World Conference on
Timber Engineering
Oslo 2023

PUSH-OUT TESTS ON CONNECTIONS FOR DEMOUNTABLE AND REUSABLE STEEL-TIMBER COMPOSITE BEAM AND FLOORING SYSTEMS

Alfredo Romero[1], Jie Yang[2], François Hanus[3], Hervé Degée[4], Christoph Odenbreit[5]

ABSTRACT: Engineered timber panels made of laminated veneer lumber (LVL) can represent an alternative to concrete in a typical steel-concrete composite beam and the entire flooring system. The performance of LVL in strength reaches values, which are comparable to concrete. In addition, and according to policies to reduce greenhouse gas emissions and resources depletion (e.g. the European Commission´s Green Deal) the construction sector demands more and more circularity in construction. On that basis, the research project "Prefa-SeTi" (FNR Grant 15695062) investigates the load bearing- and displacement behaviour of steel-timber composite beams and especially the shear connection between the steel and timber. The work pursues a development, which was started within the European REDUCE project (RFCS GA 710040), which investigated solutions for composite structures in steel and concrete, and the demo project "Petite Maison" of Esch2022 the European Capital of Culture. In "Prefa-SeTi", nine push-out specimens were tested to investigate three newly developed shear connections. To comply with circularity, the connections are dismountable and robust enough to protect the structural elements from damage at serviceability limit state. This paper presents the demountable timber connectors and results of the push-out tests. Along with the results and the respective discussions, the paper outlines the tested mechanical properties of the LVL, the push-out test setup, and the testing procedure.

KEYWORDS: Shear connection, push-out test, steel-timber composite, demountable, reuse, circular economy, LVL

1 INTRODUCTION

Timber is a renewable material with strength properties which are comparable to concrete. Therefore, engineered timber products such as LVL can represent an alternative to concrete in steel-concrete composite beam and flooring systems. In addition, timber is ideal for prefabrication, fast erection, and deconstruction.

The policies targeting carbon neutrality and minimization of resources depletion such as the European Commission's Green Deal and the United Nation's Sustainable Development Goals are pursuing a transition towards a circular economy. The construction sector is not an exception to this; consequently, the sector demands more circular solutions.

Currently, most design and construction procedures are not well suited for deconstruction and reuse of the structural components. To cope with this issue, recent studies, such as the REDUCE project [1] have developed demountable and reusable solutions for steel-composite structures [2]. The research project "Prefa-SeTi" (FNR Grant 15695062) pursues a development, which started within the European REDUCE project (RFCS GA 710040) [1]. This project investigates the load bearing- and displacement behaviour of steel-timber composite beams and especially the shear connection between the steel and timber.

In composite structures, the shear connection is a key element which transfers shear forces between the components to achieve effective composite action. The existing steel-to-timber connections (e.g. screws, bolts, C-type connectors, adhesives, and their combination) have setbacks when the target is deconstruction and reuse of the components of steel-timber composite flooring systems. Therefore, within the framework of "Prefa-SeTi" three demountable shear connectors were developed and their load-slip response were investigated through push-out tests. Along with the results and the respective discussions of the tests, this paper outlines the tested mechanical properties of the LVL, the components of the demountable shear connections, the push-out test setup, and the testing procedure.

2 LAMINATED VENEER LUMBER (LVL)

LVL is made of veneers with a thickness of 3mm, bonded together with weather-resistant phenolic adhesive (see

---

[1] Alfredo Romero, ArcelorMittal Chair of Steel Construction at the University of Luxembourg, Luxembourg, alfredo.romero@uni.lu

[2] Jie Yang, ArcelorMittal Chair of Steel Construction at the University of Luxembourg, Luxembourg, jie.yang@uni.lu

[3] François Hanus, ArcelorMittal Steligence®, Luxembourg, francois.hanus@arcelormittal.com

