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EXPERIMENTAL INVESTIGATION ON LONG-TERM BEHAVIOR OF TIMBER-TO-TIMBER SHEAR CONNECTIONS MADE BY INCLINED SELF-TAPPING SCREWS

Alessandra Gubana[1], Massimo Melotto[1], Luca De Cillia[1], Alessandro Mazelli[1]

ABSTRACT: Self-tapping screws are an interesting solution for timber-to-timber shear connections due to their performance, their economic advantages and their ease of use. The screws are preferably used inclined with respect to the shear flow direction, to improve the stiffness and the strength of the connection. The shear transfer mechanism is influenced also by the withdrawal capacity of the screw and by friction between timber elements.
These connections are useful for the bending reinforcement of existing timber floors, but the design of these composite-sections requires the knowledge of the connection behaviour. However, very few data are available on the long-term behaviour.
An experimental campaign to follow the connection behaviour during time has been performed. The results of a first group of twenty-four identic specimens were already presented. The last results of another group of sixty-three specimens are here reported. One half of the specimens was stored in a controlled environment, one half was stored in a not-controlled environment. Air temperature and humidity were regularly recorded. Push-out tests (as soon as built and after 6, 12 and 24 months) were performed and the main mechanical parameters of the connections as strength, stiffness and ductility at different ages are here compared.

KEYWORDS: Timber-to-Timber Shear Connections, Self-Tapping Screws, Long Term Behavior

1 INTRODUCTION

Self-tapping screws are nowadays commonly used for the connections and for the reinforcement of timber structural elements due to their performance, their economic advantages and their ease of use. This type of connection is largely applied for local reinforcement [1-5] and in timber-to-timber connections [6]. Besides, self-tapping screws are particularly useful for structural interventions on existing timber structures, reinforced by overlaying and joining timber or timber-based elements. The so created composite section is able to increase the bending strength and stiffness of the floor and to reduce vibrations under service loads. Examples of refurbishments of timber floors by means of timber-to-timber solutions are presented in [7-10]. Several studies in literature face the application of self-tapping screws to join together Cross Laminated panels [11,12], Cross Laminated panel and light frame timber structures [13] and to obtain timber-to-concrete composite sections [14]. The screws are preferably used inclined with respect to the shear flow direction as, in this case, the stiffness and the strength of the connection are strongly improved. The shear transfer mechanism is influenced also by the withdrawal capacity of the fastener and by the friction between the timber elements.

Several short-term tests have been performed [7-9, 15] and formulations have been proposed in literature to calculate the load-bearing capacity and the stiffness under shear/compression or shear/tension load [6, 14-17]. In addition, recent studies provide correlation approaches for Push-Out tests [18,19].
However, very few data are available on the long-term behavior [20], which can be influenced by timber moisture variation, shrinkage and creep.
An experimental campaign to follow the connection behavior during time has been performed. The results of a first group of twenty-four identic specimens were already presented [21]. Another group of sixty-three specimens were prepared in May 2020 to be tested, in clusters of nine. One half of the specimens was stored in a controlled environment, the other half was stored in a not-controlled environment, to simulate the real weathering. Air temperature and humidity were regularly recorded. Push-out tests (as soon as built, after 6 months, after 12 months and after 24 months) were performed and the experimental results are here presented. The main mechanical parameters of the connections as strength, stiffness and ductility at different ages are compared.

[1]DPIA Polytechnic Department of Engineering and Architecture, University of Udine (Italy).
alessandro.mazelli@uniud.it

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2 MATERIALS AND METHODOLOGY

The experimental campaign on the long-term behaviour of wood connections was conducted in the laboratory of the University of Udine (Italy), between May 2020 and May 2022.

Seven sets of nine specimens were built in May 2020. A first group was tested immediately. The others were left to age in the laboratory. Half of the specimens was stored in a controlled environment, the other in a non-controlled environment. Air temperature and humidity were recorded regularly for the non-controlled environment.

The mechanical behaviour of the connections at different aging times was characterized in terms of strength, stiffness and ductility with push-out tests.

2.1 TEST SPECIMENS

The specimens consist of one glued-laminated spruce timber element of strength class GL24h (EN 14080:2013 [22]), and two CLT elements symmetrically arranged (Figure 1). The connection is made by four VGZ 7X180 single-thread self-tapping screws. The screws are inclined at 45°, two for each side of the specimen, and they are subjected to shear-tension loading during the test.

