9º Congresso Nacional de Mecânica Experimental
Aveiro, 15-17 de Out., 2014

INFLUENCE OF MOISTURE CONTENT AND GAPS ON THE WITHDRAWAL RESISTANCE OF SELF TAPPING SCREWS IN CLT

Silva, C. [1]; Ringhofer, A. [2], Branco, Jorge M.. [3];Lourenço, P.B. [4];Schickhofer, G. [5]

[1] Departamento de Engenharia Civil, Universidade do Minho
[2] Institut für Holzbau und Holztechnologie, Graz University of Technology
[3] Departamento de Engenharia Civil, Universidade do Minho
[4] Departamento de Engenharia Civil, Universidade do Minho
[5] Institut für Holzbau und Holztechnologie, Graz University of Technology





ABSTRACT

Self-tapping screws (STS) have been proclaimed as the easiest solution for structural timber connections, in special for cross laminated timber (CLT) constructions. In order to understand deeply the composite model "CLT-STS", an experimental campaign which comprised 270 withdrawal tests was carried out. Maximum withdrawal load capacity of self-tapping screws inserted in plane side of a three layered CLT panel was evaluated considering three main parameters: moisture levels of CLT (i), number of gaps (ii) and the width of gaps (iii). Regarding (i), connections were tested with CLT at 8%, 12% and 18% of moisture content. Concerning (ii) and (iii), different test configurations with 1, 2 and 3 gaps, with 0 or 4mm, were tested. The influences of moisture content and number of gaps were modeled. Further a correlation between test results and a prediction model developed by Uibel and Blaß (2007) has been proposed.

1- INTRODUCTION

Cross laminated timber (CLT) construction is a versatile system allowing its adaptation to different kinds of fasteners and different connection configurations. However, self-tapping screws (STS), which dismiss predrilled holes, are an easy and economical solution and recommended by manufacturers for most of the detail joints.

STS are able to combine axial and shear loads, which make them suitable to be used in any type of connection. In comparison with standard screws, STS have important advantages, such as: (i) the special shape of the thread region allows a high load transmission into the surrounding wood; (ii) generally they are hardened after rolling the thread, increasing the yield moment, the torsional strength and the tensile bearing capacity; (iii) the stiffness of the connection increases while the danger of "slipping" decreases (Frese and Blaß 2009).

Following the design procedure for axial load conditions given in EN 1995- 1-1 (2004), withdrawal failure represents the maximum load capacity achieved by the composite model "timber-screw". Considering this European standard, maximum load capacity can be influenced by changes in timber moisture content (w) caused by climatic changes of relative humidity (RH) and temperature, and by timber density, screw diameter and the angle between the screw and grain direction. However, considering CLT specificities, such as the specific lay-up of the panels, other parameters should be also considered.

Present research will focus on (i) the relation between withdrawal capacity and moisture induced effects on CLT, which is different from the same relation obtained for solid timber or glued laminated timber (GLT), (ii) the relation between withdrawal capacity and the existence of gaps between glued boards, and (iii) the relation between withdrawal capacity and the width of gaps. In the context of this research, STS are inserted in the plane side of the CLT panel. In other words, STS are inserted perpendicularly to timber grain direction.

Regarding moisture induced effects, it is well known that it affects wood physical, mechanical and rheological properties, namely: durability, modulus of elasticity, shrinkage/swelling and strength (Mårtensson 1992; Ranta-Maunus 2003; Keunecke et al 2007). Considering a moisture content range from 12 % to fibre saturation point (fsp, w ≈ 28 % for Norway spruce), timber strength and stiffness decrease more or less linearly with increasing moisture content: approx. 2-4 % and 1-3% per % of moisture content difference, respectively (Ringhofer et al, 2014). Considering timber engineering products (CLT and GLT), moisture changes also affects material properties: either tension capacity of GLT or bending and shear stiffness of CLT reduce significantly with timber moistening (Gülzow et al. 2010; Jönsson and Thelandersson 2003).

