	7	360	0.10	0.30	0.10	60.00
		8	1300	0.70	0.40	0.30	606.67	8	265	0.10	0.35	0.10	48.58
		9	1300	0.40	0.40	0.55	585.00	9	116	0.35	0.35	0.35	40.60
							6117.05	10	400	0.40	0.40	0.40	160.00
								11	50	0.20	0.20	0.20	10.00
								12	360	0.25	0.25	0.25	90.00
								13	191	0.10	0.40	0.10	38.20
								14	68	0.10	0.40	0.10	13.60
								15	1300	0.40	0.40	0.40	520.00
													2495.35
	RH 30%	1	1300	2.00	2.00	2.50	2816.67	1	64	0.10	0.30	0.55	20.27
		2	1300	1.50	2.00	2.00	2383.33	2	1152	0.10	0.70	0.35	441.60
		3	436	0.10	0.75	0.70	225.27	3	1300	0.80	1.00	1.00	1213.33
		4	415	0.10	0.65	0.10	117.58	4	1300	0.50	0.40	0.45	585.00
		5	1300	1.50	2.00	2.50	2600.00	5	127	0.10	0.60	0.75	61.38
		6	105	0.10	0.35	0.50	33.25	6	407	0.10	0.70	0.10	122.10
		7	110	0.10	0.35	0.35	29.33	7	437	0.10	0.75	0.10	138.38
		8	1300	0.90	0.70	0.65	975.00	8	272	0.10	0.55	0.10	68.00
		9	1300	0.65	0.70	0.85	953.33	9	122	0.10	0.55	0.60	50.83
							10133.77	10	415	0.10	0.85	0.10	145.25
								11	52	0.30	0.40	0.30	17.33
								12	360	0.30	0.55	0.45	156.00
								13	192	0.30	0.65	0.50	92.80
								14	74	0.10	0.50	0.75	33.30
								15	1300	0.75	0.75	0.80	996.67
								16	160	0.10	0.60	0.65	72.00
													4214.25

Table 0.A13

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P3,WBE,3L	RH 70%	1	345	0.10	0.15	0.10	40.25	1	555	0.10	0.30	0.10	92.50
		2	110	0.10	0.15	0.10	12.83	2	170	0.10	0.20	0.10	22.67
		3	98	0.10	0.10	0.10	9.80	3	135	0.10	0.30	0.10	22.50
		4	446	0.10	0.20	0.10	59.47	4	28	0.15	0.15	0.15	4.20
		5	144	0.10	0.15	0.10	16.80	5	65	0.15	0.35	0.15	14.08
		6	1300	0.20	0.35	0.20	325.00	6	754	0.10	0.35	0.10	138.23
		7	551	0.10	0.25	0.10	82.65	7	297	0.10	0.35	0.10	54.45
		8	326	0.10	0.25	0.10	48.90	8	88	0.10	0.30	0.10	14.67
		9	271	0.10	0.25	0.10	40.65	9	75	0.10	0.25	0.10	11.25
		10	1300	0.10	0.35	0.10	238.33	10	24	0.35	0.35	0.35	8.40
		11	321	0.10	0.25	0.10	48.15	11	190	0.10	0.10	0.10	19.00
		12	217	0.10	0.30	0.10	36.17	12	180	0.10	0.10	0.10	18.00
		13	110	0.10	0.20	0.10	14.67	13	333	0.15	0.45	0.15	83.25
		14	1300	0.15	0.60	0.50	541.67	14	891	0.15	0.35	0.15	193.05
		15	1300	0.35	0.65	0.50	650.00	15	967	0.10	0.35	0.10	177.28
		16	145	0.10	0.25	0.10	21.75	16	55	0.10	0.30	0.10	9.17
							2187.08	17	35	0.30	0.30	0.30	10.50
								18	138	0.15	0.30	0.15	27.60
								20	1300	0.10	0.35	0.10	238.33
													1159.13
	RH 50%	1	1300	0.45	0.45	0.20	476.67	1	734	0.30	0.35	0.20	207.97
		2	1300	0.50	0.70	0.55	758.33	2	415	0.10	0.30	0.10	69.17
		3	287	0.10	0.50	0.70	124.37	3	135	0.35	0.35	0.35	47.25
		4	370	0.10	0.60	0.10	98.67	4	28	0.25	0.25	0.25	7.00
		5	589	0.10	0.85	0.10	206.15	5	65	0.40	0.40	0.40	26.00
		6	175	0.10	0.70	0.10	52.50	6	600	0.10	0.35	0.10	110.00
		7	1300	0.30	0.85	0.15	563.33	7	330	0.10	0.35	0.10	60.50
		8	421	0.10	0.45	0.10	91.22	8	1300	0.45	0.45	0.45	585.00
		9	380	0.10	0.50	0.65	158.33	9	100	0.10	0.15	0.10	11.67
		10	1300	0.80	1.00	0.40	953.33	10	24	0.35	0.35	0.35	8.40
		11	1300	0.95	0.95	0.70	1126.67	11	211	0.10	0.40	0.10	42.20
							4609.57	12	180	0.10	0.30	0.20	36.00
								13	1300	0.50	0.45	0.50	628.33
								14	600	0.10	0.15	0.10	70.00
								15	967	1.40	0.40	0.15	628.55
								16	55	0.10	0.35	0.35	14.67
								17	98	0.10	0.40	0.40	29.40
								18	140	0.35	0.35	0.35	49.00
								19	275	0.10	0.25	0.10	41.25
								20	1300	0.50	0.55	0.55	693.33
													3365.68
	RH 30%	1	1300	1.00	1.50	1.00	1516.67	1	1300	0.60	0.70	0.60	823.33
		2	1300	0.55	2.00	1.50	1755.00	2	150	0.10	0.70	0.50	65.00
		3	1300	0.40	1.50	0.15	888.33	3	127	0.10	0.60	0.10	33.87
		4	1300	0.95	1.00	0.90	1235.00	4	65	0.10	0.55	0.30	20.58
		5	1300	0.45	0.95	0.70	910.00	5	972	0.10	0.75	0.70	502.20
		6	66	0.10	0.80	0.70	35.20	6	304	0.10	0.50	0.10	70.93
		7	287	0.10	1.00	0.10	114.80	7	890	0.55	0.55	0.55	489.50
		8	81	0.10	0.70	0.30	29.70	8	188	0.10	0.55	0.20	53.27
		9	385	0.10	0.80	0.75	211.75	9	326	0.10	0.30	0.10	54.33
		10	195	0.10	1.00	1.00	136.50	10	165	0.10	0.25	0.10	24.75
		11	50	0.10	0.60	0.30	16.67	11	89	0.10	0.25	0.10	13.35
		12	380	0.10	1.00	0.10	152.00	12	355	0.25	0.55	0.50	153.83
		13	187	0.10	1.00	0.10	74.80	13	218	0.10	0.55	0.10	54.50
		14	600	0.10	1.50	0.10	340.00	14	110	0.10	0.25	0.10	16.50
		15	33	0.10	0.40	0.10	6.60	15	1300	0.55	0.55	0.55	715.00
							7423.02	16	417	0.10	0.50	0.50	152.90
								17	291	0.10	0.65	0.10	82.45
								18	51	0.10	0.40	0.10	10.20
								19	27	0.10	0.50	0.30	8.10
								20	604	0.10	0.55	0.10	151.00
								21	71	0.10	0.55	0.50	27.22
								22	36	0.10	0.30	0.10	6.00
								23	153	0.10	0.45	0.10	33.15
								24	730	0.10	0.55	0.35	243.33
													3805.3

Table 0.A14

Specimen	**Conditioning steps**	**Face**											
		A						**B**					
		id	**length**	**a**	**b (max)**	**c**	**area (mm2)**	**id**	**length**	**a**	**b**	**c**	**area (mm2)**
B5,BE,5L	RH 70%	1	-	-	-	-	-	1	25	0.10	0.80	0.10	8.33
							0.00						**8.33**
	RH 50%	1	-	-	-	-	-	1	25	0.10	1.00	0.10	10.00
							0.00	2	60	0.10	0.10	0.10	6.00
								3	200	0.10	0.10	0.10	20.00
								4	168	0.10	0.10	0.10	16.80
													52.80
	RH 30%	1	-	-	-	-	-	1	25	0.10	0.75	1.00	15.42
							0.00	2	165	0.10	0.40	0.30	44.00
								3	245	0.10	0.45	0.10	53.08
								4	458	0.10	0.40	0.10	91.60
								5	185	0.10	0.20	0.10	24.67
													228.77

Table 0.A15

Specimen	**Conditioning steps**	**Face**											
		A						**B**					
		id	**length**	**a**	**b (max)**	**c**	**area (mm2)**	**id**	**length**	**a**	**b**	**c**	**area (mm2)**
C5,BE,5L	RH 70%	1	-	-	-	-	-	1	-	-	-	-	-
		2	-	-	-	-	-	2	-	-	-	-	-
		3	-	-	-	-	-	3	-	-	-	-	-
							0.00						**0.00**
	RH 50%	1	-	-	-	-	-	1	658	0.10	0.30	0.25	142.57
		2	-	-	-	-	-	2	38	0.10	0.65	0.10	10.77
							0.00						**153.33**
	RH 30%	1	-	-	-	-	-	1	851	0.10	0.45	0.55	312.03
		2	-	-	-	-	-	2	1300	0.25	0.35	0.30	390.00
		3	-	-	-	-	-	3	115	0.10	0.40	0.10	23.00
							0.00						**725.03**