The screws are inserted in order to have half of the thread length in the central element and half of the length in the lateral element. The central element has a cross-section of 160x160 mm, whereas the side elements 60x160 mm. The timber longitudinal grain is aligned with the loading direction.

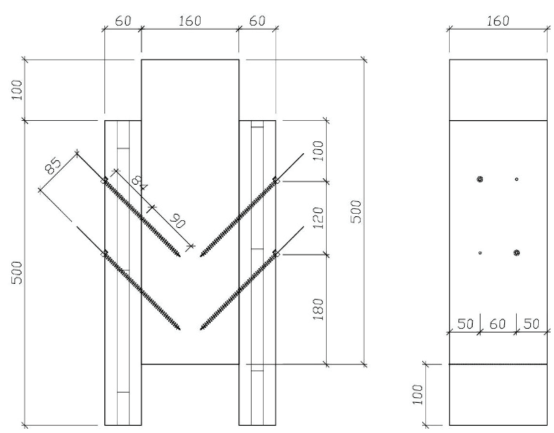

Figure 1: *Specimen geometry.*

The connections were realized by means of VGZ screws (Figure 2), which are characterized by a total thread, by a cylindrical head and by a pronounced cutter on the tip. The geometrical and mechanical properties were provided by the manufacturer and are reported in the relative European Technical Assessment ETA-11/0030 [23] and in Table 1, where $M_{y,k}$ is the characteristic yield moment, $f_{ax,k}$ is the characteristic extraction strength, $F_{tens,k}$ is the characteristic tensile strength and $f_{y,k}$ is the characteristic yield strength.

Seven groups of nine specimens each were built on the same day in May 2020.

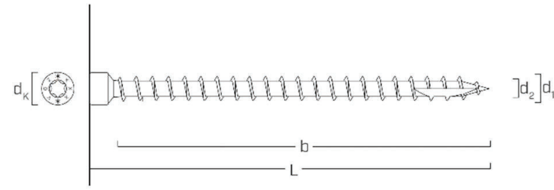

Figure 2: *Geometry of the VGZ 7x180 self-tapping screw.*

Table 1: *Geometrical and mechanical properties of the VGZ 7x180 self-tapping screw.*

Property	Symbol	Value
Length	L	180 mm
Nominal diameter	d_1	7 mm
Head diameter	d_k	9.5 mm
Tip diameter	d_2	4.6 mm
Characteristic yield moment	$M_{y,k}$	14174 Nmm
Characteristic extraction-resistance parameter	$f_{ax,k}$	11.7 MPa
Characteristic tensile strength	$F_{tens,k}$	15.4 kN
Characteristic yield strength	$f_{y,k}$	1000 MPa

All the specimens have the same configuration. A template was used to guarantee homogeneous geometrical characteristic and to correctly incline the screws on all the specimens. The timber elements were cut from different GL beams and CLT panels of the same supplies in order to reduce as much as possible the differences in terms of mechanical properties among the specimens. Every connection sample is identified by an acronym.

The first letter (from A to G) identifies the specimen group. Each group refers to a different age of testing, from 0 months (the test was performed in the same day when the specimens were built) to 24 months. The number (from 1 to 9) identifies the specimen in its group. The test groups are summarized in Table 2, where the time of testing T, the Controlled (C) or Non-Controlled (NC) environment (Env), average mass and average moisture content at time T are also reported.

Table 2: *Specimens description.*

Group	Time of testing T	Env	Avg. Mass at T [g]	Avg. Moisture content at T
A	0 months		9424	10.9
B	6 months	NC	9897	10.5
C	6 months	C	9466	10.8
D	12 months	NC	9560	10.2
E	12 months	C	9488	10.7
F	24 months	NC	9795	10.6
G	24 months	C	9407	9.9

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Environmental conditions were constantly monitored and recorded during the ageing of the NC groups specimens. A thermo-hygrometer FHT70 with datalogger was used to register air temperature and humidity every 15 minutes (accuracy ±1°C on temperature and ±2% on air humidity). The moisture content of the specimens was measured before each push-out test by averaging 5 measurements. The electronic moisture meter "Aqua-boy" by KPM (accuracy ±0.1%) was used.

The recorded air temperature and humidity are shown in Figure 3, where the test dates are also highlighted. It can be noted a period without record due to the second phase of the Covid19 pandemic, when the laboratory was not accessible.