The relation between STS withdrawal capacity and moisture content (w) is present in some literature suggesting that for 12% ≤ w ≤ 20%, withdrawal capacity decrease 2,9-3,1% and 2,5% per each % of moisture content added, for solid timber and GLT, respectively (Ringhofer et al., 2014). Both considering an angle of 90º between screw axis and timber grain direction. For an angle of 0º, withdrawal capacity decreases 2,7-3,6% and 2,7% per each % of moisture content added, respectively.

Withdrawal capacity of STS inserted in CLT panels has been studied only for moisture content around 12%. Literature present studies that compare test results with existing predicting models for withdrawal capacity (Muñoz et al. 2010), suggest new predicting models (Uibel and Blaß, 2007) and evaluate the influence of existence of gaps through the screw path, when the screw is inserted parallel to the grain direction (Uibel and Blaß, 2007 and Grabner 2013).

2- MATERIALS AND METHODS

2.1 - Experimental campaign

The present experiments pretend to understand the influence of three different parameters on the axial withdrawal capacity of STS inserted perpendicular to the face of CLT panels. The first parameter is related with simple moisture content changes on CLT. Tests performed considered three different moisture content levels, namely: 8%, 12%, and 18%.

Second parameter is related with the existence of gaps on the screw path through CLT thickness. To explore this parameter, CLT was produced considering the screw insertion through a different number of gaps across all CLT layers. CLT was produced with three layers, which allowed five different gap configurations, namely: reference (REF) – screw is inserted without the presence of gaps; gap in first layer (GAP_FL) – screw is inserted through one gap present in first layer of CLT panel; gap in middle layer (GAP_ML) - screw is inserted through one gap present in middle layer of CLT panel; gap in outer layers

(GAP_OL) - screw is inserted through two gaps present in outer layers of CLT panel; gap in three layers (GAP_3L) - screw is inserted through three gaps present in all three layers of CLT panel.

Last parameter is related with gap width, which can be 0 mm or 4 mm. Gaps with 0 mm (GAP0) were selected as the reference for the better scenario and gaps with 4 mm (GAP4) were selected to simulate the worst scenario. The decision of a maximum width of 4 mm was based on literature survey of Brandner et al. (2013), who presented a summary of main geometrical characteristics of European CLT producers. They concluded that the most common gap width varies between 2 mm and 6 mm. However, they also refer that producers are looking for improvements for CLT pressing procedures, namely lateral pressing, in order to reduce the width of gaps. So, considering these future improvements, the worst scenario was considered through a gap width of 4 mm.

The combination of these three parameters resulted in nine different test configurations and 270 withdrawal tests. All nine test configurations were tested for all three moisture levels mentioned before, with samplings of 10 specimens. Fig. 1 illustrates all nine different test configurations all produced with three layered CLT and dimensions of 170x170x102mm.

