WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

BEHAVIOUR OF PERFOBOND CONNNECTIONS IN TIMBER-CONCRETE COMPOSITES

Elif Appavuravther[1], Bram Vandoren[2], Jose Henriques[3]

ABSTRACT: Adhesively bonded plates, acting as shear connectors, in timber-concrete composites (TCC) are gaining popularity due to their high strength and stiffness. Such mechanical performance behaviour is targeted with the use of timber as a construction material for long span solutions. In this work, perfobond connectors, commonly used in steel-concrete composites (SCC) have been experimentally investigated both at the connection and beam level. The test results are then used to validate finite element models and, subsequently, to optimize the behaviour of these connectors. The study has identified the properties necessary for a strong, stiff and a ductile perfobond plate.

KEYWORDS: adhesively bonded connections, perfobond connector, timber-concrete composite

1 – INTRODUCTION

The construction sector is leaning towards the use of more structural timber due to its lower carbon emission in order to reduce the environmental impact and to contribute to the target of an 'aboslute zero' circularity economy [1]. Hybrid solutions such as timber-concrete composites (TCC) and timber-steel composites are preffered solutions to obtain maximum mechanical performances while contributing to sustainability. With TCC floos, long span solutions are also possible.

In the literature, numerous traditional solutions such as dowel-type fasteners, notches and innovative solutions such as adhesively bonded steel fasteners are available as shear connectors connecting the concrete and timber components in a TCC floor element [2]. To target long span solutions, stiff and strong connections are necessary [3]. Adhesively bonded steel plates has shown to serve this purpose [4, 5]. An early product developed in the past decades is the TiComTec, an HBV (Holz-Beton-Verbundsystem)-system [6]. This solution is a continuous steel mesh adhesively bonded to timber. The ultimate capacity of this system is controlled by the yielding of the mesh which results in a ductile behaviour. Since then, numerous researchers have worked with adhesively bonded continuous or discrete plates [7-12].

In this work, perfobond connectors, which were developed to target long spans in SCC elements are used [13]. The connectors are adopted to the timber beam by an adhesive bond. An experimental investigation at the connector level, by means of shear (push-out) tests, and at the beam level, under four-point bending loading, is performed. The connection resulted in a strong and stiff behaviour; however, ductility was lacking. A finite element model for each configuration is subsequently developed by validating the experimental results. A parametric study is performed to target ductile behaviour of the connectors. Finally, a connector with flexible behaviour is proposed and analysed at the beam level. An overview of the study conducted is illustrated in Figure 1.

[1] Elif Appavuravther, UHasselt, Faculty of Engineering Technology, Construction Engineering Research Group (CERG), Agoralaan, 3590 Diepenbeek, Belgium, eliftuba.appavuravther@uhasselt.be

[2] Bram Vandoren, UHasselt, Faculty of Engineering Technology, Construction Engineering Research Group (CERG), Agoralaan, 3590 Diepenbeek, Belgium, bram.vandoren@uhasselt.be

[3] Jose Henriques, UHasselt, Faculty of Engineering Technology, Construction Engineering Research Group (CERG), Agoralaan, 3590 Diepenbeek, Belgium, jose.gouveiahenriques@uhasselt.be

https://doi.org/10.52202/080513-0469

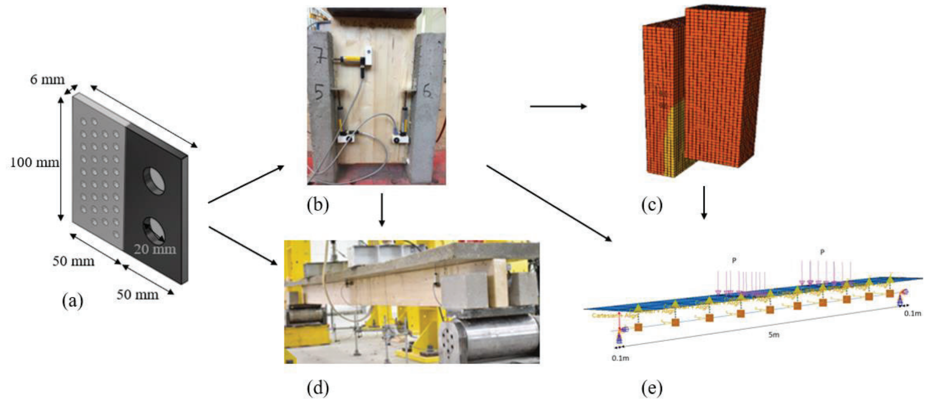


Figure 1: Test specimens: (a) Perfobond plate dimensions; (b) Shear test specimen; (c) shear test Abaqus model, (d) Bending test specimen and (e) bending test Abaqus model.

