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A new composite connector for timber-concrete composite structures

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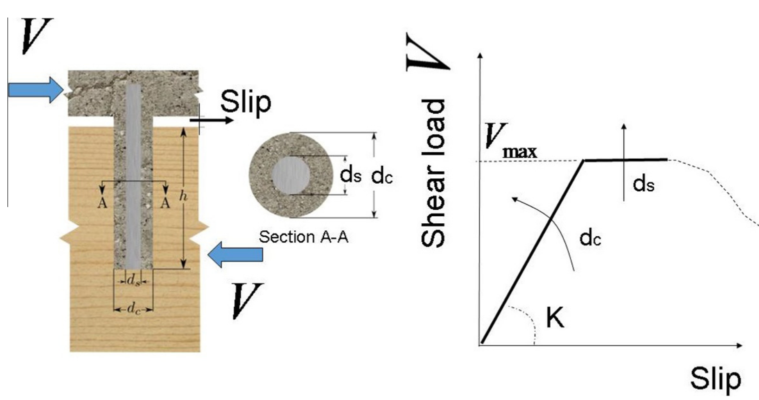
HIGHLIGHTS

- A new elongated composite connector has been developed for timber concrete composite structures.
- The stiffness and strength of the connection depend on the external and internal diameters of the connector, respectively.
- The non-linear Winkler beam model well reproduces the shear connection.
- The composite connector diameters control the deflection and the structural ductility.

GRAPHICAL ABSTRACT



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ABSTRACT

Timber-concrete composite (TCC) structures are emerging in several industrial applications as an efficient method for optimizing the structural performance and the cost of construction. Their effectiveness depends strongly on the kind of connection employed. In order to guarantee sufficient ductility to the structure without sacrificing its stiffness and strength, the connections have to be rigid, strong and deform plastically before the brittle collapse of the timber or concrete members. This work presents a new composite connector, which can be used to enhance the ductility of a structure without significant loss of stiffness at serviceability limit states. The studied composite connector consists of a composite cylinder made of ultra-high performance fibre-reinforced concrete (UHPFRC) shell with a steel cylindrical core. The UHPFRC enhances micro-cracking resistance and energy dissipation under large deformations. Performance characteristics of the connectors of various sizes have been evaluated using shear tests of connections. The results show that the connection stiffness is principally governed by the diameter of the concrete shell, while the connection resistance is principally governed by the diameter of the steel core. A beam on a Winkler foundation model has been applied to describe the behaviour of the composite connector in the shear tests. Finally, the composite beam theory has been applied to predict the structural behaviour of TCC beams with different parameters of the composite connectors. The results show that the diameters of the concrete shell and of the steel core of the connector can be conveniently varied to optimize the TCC beam performance by significantly enhancing its structural ductility without significant loss of flexural stiffness and load bearing capacity.

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1. Introduction

Timber-concrete composite (TCC) structures present an efficient method for optimizing the structural performance and the construction cost of buildings and bridges, as well as for retrofit and strengthening of existing floors, through an intelligent use of the properties of both materials [1–5]. In a TCC floor, the concrete slab increases the overall stiffness and reduces the floor vibrations, while the timber beam provides the resistance, reduces the weight and improves the environmental impact and appearance of the structure.

A TCC structure consists of a concrete slab supported by timber panel or beam, which may be attached by means of different types of connectors. The timber primarily resists tensile stress and the concrete resists compressive stress generated by moments and by the composite action. The shear connection between timber and concrete generates the axial force, which greatly contributes to the total resistant moment of a TCC structure [6,7]. The behaviour of the connection can be determined by means of a shear test, also called push-out test [8]. Fig. 1 illustrates the behaviour of different connectors in terms of shear load vs. slip curves ($V-s$) from data available in literature [9–11]. The connector law ($V-s$) is often highly non-linear within a slip range of 3 mm, especially in the case of discrete connectors, like screws, studs or dowels [12,13].

The structural behaviour of TCC floors with different types of connections has been investigated by several authors [14,10,15]. The connection parameters governing the structural behaviour of a TCC structure are: (i) stiffness, or slip modulus, (k_i); (ii) resistance, or maximum shear resistance, (V_{max}); and (iii) ductility (μ). The connection stiffness affects the degree of composite action between the members. The resistance and ductility of the connection affect the behaviour of a TCC structure only if the resistance of the connector is achieved before the main member collapse in bending or tension. If the connection behaves elastically when the timber reaches the maximum tensile strength in the external fibre, the composite structure will have a brittle failure, albeit the connection load-slip relationship is ductile [11,16]. On the other hand, when the connections yield before the collapse of the timber, the TCC structure will start deforming plastically resulting into a non-linear, ductile behaviour [17,18].

