THE EFFECT OF AN INTERLAYER ON DOWELLED CONNECTIONS IN TIMBER LIGHTWEIGHT CONCRETE COMPOSITE SYSTEMS

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ABSTRACT

The use of lightweight concrete (LWC) with timber structures is an efficient solution for renovation and, with current high strength LWC, it is also an option for new constructions. In this paper, dowelled connections for timber concrete composite systems are experimentally investigated. Often, when renovating an existing building and implementing a composite solution, but also in new constructions, wood based panels are used between the concrete layer and timber beams. In the current literature it is known that the interlayer causes reduction in strength and stiffness. In this work, the effect of an interlayer and the improvement of the connection using an adhesive are experimentally investigated with the use of lightweight concrete. In addition to these two parameters, two different fasteners, screws and ribbed rods, are also considered. This work indicates that, with the use of an adhesive, the negative effect of an interlayer can be mitigated.

KEYWORDS: timber lightweight concrete composites, shear dowel type connections, adhesively bonded connections, effect of interlayer

INTRODUCTION

The use of timber lightweight concrete composites (TLCC) is an increasing trend with various research projects and several examples in the world [1, 2]. Dowelled connections are still the most popular and simple solutions for both renovations and new constructions. Besides renovation of timber buildings, these connections can be easily replaced which will extend the life of the timber joists. For renovation purposes, the use of lightweight concrete is a better solution than using a non-structural mortar screed [3] as it contributes to the structural integrity of the floor while adding a lower weight, which can be often more appropriate for existing structures. The rehabilitation of timber floor with lightweight concrete requires a performant connection that can guarantee an efficient a composite action between these two materials.

The use of dowel connections are the most common solutions for shear connections to mobilize the composite action in timber-concrete composite members. They are the most commonly studied connections due to their optimal strength, stiffness and ductility along with a variety of choices and easy access [4-7]. In addition, in the current EN 1995-1-1, the strength models based on the Johansen/ European yield models leads to a good estimation [8, 9]. In design, the target is to obtain the most optimized solution by using a lower number of screws and obtaining highest strength and stiffness possible. Dowel connections are also a good solution for renovations. In existing structures, there is a floor system, which can serve as a permanent formwork and be referred as an interlayer. However, the interlayer leads to lower mechanical performance due to the gap layer they cause between the concrete

and the timber layer. Even though in numerous experimental work, it has been concluded that the use of an interlayer is significant, in cases such as rehabilitation or wet solutions (casting concrete layer on site), the use of an interlayer cannot be neglected. Use of adhesively bonded connections leads to a much stiffer behaviour and this solution may mitigate the effect of an interlayer [10].
In this paper, the effect of an adhesive and an interlayer on screw and ribbed rod dowelled connections are investigated by means of experimental tests. Throughout the experimental program, lightweight concrete is used. During the design of the specimens EN 1995-1-1 is used [9]. The results show that by introducing an adhesive layer, negative effects of an interlayer can be improved.

MATERIALS AND METHODS

The experimental tests within this work considered symmetrical push-out tests on dowelled connections for TLCC. An overview and dimensions of the specimens with an interlayer are given in Figure 1. For the specimens without an interlayer, the only difference is the embedment length in the concrete is smaller as the size of the interlayer.
Glulam with strength class of GL 24 h and lightweight concrete with a strength class of LC 20/22 is used. Two different types of connectors are used; i) fully threaded Wurth screws [11] and ii) S500 ribbed rods. Both of the dowels have an outer diameter of 8 mm. In all series, the embedment length of the dowel connector in the timber is 110 mm. The embedment length is 50 mm for the series without and interlayer and 32 mm for the series with an interlayer.
Three different parameters are investigated; i) effect of dowel type (screw vs. ribbed rod), ii) effect of the adhesive between the dowel and the timber (epoxy acrylate-based Sika Anchorfix-3030 [12]) and iii) effect of an interlayer (18 mm OSB-3 from Norbord). Test specimens are labelled as dowel type (S – screw or R – rod), existence of adhesive (NG – no adhesive or G – adhesive is present) and existence of an interlayer (NI – no interlayer or I – interlayer is present). Test specimen properties are presented in Table 1. The test specimens are designed by provisions given in EN 1995-1-1 [9].

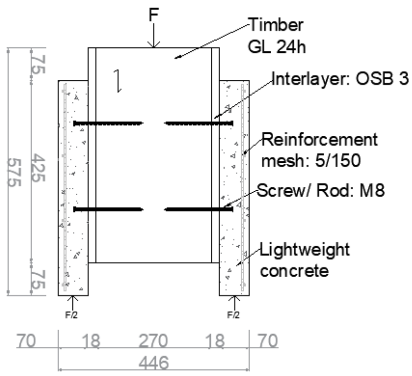

Figure 1: Test specimen with all members and dimensions

Table 1 Test specimen properties

Experiment ID	Concrete type & strength	Concrete thickness	Dowel type	Embedment length	Glue	Interlayer
S-NG-NI					No	-
S-NG-I			Screw			-
S-G-I	LC 20/22	70 mm		110 mm		Yes
R-G-NI			Rod		Yes	-
R-G-I						Yes

RESULTS

Each series had five replicas. In Figure 2 the average force slip curve for each series is presented. F_1 is a load level where initial failure occurred which is identified as the stiffness degradation in the force slip curve. At this load level, yielding of the dowel by formation of a plastic hinge occurred. After this load level, F_1, plastic hinge occurred, leading to a significant deformation with small increase of strength. After this load level, only shear loading is no longer represented. In series S-NG-NI and S-NG-I, a second stiffness degradation is observed due to the strain hardening of the screw. After this load, the maximum load capacity, Fmax, is reached by all specimens as the pull-out strength in the concrete is reached.