Table 0.A16

Specimen	Conditioning	Face											
	steps	A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P1,BE,5L	RH 70%	1	262	0.20	0.40	0.25	74.23	1	1300	0.15	0.55	0.40	476.67
		2	216	0.10	0.15	0.10	25.20	2	1208	0.10	0.65	0.15	362.40
		3	219	0.15	0.30	0.15	43.80	3	232	0.20	0.25	0.15	46.40
		4	885	0.10	0.20	0.20	147.50	4	150	0.10	0.20	0.20	25.00
		5	1362	0.10	0.20	0.15	204.30						**910.47**
		6	341	0.10	0.20	0.10	45.47						
		7	348	0.10	0.15	0.10	40.60						
		8	351	0.10	0.15	0.10	40.95						
		9	312	0.10	0.15	0.10	36.40						
		10	38	0.55	1.50	0.60	33.57						
							692.02						
	RH 50%	1	325	0.10	0.90	0.55	167.92	1	1300	0.25	0.70	0.45	747.50
		2	259	0.10	0.35	0.10	47.48	2	1210	0.10	0.85	0.10	574.75
		3	221	0.10	0.65	0.10	62.62	3	232	0.20	0.35	0.20	58.00
		4	891	0.10	0.50	0.10	207.90	4	150	0.10	0.55	0.10	37.50
		5	740	0.10	0.55	0.10	185.00	5	728	0.10	0.20	0.10	97.07
		6	341	0.10	0.30	0.10	56.83	6	276	0.10	0.20	0.10	36.80
		7	850	0.10	0.30	0.10	141.67	7	250	0.10	0.15	0.10	29.17
		8	351	0.10	0.25	0.10	52.65	8	155	0.10	0.15	0.10	18.08
		9	310	0.10	0.15	0.10	36.17						**1598.87**
		10	380	0.10	0.40	0.35	107.67						
		11	82	0.10	0.35	0.10	15.03						
		12	211	0.10	0.25	0.10	31.65						
							1112.58						
	RH 30%	1	326	0.10	2.50	1.50	445.53	1	1300	0.75	0.90	0.45	910.00
		2	264	0.10	0.80	0.10	88.00	2	1222	0.1	0.90	0.10	448.07
		3	260	0.10	1.50	0.10	147.33	3	337	0.1	0.60	0.10	89.87
		4	893	0.10	0.75	0.70	461.38	4	150	0.1	0.35	0.75	60.00
		5	741	0.10	1.00	0.10	296.40	5	740	0.1	0.50	0.65	308.33
		6	370	0.10	0.50	0.10	86.33	6	290	0.1	0.55	0.80	140.17
		7	692	0.10	0.50	0.10	161.47	7	257	0.1	0.45	0.10	55.68
		8	352	0.10	0.80	0.10	117.33	8	185	0.1	0.50	0.10	43.17
		9	314	0.10	0.25	0.10	47.10	9	105	0.1	0.25	0.10	15.75
		10	386	0.10	0.75	0.80	212.30						**2071.03**
		11	91	0.10	0.50	0.60	36.40						
		12	211	0.10	0.65	0.80	109.02						
		13	200	0.10	0.65	0.10	56.67						
		14	205	0.10	0.60	0.10	54.67						
							2319.93						

Table 0.A17

Specimen	Conditioning	Face											
	steps	A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P2,BE,5L	RH 70%	1	65	0.10	0.20	0.10	8.67	1	-	-	-	-	-
		2	1000	0.10	0.10	0.10	100.00	2	-	-	-	-	-
		3	280	0.10	0.10	0.10	28.00	3	-	-	-	-	-
		4	387	0.10	0.10	0.10	38.70	4	-	-	-	-	-
							175.37						**0.00**
	RH 50%	1	65	0.10	0.20	0.10	8.67	1	730	0.10	0.25	0.10	109.50
		2	1030	0.10	0.40	0.10	206.00	2	150	0.10	0.15	0.10	17.50
		3	280	0.10	0.40	0.10	56.00	3	380	0.10	0.20	0.10	50.67
		4	311	0.10	0.35	0.10	57.02	4	272	0.10	0.25	0.10	40.80
		5	777	0.10	0.35	0.10	142.45	5	350	0.10	0.25	0.10	52.50
		6	226	0.10	0.25	0.10	33.90						**270.97**
							504.03						
	RH 30%	1	67	0.10	0.35	0.55	22.33	1	744	0.10	0.50	0.40	248.00
		2	1034	0.10	0.70	0.70	517.00	2	150	0.10	0.40	0.10	30.00
		3	305	0.10	0.40	0.75	127.08	3	385	0.10	0.40	0.35	109.08
		4	325	0.10	0.50	0.55	124.58	4	310	0.10	0.35	0.10	56.83
		5	779	0.10	0.65	0.10	220.72	5	373	0.10	0.35	0.25	87.03
		6	256	0.10	0.45	0.75	110.93						**530.95**
							1122.65						

Table 0.A18

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P3,BE,5L	RH 70%	1	110	0.10	0.15	0.10	12.83	1	-	-	-	-	-
		2	82	0.10	0.10	0.10	8.20	2	-	-	-	-	-
		3	120	0.10	0.10	0.10	12.00	3	-	-	-	-	-
		4	119	0.10	0.10	0.10	11.90	4	-	-	-	-	-
							44.93						**0.00**
	RH 50%	1	110	0.10	0.15	0.10	12.83	1	162	0.10	0.20	0.10	21.60
		2	161	0.10	0.25	0.10	24.15	2	623	0.10	0.20	0.10	83.07
		3	120	0.10	0.20	0.10	16.00	3	365	0.10	0.25	0.10	54.75
		4	140	0.10	0.15	0.10	16.33	4	150	0.10	0.20	0.10	20.00
		5	180	0.10	0.30	0.10	30.00						**179.42**
		6	200	0.10	0.15	0.10	23.33						
		7	166	0.10	0.20	0.10	22.13						
		8	117	0.10	0.20	0.10	15.60						
		9	180	0.10	0.30	0.10	30.00						
		10	286	0.10	0.25	0.10	42.90						
		11	236	0.10	0.25	0.10	35.40						
		12	228	0.10	0.15	0.10	26.60						
		13	146	0.10	0.15	0.10	17.03						
		14	160	0.10	0.15	0.10	18.67						
		15	69	0.10	0.10	0.10	6.90						
							337.88						
	RH 30%	1	162	0.10	0.35	0.10	29.70	1	120	0.10	0.25	0.35	28.00
		2	60	0.10	0.25	0.10	9.00	2	90	0.10	0.30	0.10	15.00
		3	20	0.10	0.10	0.10	2.00	3	620	0.10	0.35	0.10	113.67
		4	132	0.10	0.25	0.10	19.80	4	225	0.10	0.50	0.10	52.50
		5	143	0.10	0.35	0.10	26.22	5	145	0.10	0.40	0.10	29.00
		6	69	0.10	0.30	0.10	11.50	6	110	0.10	0.25	0.10	16.50
		7	180	0.10	0.40	0.40	54.00	7	168	0.15	0.55	0.10	44.80
		8	250	0.10	0.40	0.10	50.00						**299.47**
		9	185	0.10	0.45	0.10	40.08						
		10	20	0.10	0.10	0.10	2.00						
		11	120	0.10	0.30	0.10	20.00						
		12	184	0.10	0.40	0.10	36.80						
		13	294	0.10	0.50	0.10	68.60						
		14	330	0.10	0.60	0.15	93.50						
		15	252	0.10	0.35	0.10	46.20						
		16	147	0.10	0.35	0.30	36.75						
		17	140	0.10	0.20	0.10	18.67						
		18	20	0.10	0.10	0.10	2.00						
		19	100	0.10	0.20	0.10	13.33						
		20	323	0.10	0.25	0.10	48.45						
		21	34	0.10	0.15	0.10	3.97						
		22	110	0.10	0.10	0.10	11.00						
							643.57						