[4] Hervé Degée, Hasselt University, Belgium, herve.degee@uhasselt.be

[5] Christoph Odenbreit, ArcelorMittal Chair of Steel Construction at the University of Luxembourg, Luxembourg, christoph.odenbreit@uni.lu

https://doi.org/10.52202/069179-0464

Figure 1). The dimensions of the final LVL product are not limited by the dimensions of the raw material, and small-diameter logs can be used to produce large LVL members. When veneer logs are peeled to produce veneer, any natural defects in the wood, such as knots, are dispersed. This together with the lamination effect, significantly reduces the impact of defects and results in homogeneous properties. Thus, the variance on the properties is smaller, this translates in a smaller partial safety factor for design calculations, and therefore, higher design strength values compared to other timber products such as cross laminated veneer lumber (CLT).

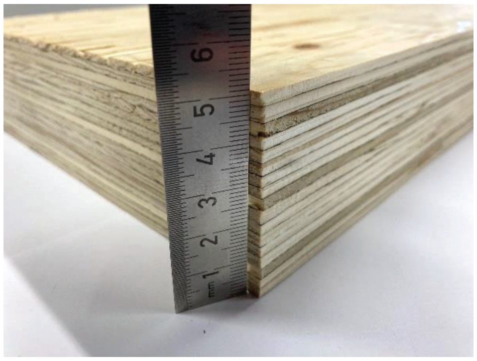


Figure 1: *Laminated veneer lumber (LVL).*

There are two main types of LVL products depending on the veneer layup: LVL with all veneers oriented in the same direction (e.g. LVL-P) and LVL with approximately 20% of veneers oriented crosswise at 90° with respect to the grain direction (e.g. LVL-C).

The mean and characteristic values of some mechanical properties of the LVL products commonly used for structural design are given by the LVL manufacturers. However, the reports of the tested mechanical properties and the respective stress-strain and load-deformation curves are hardly available. Berschoten [3] reported mechanical properties of LVL made of New Zeeland's Radiata pine and Chybinski et al. [4] reported some mechanical properties of European LVL-P panels.

To the knowledge of the authors there are no references dealing with the mechanical characterisation of LVL panels made of Scandinavian spruce wood with crossbanded veneers. Therefore, in this contribution we present mechanical properties obtained in tests of Kerto-Q panels (i.e. crossbanded LVL-C). The tests were done according to the European standards EN 408 [5] and EN 789 [6].

Wood is an anisotropic material but for engineering purposes it is considered as orthotropic. Hence, in the material testing campaign conducted within the framework of this research project, the orthogonal directions were defined as shown in Figure 2.

The mean strength values as well as elasticity modulus in the three orthogonal directions are presented in Table 1 for compression and tension. The mean stress-strain curves are shown in Figure 3 for compression and tension.

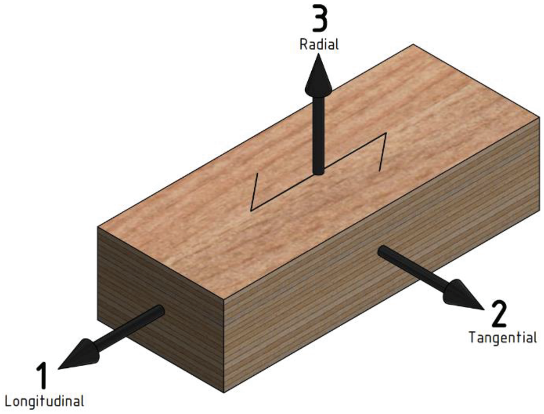


Figure 2: *Orthogonal directions of the LVL.*

Table 1: *Mean strength values and elasticity modulus of LVL made of spruce wood (Kerto-Q)*

