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Testing of timber-to-timber screw-connections in hybrid configurations

Gianni Schiro [a], Ivan Giongo [a], Wendel Sebastian [b], Daniele Riccadonna [a], Maurizio Piazza [a,*]

[a] Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano 77, 38123 Trento, Italy
[b] Department of Civil, Environmental and Geomatic Engineering, University College London, Gower Street, London WC1E 6BT, UK

HIGHLIGHTS

- 58 specimens laid out in 14 arrangements were tested under monotonic loading.
- Screw connections for new constructions and retrofit interventions were compared.
- Different fastener types, wood species and timber products were tested.
- Calibration of the theoretical models for screws in hardwood is recommended.

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ABSTRACT

This paper presents the results of an extensive experimental study on the short-term mechanical performance of timber screw connections comprising different types of fasteners (inserted at 45° and 90° to the grain) and different timber products (solid sawn timber, glued laminated timber, cross laminated timber and laminated veneer lumber) made from both softwood and hardwood species. Fifty-eight specimens laid out in fourteen arrangements were tested under quasi-static monotonic loading. The test configurations were meant to reproduce connections used in timber-to-timber hybrid composite structures for applications in both new constructions and retrofit interventions. Result comparisons regarding connection stiffness, strength, static ductility, residual strength and failure mode are presented and discussed. Additionally, the experimental data are used to check the extents of validity of existing analytical approaches (mainly developed for softwoods) to screw connections comprising hardwood elements. Practical aspects concerning screw insertion into hardwood elements are also addressed within the paper.

1. Introduction

Several typologies of self-tapping screws (for use in timber constructions) covering a wide variety of structural applications have been developed over the past two decades and are currently available on the market [1]. A possible way to classify them can be to refer to the fastener threaded part. Three main classes can be identified, namely partially threaded screws (also referred to as single-threaded screws, ST), double threaded screws (DT) and fully-threaded screws (FT, also referred to as all-threaded screws). There are also screws that do not neatly fit into either of these three categories, as they are designed for special purposes like coupling timber with other materials, such as concrete or steel. In contrast to other connector types (e.g. lag screws), there is currently no harmonized standard that establishes the requirements for structural screws. Consequently, each of the three classes (ST, DT and FT) includes fasteners that differ from each other for thread, head and tip geometry. The mechanical properties are provided by the producers in the product standards (e.g. European Technical Assessment, ETA: [22–25]).

It is evident that when such connectors are used in configurations that are not specifically described by the product standards, their performance needs to be evaluated experimentally [2,13]. Extrapolation of the results from other "similar" fastener types is inadvisable, unless these extrapolations are proof-checked by testing. For example, in Eurocode 5 [15] it is advised that the slip modulus of a timber-concrete connection is taken as double the value of the modulus calculated by means of the formula given for a parallel timber-timber connection. That is because an approach has not yet been developed specifically for timber-concrete connections. Hence, in the status quo, these timber-timber extended predictions are backed up by tests on the timber-concrete connections under consideration.

* Corresponding author.
E-mail addresses: gianni.schiro@unitn.it (G. Schiro), ivan.giongo@unitn.it (I. Giongo), w.sebastian@ucl.ac.uk (W. Sebastian), daniele.riccadonna@unitn.it (D. Riccadonna), maurizio.piazza@unitn.it (M. Piazza).

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Notations

The following symbols are used in this paper:

$F_{max,R}$	actual maximum load reached during test [kN]
$v_{max,R}$	connection slip corresponding to the actual maximum load reached during test [mm]
F_{15}	load corresponding to a connection slip of 15 mm [kN]
F'_{max}	mean maximum load according to EN 26891 [kN]
$F'_{max,i}$	maximum load of the i-*th* sample according to EN 26891 [kN]
$v_{0.1}$	connection slip corresponding to a load of $0.1{\cdot}F'_{max}$ [mm]
$v_{0.4}$	connection slip corresponding to a load of $0.4{\cdot}F'_{max}$ [mm]
K_s	slip modulus according to EN 26891 [N/mm]
K_{ser}	slip modulus according to EN 1995-1-1 [N/mm]
K_{lat}	lateral slip modulus (perpendicular to the screw shank) [N/mm]
K_{ax}	axial slip modulus (parallel to the screw shank) [N/mm]
F_y	yield load according to EN 12512 [kN]
v_y	yield connection slip according to EN 12512 [mm]
F_u	ultimate load according to EN 12512 [kN]
v_u	ultimate connection slip according to EN 12512 [mm]
D	ductility of connection
μ	friction coefficient for wood to wood surface

The present paper focuses on connection configurations that are intended for use in the field of timber-to-timber composite structures where the fasteners may be inserted at an angle to the grain other than 90° and may connect different timber products (e.g. solid sawn timber with cross laminated timber) and/or elements from different timber species (e.g. softwood elements with hardwood elements). Extensive details on the tested configurations and the purposes they are designed for, will be provided in Section 2.