Table 0.A19

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
A3,BE,3L	RH 70%	1	66	0.10	0.15	0.10	7.70	1	200	0.10	0.45	0.10	43.33
		2	1010	0.10	0.25	0.10	151.50	2	310	0.10	0.40	0.10	62.00
		3	1300	0.10	0.10	0.10	130.00	3	461	0.10	0.10	0.10	46.10
		4	50	0.10	0.20	0.10	6.67	4	232	0.10	0.10	0.10	23.20
		5	1050	0.10	1.50	0.10	595.00	5	681	0.10	0.15	0.10	79.45
		6	1200	0.30	1.00	0.30	640.00						**254.08**
							1530.87						
	RH 50%	1	66	0.10	0.15	0.10	7.70	1	200	0.10	0.55	0.10	50.00
		2	1010	0.10	0.25	0.10	151.50	2	310	0.10	0.45	0.10	67.17
		3	1300	0.10	0.10	0.10	130.00	3	461	0.10	0.20	0.10	61.47
		4	1300	0.10	0.60	1.50	953.33	4	232	0.10	0.10	0.10	23.20
		5	1300	0.25	0.85	1.50	1126.67	5	681	0.10	0.15	0.10	79.45
							2369.20						**281.28**
	RH 30%	1	1300	0.25	0.15	0.10	216.67	1	193	0.10	0.30	0.75	73.98
		2	1300	0.25	0.15	0.10	216.67	2	310	0.10	0.40	0.60	113.67
		3	1300	0.10	0.70	1.50	996.67	3	465	0.10	0.15	0.35	93.00
		4	1300	1.50	1.50	0.40	1473.33	4	235	0.10	0.15	0.10	27.42
		5	160	0.10	0.25	0.10	24.00	5	680	0.10	0.15	0.10	79.33
							2927.33	6	435	0.10	0.25	0.10	65.25
								7	645	0.10	0.25	0.25	129.00
								8	471	0.10	0.35	0.10	86.35
								9	310	0.10	0.35	0.10	56.83
								10	280	0.10	0.35	0.30	70.00
								11	185	0.10	0.15	0.10	21.58
													816.42

Table 0.A20

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
B3, BE,3L	RH 70%	1	1300	0.10	0.65	0.10	368.33	1	115	0.25	0.35	0.25	32.58
		2	1300	0.65	1.00	0.45	910.00	2	212	0.10	0.35	0.10	38.87
		3	72	0.10	0.25	0.10	10.80	3	26	0.40	0.40	0.40	10.40
		4	175	0.10	0.65	0.10	49.58	4	175	0.10	0.15	0.10	20.42
		5	219	0.10	0.35	0.10	40.15	5	282	0.10	0.10	0.10	28.20
							1378.87						**130.47**
	RH 50%	1	1300	0.10	0.85	0.10	455.00	1	115	0.25	0.40	0.25	34.50
		2	1300	0.70	0.85	0.75	996.67	2	212	0.10	0.50	0.10	49.47
		3	72	0.10	0.25	0.10	10.80	3	26	0.40	0.50	0.40	11.27
		4	175	0.10	0.65	0.10	49.58	4	175	0.10	0.15	0.10	20.42
		5	219	0.10	0.50	0.10	51.10	5	282	0.10	0.10	0.10	28.20
							1563.15						**143.85**
	RH 30%	1	1300	0.30	1.00	0.10	606.67	1	115	0.50	0.65	0.40	59.42
		2	1300	0.85	1.50	0.90	1408.33	2	212	0.10	0.70	0.10	63.60
		3	74	0.10	0.20	0.10	9.87	3	30	0.65	0.65	0.65	19.50
		4	181	0.10	0.60	0.10	48.27	4	280	0.10	0.15	0.10	32.67
		5	220	0.10	0.50	0.55	84.33	5	175	0.10	0.25	0.10	26.25
							2157.47	6	513	0.10	0.35	0.10	94.05
								7	103	0.10	0.15	0.10	12.02
								8	850	0.10	0.10	0.10	85.00
													295.48

Table 0.A21

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
C3,BE,3L	RH 70%	1	-	-	-	-	-	1	-	-	-	-	-
		2	-	-	-	-	-	2	-	-	-	-	-
		3	-	-	-	-	-	3	-	-	-	-	-
							0.00						**0.00**
	RH 50%	1	-	-	-	-	-	1	658	0.10	0.30	0.25	142.57
		2	-	-	-	-	-	2	38	0.10	0.65	0.10	10.77
							0.00						**153.33**
	RH 30%	1	-	-	-	-	-	1	851	0.10	0.45	0.55	312.03
		2	-	-	-	-	-	2	1300	0.25	0.35	0.30	390.00
		3	-	-	-	-	-	3	115	0.10	0.40	0.10	23.00
							0.00						**725.03**

Table 0.A22

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P1,wge,3L	RH 70%	1	-	-	-	-	-	1	480	0.10	0.10	0.10	48.00
		2	-	-	-	-	-	2	126	0.10	0.20	0.10	16.80
		3	-	-	-	-	-	3	1300	0.35	0.50	0.50	585.00
							0.00						**649.80**
	RH 50%	1	-	-	-	-	-	1	480	0.10	0.10	0.10	48.00
		2	-	-	-	-	-	2	126	0.10	0.20	0.10	16.80
		3	-	-	-	-	-	3	1300	0.50	0.50	0.90	823.33
		4	-	-	-	-	-	4	462	0.10	0.20	0.10	61.60
		5	-	-	-	-	-	5	1046	0.10	0.30	0.10	174.33
							0.00						**1124.07**
	RH 30%	1	-	-	-	-	-	1	481	0.10	0.15	0.10	56.12
		2	-	-	-	-	-	2	150	0.10	0.25	0.10	22.50
		3	-	-	-	-	-	3	1300	0.90	1.00	1.50	1473.33
		4	-	-	-	-	-	4	515	0.10	0.40	0.10	103.00
		5	-	-	-	-	-	5	1072	0.10	0.80	1.00	678.93
							0.00						**2333.88**

Table 0.A23

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P2,BE,3L	RH 70%	1	65	0.10	0.15	0.15	8.67	1	201	0.10	0.35	0.10	36.85
		2	35	0.10	0.15	0.15	4.67	2	416	0.10	0.30	0.10	69.33
		3	240	0.10	0.20	0.10	32.00	3	214	0.10	0.15	0.10	24.97
		4	106	0.10	0.20	0.20	17.67	4	277	0.10	0.20	0.10	36.93
		5	66	0.10	0.10	0.10	6.60	5	131	0.10	0.10	0.10	13.10
		6	51	0.10	0.10	0.10	5.10	6	238	0.10	1.00	0.10	95.20
		7	73	0.10	0.22	0.20	12.65						**276.38**
		8	21	0.15	0.25	0.15	3.85						
		9	29	0.15	0.15	0.15	4.35						
		10	40	0.10	0.15	0.15	5.33						
		11	30	0.10	0.15	0.10	3.50						
		12	48	0.10	0.15	0.10	5.60						
		13	53	0.10	0.30	0.10	8.83						
		14	75	0.10	0.20	0.10	10.00						
		15	87	0.10	0.35	0.30	21.75						
		16	211	0.10	0.30	0.10	35.17						
							185.74						
	RH 50%	1	35	0.10	0.45	0.10	7.58	1	551	0.10	0.45	1.50	376.52
		2	28	0.30	0.30	0.30	8.40	2	180	0.10	0.30	0.10	30.00
		3	450	0.10	0.50	0.10	105.00	3	275	0.10	0.35	0.10	50.42
		4	115	0.10	0.40	0.10	23.00	4	126	0.10	0.10	0.10	12.60
		5	260	0.10	0.45	0.10	56.33	5	235	0.10	1.50	0.10	133.17
		6	67	0.10	0.15	0.10	7.82	6	622	0.10	0.25	0.10	93.30
		7	51	0.10	0.10	0.10	5.10	7	270	0.10	0.20	0.10	36.00
		8	718	0.10	0.50	0.10	167.53	8	205	0.10	0.30	0.10	34.17
		9	120	0.10	0.35	0.10	22.00	9	70	0.10	0.15	0.10	8.17
		10	585	0.10	0.55	0.10	146.25						**774.33**
		11	318	0.10	0.25	0.10	47.70						
		12	566	0.10	0.25	0.10	84.90						
		13	65	0.10	0.25	0.10	9.75						
		14	396	0.10	0.25	0.10	59.40						
							750.77						
	RH 30%	1	40	0.10	0.45	0.65	16.00	1	556	0.10	0.70	2.00	518.93
		2	30	0.50	0.50	0.50	15.00	2	215	0.10	0.55	0.10	53.75
		3	454	0.10	1.00	0.70	272.40	3	193	0.10	0.55	0.10	48.25
		4	114	0.10	0.50	0.70	49.40	4	50	0.10	0.40	0.10	10.00
		5	275	0.10	0.95	0.10	105.42	5	235	0.10	1.50	0.50	164.50
		6	66	0.10	0.30	0.10	11.00	6	634	0.10	0.50	0.10	147.93
		7	50	0.10	0.15	0.10	5.83	7	275	0.10	0.55	0.10	68.75
		8	732	0.10	1.50	0.10	414.80	8	205	0.10	0.55	0.40	71.75
		9	132	0.10	0.80	1.50	105.60	9	78	0.10	0.45	0.10	16.90
		10	882	0.10	1.00	0.10	352.80						**1100.77**
		11	105	0.10	0.80	0.95	64.75						
		12	587	0.10	0.85	0.10	205.45						
		13	78	0.10	0.65	0.10	22.10						
		14	423	0.10	0.60	0.10	112.80						
		15	100	0.10	0.50	0.70	43.33						
		16	78	0.10	0.45	0.45	26.00						
							1822.68						