2 – EXPERIMENTAL INVESTIGATION

2.1 TEST SPECIMENS

In both shear and bending tests, the connector and the structural elements were designed according to relevant codes and literature [14-17]. The dimensions of the perfobond plate can be found in Figure 2(a). In the shear tests, symmetric specimens with central timber and concrete layers on both sides were experimentally investigated. The timber dimension were 90 mm × 270 mm and the concrete dimensions were 70 mm × 190 mm. The dimensions of the specimens can be found in Figure 2(b). The tests considered five replicas. In the bending tests, the cross-section of the concrete slab is 70 mm × 600 mm and the span length of TCC beam was 5.2 m. The perfobond plates are placed every 500 mm, with a total of 10 connections. The T-shaped cross-section is presented in Figure 2(c). Three identical replicas were tested in this case.

For the installation of the perfobond plate, the timber is predrilled to open grooves of 110 × 10 × 55 mm after which 2/3 of each groove is filled with Sika Anchorfix-3030, an epoxy-based acrylate [18]. The connectors are inserted with an embedment depth of 50 mm. The specimens are left for drying during a minimum of 24 hours. The concrete is casted on the dry specimens.

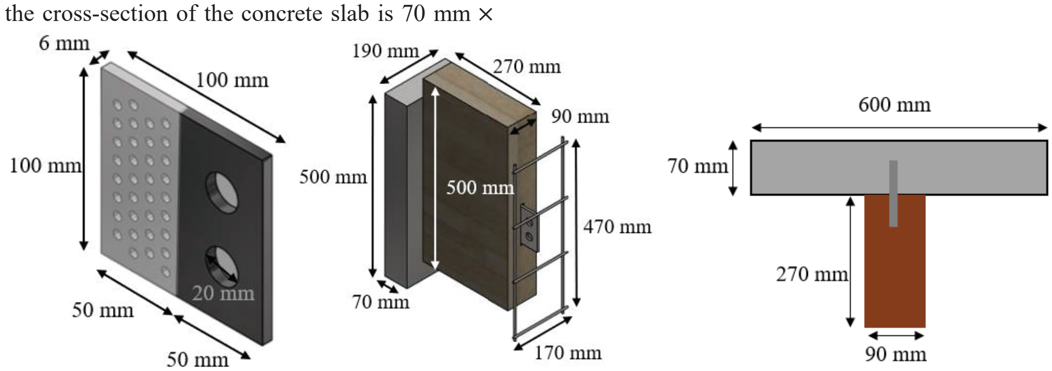


Figure 2: Test specimens, from left to right: (a) Perfobond plate dimensions; (b) Shear test specimen cross-section; (c) Cross-section of the TCC beam tested in bending.

2.2 MATERIALS AND METHODS

The timber used in this study is glulam with a strength class of GL 24h with an average density of 483 kg/m^3 and 12.34% humidity. The perfobond has a steel grade S355 without any surface treatment. The concrete is C35/45 with a 28-day cubic strength of 78 MPa and 41 MPa for the shear and bending specimens, respectively.

https://doi.org/10.52202/080513-0469

2.3 TEST SETUP, MONITORING AND TEST PROCEDURE

In both test setups, an hydraulic jack, load cell and several Linear Variable Differential Transformers (LVDT) are used [19, 20]. In the shear tests, the slip between the concrete and the timber is recorded with four LVDTs at various locations.