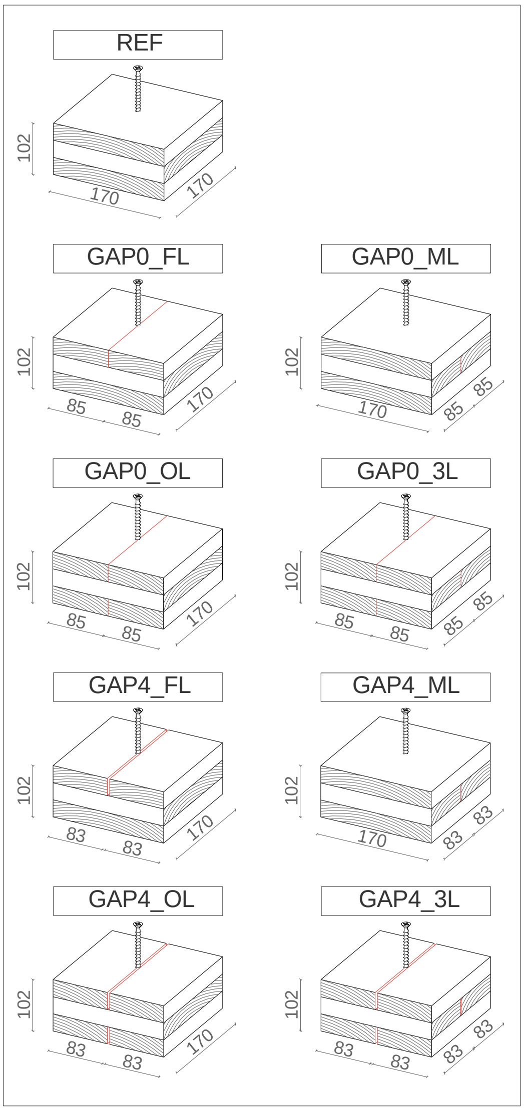

Fig. 1 –All nine test configurations. (Dimensions in mm).

2.2 - Preparation and conditioning of test specimens

The CLT used to materialize the specimens was carefully produced in laboratory in order to obtain specimens free of significant knots ensuring test groups with similar density distribution and guarantee the exact position of gaps. Timber used to produce CLT was Norway spruce (*Picea abies*) with nominal strength class C24, a mean density value of ≈ 460 kg/m^3 and moisture content of ≈ 10 %.

Conditioning of test specimens followed the next main steps: (1) preparation of CLT specimens - climatic conditioning, with environmental conditions of 20 ºC and 65% RH, in order to reach a moisture content close to 12 %; (2) pre-drilling the specimens with a hole of 5 mm (similar to the core diameter of the threaded part of the screw, recommended by European TGechnical Approvals for softwood application), in order to guarantee the right screw path through the gaps; (3)

inserting the screw (Rapid® Vollgewinde from Schmid (ETA-12/0373) with a diameter of 8 mm, (4) divide specimens by moisture groups and conditioning them till target moisture content was reached; and finally (5) withdrawal test.

Three groups were conditioned in three different environmental conditions, namely: 20 ºC and 29 %RH to reach 8 % of moisture content; 20 ºC and 65 %RH to keep 12 % of moisture content; and 20 ºC and 90 %RH to reach a moisture content of 18 % of moisture content.

2.3 - Test procedure

All tests were performed under "push-pull" load conditions on LIGNUM-UNI-275 (All round-Line testing machine by manufacturer Zwick GmbH & Co. KG) at Lignum Test Center (LTC) of Graz University of Technology, following the suggestions of EN 1382 (1999) (Fig. 2).

From all suggestions given in this standard, only two were not followed. First is related with screw penetration: as shown in Fig. 3, a fully threaded screw (ETA-12/0373, 2012) was penetrated through the whole test specimen in order to avoid tip caused influences on layer orientation. Second is related with the withdrawal strength, f_{ax}, which was determined according to Eq. (1).

$$f_{ax} = \frac{F_{\max}}{d \cdot l_p \cdot \pi} \tag{1}$$

Where $F_{\max}$ is the maximum force reached per test, d the thread diameter and l_{p} the inserted threaded part of the screw.

3- TEST RESULTS

3.1 - Results obtained by different moisture groups

The mean values of moisture content for different conditioned groups were: 8.04 %, 11.3 % and 17.3 %, for moisture groups of 8 %, 12 % and 18 %, respectively.

Densities varied between 344.8 and 576.4 kg/m^3, and its distribution between groups is quite similar with low CoV (coefficient of variation) values, between 0.08 and 0.11.

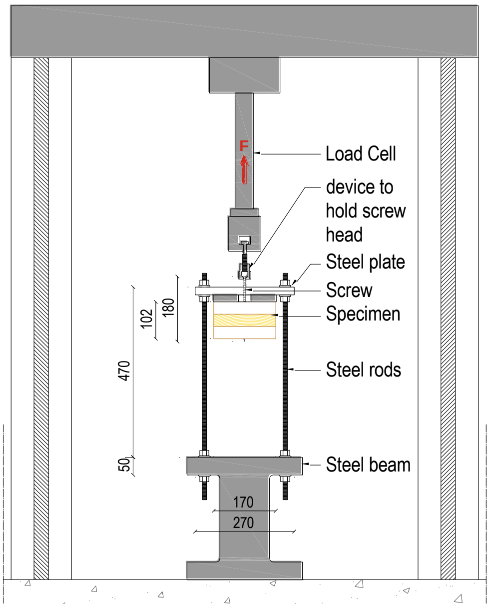

Fig. 2 – Front view of test layout, push-pull configuration.