Table 0.A24

Specimen	Conditioning steps	Face											
		A						B					
		id	length	a	b (max)	c	area (mm2)	id	length	a	b	c	area (mm2)
P3,BE,3L	RH 70%	1	589	0.10	0.10	0.10	58.90	1	1300	0.10	0.20	0.10	173.33
		2	98	0.10	0.10	0.10	9.80	2	1300	0.15	0.15	0.15	195.00
		3	504	0.10	0.10	0.10	50.40	3	700	0.10	0.45	0.10	151.67
		4	508	0.10	0.45	0.10	110.07	4	84	0.10	0.10	0.10	8.40
		5	44	0.10	0.60	0.10	11.73	5	71	0.10	0.15	0.10	8.28
							240.90						**536.68**
	RH 50%	1	589	0.10	0.65	0.10	166.88	1	1300	0.10	0.45	0.10	281.67
		2	386	0.10	1.00	0.10	154.40	2	1300	0.15	0.15	0.15	195.00
		3	504	0.10	0.10	0.10	50.40	3	702	0.10	0.65	0.10	198.90
		4	508	0.10	0.55	0.10	127.00	4	84	0.10	0.10	0.10	8.40
		5	44	0.10	0.60	0.10	11.73	5	71	0.10	0.15	0.10	8.28
		6	552	0.10	0.45	0.10	119.60	6	825	0.10	0.45	0.20	206.25
		7	271	0.10	0.45	0.45	90.33	7	241	0.10	0.15	0.10	28.12
		8	211	0.10	0.45	0.35	63.30	8	115	0.10	0.20	0.10	15.33
		9	82	0.10	0.45	0.45	27.33						**941.95**
		10	145	0.10	0.30	0.10	24.17						
		11	310	0.10	0.35	0.10	56.83						
		12	480	0.10	0.35	0.10	88.00						
		13	24	0.10	0.40	0.10	4.80						
		14	15	0.10	0.25	0.10	2.25						
		15	964	0.10	0.40	0.30	257.07						
		16	371	0.10	0.40	0.35	105.12						
		17	470	0.10	0.40	0.10	94.00						
		18	215	0.10	0.40	0.30	57.33						
							1500.55						
	RH 30%	1	70	0.50	0.65	0.20	31.50	1	285	0.10	0.25	0.10	42.75
		2	150	0.10	0.60	0.10	40.00	2	73	0.10	0.15	0.10	8.52
		3	315	0.10	0.75	0.10	99.75	3	455	0.10	1.00	0.10	182.00
		4	485	0.10	0.65	0.10	137.42	4	450	0.10	1.00	0.30	210.00
		5	210	0.10	0.80	0.10	70.00	5	84	0.10	0.15	0.10	9.80
		6	150	0.10	0.40	0.40	45.00	6	15	0.10	0.10	0.10	1.50
		7	225	0.10	0.35	0.10	41.25	7	700	0.10	1.00	0.10	280.00
		8	228	0.10	0.30	0.10	38.00	8	69	0.10	0.25	0.10	10.35
		9	960	0.50	0.55	0.10	368.00	9	83	0.30	0.55	0.60	40.12
		10	370	0.10	0.65	0.60	166.50	10	390	0.10	1.00	0.15	162.50
		11	480	0.10	0.70	0.10	144.00	11	270	0.10	0.60	0.30	90.00
		12	243	0.10	0.25	0.10	36.45	12	440	0.10	0.40	0.10	88.00
		13	80	0.10	0.20	0.10	10.67	13	203	0.10	0.35	0.10	37.22
		14	225	0.10	0.55	0.60	93.75	14	1300	0.15	0.15	0.15	195.00
		15	250	0.15	1.00	0.40	129.17						**1357.75**
		16	450	0.20	2.50	0.10	420.00						
		17	230	0.10	0.80	0.55	111.17						
		18	565	0.10	0.75	0.10	178.92						
		19	270	0.10	0.80	0.70	144.00						
		20	510	0.10	0.75	0.10	161.50						
							2467.03						

Appendix B

Air permeability test data

Table 0.B1

Specimen	Pressure, Pa	Conditioning		
		RH 75%	RH 43%	RH 30%
		Air leakage, $m^3/(m^2.h)$		
A5,WBE, 5L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.00	0.00
B5,WBE, 5L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.00	0.00
C5,WBE, 5L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.00	0.00

Table 0.B2

Specimen	Pressure, Pa	Conditioning		
		RH 75%	RH 43%	RH 30%
		Air leakage, $m^3/(m^2.h)$		
P1,WBE, 5L	50	0.000	0.000	0.000
	73	0.000	0.000	0.000
	108	0.000	0.000	0.000
	158	0.000	0.000	0.000
	232	0.000	0.000	0.000
	341	0.000	0.000	0.000
	500	0.000	0.000	0.000
P2,WBE, 5L	50	0.000	0.000	0.000
	73	0.000	0.000	0.000
	108	0.000	0.000	0.000
	158	0.000	0.000	0.000
	232	0.000	0.000	0.000
	341	0.000	0.000	0.000
	500	0.000	0.000	0.000
P3,WBE, 5L	50	0.000	0.000	0.000
	73	0.000	0.000	0.000
	108	0.000	0.000	0.000
	158	0.000	0.000	0.022
	232	0.000	0.000	0.032
	341	0.000	0.000	0.044
	500	0.000	0.000	0.063
P4, WBE, 5L	50	0.000	0.000	0.000
	73	0.000	0.000	0.000
	108	0.000	0.000	0.000
	158	0.000	0.000	0.000
	232	0.000	0.000	0.000
	341	0.000	0.000	0.000
	500	0.000	0.000	0.000

Table 0.B3

Specimen	Pressure, Pa	Conditioning		
		RH 75%	RH 43%	RH 30%
		Air leakage, $m^3/(m^2.h)$		
A3, WBE, 3L	50	0.000	0.000	0.000
	73	0.000	0.000	0.000
	108	0.000	0.000	0.000
	158	0.000	0.000	0.027
	232	0.022	0.025	0.033
	341	0.034	0.038	0.047
	500	0.047	0.053	0.066
B3,WBE, 3L	50	0.000	0.041	0.058
	73	0.027	0.055	0.076
	108	0.037	0.076	0.103
	158	0.053	0.102	0.138
	232	0.076	0.137	0.181
	341	0.106	0.182	0.242
	500	0.144	0.244	0.318
C3,WBE, 3L	50	0.000	0.000	0.000
	73	0.000	0.000	0.000
	108	0.000	0.000	0.021
	158	0.000	0.023	0.031
	232	0.027	0.034	0.045
	341	0.027	0.049	0.062
	500	0.054	0.073	0.084
D3,WBE, 3L	50	0.026	0.052	0.085
	73	0.036	0.068	0.110
	108	0.050	0.093	0.140
	158	0.068	0.125	0.180
	232	0.095	0.166	0.231
	341	0.130	0.219	0.306
	500	0.174	0.294	0.389

Table 0.B4

Specimen	Pressure, Pa	Conditioning		
		RH 75%	RH 43%	RH 30%
		Air leakage, $m^3/(m^2.h)$		
P1,WBE, 3L	50	0.000	0.000	0.000
	73	0.000	0.025	0.022
	108	0.000	0.032	0.029
	158	0.000	0.041	0.037
	232	0.000	0.050	0.049
	341	0.000	0.065	0.065
	500	0.000	0.085	0.090
P2,WBE, 3L	50	0.000	0.000	0.037
	73	0.000	0.000	0.047
	108	0.000	0.000	0.060
	158	0.000	0.021	0.078
	232	0.000	0.028	0.100
	341	0.000	0.035	0.128
	500	0.000	0.051	0.160
P3,WBE, 3L	50	0.000	0.000	0.000
	73	0.000	0.000	0.000
	108	0.000	0.000	0.023
	158	0.000	0.000	0.032
	232	0.000	0.000	0.045
	341	0.000	0.022	0.059
	500	0.000	0.034	0.081

Table 0.B5

Specimen	Pressure, Pa	Conditioning		
		RH 75%	RH 43%	RH 30%
		Air leakage, $m^3/(m^2.h)$		
B5,BE, 5L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.00	0.00
C5,BE, 5L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.00	0.00

Table 0.B6

Specimen	Pressure, Pa	Conditioning		
		RH 75%	RH 43%	RH 30%
		Air leakage, $m^3/(m^2.h)$		
P1,BE, 5L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.00	0.00
P2,BE, 5L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.00	0.00
P3,BE, 5L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.00	0.00

Table 0.B7

Specimen	Pressure, Pa	Conditioning		
		RH 75%	RH 43%	RH 30%
		Air leakage, $m^3/(m^2.h)$		
A3,BE, 3L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.00	0.00
B3,BE, 3L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.00	0.00

Table 0.B8

Specimen	Pressure, Pa	Conditioning		
		RH 75%	RH 43%	RH 30%
		Air leakage, $m^3/(m^2.h)$		
P1,BE, 3L	50	0.00	0.00	0.00
	73	0.00	0.00	0.00
	108	0.00	0.00	0.00
	158	0.00	0.00	0.00
	232	0.00	0.00	0.00
	341	0.00	0.00	0.00
	500	0.00	0.02	0.03
P2,BE, 3L	50	0.00	0.00	0.02
	73	0.00	0.02	0.04
	108	0.00	0.02	0.06
	158	0.00	0.05	0.08
	232	0.00	0.06	0.10
	341	0.00	0.09	0.14
	500	0.00	0.12	0.18
P3,BE, 3L	50	0.00	0.02	0.05
	73	0.00	0.03	0.07
	108	0.00	0.04	0.09
	158	0.00	0.06	0.13
	232	0.00	0.09	0.17
	341	0.03	0.12	0.23
	500	0.04	0.17	0.31