Strength		Modulus of elasticity	
Symbol	Value [MPa]	Symbol	Value [MPa]
$f_{c,1}$	40.41	$E_{c,1}$	7 917.08
$f_{c,2}$	11.14	$E_{c,2}$	1 764.47
$f_{c,3}$	3.99	$E_{c,3}$	95.49
$f_{t,1}$	37.76	$E_{t,1}$	10 680.01
$f_{t,2}$	8.33	$E_{t,2}$	2 199.90
$f_{t,3}$	0.56	$E_{t,3}$	92.05

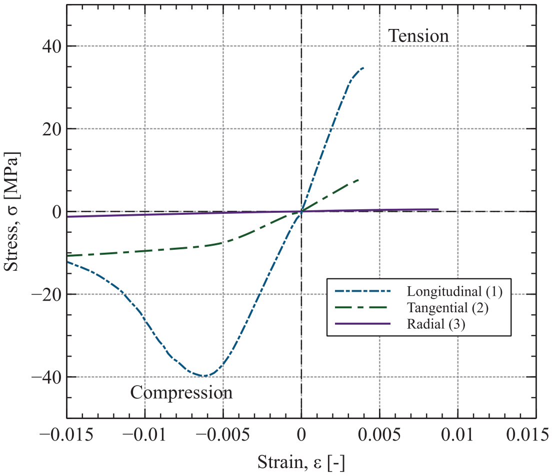


Figure 3: *Mean stress-strain curves of LVL for uniaxial tension and compression in the three orthogonal directions.*

These tests show that the strength of LVL in compression in the direction of the grain (i.e. $f_{c,1} = 41.03\,MPa$) reaches values which are comparable to concrete. Therefore, this material could represent an alternative to concrete in steel-composite beams and flooring systems.

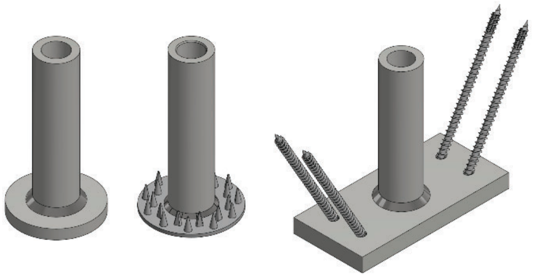
3 THE DEVELOPED DEMOUNTABLE SHEAR CONNECTORS

Steel-to-timber connections with screws and bolts alone or in combination with C-type connectors and/or glue allow for deconstruction of STC structures. However, the drilling effect of screws and the preloading of high-strength bolts lead to damages in the timber elements which hinders the reusability of the structural components. Hence, alternative shear connectors are needed to develop structural solutions complying the principles of circular economy.

The three connections presented in this paper were developed to comply circularity and are robust enough, to protect the structural elements from damage at serviceability limit state (SLS).

The three demountable connections were denominated as follows: <u>S</u>hear <u>C</u>onnection -<u>T</u>ype <u>1</u> (SCT-1), -<u>T</u>ype <u>2</u> (SCT-2), and -<u>T</u>ype <u>3</u> (SCT-3).

These connections consist of a part embedded in the timber, the “shear connection device” (see Figure 4), and removable parts (i.e. bolt, washers, nut). The shear connection device consists of a steel-tube (S460) fitting the drilled hole in timber, at the steel-timber interface the connection is reinforced by steel elements welded to the tube: (i) a round steel plate (S460), (ii) a geka connector or (iii) a rectangular steel plate (S460) with four inclined screws, respectively for each connection type (see Figure 4). The details of the connections are shown in Figure 5 to Figure 8.