On the other hand, the specimens of the controlled environment were stored in a separate room of the laboratory, in order to avoid wide fluctuations in temperature and humidity.

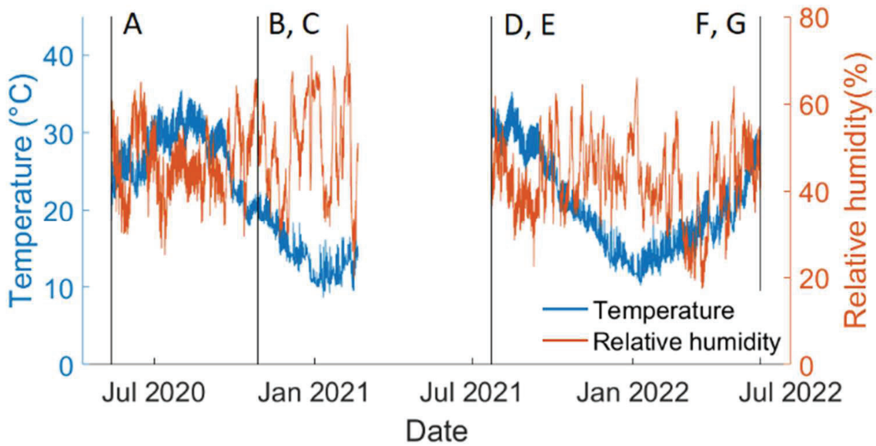

Figure 3: *Temperature (in blue) and relative humidity (in orange) during the test campaign.*

2.2 TEST SETUP AND PROCEDURE

The load-slip behaviour of the connections was obtained by push-out tests according to EN26891:1991 [17]. All the specimens are symmetric with respect to the loading plane and 4 screws are tested at time, 2 for each side of the specimen.

The test setup is shown in Figure 4.

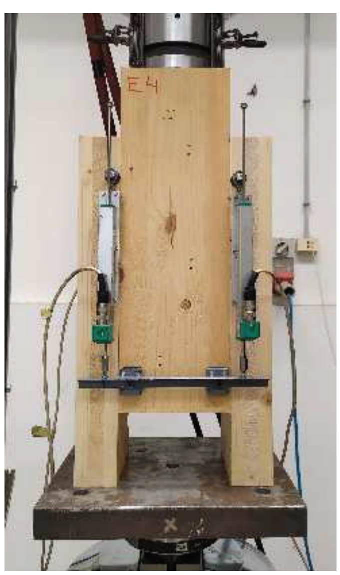

Figure 4: *Test setup.*

Load was applied in compression by a universal testing machine through a hydraulic actuator. During the test, the load was recorded by means of a load cell and the relative displacement was acquired by 4 transducers Gefran PY-150 (150 mm stroke, ±0.05% linearity). Two transducers were located on the front of the specimen and two on the back. The slip is then evaluated as the mean value of the four measures.

The load procedure according to EN 26981:1991 [17] is shown in Figure 5.

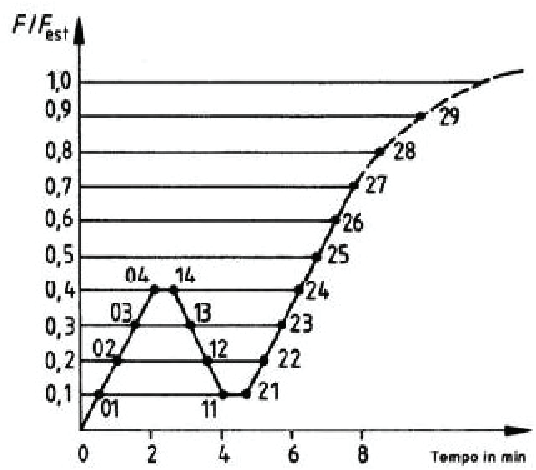

Figure 5: *Loading procedure according to EN 26981:1991 [17].*

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The load is applied up to a value of $0.4F_{est}$, where F_{est} is the expected resistance, and maintained for 30s. Then, the load is reduced to $0.1F_{est}$ and again increased up to $0.7F_{est}$. After the reaching of this value, the machine is set into displacement control (speed of 0.05 mm/s). The specimen is pushed up to the actual failure limit state, in order to evaluate the residual capacity also for high values of displacement. As prescribed, the collapse load or a slip of 15 mm is considered as ultimate condition.
The estimated load F_{est} was assumed after the first test, and then it was considered constant for all the specimens.