Appendix C

Moisture content data

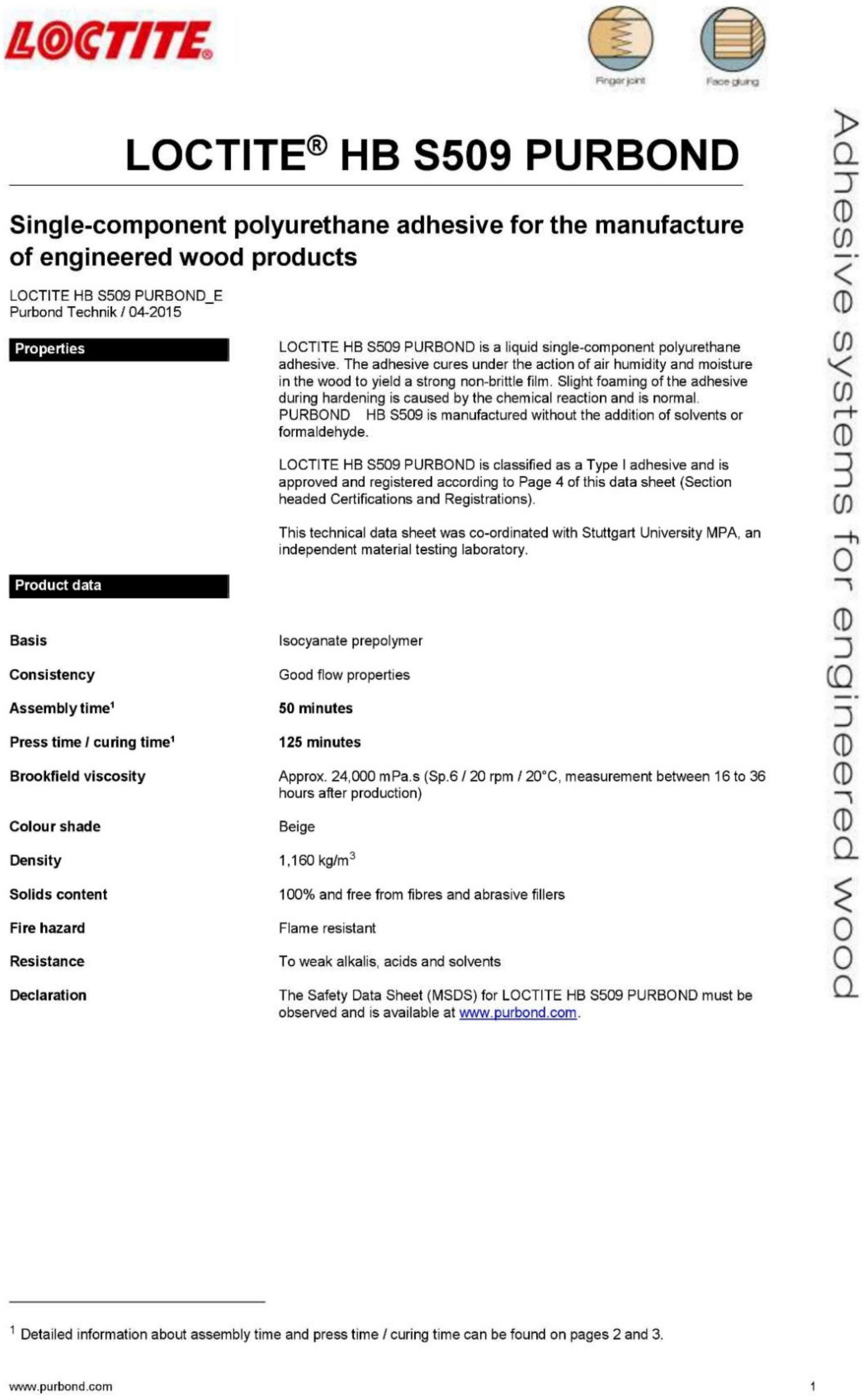
Table 0.C1

Specimen		MC (%)		
		RH 75%	RH 43%	RH 30%
5L-WBE	P1	14.00	10.10	7.27
	P2	13.80	10.20	7.20
	P3	13.30	9.60	7.77
	P4	12.50	8.60	7.73
	A5	12.00	8.40	7.70
	B5	13.40	9.60	7.60
	C5	12.80	9.10	8.10
3L-WBE	A3	13.30	9.40	7.13
	B3	13.50	9.50	7.47
	C3	13.50	9.40	7.00
	D3	13.60	9.40	7.20
	P1	13.50	9.50	6.50
	P2	13.20	9.20	6.93
	P3	13.50	9.40	7.37
5L-BE	B5	13.20	9.60	7.57
	C5	13.40	9.60	7.50
	P1	11.90	8.10	7.27
	P2	12.40	8.50	7.73
	P3	12.20	8.50	7.37
3L-WBE	A3	13.90	9.80	7.93
	B3	13.30	9.30	6.57
	C3	14.10	10.10	6.80
	P1	13.70	9.60	7.47
	P2	13.60	9.40	7.23
	P3	13.70	9.70	7.40

Appendix D

Adhesive data sheet

Figure 0.D1



LOCTITE® HB S509 PURBOND

Single-component polyurethane adhesive for the manufacture of engineered wood products

LOCTITE HB S509 PURBOND_E
Purbond Technik / 04-2015

Adhesive systems for engineered wood

Properties

LOCTITE HB S509 PURBOND is a liquid single-component polyurethane adhesive. The adhesive cures under the action of air humidity and moisture in the wood to yield a strong non-brittle film. Slight foaming of the adhesive during hardening is caused by the chemical reaction and is normal. PURBOND HB S509 is manufactured without the addition of solvents or formaldehyde.

LOCTITE HB S509 PURBOND is classified as a Type I adhesive and is approved and registered according to Page 4 of this data sheet (Section headed Certifications and Registrations).

This technical data sheet was co-ordinated with Stuttgart University MPA, an independent material testing laboratory.

Product data

Basis	Isocyanate prepolymer
Consistency	Good flow properties
Assembly time[1]	**50 minutes**
Press time / curing time[1]	**125 minutes**
Brookfield viscosity	Approx. 24,000 mPa.s (Sp.6 / 20 rpm / 20°C, measurement between 16 to 36 hours after production)
Colour shade	Beige
Density	1,160 kg/m^3
Solids content	100% and free from fibres and abrasive fillers
Fire hazard	Flame resistant
Resistance	To weak alkalis, acids and solvents
Declaration	The Safety Data Sheet (MSDS) for LOCTITE HB S509 PURBOND must be observed and is available at www.purbond.com.

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[1] Detailed information about assembly time and press time / curing time can be found on pages 2 and 3.

www.purbond.com 1

Application

Processing guideline for finger-jointing

Preparation

LOCTITE HB S509 PURBOND is a single-component adhesive and is processed in a closed system directly from the container in which it is supplied.
Automatic finger joint machines must be specially equipped with an appropriate application system to process LOCTITE HB S509 PURBOND. All machine parts that come into contact with the adhesive must be treated with LOCTITE TRENNMITTEL/RELEASE AGENT PURBOND resp. LOCTITE TRENNPASTE/RELEASE PASTE PURBOND before processing.

Wood moisture content

The wood moisture content at the joint surfaces that are to be glued together must be not less than 8%. The permissible upper limit of the wood moisture content is governed by the respective national product standards (e.g. EN 385 / EN 386 or DIN 68140) but must be below 18 %.
According to DIN 68140-1, the maximum permissible difference in wood moisture content between the ends of the wood that are to be joined is:

- for single-piece finger jointed components: max. 5%
- for finger jointed lamellas for glued laminated beams: max. 4%

According to EN 385, the maximum permissible difference in wood moisture content between the ends of the pieces that are to be joined is 5%.

Adhesive application

Application of the adhesive takes place via a suitable application system (comb application or contactless application in conjunction with the relevant approvals where necessary). Depending on the application system, the adhesive is applied to one or both sides at the rate of approx. 120 - 160 g/m^2. Uniform wetting of the finger profile of the compressed finger joint must be guaranteed. The components are pressed together immediately afterwards.

Assembly time

The components to be glued must be assembled together and the press force applied immediately, but at the latest 50 minutes after the start of adhesive application (maximum assembly time). The maximum assembly time of the moisture-reactive LOCTITE HB S509 PURBOND is influenced by the climate conditions prevailing in the room during processing. Higher temperature and higher air humidity shorten the assembly time. It is absolutely essential that the adhesive is still capable of adhering when the press force is applied.

Curing time

The curing time of the adhesive is 125 minutes at 20°C and 65% air humidity.

Press force

The press force applied (depending on the finger length and profile) must guarantee a precisely fitting joint. The specifications in accordance with EN 385 and/or DIN 68140-1 or other national guidelines must be observed in this respect.