SCT-1 SCT-2 SCT-3

Figure 4: *Shear connection devices developed in Prefa-SeTi project.*

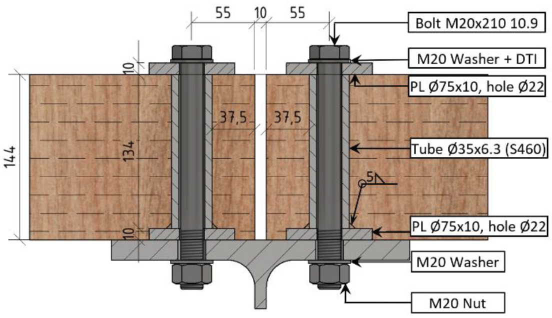


Figure 5: *Details of shear connection type 1 (SCT-1).*

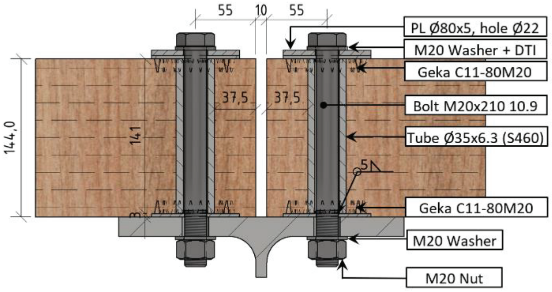


Figure 6: *Details of shear connection type 2 (SCT-2).*

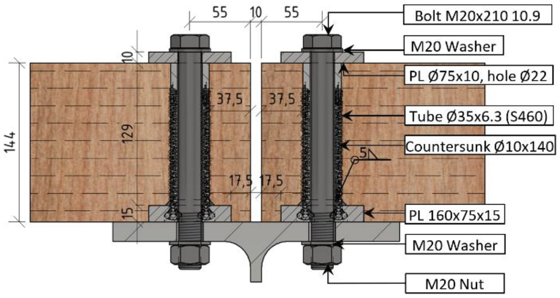


Figure 7: *Details of shear connection type 3 (SCT-3), transversal cut.*

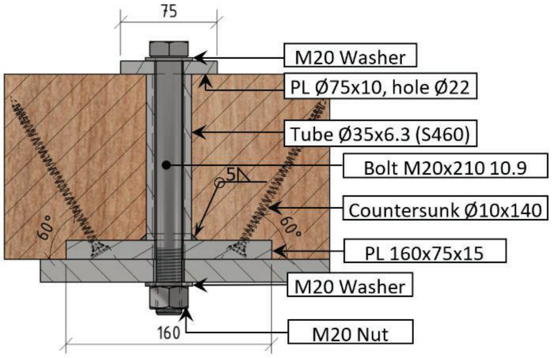


Figure 8: *Details of shear connection type 3 (SCT-3), longitudinal cut.*

The steel tube reinforces the hole, increases the surface in which the forces are transferred to the timber, and allows to achieve the preload of the high-strength bolts while preventing crushing of the timber.

4 EXPERIMENTAL PUSH-OUT TESTS

4.1 TEST SERIES

The load-slip behaviour of the connections was investigated through a series of push-out tests. Three identical specimens of each connection were tested. Therefore, in total 9 push-out tests were performed in this testing campaign. A summary of the test series is presented in Table 2.

https://doi.org/10.52202/069179-0464

Table 2: *Mean strength values and elasticity modulus of LVL made of spruce wood (Kerto-Q)*

Test series	Connection	Test IDs	Specimen IDs
Push-out test series 1	Type 1 (SCT-1)	POT1	POT1-1 POT1-2 POT1-3
Push-out test series 2	Type 2 (SCT-2)	POT2	POT2-1 POT2-2 POT2-3
Push-out test series 3	Type 3 (SCT-3)	POT3	POT3-1 POT3-2 POT3-3

4.2 SPECIMEN DETAILS

The connections were installed and tested in Kerto-Q LVL (LVL-C) plates made of spruce wood with dimensions of 650x300x144mm. The grain direction of the plates was aligned with the load direction.

The steel profile used in the setup was a standard European section HEB 260 (S355) with a length of 700mm.

The connections were installed symmetrically in both flanges of the beam. In total, 8 shear connectors were installed in each specimen, 4 connectors in each flange of the steel beam arranged in two rows. The spacing between the two rows of connectors was 250mm.