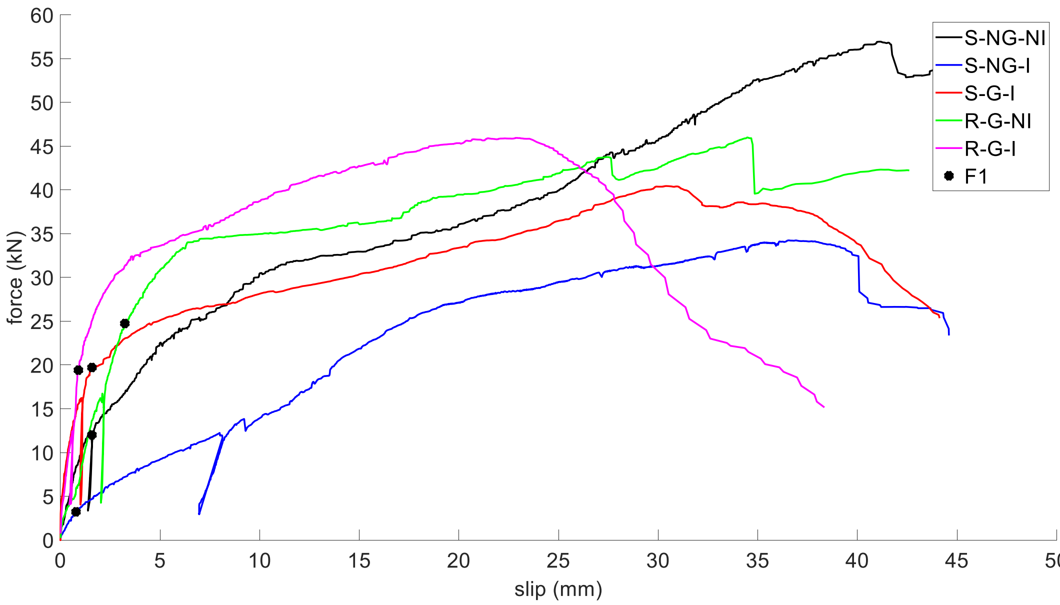

Figure 2 Average force-slip curve of all series

The mean results from the shear tests are presented in Table 2. Two different load levels are identified and the patterns were very similar for all five series. At initial damage, reduction in the stiffness is caused due to the plastic hinge formation of the connector. At the maximum load capacity, F_{max}, failure occurs due to the connector reaching its withdrawal strength in the concrete. Stiffness, K_{ser}, is calculated using EN 26891 [13]. The ultimate slip, v_u, is the slip corresponding to the 80% of F_{max} after the F_{max}. From *Table 2*, following observations can be made;

- The stiffest and the strongest series is R-G-NI.

- The use of an adhesive layer had a positive impact in the initial failure load, F*1* and stiffness, K_{ser}.
- The negative effect of an interlayer on load capacity and stiffness are removed by introducing an adhesive layer (S-NG-I vs S-G-I)
- Same initial damage and failure mode is observed.
- There is a similarity between the maximum load carrying capacity in all series (37 – 49 kN)
- There is a same order between the ultimate slip in all series (32 – 39 mm)

Table 2: Test results

Specimen ID	F_1 (kN)	F_{max} (kN)	K_{ser} (kN/mm)	v_u (mm)	Initial damage mode (F_1)	Failure mode (F_{max})
S-NG-NI	11.24	42.87	8.52	37.42	Plastic hinge formation	Withdrawal strength at the concrete is reached
S-NG-I	3.19	37.08	1.59	39.53		
S-G-I	17.14	40.46	15.13	38.60		
R-G-NI	22.14	49.48	11.86	39.02		
R-G-I	19.07	42.69	15.55	32.54		

EFFECT OF TESTING VARIABLES ON MECHANICAL PROPERTIES

In this experimental campaign, three different parameters are investigated. The effect on strength, stiffness and ultimate slip are hereafter discussed.

i) Effect of the dowel type (screw vs. ribbed rod) – series S-G-I and R-G-I are compared. In both connectors, an outer diameter of 8 mm is used, however, the inner diameter and the tensile strength of the connector varied. Changing the connector from screw to rod lead to an increase of 11% and 5% in F_1 and F_{max}, respectively. In terms of stiffness however, only an increase of 3% is observed. As the adhesive layer caused a stiff connector between the dowel and the timber, such behaviour in the elastic range is expected. There was a 15% reduction in the ultimate slip, which reflects the post-elastic behaviour difference between the two connectors (F_1 vs F_{max}).