Further processing

The components can undergo further processing after the curing time of the adhesive has elapsed.

Storage time after bonding

The bonded components must be stored at a temperature of approx. 20 °C for at least 10 hours after the press time has elapsed.

Additional instructions

The following supplementary instructions must be observed when manufacturing finger joints for load-bearing structural components:

1. The approvals (see the Section headed Certifications and Registrations).
2. The temperature in the production room should be 20°C and must not be lower than 18°C. This applies equally for the wood and the adhesive.
3. Suitable quality control scheme in accordance with EN 385 and/or EN 14080 or other national guidelines is recommended to guarantee a high quality of glued joints.

Application — **Processing guideline for face gluing**

Preparation

LOCTITE HB S509 PURBOND is a single-component adhesive and is processed in a closed system directly from the container in which it is supplied.
The surfaces to be glued together must be clean and free from adhesive-repellent substances such as oils, greases or release agents. All machine parts that come into contact with the adhesive must be treated with LOCTITE TRENNMITTEL/RELEASE AGENT PURBOND resp. LOCTITE TRENNPASTE/RELEASE PASTE PURBOND before processing.

Wood moisture content

The wood moisture content at the joint surfaces that are to be glued together must be not less than 8%.
In accordance with EN 386, the moisture difference between the individual lamellas must not exceed 4%.

Adhesive application

LOCTITE HB S509 PURBOND is applied automatically using a special application system in a through-feed process. The adhesive is applied one-sided at the rate of 140-180 g/m². The amount of adhesive applied must guarantee uniform wetting of the joint component surface. Squeeze-out of the adhesive must be present all along the edge of the glued joint. In the event of a quantity of adhesive being in the lower permissible region, this must be co-ordinated with the adhesive manufacturer.

Assembly time

The components to be glued must be assembled together and the press force applied immediately, but at the latest 50 minutes after the start of adhesive application (maximum assembly time). The maximum assembly time of the moisture-reactive LOCTITE HB S509 PURBOND is influenced by the climate conditions prevailing in the room during processing. Higher temperature and higher air humidity shorten the assembly time. It is absolutely essential that the press force is applied before any skinning on the adhesive surface and while the adhesive is still capable of adhering.

Press time

The press time depends on the temperature and moisture content of the joint components and surroundings. Lower temperature and air humidity delay the curing process, higher temperature and air humidity speed up the curing process. The minimum press time for straight structural beams at 20°C with 65% relative air humidity and a wood moisture content of 12% is 125 minutes, provided optimum fit of the joint components is guaranteed (joint thickness approx. 0.1 mm). If an exactly fitting joint is not guaranteed, the press time must be at least 145 minutes.

Press force

The applied press force must guarantee optimum fitting of the joint components. Normally, a press force of 0.6 N/mm² to 1.0 N/mm², which is generally customary in glued timber construction, is applied.

Further processing

The components can undergo further processing immediately after the press time has elapsed.

Storage time after bonding

The bonded components must be stored at a temperature of approx. 20 °C for at least 10 hours after the press time has elapsed.

Additional instructions

The following supplementary instructions must be observed when manufacturing load-bearing structural components:

1. The approvals (see the Section headed Certifications and Registrations).
2. Glued joints as thin as possible (max. 0.3 mm).
3. In accordance with EN 386, the maximum permissible moisture content of the joint components to be glued together is 15%.
4. The temperature in the production room should be 20°C and must not be lower than 18°C. This applies equally for the wood and the adhesive.
5. Suitable quality control scheme in accordance with EN 386 and/or EN 14080 or other national guidelines is recommended to guarantee a high quality of glued joints.

Protection/safety and cleaning

Safety precautions and cleaning measures

Occupational safety/protection

The wearing of protective gloves – Purbond Arbeitshandschuhe/Handling Gloves – and protective goggles is urgently recommended when handling liquid adhesive and release agent.

Plant protection and cleaning

LOCTITE TRENNMITTEL/RELEASE AGENT PURBOND resp. LOCTITE TRENNPASTE/RELEASE PASTE PURBOND prevent adhesive adhering to plant and tools. Before bringing a plant into operation, all the parts that come into contact with adhesive must be treated (see the corresponding TDS).

Purbond Reinigungsmittel/Cleaning Agent is suitable for cured adhesive on tools or machine parts. Compatibility must be checked before using the cleaning agent.

Protective goggles and chemically resistant Purbond Reinigungs-handschuhe/Cleaning Gloves (special black gloves) must be worn when working with Purbond Reinigungsmittel/Cleaning Agent.

Certifications and registrations

Certifications and registrations

Purbond AG
Z-9.1.711
Z-9.1.765
Z-9.1.833

National Technical Approval by the DIBt (Deutsches Institut für Bautechnik) for the "LOCTITE HB S509 PURBOND PUR adhesive for the fabrication of load-bearing engineered wood components."

Approval number **Z-9.1-765, Z-9.1-711, /-9.1-833**

Europe

Compliance with EN 14080 confirmed by MPA University Stuttgart. The adhesive can be used for the manufacture of glued laminated timber in accordance with EN 14080.

ATG 12/2888

National Technical Approval No. ATG 12/2888 by the Union Belge pour l'Agrément Technique dans la Construction (UBAtc).

FCBA
INSTITUT TECHNOLOGIQUE

Classification Type I pursuant to EN 15425 (2008) of LOCTITE HB S509 PURBOND adhesives for finger-jointed and glue-laminated load-bearing wood structures, by the FCBA based on following documents:

FCBA n° LBO/GL/MP/403/09/274
FCBA n° LBO/GL/MP/403/09/275
FCBA n° LBO/GL/MP/403/09/276

SATAS
SANS 10183

Certificate from the South African Technical Auditing Services Pty. Ltd. in compliance with SANS 10183 part 2 for „exposure class S3 for finger-jointing".

Certificate Number: **107**

Australia/New Zealand

Fulfils the requirements as a Type I adhesive in accordance with AS/NZS 4364.

JAIA F☆☆☆☆

Formaldehyde Classification:
JAIA (Japan Adhesive Industry Association) Independent Control Standard against Indoor Air Pollution.

Register Number: **JAIA-008745**

Guarantee

This information is based on the test results of the Otto-Graf-Institute (MPA, University Stuttgart), our Purbond application laboratory and our customers' experience.

We guarantee a consistent quality of this product which is manufactured in accordance with ISO 9001 / ISO 14001 guidelines.

The product was found suitable for all applications and uses listed above; for other uses or applications we strongly suggest you to contact our technical support staff.

In general the sales and delivery conditions of Purbond AG apply.

Identity of ingredients:

Chemical ingredients	CAS-No.	Proportion
Isocyanic acid, polymethylenepolyphenylene ester, polymer with 1,3-diisocyanatomethylbenzene, hydrazine and methyloxirane polymer wi	915152-15-7	60- <= 100 %
Isocyanic acid, polymethylenepolyphenylene ester	9016-87-9	10- < 30 %
o-(p-Isocyanatobenzyl)phenyl isocyanate	5873-54-1	< 10 %
4,4'- methylenediphenyl diisocyanate	101-68-8	< 10 %
Hexane, 1,6-diisocyanato-, homopolymer	28182-81-2	< 5 %
non hazardous ingredients~		< 10 %

Section 4. First aid measures

Ingestion:	Rinse mouth, do not induce vomiting, consult a doctor.
Skin:	Immediately remove soiled or soaked clothing. Immediately wash skin thoroughly with soap and water. Seek medical advice.
Eyes:	Rinse immediately with plenty of running water (for 10 minutes). Seek medical attention if necessary.
Inhalation:	Move to fresh air. Seek medical advice.
First Aid facilities:	Eye wash and safety shower Normal washroom facilities
Medical attention and special treatment:	Treat symptomatically. Exposed persons should be kept under medical observation for at least 48 hours because delayed effects may occur.

Section 5. Fire fighting measures

Suitable extinguishing media:	Foam, dry chemical or carbon dioxide.
Improper extinguishing media:	High pressure waterjet
Decomposition products in case of fire::	nitrogen oxides Oxides of carbon. Isocyanates.
Special protective equipment for fire-fighters:	Wear self-contained breathing apparatus. Wear protective equipment.

Section 6. Accidental release measures

Personal precautions:	Avoid contact with skin and eyes. Danger of slipping on spilled product. Keep unprotected persons away. See advice in section 8
Environmental precautions:	Do not empty into drains / surface water / ground water.
Clean-up methods:	Absorb spill with inert material. Shovel material into appropriate container for disposal. Dispose of contaminated material as waste according to Section 13.

Section 7. Handling and storage

Appendix E

Liquid membrane data sheet

Figure 0.E1

TECHNICAL DATA SHEET

www.blowerproof.co.uk

CHECK FOR REFERENCES

BLOWERPROOF® LIQUID BRUSH

APPLY WITH paintbrush

Water based, VOC free, fibre reinforced polymer emulsion applied with paintbrush.
Dries to form a continuous, permanent, flexible airtight seal.

DESCRIPTION

BLOWERPROOF LIQUID BRUSH is a VOC free, polymer based paste that is applied with a paintbrush and dries to form an airtight flexible coating with good adhesion on different substrates. This product is ready–to–use and can be applied both vertically and horizontally.

