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Derikvand, Mohammad; Fink, Gerhard

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Deconstructable Timber-Concrete Composite Connectors

Mohammad Derikvand[1*]*– Gerhard Fink*[2]

[1] Postdoctoral Researcher, Department of Civil Engineering, Aalto University, 02150 Espoo, Finland* *Corresponding author*
Mohammad.derikvand@aalto.fi

[2] Assistant Professor, Department of Civil Engineering, Aalto University, 02150 Espoo, Finland
Gerhard.fink@aalto.fi

Abstract

The application of deconstructable connectors in timber-concrete composite (TCC) floors enables the possibility of disassembly and reuse of timber materials at the end of building's life. This paper introduces the initial concept of a deconstructable TCC connector comprised of a self-tapping screw embedded in a plug made of rigid polyvinyl chloride and a level adjuster made of silicone rubber. This connection system is versatile and can be applied for prefabrication and in-situ concrete casting of TCC floors in both wet-dry and dry-dry systems. The paper presents the results of preliminary tests on the shear performance of four different configurations of the connector system in T-section glulam-concrete composites. The shear performance is compared to that of a permanent connector made with the same type of self-tapping screw. The failure modes observed are also analyzed to provide technical information for further optimization of the connector in the future.

Key words: deconstructable connector, timber-concrete composite, push-out test, shear strength, slip modulus, failure mode.

Introduction

Timber-concrete composite (TCC) floors can be described as a slab-type engineered wood product or a number of individual timber beams connected to a (thin) concrete slab through shear connectors. The concrete slab, placed on top of the timber component, predominantly resists compression in the composite system, the timber component predominantly resists tension, and the connectors transfer shear loads between the two components. When designed properly, TCC floors can benefit from the high compressive strength of concrete and the high tensile strength of timber (Dias et al. 2018). In previous research works, TCC floors have most commonly been constructed using permanent connectors. Although structurally effective, the application of permanent connectors in the construction of TCC floors can represent challenges for the sustainability and disposal of such structures and result in waste management problems at the end of building's life (Khorsandnia et al. 2018). This is because most of the timber materials used could not be easily recycled or reused due to the permanent connections between the timber elements and the concrete slab. This problem can be addressed when a design for disassembly approach is considered by making use of deconstructable connectors. The use of deconstructable connectors can facilitate the process of dismantling and recycling of TCC structures (Khorsandnia et al. 2016). However, while the structural capacities of various types of permanent connectors have been investigated in numerous studies over the past two decades, little effort has been put into developing and evaluating the performance of deconstructable connectors for TCC floors.

With a focus on design for disassembly and reuse of timber materials at the end of building's life, the goal of this research is to develop a deconstructable connector that can be used for both on-site concrete casting and offsite prefabrication of TCC floors in wet-dry and dry-dry systems. The results of a series of preliminary tests on the shear performance and failures modes of the initial prototype of the deconstructable connector are reported in this paper. The prototype of this connector is comprised of a self-tapping screw embedded in a plug made of rigid polyvinyl chloride (PVC) and a lid and a level adjuster made of silicone rubber. The preliminary tests were performed on five T-section glulam-concrete connections made with four different types of the connector and a permanent screw connector of the same configuration under monotonic shear loads.

Specification of the deconstructable connector and preliminary tests

The concept of the presented approach is that the self-tapping screw itself can directly be used as a deconstructable connector. For this purpose, a solution is required that can prevent the screw from coming into direct contact with the fresh concrete during the construction process. One of the main challenges here, however, is to make sure that the structural properties of the resulting deconstructable connection will be comparable to that of an equivalent permanent connection of the same configuration. Another aim of this research project is that the connector can be used in various construction procedures (i.e., wet-dry and dry-dry systems) and floor configurations. This might be achievable by adding an extra protective layer to the screw itself instead of producing a connector separately.