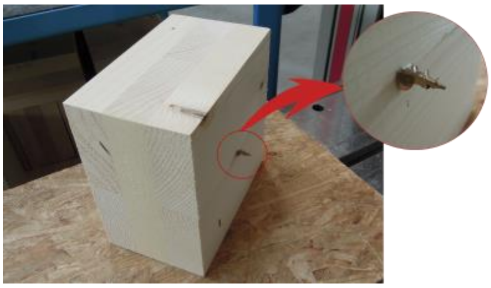

Fig. 3 –Penetration of screw through entire thickness of specimen until avoids the tip effect.

As expected, for all moisture groups, the highest withdrawal strengths were obtained by configuration GAP0_3L: 7.34 N/mm^2, 7.31 N/mm^2 and 7.76 N/mm^2 for moisture contents of 8 %, 12 % and 18 %, respectively. The lowest values were obtained by configuration GAP4_3L: 4.04 N/mm^2, 4.68 N/mm^2 and 4.72 N/mm^2 for moisture contents of 8 %, 12 % and 18 %, respectively.

Figs. 4, 5 and 6 summarise the results obtained for all three moisture groups, regarding: withdrawal strength (f_{ax}), density of reference (ρ_{12}) and moisture content (w).

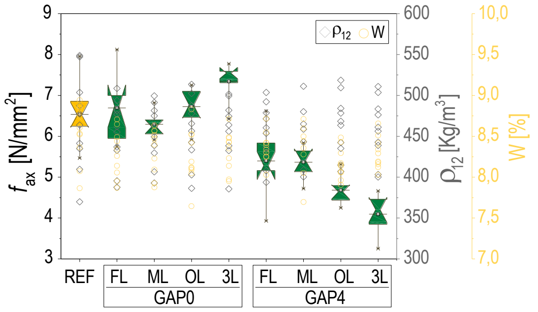

Fig. 4 – Results obtained by all nine test configurations with 8% of moisture content, concerning f_{ax}, ρ_{12}, and w.

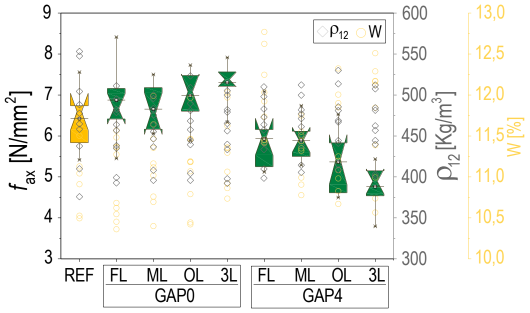

Fig. 5 – Results obtained by all nine test configurations with 12% of moisture content, concerning f_{ax}, ρ_{12}, and w.

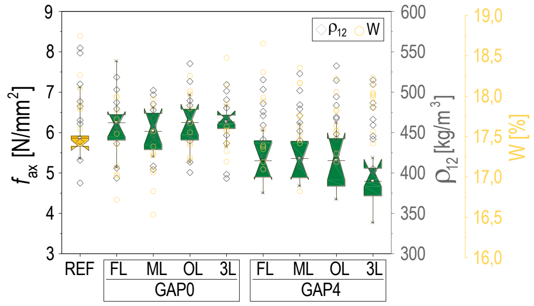

Fig. 6 – Results obtained by all nine test configurations with 18% of moisture content, concerning f_{ax}, ρ_{12}, and w.

3.2 - Effect of GAP

As depicted in Fig. 5 and 6, groups with 12 % and 18 % of moisture content exhibit a higher influence of GAP0 on withdrawal strength. Taking REF_12% and REF_18% as reference, groups GAP0_3L_12% and GAP0_3L_18%, present increases for withdrawal strength of 10% and 9%, respectively.