Structural solutions in which DT and FT screws are loaded in a combination of shear and tension are becoming more common. Interesting studies into the mechanical performance of such connections (softwood) can be found in the literature [3,4], where formulations to evaluate connection strength and stiffness are also proposed. However, to the best of the authors' collective knowledge there are no data available on ST screws loaded in a shear-tension configuration, despite available evidence of applications showing advantages from such use [5].

The optimization/specialization process that leads to widening of the timber fastener range also involves timber as a construction material. Wood based structural products now include solid sawn timber, glued-laminated timber, laminated veneer lumber and cross-laminated timber. "New" wood species (such as poplar, oak, birch and beech) are being actively considered for structural purposes by the construction industry (see [6–8]) and will soon compete with the traditional (for construction) softwood species (e.g. pine, spruce, larch).

This will only be really possible once the performance of mechanical connections realized with these new products (often characterized by very high density values) has been thoroughly investigated and sound analytical formulations to predict their behavior have been developed.

Studies including [9–12] have provided first insights that will help close the gap between the availability of new engineered components in renewable materials with high mechanical performance and the wide application of these components in real construction projects.

In the following sections of this paper, the outcomes of an extensive experimental campaign on short-term testing of timber screw-connections comprising specimens realized with multiple combinations of timber products, screw types and screw configurations, will be presented. The specimens and tests are first described, following which interpretation of the results to infer connection properties on strength, stiffness and ductility will be presented. Finally, conclusions are drawn.

2. Connection tests

2.1. Test configuration and geometry

The experimental campaign was carried out at the laboratory of the Department of Civil, Environmental and Mechanical Engineering (DICAM) of the University of Trento and totalled 58 pushout tests covering 14 configurations. Different solutions were investigated in order to characterise the mechanical behaviour, in terms of stiffness, strength, static ductility and residual strength of connections mainly designed for the realisation of timber-to-timber composite (TTC) floors. The significant parameters that describe

Table 2-1
Test configurations.

Test		App.	Central element	Interlayer	Side elements		Connections		
ID	n°		Type	t_i [mm]	Type	t_s [mm]	Type	Washer	α
PA	4	N	Beech LVL beam	–	CLT panel	57	DT_A 8.5 × 150	–	45°
PB	4	N	Beech LVL beam	–	CLT panel	57	ST_A 10 × 220	W+GC	45°
PC	4	N	Beech LVL beam	–	Beech LVL panel	40	ST_A 10 × 160	W+GC	45°
PD	5	N	Beech LVL beam	–	Beech LVL panel	40	ST_A 10 × 220	SW	45°
PE	5	N	Beech LVL beam	–	Beech LVL panel	40	ST_A 10 × 220	W	90°
PF	5	R	Spruce Solid wood	20	Beech LVL on its side	50	ST_A 10 × 220	W+GC	45°
PG	2	R	Spruce Solid wood	20	Beech LVL on its side	50	ST_A 10 × 220	GC	45°
PH	3	R	Spruce Solid wood	20	Beech LVL on its side	50	DT_A 8.5 × 190	–	45°
PI	3	N	Spruce Solid wood	–	CLT panel	57	DT_A 8.5 × 150	–	45°
PL	3	N	Spruce Solid wood	–	CLT panel	57	ST_A 10 × 220	W+GC	45°
PM	5	R	Spruce Solid wood	20	CLT panel	57	DT_B 8.2 × 190	–	45°
PN	5	R	Spruce Solid wood	20	CLT panel	57	ST_B 10 × 200	W+GC	45°
PO	5	R	Spruce Solid wood	20	CLT panel	57	ST_B 10 × 200	W	90°
PP	5	R	Spruce Solid wood	20	CLT panel	57	ST_B 10 × 200	–	90°

Note: n°: Number of repetitions; App.: Application; N: New application; R: Retrofit application; W: Washer; ST: Single threaded screw; GC: Groove cut; SW: Special washer; DT: Double threaded screw.