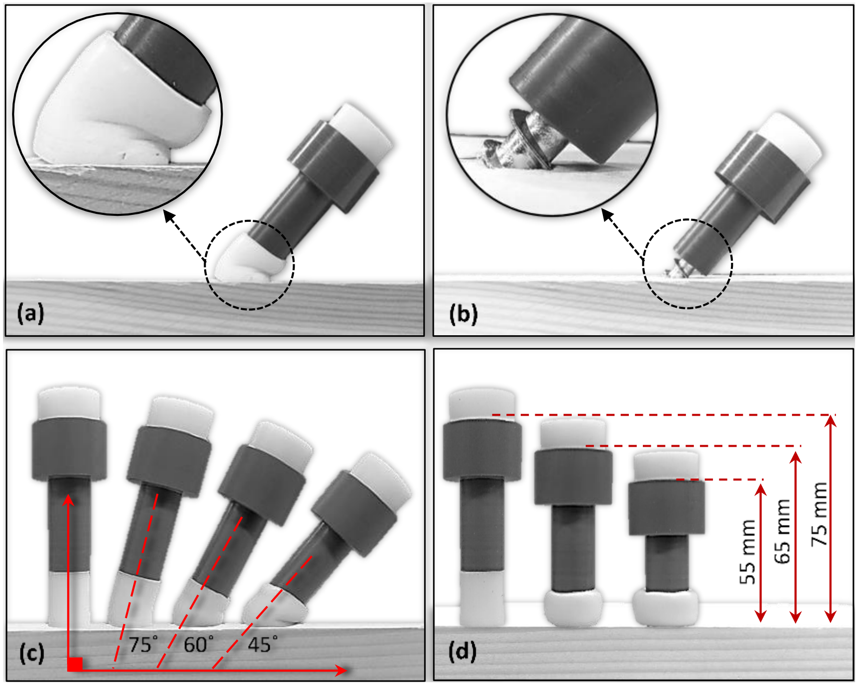

Figure 1. Illustration of the connector (a) with level adjuster, (b) without level adjuster, (c) inserted at different angles, and (c) inserted at different heights by compressing the level adjuster.

The extra protective layer could be in the form of a pipe or an internally threaded plug that can fully cover the portion of the screw that is exposed to the fresh concrete. The resulting connector will be a single deconstructable screw that can directly be driven into the timber component without the need for any additional element or process. Based on this idea, a fully threaded self-tapping screw is inserted into a plug made of rigid PVC. In addition, the connector had a lid and a level adjuster made of silicone rubber. The level adjuster can easily deform and be compressed while the connector is being inserted into the timber component. This enables the possibility of using the same connector with the same dimensions at different insertion angles and concrete slab heights without exposing any part of the screw to the fresh concrete (Fig. 1). The presence of a level adjuster, however, may result in reduced shear performance as well. This effect was studied as a variable during the preliminary tests. For this purpose, per each deconstructable connector tested with level adjuster an equivalent of the same connector was also manufactured and tested without level adjuster. Another important parameter that was considered for the preliminary testing was the configuration of the inner side of the PVC plug. Two types of PVC plugs with and without internal threads were tested for this purpose (Fig. 2). It was assumed that the connector with internal threads would lead to a better shear behaviour as there will be no gap between the screw and the PVC plug in such configuration resulting in a tight fit between the two elements. The diameter of the hole inside the PVC plug with internal threads was equal to the shank diameter of the screw. In the PVC plug without internal threads, however, the diameter of the hole inside the plug was equal to the thread diameter of the screw. This resulted in some unfilled gaps between the inner sides of the hole in the plug and the shank of the screw.

Figure 2. PVC plugs with internal threads (left) and without internal threads (right).

Table 1: Compilation of the experimental tests.

Connector Symbol	Test variables			Level adjuster height (mm)	Insertion angle (˚)	Embedment depth (mm)
	Connector type	Internal threads	Level adjuster			
P	Permanent	-	-	-	90	80
DTL	Deconstructable	Yes	Yes	20	90	80
DTN	Deconstructable	Yes	No	20	90	80
DNL	Deconstructable	No	Yes	20	90	80
DNN	Deconstructable	No	No	20	90	80