On contrast, the effect of GAP4 on withdrawal strength is more pronounced on group with 8 % of moisture content (Fig. 4). Taking REF_8% as reference, configuration GAP4_3L_8% presents a decrease of withdrawal strength of 38 %. This significant decrease is directly related with the enlargement of gap width due to timber shrinkage. On contrary, in group with 18 % of moisture content gap width reduces due to timber swelling. For this reason the expected decrease of withdrawal resistance caused by high moisture content as well by gaps is not that significant. Taking REF_18% as reference, configuration GAP4_3L_18% presents a decrease of 18 %. Free of shrinkage/swelling movements, GAP4 effect on groups with 12 % of moisture content is in an intermediate position. Taking REF_12% as reference, configuration GAP4_3L_12% presents a decrease of withdrawal strength of 26 %.

It is also important to refer that, contrary to expectations, for all moisture groups, GAP0 configurations present an increase of withdrawal strength dependent on the increase of number of gaps. The reason why this happens is not clear and further investigation is needed. However, there is the suspicion that the positive effect of crosswise lamination can be one reason.

3.3 - Effect of moisture content w

As expected, for configurations REF and GAP0, withdrawal strength keeps more or less constant for moisture content between 8 % and 12 % and decreases for moisture content $18\ \% \geq w \geq 12\ \%$. Differently, GAP4 configurations, due to GAP enlargement, present decreases of withdrawal strength when moisture content decreases from 12 % to 8 %. When moisture content increases from 12% to 18% withdrawal strength tends to be constant when the number of gaps increases. In section 4.2, this topic will be more treated in more detail.

4- MODELLING

In order to obtain more accurate values for the influence of gaps and moisture content, linear regressions based on the method of least squares were performed. Slope of obtained lines give values for k_{gap} and k_W, which represent the influence of each gap added, and each percentage unit of moisture content added/subtracted in the withdrawal strength.

These linear regressions ended up with the suggestion of linear models which express the influence of number of gaps and the influence of moisture content in the withdrawal strength.

4.1 - Modelling the influence of number of gaps

Taking REF (zero gaps) configuration as reference, linear regressions were performed considering different number of gaps and diverse gap widths. Fig. 7 depicts linear regressions obtained for configurations GAP0_8% and GAP4_8%, which suggested that for each gap added, the withdrawal strength increases 3.4 % and decreases 14.4 %, respectively. It is important to refer that due to shrinkage effects, group with w = 8% present higher differences between k_{gap} obtained for GAP0 and GAP4 configurations.

Table 1 present the k_{gap} values and shows that, independent of moisture content, as the number of GAP0 increases, f_{ax} also increases and as the number of GAP4 increases, f_{ax} decreases.

Considering GAP0 configurations, and contrary to GAP4 configurations, it can be observed that, if moisture content is not changed, the existence as well as the number of the gaps has nearly no influence. IF moisture content decreases, 0 mm gaps also open up and decrease fax.

Eq. 2 presents the linear model to predict the influence of gaps on withdrawal strength.

$$\eta_{gap} = \frac{f_{ax,gap,i}}{f_{ax,gap(0)}} = 1.00 + k_{gap} \cdot N \quad (2)$$

Where $f_{ax,gap,i}$ is the mean withdrawal strength of a given configuration, $f_{ax,gap(0)}$ is the mean withdrawal strength of REF configuration with the same range of moisture content, and N is the number of gaps.

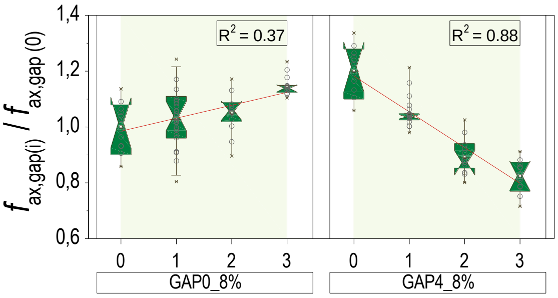

Fig. 7 – Example of linear regressions performed to obtain k_{gap} values.

Table 1 – Obtained values for k_{gap}, depending on moisture content and gap width.