To analyse the non-linear behaviour of TCC structures in bending, the composite beam theory has been recently extended to account for the non-linear load-slip ($V-s$) of connections [19–21]. In the case where connections fail before the timber collapse,

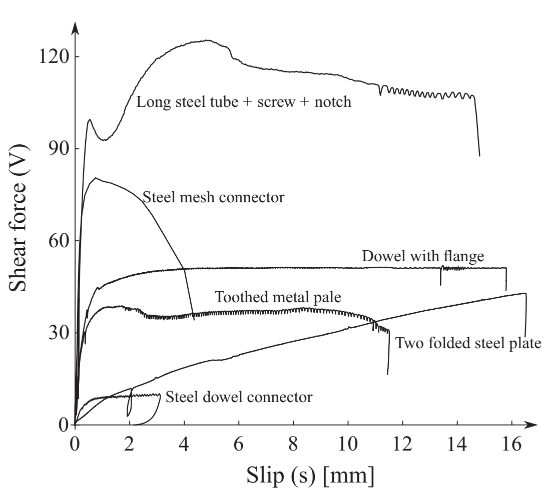

Fig. 1. Load vs. slip curves of various connectors (After [10]).

[18] proposed a simplified estimation of the maximum load for TCC structures by assuming a rigid-perfectly plastic load-slip relationship ($V-s$) where the maximum connection shear strength is reached at the interface. In design practice, when serviceability limit states, such as deflection and vibration, govern the design of the floor, a simplified linear elastic calculation model, such as the γ-method in the Annex B of Eurocode 5 [22], is suitable to design a TCC structure.

By optimizing the connection it is possible to enhance ductility of a TCC structure without compromising its stiffness at the serviceability state. However, in the case of steel dowel connectors, [17] found that the connection stiffness is approximately linearly proportional to the dowel diameter, while the maximum shear resistance of the connection is proportional to the square root of the dowel diameter. In the context of the present discussion, it is challenging to vary the diameter of a steel dowel to achieve the suitable connection resistance, which allows the ductile failure of the structure, as it also affects the connection stiffness and, hence, the flexural stiffness of the structure. The underlying idea of this work is to develop a composite connector with variable properties allowing optimisation of the flexural stiffness, resistance and ductility of TCC structures. The objective of the present work is two-fold: (i) to develop a concept of a new composite connector and characterize its performance by experimental shear tests; and (ii) to assess the gain in the structural performance of a TCC beam by varying the composite connector parameters. The article is structured as follows: Section 2 introduces the connector concept and theoretical background for analysis of the connection and of TCC beams; Section 3 presents and discusses the experimental tests on the proposed connections; Section 4 analyses the experimental results using numerical modelling for better understanding the behaviour of the connection; and Section 5 predicts the structural response of TCC beams with the new connectors using the numerical modelling with the emphasis on the stiffness and ductility of the structure.

2. New connector concept and theoretical background

2.1. Concept of a new composite connector

According to the capacity design approach, in a ductile TCC structure the connection should undergo non-linear deformation before the collapse of the main member. In this study, we developed a prototype of a cylindrical connector made of a concrete shell with or without a steel core. The concrete shell diameter governs the connection stiffness, while the steel core governs the connection resistance. To allow large energy dissipation and micro-cracking resistance special ultra-high performance fibre-reinforced concrete (UHPFRC) is employed. Furthermore, the connector has an elongated shape to provide flexural behaviour, which is predictable by simple models.

2.2. Background on composite beam theory

For the analysis of the connections and TCC beams in this work we employed two existing methods well established for composite structures, such as follows:

1. For the connection analysis, the Winkler model is used, which allows predicting the shear behaviour ($V-s$) of a connection by representing the connector as a beam on an elastic foundation [17,23], as schematically shown in Fig. 2, where: k_c and k_w are the elastic foundation with moduli of the concrete and the timber, respectively; E_sI_s is the flexural stiffness of the steel