In total, four groups of deconstructable connectors and a permanent screw connector with the same configuration were constructed as given in Table 1. The permanent screw connector served as a control specimen. The fully threaded self-tapping screw was made of high resistance galvanized carbon steel with a length of 150 mm, a shank diameter of 6.6 mm, and a thread diameter of 11 mm. The timber component in the T-section connection specimens in this study were cut from a 5-layer glulam beam (Nordic whitewood) with $b \times h \times l = 90 \times 200 \times 300$ mm^3.
A low-shrinking concrete with a maximum aggregate size of 16 mm was used for preparing the specimens. The density and compressive strength of the concrete used were 2388 kg/m3 and 55.3 MPa, respectively. The concrete properties were measured by testing six cubic specimens with the dimensions of $b \times h \times l = 100 \times 100 \times 100$ mm^3.
To prepare the glulam-concrete connection specimens for the preliminary testing, the connectors were driven into the glulam component to a penetration depth of 80 mm. Before casting the concrete, the top surface of the glulam in each specimen was covered by a layer of waterproof paint to prevent the glulam from absorbing moisture from the wet concrete. A plywood formwork was then fixed around the specimens and a steel reinforcement wire mesh was installed to maintain the integrity of the concrete and minimize any crack development (Fig. 3). The concrete was then poured onto the formwork to a height of 75 mm. The test specimens were left to cure for 28 days. The formwork was removed prior to testing.

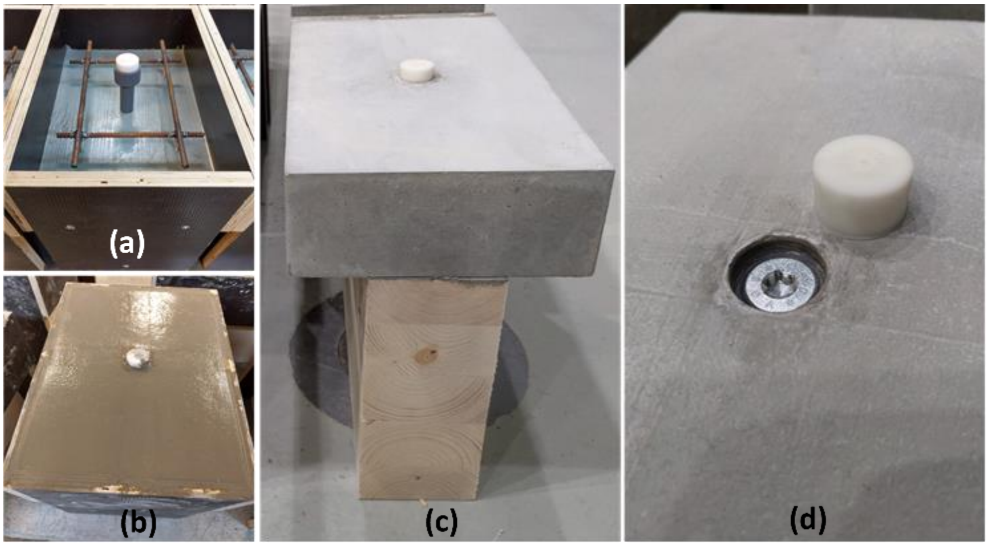

Figure 3. A T-section glulam-concrete deconstructable connection. (a): the prepared formwork, (b): concrete cast onto the formwork, (c): the resulting T-section connection, and (d): the screw head inside the connector after removing the rubber lid.

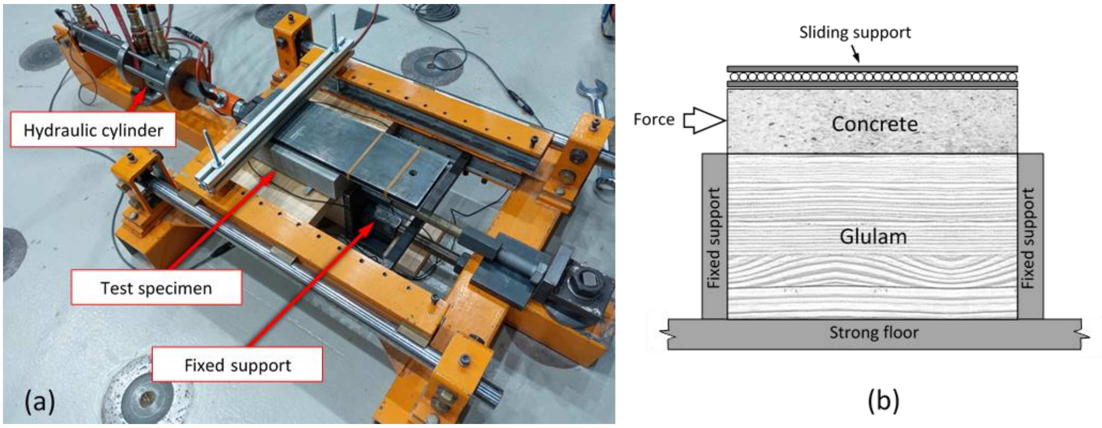

Figure 4. (a) The push-out test set-up used and (b) the side-view of a specimen under loading.