2.3 ESTIMATION OF THE MECHANICAL PARAMETERS

Stiffness, strength and ductility are evaluated for each connection according to EN12512:2006 [24].
The secant stiffness K is evaluated by means of equation (1):

$$K = \frac{0.4F'_{max} - 0.1F'_{max}}{s_{0.4} - s_{0.1}} \quad (1)$$

where F'_{max} is the actual maximum value when the corresponding slip is less than 15 mm, otherwise the load corresponding to a 15 mm slip is chosen, and $s_{0.4}$ and $s_{0.1}$ are the slip of the connection corresponding to loads equal to $0.4F'_{max}$ and $0.1F'_{max}$ respectively.
The ductility of the connection μ is defined in equation (2):

$$\mu = \frac{s_u}{s_y} \quad (2)$$

where s_u and s_y are the ultimate slip and the slip at the yield point respectively.
The ultimate slip corresponds to $0.80F'_{max}$. According to [24], when the curve does not have two well-defined linear parts, yield value is determined by the intersection of the following two lines: the first is the line drawn between points $0.4\ F'_{max}$ and $0.1\ F'_{max}$ of the curve, the second is the tangent line with an inclination of ⅙K. (Figure 6).

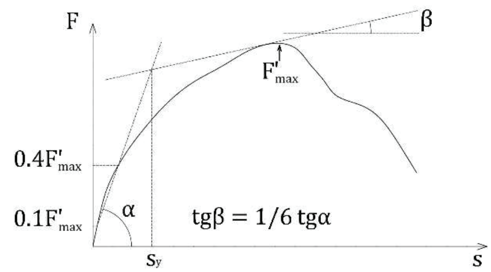

Figure 6: *Evaluation of the yield slip s_y according to EN 12512:2006 [24].*

3 EXPERIMENTAL RESULTS AND DISCUSSION

Figure 7 shows a few specimens at the end of the push-out test. Most of them gave evidence of a ductile rupture mode, consisting in the occurrence of two plastic hinges in the screws. In several samples, at the ultimate condition, screw head penetration was observed, in some cases the tip withdrawal took place.
The specimen experimental results for each group are shown in Figure 8, where the load-displacement relationships are illustrated. The reported load is the one on a single screw (i.e. the total measured load divided by 4). The slip is the average reading of the 4 transducers.
The results are generally dispersed. The dispersion is lower in groups A, D and G. It is worth noticing that specimen B2, D2 and G4 were damaged and the results are not shown.
Maximum load F_{max}, secant stiffness K and ductility μ are evaluated for each specimen with the procedure previously described. Average value (Avg) and coefficient of variation (CoV) are reported in Table 3.