Partially threaded bolts M20x210 grade 10.9 were implemented in the connections. These bolts were preloaded at 70% of their ultimate tensile strength. This preload was achieved using a calibrated torque wrench plus a certain nut rotation. In addition, direct tension indicators (DTI) were used to ensure the minimum preload was reached.

The specimen details and dimensions are shown in Figure 9 and Figure 10.

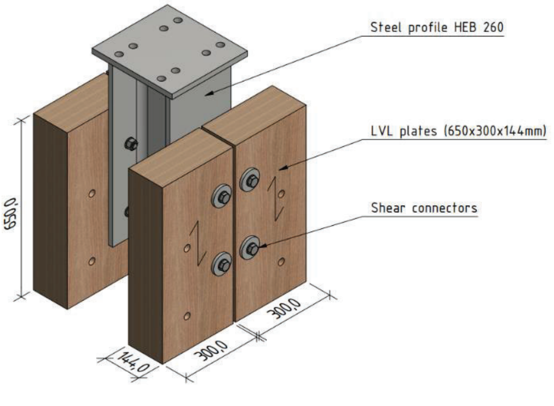


Figure 9: *Main components and dimensions of the push-out test specimens.*

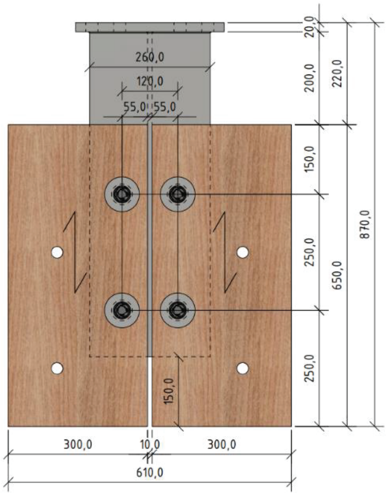


Figure 10: *Dimensions of the push-out test specimens.*

4.3 TEST SETUP

The specimen was placed on a thick steel block covered by neoprene strips (see Figure 11 and Figure 12). Steel L-profiles fixed with threaded rods were used to prevent the opening of the gap between the timber plates in the bottom of the specimen and a steel plate was used on the top to prevent the closing of the gap. Similar L-profiles were placed in the parallel faces of the timber plates to prevent the parts from falling apart once the connection was lost. In this case, a gap of 3 mm between the timber plates and the L-profiles was left to allow detaching of the timber from the steel beam.

Linear Variable Differential Transformer (LVDT) sensors were installed to measure the relative displacements between the steel beam and the timber plates in the direction of the load (measuring the slip) and perpendicular to the load (measuring the timber plates detachment from the beam flanges). Figure 11 and Figure 12 show the push-out test setup.

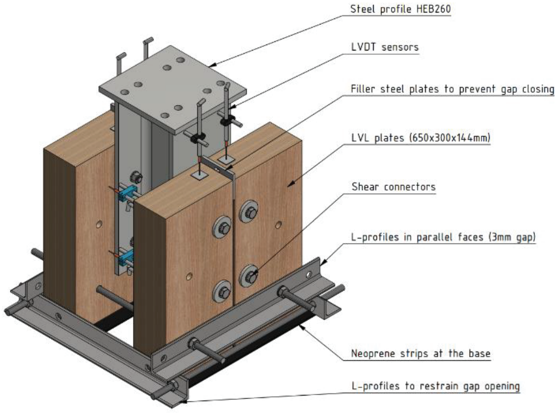


Figure 11: *Components of the test setup.*

https://doi.org/10.52202/069179-0464

Figure 12: Push-out test setup.

4.4 LOADING PROCEDURE

To define the loading procedure a maximum load of 1200kN was considered. This loading procedure consists of an initial load to reach 40% of the maximum estimated load (480 kN) and then 25 cycles between 5% (60 kN) and 40% (480 kN) of the expected maximum load (1200 kN) at a frequency of 1 cycle per minute. Subsequent loading and unloading steps were carried out. For two of the specimens of each series the load was stopped when the failure of the connection or the maximum displacement was reached, for the remaining specimen the load was stopped at a displacement of about 40mm.