The specimens were tested under monotonic shear load in accordance with the procedures described in EN 26891 (1991) using the test set-up depicted in Figure 4. The slip between the concrete and glulam components was recorded from both sides of the test specimens using two linear variable differential transformers (LVDT). The shear strength of the connections was quantified as the peak load (F_{max}) obtained at u = 15 mm slip. The stiffness of the permanent connector was quantified by calculating the slip modulus (K_s) of the connector at 40% of its estimated peak load (F_{est}). An accurate F_{est} is vital for a realistic slip modulus calculation of connectors (Dias 2012). However, in the absence of a reliable F_{est} for the deconstructable connectors in this study, the slip modulus of these connectors was calculated based on their individual F_{max}. The F_{max} values will then be used as F_{est} for the subsequent experiments on these connectors in the future.

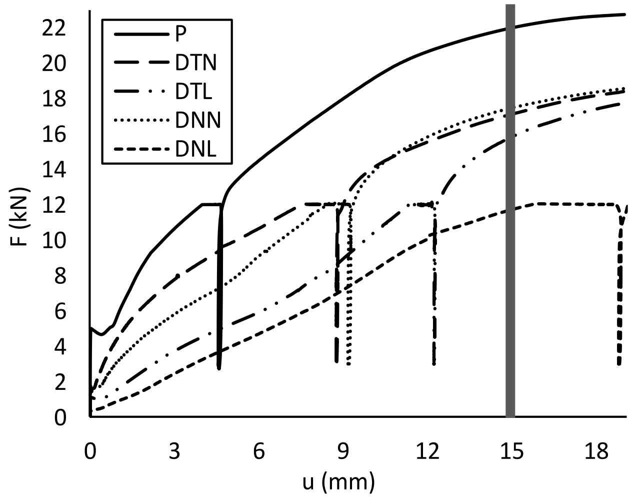

Figure 5. The load-slip curves of the connections. The vertical bar indicates the point where F_{est} is taken for the subsequent testing.

Table 2: F_{max} and K_s of the connectors.

Connector symbol	F_{max} (kN)	K_s (kN/mm)
P	22.0	6.00
DTN	17.1	4.30
DTL	15.8	1.53
DNN	17.4	2.21
DNL	11.7	1.39

Results

The load-slip curves of the test connectors are illustrated in Figure 5. As expected, the permanent screw connector exhibited higher F_{max} and K_s under loading than the deconstructable ones (Table 2). In the group of deconstructable connectors, the two connectors with internal threads in the PVC plug (DTN and DTL) showed a higher K_s value than the identical connectors without internal threads (DNN and DNL). The existence of the level adjuster also appeared to negatively influence both F_{max} and K_s of the deconstructable connectors.

The failure modes of the connectors can be seen in Figure 6. In all the test connectors, some slight crushing of the concrete was observed at the interface of the slab and glulam. Despite this, the concrete section in the permanent connector exhibited a rigid behavior and all the deformation took place in the glulam and the screw itself. The plastic hinge was observed in the timber concrete interface. The DTN and DNN connectors also showed a failure mode almost similar to that observed in the permanent connector together with some plastic deformation at the bottom of the PVC plug. For the DTL and DNL connectors, plastic hinge was above the timber concrete interface due to the level adjuster.