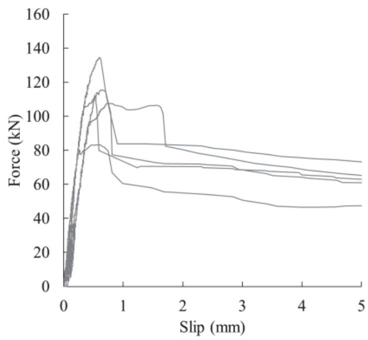
The loading procedure from EN 26891 is followed for both series of experiments. A detailed experimental investigation can be found in the literature [21].

2.4 EXPERIMENTAL RESULTS

In Figure 3, the force-slip curves for the shear tests, P-ST and force-midspan deflection curves for bending tests, P-BT are presented.

In P-ST, the specimens follow a linear trend until a load level of 94 kN, on average, and loses stiffness due to bondline failure and its bond to the timber. The forces are still transferred through contact until the maximum load capacity of the connection is reached at 117 kN due to crushing of the timber. The curves reveal that a sudden drop in the load due to the nature of the timber failure [20]. The results showed that the connection has a strong and a stiff behaviour, however, lacks ductility.

In P-BT, a similar linear trend is observed until the maximum load-carrying capacity is reached at 68 kN. A sudden loss in load capacity is observed and is due to failure of the edge connection(s). A few percentage of the load transfer could be regained due to redistribution of the shear forces until the timber beam reached its maximum tension (bending) capacity. It is worth noting that the behaviour of connections from the shear tests where a stiff linear response followed by a brittle failure were reflected in the bending behaviour of the TCC beams.



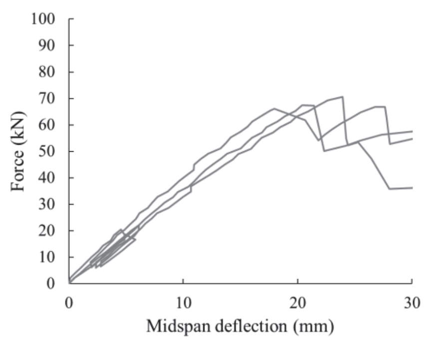


Figure 3: Experimental results, from left to right: (a) Force-slip curve of shear tests, P-ST; (b) Force-midspan deflection curve of bending tests, P-BT.

3 – NUMERICAL INVESTIGATION

3.1 SHEAR TESTS

The finite element analysis is conducted in the Abaqus software [22]. For the shear tests, a 3D FE model is built using hexahedral solid element with reduced integration (C3D8R).

The material and geometric nonlinearities are included. For the timber, Hill's criteria available in the Abaqus library is used, where the failure mode of the timber (compression failure or tension failure) is introduced. For the concrete model, the build-in concrete damage plasticity model from the Abaqus library is used [22]. To capture the local crushing of the concrete, the model proposed by Pavlovic is integrated [23], which results in an improved strain response from 0.35% to 10%.

In the sensitivity study, mesh size, mesh element type, material properties, friction coefficients and interactions were analysed [14]. As a conclusion, in the validated model four types of interactions are defined for the analysis:

1. Frictionless surface-to-surface contact between the concrete and the timber (due to use of a plastic film in the experiments);
2. Rigid connection between the timber groove and the perfobond plate (the adhesive layer is neglected as no fracture on this layer was observed in the experiments);
3. Surface-to-surface contact with a friction coefficient of 0.5 between the perfobond plate and the concrete layer;
4. Rigid connection between the reinforcement and the concrete.

The results of the validated model, P-ST-FEM, is presented in Figure 4(a). The model predicts the elastic

https://doi.org/10.52202/080513-0469

response of the connection accurately. The maximum load capacity is in agreement with the experimental results.

In the post-elastic range, due to a sudden increase of tensile stresses, the experimentally observed delamination can be detected. This is presented with the shear stress distribution on the timber groove, given in Figure 4 (b). With the rotation of the perfobond plate, the plate caused a cut-through effect on the timber (Figure 4(c)).