The initial loading/unloading steps along with the 25 cycles were performed in force control mode, the subsequent loading/unloading steps were carried out in displacement control mode. Figure 13 shows the time history of the loading procedure.

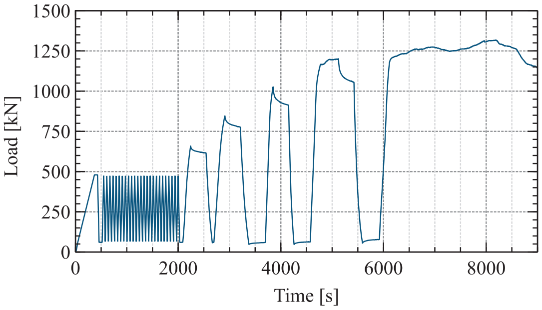


Figure 13: Time history of the loading sequence.

5 RESULTS AND COMPARISSON

5.1 RESULTS

The load slip curves of the three push-out test series are shown in Figure 14 to Figure 19.

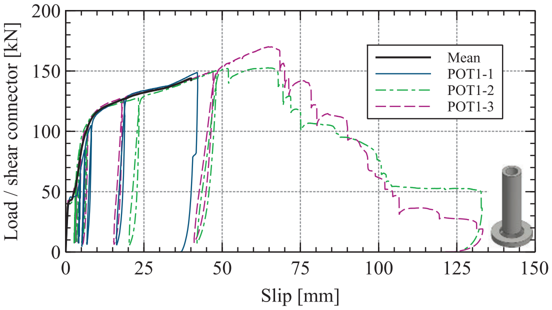


Figure 14: Load-slip curves up to 150mm slip of push-out tests series 1 (POT1) of shear connection type 1 (SCT-1).

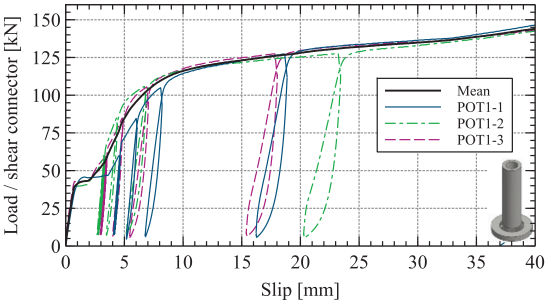


Figure 15: Load-slip curves up to 40mm slip of push-out tests series 1 (POT1) of shear connection type 1 (SCT-1).

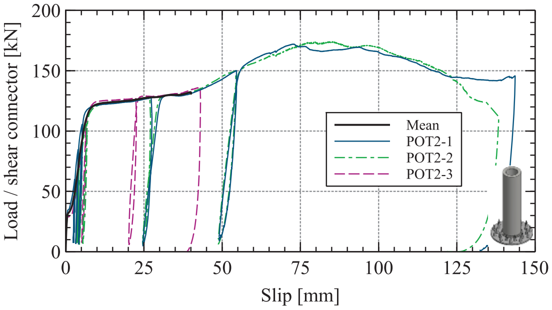


Figure 16: Load-slip curves up to 150mm slip of push-out tests series 2 (POT2) of shear connection type 2 (SCT-2).

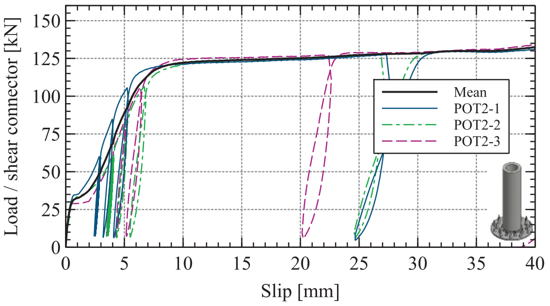


Figure 17: Load-slip curves up to 40mm slip of push-out tests series 2 (POT2) of shear connection type 2 (SCT-2).