ii) Effect of the adhesive between the dowel and the timber – series S-NG-I and S-G-I are compared. By introducing an adhesive layer for the series with the use of screws and an interlayer, a 438% increase in F_1 and 9% increase in F_{max} is recorded. The quadruple increase in the initial damage load is expected as the adhesive reinforced the screw, timber and the interlayer to work as a single connection. The consistency in the F_{max} is also expected as in both cases the maximum load capacity is by the pull-out strength at the concrete layer. In both series, the mechanical properties were the same (embedment length of the screws in the concrete and the concrete strength). The stiffness was increased by an 850% with the introduction of an adhesive, due to the stiff layer. In term of ultimate slip, only 2% reduction is recorded.

iii) Effect of an interlayer – in this comparison, two separate comparisons are made for the screw connectors (S-NG-NI vs S-NG-I) and rod connectors (R-G-NI vs R-G-I).

   a. For screw connectors, introducing an interlayer (without an adhesive) lead to a decrease of 71% and 17% in the $F1$ and F_{max}. In terms of stiffness, 81% reduction is observed. As the interlayer acts as a gap layer, this is an expected behaviour and in agreement with the literature [14]. In terms of ultimate slip, a 5% increase is observed which can be neglected.

b. For rod connectors, introduction of an interlayer lead to a reduction of 14% in F_1 and F_{max}. Even though there was an adhesive layer which connected the rod connection to the interlayer, such decrease is acceptable since the interlayer changes the force transfer mechanism. In the stiffness, an increase of 31% is recorded, this proves that the adhesive stiffens the connection significantly. A 16% decrease is observed in ultimate slip. The maximum load capacity is reached by the pull-out strength of the concrete, which was smaller for the series with an interlayer (as the embedment length is smaller) therefore the ultimate slip is affected from this.

CONCLUSION

In this paper, dowelled connections within TLCC with the effect of an interlayer, adhesive and fastener type are experimentally investigated. Lightweight concrete is used throughout the entire experimental program as the target of these connections is for renovation reasons. In this experimental campaign, glulam is used for the timber layer due to its easy access.

Introducing an interlayer caused significant reduction in stiffness and in load capacity. Introducing an adhesive layer between the screw and the interlayer compensates the negative effect/impact of an interlayer. With this solution, renovation of existing timber buildings will be possible without a high loss in strength and stiffness capacity of the dowel connectors.

The use of an adhesive has a positive impact on the strength and the stiffness. Even though an adhesive increases execution sensitivity of the connector and the cost of the execution, for special projects, it may be considered.

The use of a rod rather than a screw (in specimens with adhesive and an interlayer) lead to a slightly better strength and stiffness, however, the ultimate slip is limited.

The results in this paper gives a good indication of dowel connections that can be used for renovation purposes. Nevertheless, further research is still necessary to evaluate the impact of used/old timber on the mechanical performance of the investigated connections.

REFERENCES

[1] ARUP. (2019) Rethinking Timber Buildings.

[2] E. Appavuravther, B. Vandoren, and J. Henriques, "Behaviour of screw connections in timber-concrete composites using low strength lightweight concrete," *Construction and Building Materials,* vol. 283, 2021.

[3] S. Carvalho, T. Panzera, A. Christoforo, J. Fiorelli, F. Lahr, and R. Freire, "Epoxy mortar timber beam upgrading," *International Wood Products Journal,* 2017.

[4] M. Van der Linden, "Timber-Concrete Composite Floor Systems," PhD Dissertation, Technical University of Delft, Delft, The Netherlands, 1999.

[5] A. Dias, "Mechanical behaviour of timber-concrete joints," PhD, TU Delft, Delft, Netherlands, 2005.

[6] L. Jorge, "Timber-concrete structures using lightweight aggregate concrete / Estruturas mistas madeira-betão com a utilização de betões de agregados leves [In Portuguese] " Ph. D., University of Coimbra, Coimbra, Portugal, 2005.

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

[8] K. Johansen, "Theory of timber connections," *International association of bridge and structural engineering,* vol. 9, pp. 249-262, 1949.

[9] *EN 1995-1-1 - Design of timber structures - Part 1-1: General rules and rules for buildings,* E. C. f. Standardization, 2004.
[10] G. Tlustochowicz, E. Serrano, and R. Steiger, "State-of-the-art review on timber connections with glued-in steel rods," *Materials and Structures,* 2011.
[11] ETA-13/0029, "Self-tapping screws for use in wood-concrete slab kits," ed. ETA-Denmark A/S, 2017.
[12] Sika, "Product Data Sheet Sika Anchorfix - 3030," ed: Sika.
[13] *EN 26891 - Timber Structures - Joints Made with Mechanical Fasteners - General Principles for the Determination of Strength and Deformation Characteristics*, 1991.
[14] L. Jorge, S. Lopes, and H. Cruz, "Interlayer Influence on Timber-LWAC Composite Structures with Screw Connections," (in English), *Journal of Structural Engineering-Asce,* Article vol. 137, no. 5, pp. 618-624, MAY 2011 2011.