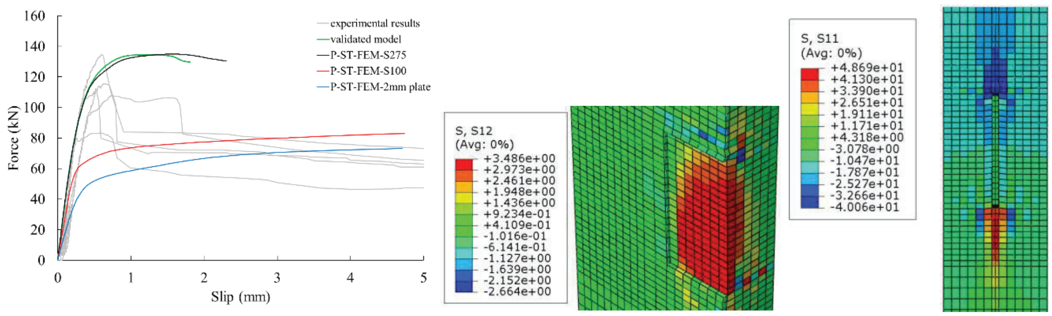


Figure 4: Numerical analysis results, from left to right: (a) Force-slip curve of the validated model against experiments and parametric study; (b) Shear distribution at the groove – the fibers reaching shear capacity; (c) Crushing of the timber under the perfobond plate.

To improve the ductility, the perfobond plate must plastify before debonding occurs in the timber part. Accordingly, a small parametric study was conducted where the parameters analysed are: i) a reduction of the steel plate grade to S 275 (P-ST-FEM-S275) and replacement by aluminium S 40 (P-ST-FEM-S40) and ii) a reduction of the plate thickness in the concrete element to 2 mm, P-ST-FEM-P-2mm plate. In Table 1, the summary of the models can be found.

Table 1 Studied parameters

Shear test models	**Parameters**	**Bending test models**
P-ST-FEM	validated model	P-BT-FEM
P-ST-FEM-2mm plate	steel plate reduction only	P-BT-FEM-2mm plate
P-ST-FEM-S275	steel plate S275	P-BT-FEM-S275
P-ST-FEM-S40	aluminium 5005	P-BT-FEM-S100
		P-BT-FEM-plastic

In Figure 4(a), the force-slip curve of the parametric study can be found. The results showed that changing the steel grade from S355 to S275 had no impact in the initial stiffness. The impact was only observed at the load level where plastic behaviour has started. As expected, yielding of the perfobond plate had started before debonding. The maximum load capacity is reached by crushing of the timber. Reducing the plate strength to 100 MPa (changing the material to an aluminium of 5005/O/H111 [24]), has lead to an initial stiffness similar as in the experiments, as expected. At 21 kN, the plate started yielding, causing the connection to enter into a nonlinear range. No debonding or nonlinearity in the other materials was obtained. When the plate thickness in the concrete layer is decreased from 6 mm to 2 mm, a flexible behaviour is recorded in the linear range. The load capacity is limited by the yielding of the plate. This analysis shows that ductility of the connection can be obtained by using a weaker material or by reducing the plate thickness.

3.2 BENDING TEST

For the bending tests, a simplified 2D model is developed with beam elements (B31) for the timber beam and a 4-node shell element (S4R) for the concrete slab. The shear connection is modelled using a spring-like connector element. The force-slip curve from the shear tests is used as an input. At the maximum load level, the connector is assumed to exhibit a sudden failure. Material properties and connector location are investigated in the validation of the model; a detailed overview can be found in the reference [19]. Since in the connector behaviour, the response of the concrete and the timber was captured, the linear elastic material properties are defined for the timber and the concrete to avoid double stresses from occuring. The validated model is presented in Figure 5(a). The deviations are caused due to the simplicity of the modelling approach, assumption of uncracked concrete and possible deviations in the connection behaviour when loaded under shear or bending [25].

The validated model is used to assess the response of a TCC beam when flexible connectors from the previous

https://doi.org/10.52202/080513-0469

section are introduced. The force-midspan deflections are presented in Figure 5(b). The connector behaviour, presented in Figure 4(a), is used as an input. The input parameters are limited to either of 1 mm of slip or to the maximum load capacity, depending on which occurred first. The reason for this limitation is the misleading of the post-elastic range recorded in the validation (Figure 4 (a)), as a result of the Hill constitutive model.