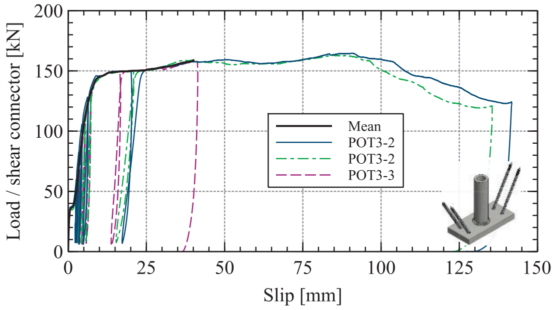


Figure 18: Load-slip curves up to 150mm slip of push-out tests series 3 (POT3) of shear connection type 3 (SCT-3).

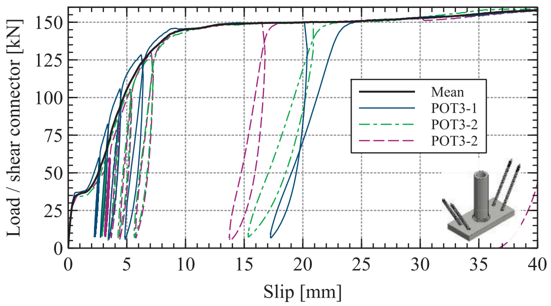


Figure 19: Load-slip curves up to 40mm slip of push-out tests series 3 (POT3) of shear connection type 3 (SCT-3).

The three connections showed large deformation capacity. The load-slip behaviour and the stiffness of the connections is different in terms of magnitude for each connection type. However, the three connections follow a similar pattern in their load slip behaviour.

Due to the preload of the bolts, the three connections have an initial slip capacity, when this slip capacity is reached, there is a slip of about 2-4mm with no increase in load because the bolt moves within the hole until there is contact between the bolt and both the flange of the beam and the inner surface of the connection device. After contact, there is bearing and shear in the bolt and then, there is embedment of the connection device in the timber plate.

Figure 20 is a longitudinal cutting of SCT-1, this figure illustrates the typical deformed shape observed in the three shear connection types. The veneers closer to the steel-timber interface crushed and one plastic hinge appeared in the connectors.

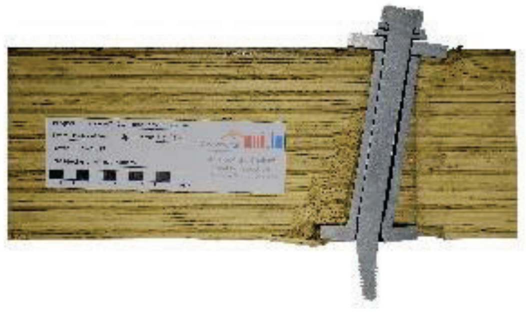


Figure 20: Longitudinal cutting of SCT-1 showing the deformed shape after the test.

5.2 COMPARISSON

SCT-1 and SCT-2 exhibited similar behaviour in the initial loading stages, whereas the SCT-3 showed higher stiffness. However, higher peak loads were reached with SCT-2. In addition, only in some specimens of SCT-1 the bolts failed, in SCT-2 and SCT-3 the tests were stopped because the maximum possible deformation (about 140mm) of the test setup was reached.

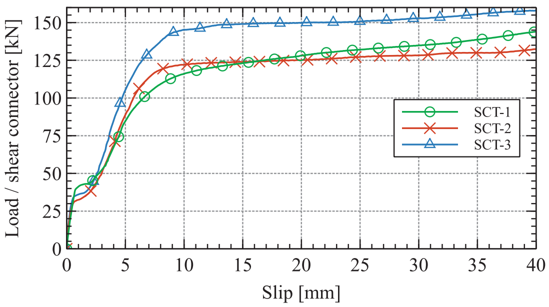


Figure 21: Comparison of the mean load-slip curves of the three shear connections.