Moisture content (w)		8%	12%	18%
k_{gap}	GAP0	0.034	0.048	0.052
	GAP4	- 0.144	- 0.088	- 0.057

4.2 - Modeling the influence of moisture content

Taking 12% moisture content as reference, linear regressions were performed considering different ranges of moisture content. Fig. 8 depicts the linear regressions defined for configurations REF and GAP4_3L, which suggest opposite behaviours. When 8 % ≤ w ≤ 12 %, REF configuration suggest a constant behaviour (k_W = 1.00), while GAP4_3L configuration suggests that withdrawal strength decreases 4.8 % per each % of moisture content less. On contrary, when 12 % ≤ w ≤ 18 %, REF configuration suggests that withdrawal strength decreases 1.8 % per each % of moisture content added, while GAP4_3L configuration suggests a constant behaviour (k_W = 1.00). As mentioned before, this phenomenon is closely related with shrinkage and swelling effects, which causes enlargement and closing of GAP4.

Table 2 present obtained values for k_W and shows that REF and GAP0 configurations present similar behaviour, while GAP4 configurations invert the behaviour gradually, dependent on the number of gaps. Timber swelling caused by moisture increase had a significant effect on the results obtained, avoiding the GAP influence and, in some cases, even the influence of moisture increases.

Eq. 3 presents a bi-linear model to predict the influence of moisture content on the withdrawal strength of STS.

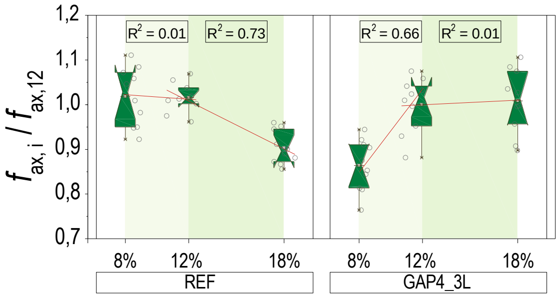

Fig. 8 – Example of linear regressions performed to obtain k_W values.

$$\eta_W = \frac{f_{ax,W,i}}{f_{ax,W(12)}} = \begin{cases} 1.00,\ for \begin{cases} REF \\ GAP0 \end{cases},\ when,\ 8\% \le W \le 12\% \\ 1.00 - k_W \cdot (W-12),\ for \begin{cases} GAP4, & when\ 8\% \le W \le 18\% \\ REF, & when\ 12\% \le W \le 18\% \end{cases} \end{cases} \tag{3}$$

Where $f_{ax,W,i}$ is the mean withdrawal strength of a given configuration, $f_{ax,W(12)}$ is the mean withdrawal strength of the same configuration with 12% of moisture content, and N is the number of gaps.

Table 2 – Obtained values for k_W, depending on moisture content, gap width and number of gaps.

Moisture Range	**REF**	**GAP0**	**GAP4 FL/ML**	**GAP4 OL/3L**
8%-12%	1.000	1.000	- 0.024	- 0.048
12%-18%	0.018	0.017	0.016	1.000

4.3 - Applying $\eta\eta_{gap}$ and η_W to Uibel & Blaß Model

In order to evaluate the accuracy of defined η_{gap} and η_W, the Uibel & Blaß (2007) model was used (Eq. 4). Then, η_{gap} and η_W were applied to this model as shown in Eq. 5.

$$R_{ax,s,pred} = 0.44 \cdot d^{0.8} \cdot l_{ef}^{0.9} \cdot \rho^{0.75} \tag{4}$$

Where $R_{ax,s,pred}$ is the predicted value for withdrawal capacity of STS inserted in plane side of CLT, in Newton; d is nominal or outer diameter of the screw, in mm; l_{ef} is effective pointside penetration length, in mm; ρ is density of CLT (whole cross section), in kg/m³.

$$F_{ax,pred} = R_{ax,s,pred} \cdot \eta_{gap} \cdot \eta_W \tag{5}$$

Where $F_{ax,pred}$ is the predicted withdrawal strength, for STS inserted in the plane side of CLT, considering moisture content level, number of gaps present in screw path and width of gaps.