In series P-ST-FEM-S40, P-ST-FEM-S275 and P-ST-FEM-P-2mm plate, the maximum load capacity is obtained due to failure of the connection at 21 kN, 76 kN and 35 kN, respectively. With the horizontal slip caused between the timber and the concrete, the connections at the beam ends bear higher stresses, causing them to reach their maximum capacity. Failure on the outer connections on the TCC beam is followed by a shear load redistribution among the remaing connections until the timber beam reaches the maximum tension strength (bending capacity).

The model P-ST-FEM-plastic is used to determine the necessary slip for redistribution of forces. In this model, a plastic plateau in the behaviour of the connection is assumed. The analysis shows that a slip of 1.34 mm is necessary to target sufficient redistribution of forces in the same TCC beam under a four-point loading with 10 connections. This is five times the slip obtained in the experiments.

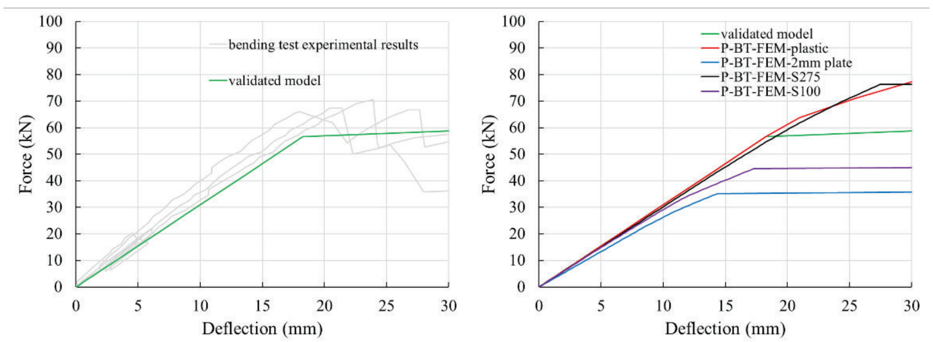


Figure 5: Force-midspan deflection curves, from left to right: (a) Experimental and validated model; (b) Parametric study.

4 – CONCLUSION

In this work, adhesively bonded perfobond connectors are investigated as shear connectors in TCC floor elements. An experimental and numerical investigation is performed both at the connector and beam level. The results showed a strong and stiff behaviour of the perfobond plate with limited deformation capacity leading to brittle failure. The validated FE model is used to optimize the connector by reducing the material strength or the cross section, which shifts the failure to the reinforced concrete layer, thus resulting in a ductile failure pattern. The ductile connector response is used to simulate the behaviour in a TCC beam. The results showed that, once again, the connection behaviour is followed at the beam level due to redistribution of forces. This solution improves the mechanical properties and consequently, demonstrates potential for longer spans under equivalent service conditions.

5 – REFERENCES

[1] L. Ottenhaus, Z. Yan, R. L. Brandner, P, G. Fink, and R. Jockwer, "Design for adaptability, disassembly and reuse – A review of reversible timber connection systems," Construction and Building Materials, vol. 400, 2023.

[2] D. Yeoh, F. Fragiacomo, M. D. Franceschi, and K. Heng Boon, "State of the Art on Timber-Concrete Composite Structures: Literature Review," Journal of Structural Engineering, vol. 137, 2011, doi: 10.1061/(ASCE)ST.1943-541X.0000353.

[3] COST, Design of timber-concrete composite structures - A state-of-the-art report by COST Action FP1402 / WG 4. Shaker Verlag Aachen, 2018.

[4] P. Clouston, L. Bathon, and A. Schreyer, "Shear and bending performance of a novel wood-concrete composite system," (in English), Journal of Structural Engineering, Article vol. 131, no. 9, pp. 1404-1412, SEP 2005 2005, doi: 10.1061/(ASCE)0733-9445(2005)131:9(1404).

[5] L. Bathon and M. Graf, "A continuous wood-concrete-composite system," in 6th World Conference on Timber Engineering, Whistler Resort, British Columbia, Canada, 2000.