6 CONCLUSIONS

The main conclusions of this contribution are the following:

- The three newly developed connections are capable of withstanding significant deformations and can bear loads of comparable magnitude. To illustrate, at a 6mm slip, SCT-1, SCT-2, and SCT-3 had average loads of 96kN, 104kN, and 120kN, respectively.
- The connections presented in this paper comply with the principles of circular economy.
- The novel connections, unlike existing steel-to-timber connections allow to reach the required preload for high strength bolts while preventing premature damages in timber due to crushing of the timber in the radial direction. Meaning the slip resistance can be activated.
- The use of crossbanded LVL prevented the occurrence of splitting failure. This demonstrates one of the benefits of using this type of LVL compared to non-crossbanded LVL and other timber materials which are known to be susceptible to this type of failure, as shown by other researchers in similar tests [7,8].
- The behaviour of the connections is non-linear, it is characterized by (i) an initial stiff response until the slip resistance given by the bolt preload is overcome, (ii) when the slip resistance is overcome, there is sliding friction, which results in a small displacement of about 2-4mm with no increase in the load until contact bearing between the bolt and both the steel flange and the connection device starts, (iii) then there is bearing and shear in the bolt and embedment of the connection device in the timber, which produce a monotonic increasing branch in the load-slip curve.
- Further studies will be useful to determine the influence of certain parameters such as the thickness of the timber plates, bolt size and grade, size of bottom steel plate, connectors arrangement, etc.

https://doi.org/10.52202/069179-0464

ACKNOWLEDGEMENT

The authors gratefully acknowledge Prefalux, ArcelorMittal and MetsäWood for their support in this research project; and the Luxembourg's National Research Fund (FNR) for its support through the PhD Industrial Fellowship Grant No. 15695062. The authors wish to thank also the laboratory team (Gilbert Klein, Marc Seil and Ed Weyer) and the former student Melis Pelivani for their support in this testing campaign.

REFERENCES

[1] M. Sansom, A. Girao Coelho, R. Lawson, and et. al.: Reuse and demountability using steel structures and the circular economy (REDUCE). Final Report, Project No. 710040, European Commission, Directorate-General for Research and Innovation, Brussels, Belgium, 2020.

[2] I. Jakovljević, M. Spremić, and Z. Marković: Demountable composite steel-concrete floors: A state-of-the-art review. Gradjevinar, vol. 73, no. 3. 2021, doi: 10.14256/JCE.2932.2020.

[3] W.A. Beerschoten: Structural Performance of Post-tensioned Timber Frames under Gravity Loading. PhD Thesis, University of Canterbury, 2013.

[4] M. Chybinski: Experimental and numerical investigations of laminated veneer lumber panels. Archives of Civil Engineering, Vol. 67, pages 351-372, 2021, doi: 10.24425/ace.2021.138060

[5] CEN, EN 408:2010+A1:2012: Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties, European Committee for Standardization (CEN), 2012.

[6] CEN, EN 789:2004: Timber structures - Test methods - Determination of mechanical properties of wood based panels, European Committee for Standardization (CEN), 2004.

[7] M. Chybinski and L. Polus: Experimental study of Aluminium-Timber Composite Bolted Connections Strengthened with Toothed Plates. Materials 2022, Vol. 15, Page 5271, vol. 15, p. 5271, Jul. 2022, doi: 10.3390/MA15155271.

[8] Y. Zhao et al.: Experimental study on shear performance of steel-timber screw connectors with grout pockets, Engineering Structures, vol. 266, p. 114535, Sep. 2022, doi: 10.1016/J.ENGSTRUCT.2022.114535.

https://doi.org/10.52202/069179-0464