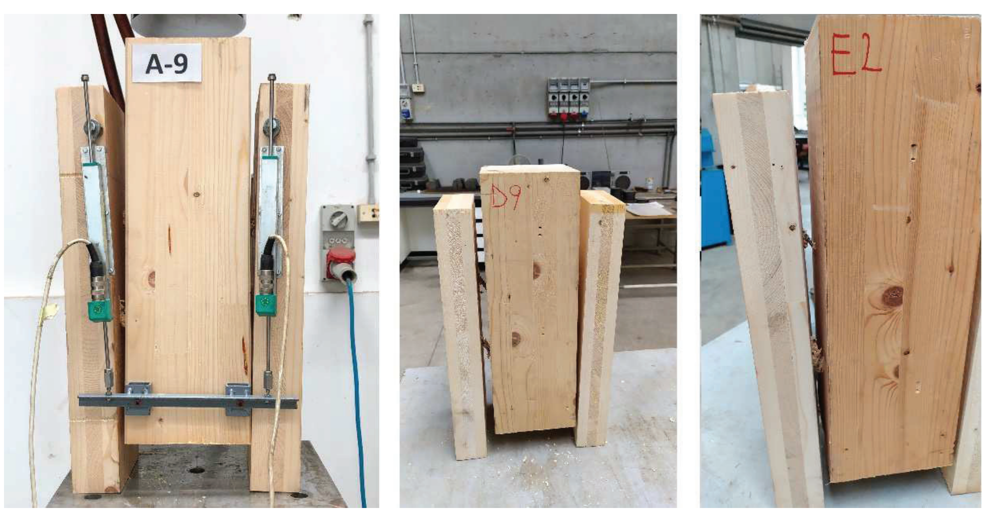

Figure 7: *Specimens of different groups after the tests.*

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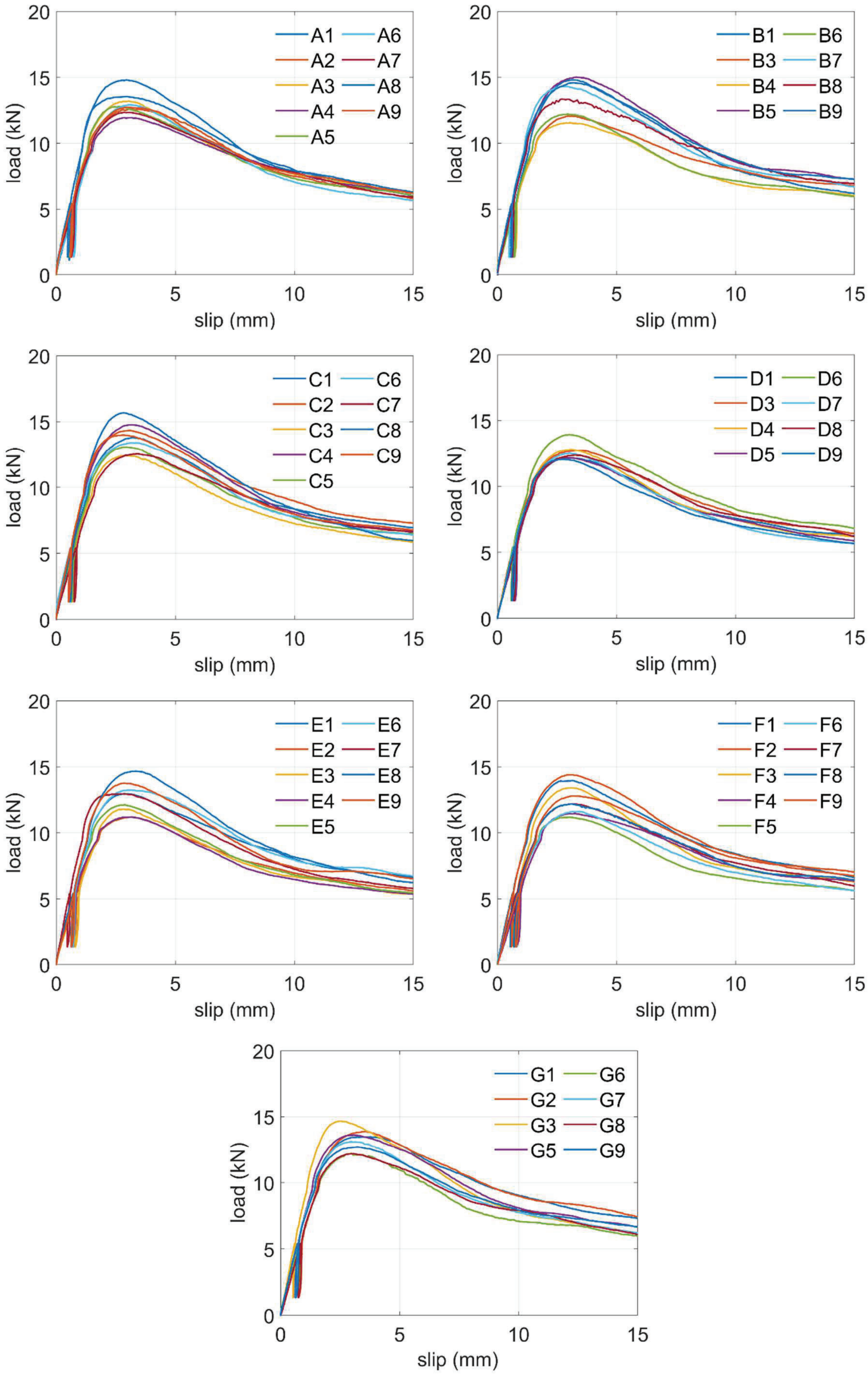

Figure 8: *Load-slip experimental curves for each specimen of the 7 tested groups.*

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Table 3: Summary of the test results. (NC: Non-Controlled environment, C: Controlled environment).