Fig. 8 shows the correlation between test results and predicted values for REF configuration considering different levels of moisture content. REF_8% and REF_12% present conservative predicted values, while REF_18% present predicted values predominantly higher than test results. Fig. 9 shows the correlation for GAP0 configurations, which is quite similar to correlation obtained for REF configuration. GAP0_18% presents predicted values predominantly higher than test results. In Fig. 10 it is possible to observe that results obtained for GAP4 configurations are on conservative side.

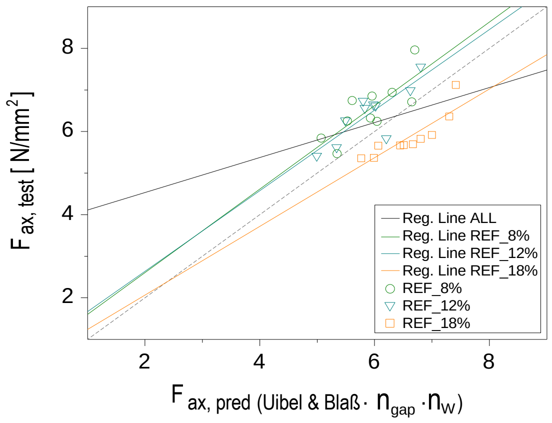

Fig. 8 – Correlation between test results and predicted values for REF configuration.

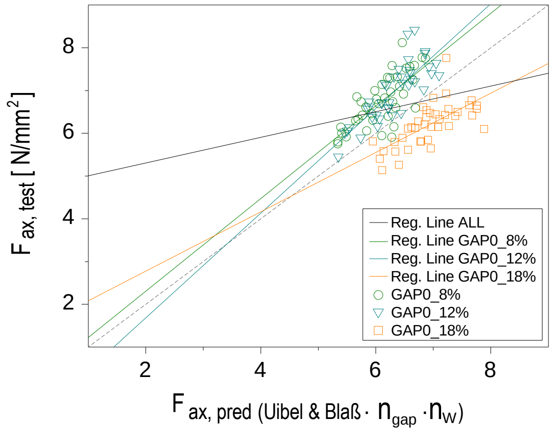

Fig. 9 – Correlation between test results and predicted values for GAP0 configurations.

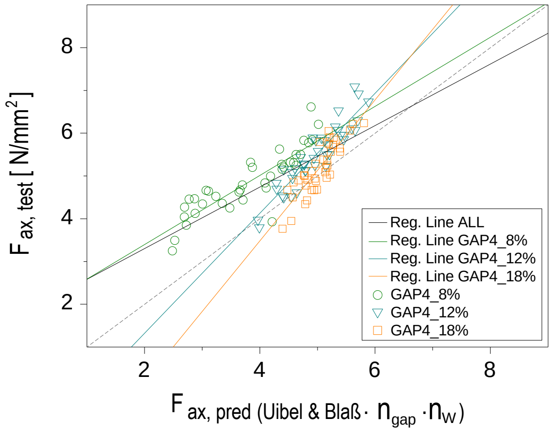

Fig. 10 – Correlation between test results and predicted values for GAP4 configurations.

5- CONCLUSIONS

In present paper, it was showed and discussed the results of a test program, which aimed to investigate the influence of moisture content variation and existence of gaps on the withdrawal behavior of axially loaded STS when inserted in the pane side of CLT panels. Moisture content covered a range between 8 % and 18 %, number of gaps present in the screw path varied from 0 to 3 and gap widths were of 0 and 4 mm.

First it was made a preliminary analysis of results, observing main differences between nine test configurations for all moisture content levels. Then, the influence of CLT moistening or drying (k_w) and the influence of number gaps (k_{gap}) on withdrawal strength f_{ax} were quantified, ending up in the suggestion of simple linear models. According to performed analysis some final remarks should be pointed out:

Regarding to moisture content influence, REF and GAP0 configurations express the tendency to keep f_{ax} constant when $8\ \% \leq w \leq 12\ \%$, while when $12\ \% \leq w \leq 18\ \%$ f_{ax} tends to decrease expressing a $k_w = 0.017$. Despite the similarity with the behavior observed for solid timber or GLT, it is important to say that k_w present a lower value for tests performed with CLT. This fact can be related with cross lamination of CLT, and further investigation is needed in this field.