[6] T. D. HBV-Systems. (2014). Load bearing constructions using wood-concrete-composite technique with glued-in HBV®—Shear connectors.

[7] C. Avez, "Design of an adhesively bonded-in steel plate connection for Cross Laminated Timber," PhD in Engineering Science and Technology, University of Mons, Mons, Belgium, 2021.

[8] F. Suarez-Riestra, J. Estevez-Cimadevila, E. Martin-Gutierrez, and D. Otero-Chans, "Timber-Timber-Composite (TTC) beam long-term behaviour. Full scale experimental campaign and simplified analytical model," Construction and Building Materials, vol. 361, 2022.

[9] E. Martin-Gutierrez, J. Estevez-Cimadevila, D. Otero-Chans, and F. Suarez-Riestra, "Discontinuous pi-form steel shear connectors in timber-concrete composites. An experimental approach," Engineering Structures, vol. 216, no. 110719, 2020.

[10] D. Otero-Chans, J. Estevez-Cimadevila, F. Suarez-Riestra, and E. Martin-Gutierrez, "Experimental analysis of glued-in steel plates used as shear connectors in Timber-Concrete-Composites," (in English), Engineering Structures, Article vol. 170, pp. 1-10, SEP 1 2018 2018, doi: 10.1016/j.engstruct.2018.05.062.

[11] J. Miotto and A. Dias, "Evaluation of perforated steel plates as connection in glulam-concrete composite structures," (in English), Construction and Building Materials, Article vol. 28, no. 1, pp. 216-223, MAR 2012 2012, doi: 10.1016/j.conbuildmat.2011.08.045.

[12] E. Lukaszewska, "Development of Prefabricated Timber-Concrete Composite Floors," PhD, Department of Civil, Mining and Environmental Engineering, Lulea University of Technology, Sweden, 2009.

[13] L. C. Neves, P. Vellasco, and I. Valente, Shear connectors that use concrete dowels, 1st Edition ed. (ECCS TC 11 - Composite Sturctures - WG1 - Shear Connectors). 2018.

[14] E. Appavuravther, B. Vandoren, and J. Henriques, "Analytical and numerical investigation of adhesively bonded perfobond shear connectors for timber-concrete composite floors," Structures, vol. 70, 2024.

[15] E. Oguejiofor and M. Hosain, "A parametric study of perfobond rib shear connectors," (in English), Canadian Journal of Civil Engineering, Article vol. 21, no. 4, pp. 614-625, AUG 1994 1994, doi: 10.1139/l94-063.

[16] EN 1993-1-8: Design of steel structures - Part 1-8: Design of joints, European Committee for Standardization, 2005.

[17] EN 1993-1-1: Design of steel structures - Part 1-1: General rules and rules for buildings, European Committee for Standardization, 2005.

[18] Product Data Sheet Sika Anchorfix - 3030, Sika.

[19] E. Appavuravther, C. Martins, B. Vandoren, A. Dias, and J. Henriques, "Efficiency of timber-concrete composite floors with discrete perfobond connections: A numerical study," Engineering Structures, vol. 303, 2024.

[20] E. Appavuravther, B. Vandoren, and J. Henriques, "Push-out tests on adhesively bonded perfobond shear connectors for timber-concrete composites," Journal of Building Engineering, 2022.

[21] EN 26891 - Timber Structures - Joints Made with Mechanical Fasteners - General Principles for the Determination of Strength and Deformation Characteristics, 1991.

[22] User's Manual. (2000). Hibbitt, Karsson & Sorensen.

[23] M. Pavlovic, "Resistance of bolted shear connectors in prefabricated steel-concrete composite decks," Dissertation, Faculty of Civil Engineering, University of Belgrade, Belgrade, 2013.

[24] EN 1999-1-1: Design of aluminium structures - Part 1-1: General rules, European Committee for Standardization, 2023.

[25] J. Schänzlin and S. Mönch, "Push-out vs. Beam: Can the Results of Experimental Stiffness of TCC-Connectors be Transferred?," presented at the COST Action FP1402 - Workshop on "Future challenges and need for research in timber engineering", Zürich, Switzerland, 2018.

 https://doi.org/10.52202/080513-0469