Group	Environment	Time of testing	Secant Stiffness K		Maximum Load F_{max}		Ductility μ	
			Avg [kN/mm]	CoV	Avg [kN]	CoV	Avg [-]	CoV
A	-	0 months	7.21	8.9%	12.99	6.0%	4.06	11.9%
B	NC	6 months	7.24	10.4%	13.49	9.6%	4.06	10.3%
C	C	6 months	7.28	7.2%	13.77	7.3%	3.86	9.0%
D	NC	12 months	7.37	7.5%	12.59	4.5%	4.24	9.4%
E	C	12 months	7.06	13.2%	12.66	8.8%	3.91	12.9%
F	NC	24 months	6.87	9.7%	12.58	8.5%	4.04	6.9%
G	C	24 months	7.18	12.2%	13.22	6.1%	3.98	9.7%

For an overall view of the results, all the curves are reported together in Figure 9, where the unload-reload branches were removed to improve the clarity of the chart. The results highlight a difference of 7% between the maximum and the minimum value of the secant stiffness, which reached a minimum after 24 months (6.87 kN/mm). The maximum force reached a peak value after 6 months, both in the controlled and in the non-controlled environment (maximum load increased by 6%). The results highlighted a slight decrease of F_{max} after 12 and 24 months.
Ductility showed variation for specimens of the same age but stored in different environments (difference of 5% between groups B and C, 8% between groups D and E, 1% between groups F and G). The ductility values calculated in the controlled environment are always lower than the starting ductility value of group A (ductility decreased by 5%).

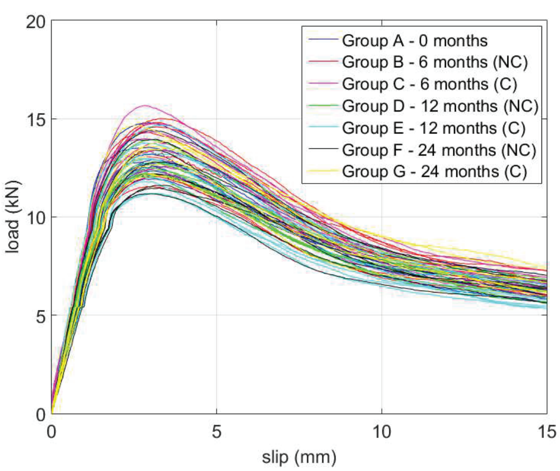

Figure 9: *Load-slip curves of the 7 tested groups. (NC: Non-Controlled environment, C: Controlled environment).*

4 CONCLUSIONS

An experimental campaign to study the self-tapping screw timber-to-timber connection during time was performed at University of Udine between 2020 and 2022. Samples of different ages were tested by a push-out procedure. The tests were performed for specimens as soon as built and after 6, 12 and 24 months. Half of the specimens was stored in a controlled environment, the other in a non-controlled environment. Air temperature and humidity were recorded regularly for the non-controlled environment.
The mechanical parameters of the connections were calculated after each test. In this paper, the results in term of secant stiffness, maximum force and ductility were compared. The trend now seems to signal only a slight variation of the mechanical characteristics over time. A minimum value of the secant stiffness was reached after 24 months and a peak in term of maximum strength was found after 6 months. Besides, the results showed a decrease in ductility for samples stored in a controlled environment compared to those in the non-controlled environment.
In the following post-processing phase of the data, it will be necessary to highlight the influence of the environmental humidity and the consequent variation of wood moisture content on the mechanical characteristics of the connections.

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REFERENCES

[1] Blaß H.J., Bejtka I., Aicher, S., and Reinhardt, H.W.: Screws with continuous threads in timber connections. In: Proceedings of International RILEM Symposium on Joints in Timber Structures, Stuttgart, Germany, pp. 193-201, 2001.

[2] Blaß H.J., Bejtka I.: Reinforcements perpendicular to the grain using self-tapping screws. In: Proceedings of WCTE 2004, Lahiti, Finland, 2004.

[3] Bejtka I., Blaß H.J.: Self-tapping screws as reinforcements in connections with dowel-type fasteners. In: Proceedings of the CIB-W18/38 Meeting, Karlsruhe, Germany, Vol. 38, p. 20, 2005.