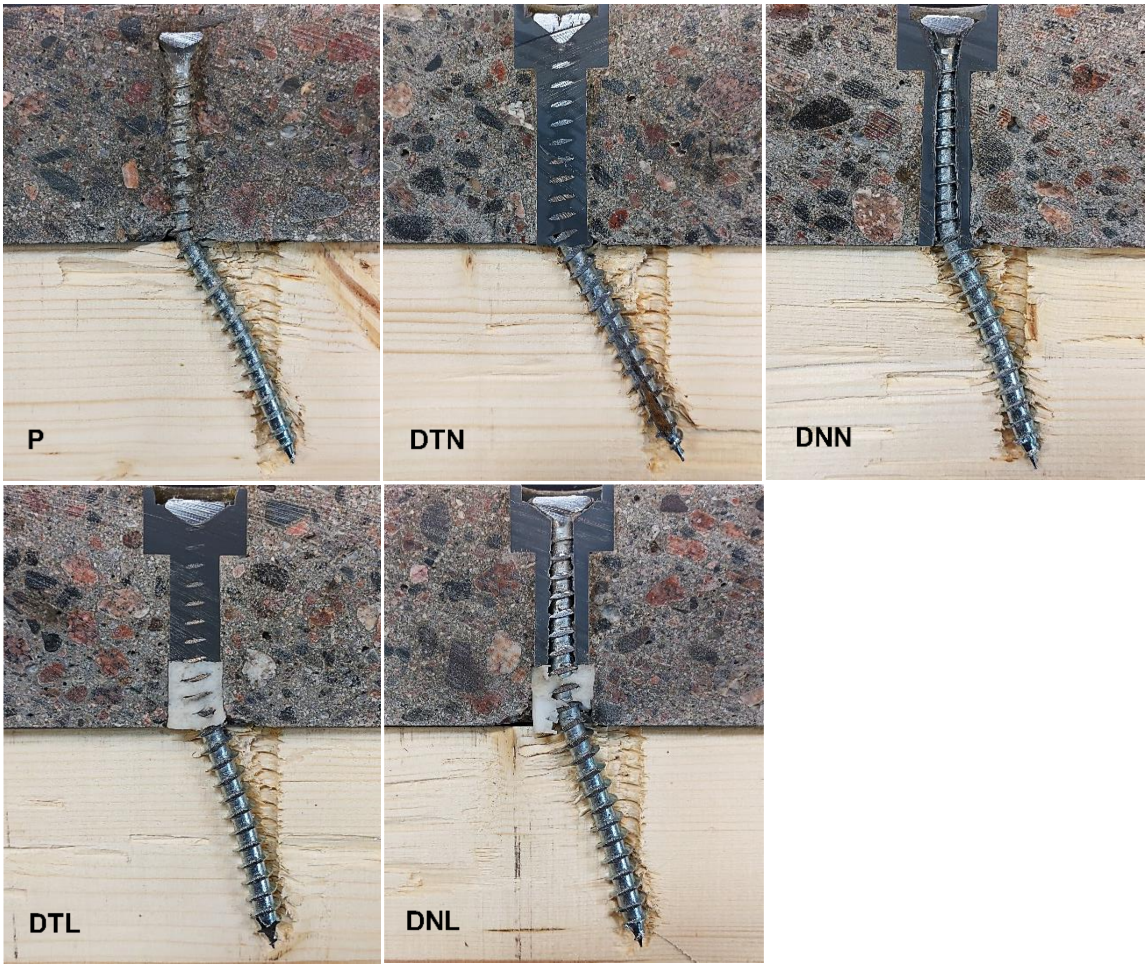

Figure 6. Failure modes of the test connections.

From the failure modes of the test connectors, it can be seen that the deformation and crushing of the glulam occurred all the way through the length of the self-tapping screw in the glulam section. However, in all cases almost only one major plastic hinge was formed in the screw itself. This might suggest that the 80 mm embedment depth of the self-tapping screw should be larger for alpha = 90˚. Nevertheless, in the present study the focus lies on the behavior near the timber-concrete interface.

Conclusions and Outlook

In this paper, the initial concept of a deconstructable connector for TCC floors was introduced. The results of some preliminary tests on the shear behaviour of five glulam-concrete connections were presented and compared. Four different configurations of the deconstructable connector were examined: with or without the presence of a level adjuster and with or without internal threads in the connector plug. The relevant failure modes under monotonic load exposure were analyzed. In all samples the screws were inserted at 90˚ angle, and accordingly the slip modulus and load-carrying capacity were low. Even though the number of tests was limited, some differences were observed

between the slip modulus and load-carrying capacity of the deconstructable connectors and those of the permanent screw connector of the same configuration.
Based on the results of this preliminary project, ongoing research is underway in order to optimize and characterize the properties of deconstructable connector systems under different insertion angles and connection arrangements. The subsequent experimental steps also include some modification on the geometry and material type of the protective layer around the self-tapping screw in order to replace PVC with a more sophisticated material. Some structural and practical aspects of the deconstructable connector introduced in this paper will also be addressed in the future experiments that have been planned for this research.

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