Still regarding moisture effects, GAP4 configurations tend to invert this tendency gradually with the increase of number of gaps. This fact is directly related with shrinkage/swelling which causes the opening/closing of gaps.

Concerning the effect of gaps, surprisingly it was observed an increase of f_{ax} when number of GAP0 increases. There is the suspicion that it is related with internal stresses caused by cross lamination, but also for this matter further investigation is required before fix conclusions.

The correlation between test results and predicted values based on Uibel & Blaß (2007) model obtained reasonable results, with majority of predicted values located in conservative side. The exceptions were configurations REF_18% and GAP0_18%.

Beyond the suggestions for future research already mentioned, another topic to be developed is the influence of moisture content variations and gaps on withdrawal capacity of STS inserted in lateral side of CLT panels.

6- LITERATURE

Brandner, R (2013). Production and Technology of Cross Laminated Timber (CLT): A state-of-the-art Report. In R. Harris, A. Ringhofer, & G. Schickhofer (Eds.), COST Action FP1004, Focus STS – European Conference on Cross-Laminated Timber (CLT)(pp. 2–36). Graz, Austria: University of Bath.

EN 1382: EUROPEAN STANDARD. 1999 - Timber Structures - Test Methods - Withdrawal Capacity of Timber Fasteners.

EN 1995-1-1. EUROCODE 5. 2004. Design of timber structures. Part 1-1 : General – Common rules and rules for buildings.

ETA-12/0373. EUROPEAN TECHNICAL APPROVAL. 2012. Schmid screws rapid, stardrive and sp – Self-tapping screws for use in timber constructions. Österreichisches Institut für Bautechnik

Frese, M., & Blaß, H. J. 2009. Models for the calculation of the withdrawal capacity of self-tapping screws. Proceedings of International Council for Research and Innovation in Building and Construction. Duebendorf, Switzerland.

Grabner, M. 2013. Einflussparameter auf den Ausziehwiderstand selbstbohrender Holzschrauben in BSP-Schmalflächen, 148 p. Master Thesis, Graz University of Technology.

Gülzow, A., Richter, K., & Steiger, R. 2010. Influence of wood moisture content on bending and shear stiffness of cross laminated timber panels. European Journal of Wood and Wood Products, 69(2), 193–197. doi:10.1007/s00107-010-0416-z

Jönsson, J., & Thelandersson, S. 2003. The effect of moisture gradients on tensile strength perpendicular to grain in glulam. Holz Als Roh- Und Werkstoff, 61(5), 342–348. doi:10.1007/s00107-003-0405-6

Keunecke D., Sonderegger W., Pereteanu K., Lüthi T., Niemz P. 2007. Determination of Young's and shear moduli of common yew and Norway spruce by means of ultrasonic waves. Wood Science and Technology 41: 309-327.

Mårtensson A. 1992. Mechanical behaviour of wood exposed to humidity variations, 189 p. Ph.D. thesis. Lund Sweden: Lund Institute of Technology.

Muñoz, W., Mohammad, M., & Gagnon, S. 2010. Lateral and Withdrawal Resistance of typical CLT connections. Proceedings of World Conference on Timber Engineering. Riva del Garda, Italy.

Ranta-Maunus A. 2003. Effects of climate and climate variations on strength, Timber engineering. Chichester: John Wiley & Sons Incorporated.

Ringhofer, A., Grabner, M., Silva, C. V., & Branco, J. (2014). The influence of moisture content variation on the withdrawal capacity of self-tapping screws. Holztechnologie, 55(3), 33–40.

Uibel, T., & Blaß, H. J. 2007. Edge Joints with Dowel Type Fasteners in Cross Laminated Timber. Proceedings of International Council for Research and Innovation in Building and Construction. Bled, Slovenia.