https://doi.org/10.52202/069179-0080

[4] Bejtka I., Blaß H.J.: Self-tapping screws as reinforcements in beam supports. CIB-W18/39 Meeting, Florence, Italy, 2006.
[5] Dietsch P., Brandner R.: Self-tapping screws and threaded rods as reinforcement for structural timber elements. A state-of-the-art report. Construction and Building Materials, 97, pp. 78-89, 2015. doi:10.1016/j.conbuildmat.2015.04.028
[6] Tomasi R., Crosatti A. and Piazza M.: Theoretical and experimental analysis of timber-to-timber joints connected with inclined screws. Construction and Building Materials, 24(9), pp.1560-1571, 2010.
[7] Giongo I., Piazza M. and Tomasi R.: Out of plane refurbishment techniques of existing timber floors by means of timber to timber composite structures. In: Proceedings of WCTE 2012, Auckland, New Zealand, 2012.
[8] Riggio M, Tomasi R. and Piazza M.: Refurbishment of a Traditional Timber Floor with a Reversible Technique: Importance of the Investigation Campaign for Design and Control of the Intervention. International Journal of Architectural Heritage, 8:1, 74-93, 2014. doi:10.1080/15583058.2012.670364
[9] Roensmaens B., Van Parys L., Carpentier O. and Descamps T.: Refurbishment of existing timber floors with screwed CLT panels. International Journal of Architectural Heritage, 12 (4), pp. 622-631, 2018. doi: 10.1080/15583058.2018.1442522
[10] Gubana A., Melotto M.: Experimental tests on wood-based in-plane strengthening solutions for the seismic retrofit of traditional timber floors. Construction and Building Materials, 191, pp. 290-299, 2018. doi:10.1016/j.conbuildmat.2018.09.177
[11] Hossain A., Danzig I. and Tannert T.: Cross-laminated timber shear connections with double-angled self-tapping screw assemblies. Journal of Structural Engineering, ASCE, 142(11), 2016. doi: 10.1061/(ASCE)ST.1943-541X.0001572
[12] Brown J.R., Li M.,Tannert T., Moroder D.: Experimental study on orthogonal joints in cross-laminated timber with self-tapping screws installed with mixed angles. Engineering Structures, 228, 111560, 2021. doi: https://doi.org/10.1016/j.engstruct.2020.111560
[13] Eini A., Zhou L., Ni C.: Behavior of Self-Tapping Screws Used in Hybrid Light Wood Frame Structures Connected to a CLT Core. Buildings, 12, 1018, 2022. doi: https://doi.org/10.3390/buildings12071018
[14] Marchi L., Scotta R. and Pozza L.: Experimental and theoretical evaluation of TCC connections with inclined self-tapping screws. Materials and Structures, 50 (3), 2017. doi:10.1617/s11527-017-1047-1
[15] Schiro G., Giongo I., Sebastian W., Riccadonna D. and Piazza M.: Testing of timber-to-timber screw-connections in hybrid configurations. Construction and Building Materials, 171, pp. 170-186, 2018. doi: 10.1016/j.conbuildmat.2018.03.07
[16] Bejtka I. and Blaß H.J.: Joints with inclined screws. In: Proceedings of the CIB-W18/35 Meeting, Kyoto, Japan, 2002.
[17] EN 26891:1991. Timber structures. Joints made with mechanical fasteners. General principles for the determination of strength and deformation characteristics.
[18] Bedon C., Sciomenta M., Fragiacomo M.: Mechanical Characterization of Timber-to-Timber Composite (TTC) Joints with selftapping Screws in a Standard Push-Out Setup. Applied Sciences, 10, 6534, 2020. doi:10.3390/app10186534
[19] Bedon C., Sciomenta M., Fragiacomo M.: Correlation approach for the Push-Out and full-size bending short-term performances of timber-to-timber slabs with Self-Tapping Screws. Engineering Structures, 238, 112232, 2021. doi: https://doi.org/10.1016/j.engstruct.2021.112232
[20] Giongo I., Schiro G., Piazza M. and Tomasi R.: Long-term out-of-plane testing of timber floors strengthened with innovative timber-to-timber solutions. In: Proceedings of WCTE 2016 - World Conference on Timber Engineering, 2016.
[21] Gubana A., Melotto M., and De Cillia L.; Long Term behavior of Timber-to-Timber Shear Connections made by inclined Self-tapping Screws. In: Proceedings of the International Conference on Structural Health Assessment of Timber Structures, SHATiS'2019 25-27 September 2019, Guimarães Portugal, 457-466, 2019.
[22] EN 14080:2013. Timber structures. Glued laminated timber and glued solid timber. Requirements.
[23] ETA European Technical Approval 11/0030: RothoBlaas self-tapping screws.
[24] EN 12512:2006. Timber structures. Test methods. Cyclic testing of joints made with mechanical fasteners.