AREAS OF USE

» Floor/wall connections
» Wall/ceiling connections
» Window/wall connections
» Pipe penetrations
» Walls
» Wall/wall connections
» Vertical and horizontal joints
» Curtain walls
» Wall/roof connections (steel deck)

APPLICATION

PRIOR TO STARTING THE APPLICATION:

» Remove salt efflorescence, dust and loose parts from the surface, remove surface contaminants which may affect adhesion. Remove standing water.
» Fill holes and joints > 3mm with **BLOWERPROOF GAP FILLING MORTAR** or other fast setting cement based product or polyurethane foam
» Do not apply **BLOWERPROOF LIQUID BRUSH** at < 5°C (including substrate surface temperature).
» Application on humid (but hand dry) surfaces is allowed.

APPLICATION

» **BLOWERPROOF LIQUID BRUSH** is ready-to-use; stir before use. Do not dilute with water or solvents.
» Apply with a flat paintbrush, suitable for water-based paints. Apply in two layers, the second layer after complete drying of the first layer. Total advised indicative consumption: 0.5 - 1 kg/m².
» Clean paint brush and other tools with water.
» During drying avoid contact with any type of water, liquids or other construction products.
» Complete drying is required prior to applying another product on **BLOWERPROOF LIQUID BRUSH** (such as plaster). Drying time may vary and depends on local conditions and condition of the substrate. Indicative: 24 - 48 hours.
» For large applications we recommend **BLOWERPROOF LIQUID SPRAY** applied with an airless paint spray machine. Please contact us to locate an approved installer.

A DETAILED APPLICATION GUIDE IS AVAILABLE ON REQUEST.

Page 1/3

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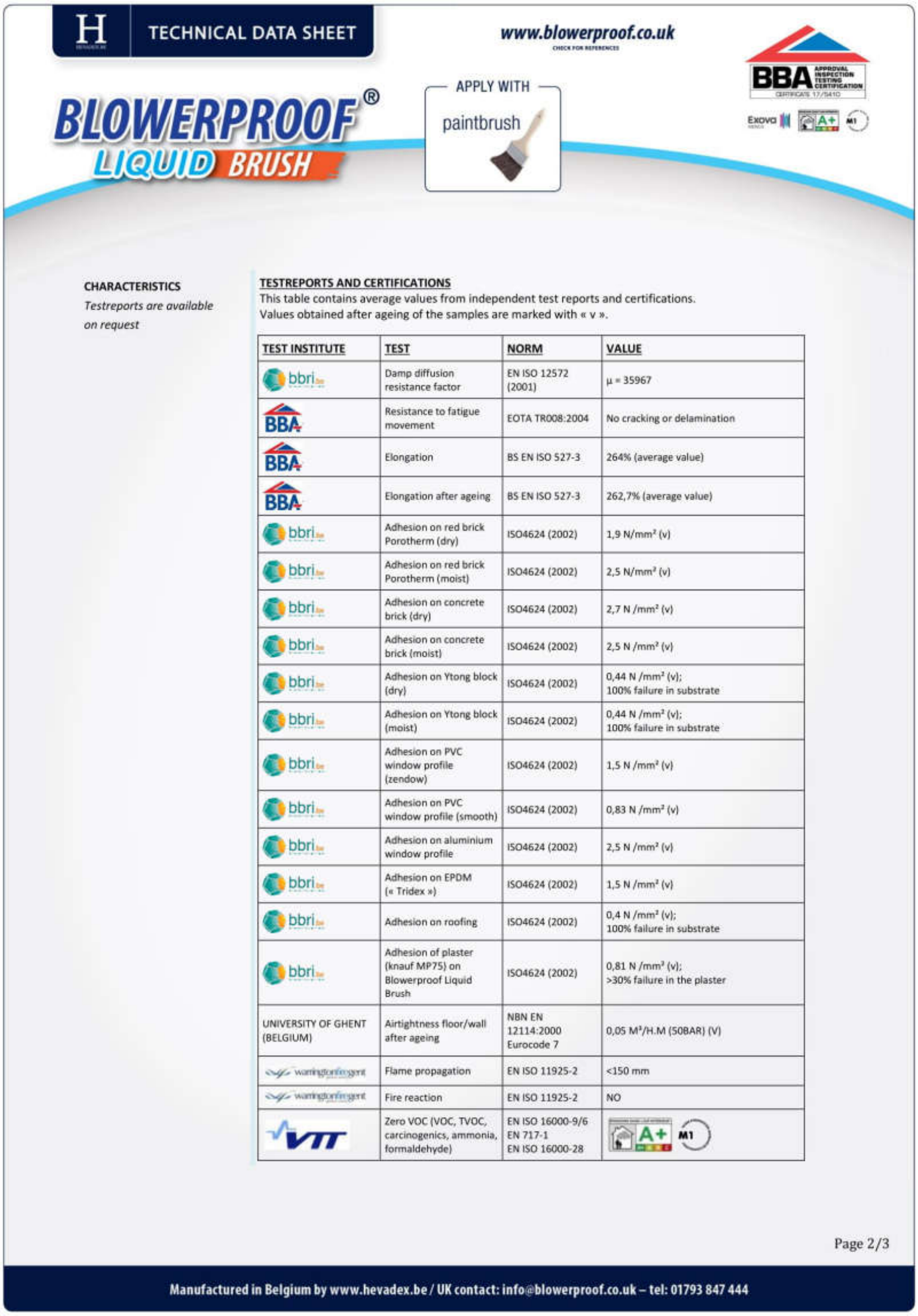

H TECHNICAL DATA SHEET

www.blowerproof.co.uk
CHECK FOR REFERENCES

BLOWERPROOF®
LIQUID BRUSH

APPLY WITH
paintbrush

BBA APPROVAL INSPECTION TESTING CERTIFICATION
CERTIFICATE 17/5410

CHARACTERISTICS
Testreports are available on request

TESTREPORTS AND CERTIFICATIONS

This table contains average values from independent test reports and certifications.
Values obtained after ageing of the samples are marked with « v ».

TEST INSTITUTE	TEST	NORM	VALUE
bbri.be	Damp diffusion resistance factor	EN ISO 12572 (2001)	µ = 35967
BBA	Resistance to fatigue movement	EOTA TR008:2004	No cracking or delamination
BBA	Elongation	BS EN ISO 527-3	264% (average value)
BBA	Elongation after ageing	BS EN ISO 527-3	262,7% (average value)
bbri.be	Adhesion on red brick Porotherm (dry)	ISO4624 (2002)	1,9 N/mm² (v)
bbri.be	Adhesion on red brick Porotherm (moist)	ISO4624 (2002)	2,5 N/mm² (v)
bbri.be	Adhesion on concrete brick (dry)	ISO4624 (2002)	2,7 N /mm² (v)
bbri.be	Adhesion on concrete brick (moist)	ISO4624 (2002)	2,5 N /mm² (v)
bbri.be	Adhesion on Ytong block (dry)	ISO4624 (2002)	0,44 N /mm² (v); 100% failure in substrate
bbri.be	Adhesion on Ytong block (moist)	ISO4624 (2002)	0,44 N /mm² (v); 100% failure in substrate
bbri.be	Adhesion on PVC window profile (zendow)	ISO4624 (2002)	1,5 N /mm² (v)
bbri.be	Adhesion on PVC window profile (smooth)	ISO4624 (2002)	0,83 N /mm² (v)
bbri.be	Adhesion on aluminium window profile	ISO4624 (2002)	2,5 N /mm² (v)
bbri.be	Adhesion on EPDM (« Tridex »)	ISO4624 (2002)	1,5 N /mm² (v)
bbri.be	Adhesion on roofing	ISO4624 (2002)	0,4 N /mm² (v); 100% failure in substrate
bbri.be	Adhesion of plaster (knauf MP75) on Blowerproof Liquid Brush	ISO4624 (2002)	0,81 N /mm² (v); >30% failure in the plaster
UNIVERSITY OF GHENT (BELGIUM)	Airtightness floor/wall after ageing	NBN EN 12114:2000 Eurocode 7	0,05 M³/H.M (50BAR) (V)
warringtonfiregent	Flame propagation	EN ISO 11925-2	<150 mm
warringtonfiregent	Fire reaction	EN ISO 11925-2	NO
VTT	Zero VOC (VOC, TVOC, carcinogenics, ammonia, formaldehyde)	EN ISO 16000-9/6 EN 717-1 EN ISO 16000-28	A+ M1

Page 2/3

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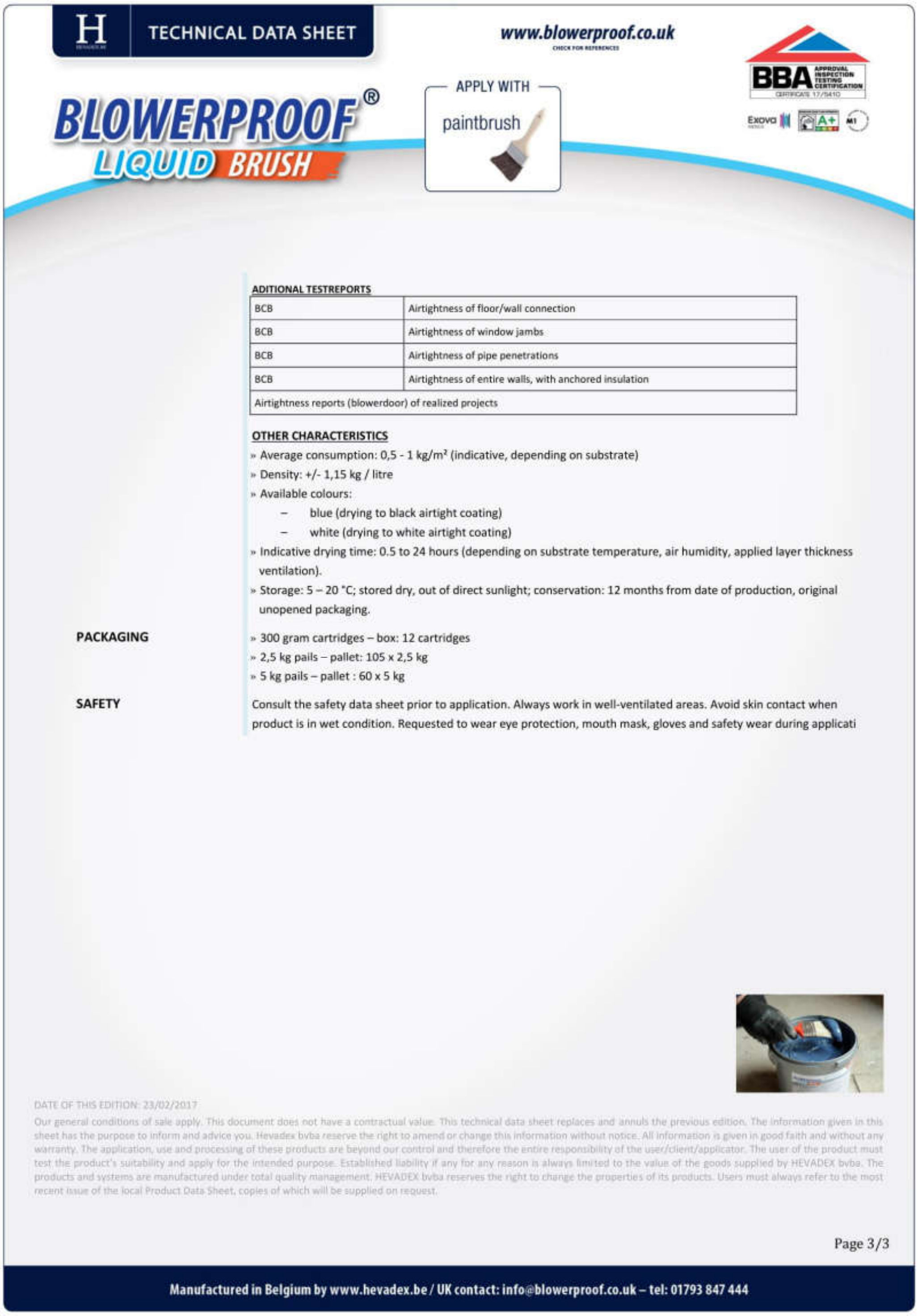

TECHNICAL DATA SHEET

www.blowerproof.co.uk
CHECK FOR REFERENCES

BLOWERPROOF®
LIQUID BRUSH

APPLY WITH
paintbrush

BBA APPROVAL INSPECTION TESTING CERTIFICATION
CERTIFICATE 17/5410

ADITIONAL TESTREPORTS

BCB	Airtightness of floor/wall connection
BCB	Airtightness of window jambs
BCB	Airtightness of pipe penetrations
BCB	Airtightness of entire walls, with anchored insulation
Airtightness reports (blowerdoor) of realized projects	

OTHER CHARACTERISTICS

- Average consumption: 0,5 - 1 kg/m² (indicative, depending on substrate)
- Density: +/- 1,15 kg / litre
- Available colours:
  - blue (drying to black airtight coating)
  - white (drying to white airtight coating)
- Indicative drying time: 0.5 to 24 hours (depending on substrate temperature, air humidity, applied layer thickness ventilation).
- Storage: 5 – 20 °C; stored dry, out of direct sunlight; conservation: 12 months from date of production, original unopened packaging.

PACKAGING

- 300 gram cartridges – box: 12 cartridges
- 2,5 kg pails – pallet: 105 x 2,5 kg
- 5 kg pails – pallet : 60 x 5 kg

SAFETY

Consult the safety data sheet prior to application. Always work in well-ventilated areas. Avoid skin contact when product is in wet condition. Requested to wear eye protection, mouth mask, gloves and safety wear during applicati

DATE OF THIS EDITION: 23/02/2017

Page 3/3

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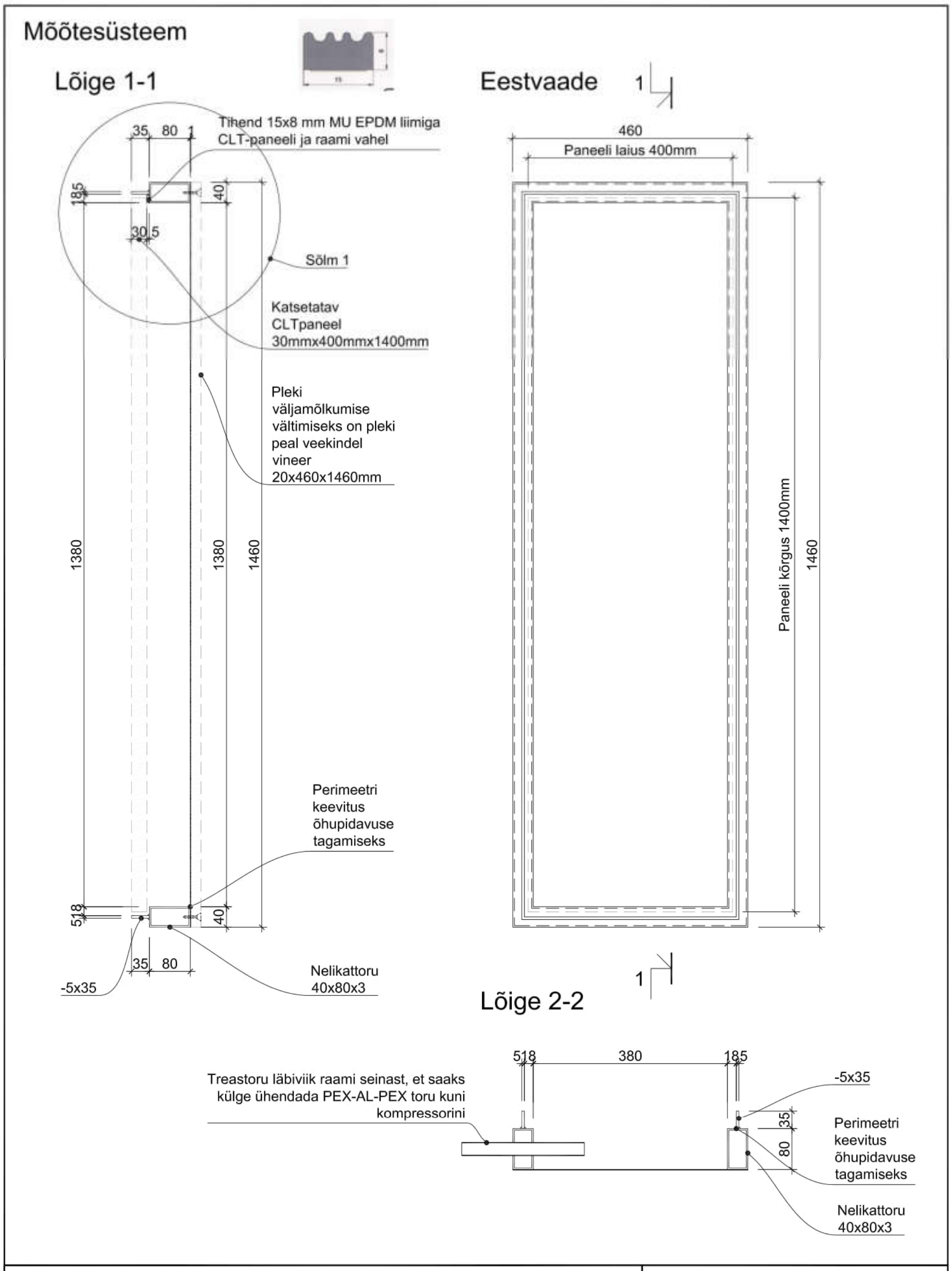
Appendix F

Air permeability box technical drawing



TELLIJA	Tallinna Tehnikaülikool Ehitusfüüsika ja energiatõhususe õppetool Ehitajate tee 5, 19086, Tallinn	TÖÖ	TK-03-12		
OBJEKT	Õhulekete katseraam .	Prof. T. Kalamees. Prof. J. Kers Ins. V, Kukk			
JOONIS	Mõõtesüsteem	KUUPÄEV 28.11.2016	STAADIUM TJ	MÕÕTK. M1:10	LEHT 1