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Experimental analysis of Maritime pine and Iroko single shear dowel-type connections

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HIGHLIGHTS

- Timber connections represent a reduction of continuity and strength.
- An extensive experimental campaign is presented with Maritime pine and Iroko.
- Iroko presents higher embedment strength for parallel to the grain direction.
- Maritime pine and Iroko have similar performance for self-tapping screwed connections.
- Both species comply with the requirements from Eurocode 5.

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ABSTRACT

In this study, screwed connections were experimentally evaluated, checking the plausibility of Eurocode 5 for two selected wood species, Iroko (*Milícia excelsa*) and Maritime pine (*Pinus pinaster*). Single shear screwed connections, considering self-tapping screws, were tested and the experimental campaign aimed at evaluating various mechanisms of resistance suggested by Eurocode 5 for this typology of connection, including axial withdrawal capacity of the screw, pull through parameter for screws, and local embedment of wood. The experimental results evidenced that the analyzed connection system had similar results with either wood species. The results were consistent with the calculation through Eurocode 5.

1. Introduction

In timber structures, connections are weak regions as they represent a reduction of continuity and strength, leading to the need to have overdesigned elements. Around 80% of failures occurring in timber structures are caused by connection related issues [24].

Dowel-type connections are among the most common connections in timber structures. The term dowel is broadly used for normal, self-drilling or tapping screws, nails, pins and dowels themselves.

Calculation of the load bearing capacity of dowel-type connectors subjected to shear, as example screwed connections, are based on Johansen's theory [25]. The model proposed by Johansen and its developments were the source for the EYM (European Yield Model), which is present in several standards and design codes, such as the present version of Eurocode 5 (EN 1995-1-1:2004) [13] with the adaptations that have been done since it was first published. The EYM is an analysis model that allows to determine the load bearing capacity of dowel-type connections between two or three timber elements and is based on the stress equilibrium applied to the connector inserted in the timber element. It is a rather simple method, which provides better results for slim ductile connectors [31], however it lacks a stringent mechanical basis [9]. Besides the geometrical characteristics of the connection, there are two essential parameters: the embedment strength of timber and the yielding moment of the fastener.

The validity of Johansen's theory has been verified several times, as instance in the experimental campaigns of Trayer [44], McLain and Thangjitham [28] and Soltis et al. [42], among others. According to it, the embedment strength of timber and the yielding moment of the fastener are the main parameters that govern the strength of dowel-type connections. Several studies have analyzed embedment strength of timber and of wood products.

Whale et al. [49] made an extensive work on the embedment strength of softwoods, hardwoods and plywood using nails and

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screws as connectors, while Ehlbeck and Werner [10] studied the embedment strength of hardwoods under loading with different angles of application.

These two studies, that make part of the basis of Eurocode 5, only deal with the ultimate embedment strength, does not presenting any information regarding the elastic range. Kawamoto et al. [26] experimentally analyzed the embedment strength on the direction perpendicular to the grain on glued laminated timber. Harada et al. [19] and Hwang and Komatsu [21] analyzed the relation between the dowel diameter and the embedment strength on glued laminated timber and wood products, respectively.

Sawata and Yasumura [39] conducted a wide experimental campaign for the quantification of the embedment strength in both parallel and perpendicular to the grain directions. Recently, Santos et al. [37], Santos et al. [38] analyzed the embedment strength of *Pinus pinaster* in the parallel to the grain direction. In the study of Sandhaas et al. [36], embedment tests parallel to the grain direction and ductility aspects using various species were analyzed and comparisons were made with the design equation from Eurocode 5. In that study it was found that the equations penalises species with higher density.

Screwed connections, which are specially designed to transfer load in the axial direction, present an excellent solution for timber structures due to its easy application and higher withdrawal resistance. In the past years, several types of screws, with different shapes and materials, have been subject of interest by the scientific and technical communities. In Blass and Bejtka [5], a comparison between results of connections with inclined screws and fasteners loaded perpendicular to their axis evidenced the opportunity of use for connections with inclined screws, especially concerning the rationalization and reduction of costs for timber-to-timber connections on design and installation. Moreover, in Bejtka and Blass [4], a proposal for design rules for single-shear joints with inclined screws is presented, where it is possible to determine the load-carrying capacity for timber-to-timber connections with inclined screws taking into account the withdrawal and bending capacity of the screws, the timber embedding strength and the friction stress between the timber members. In that study, the withdrawal behaviour of the screws is taken into account in Johanseń's extended yield theory using a modified withdrawal capacity parameter.

The load carrying capacity and base parameters for screwed connections is also discussed in Blass et al. [6] and Pirnbacher et al. [32] and the withdrawal capacity of self-tapping screws is further analyzed in Frese and Blass [11], in Hübner [20] for hardwoods and in Ringhofer et al. [35] for unidirectional and layered timber products.

In Tomasi et al. [43], an analysis was made to timber-to-timber joints (*Picea abies* Karst. glued laminated timber) connected with inclined screws, where the experimental values of strength and stiffness were compared with the theoretical ones obtained using Eurocode 5. On that study it was concluded that Eurocode 5 is partially unsuitable for describing the experimental results of strength and stiffness for those particular connector configurations. Comparison of the Eurocode 5 formulation with experiments on dowel-type connectors (on Norway spruce, *Picea abies*) has also been considered in Dorn et al. [9], where for connections of intermediate slenderness, the theoretical formulation provided conservative design values for strength. Whereas, in some of the experiments, the design values overestimated the actual strengths considerably in connections of low, as well as of high, slenderness. These studies revealed the importance to test different connection systems and to compare the results with the theoretical formulation.

To that aim, this work analysis the use of two different wood species which until now have not been aim of thorough investigation. Actually, few are the studies that compare connection systems with self-tapping screws using European and African native woods, such as Maritime pine (the most important Portuguese wood species) and Iroko. The mechanical behaviour of the connections obtained experimentally will be compared with the formulation of Eurocode 5 (EN 1995-1-1:2004) [13] including its adaptations.

With respect to Maritime pine, Machado and Cruz [27] analyzed its mechanical properties accounting to the within stem variation, whereas in Branco et al. [7], an experimental campaign was made considering laterally loaded nailed timber-to-timber connections for evaluation of the adequacy of Eurocode 5 formulation. In Santos et al. [37], Maritime pine was experimentally analyzed to obtain data for implementation in an analytical model and for a three dimensional finite element model, whereas in Cruz [8] a predictive model based on embedment properties was proposed considering the behaviour of structural timber joints of Maritime pine under cycling loading.

On the other hand, connections used with Iroko wood have even been less studied than those used with Maritime pine. As instance, the use of Iroko for carpentry and construction purposes has only been residual in some African countries [1,30], even if studies have been made to grade different types of native African species where Iroko was found to be suitable for structural purposes [2,29]. However, its use has been only considered in small elements, such as for studs between limecrete slabs and spruce glulam beams [40]. Therefore, this work also intends to provide information about the possible use of Iroko in a common structural connection system, comparing it to the use of Maritime pine timber.

2. Experimental campaign

In this topic, the main steps of an extensive experimental campaign are presented with the objective of assessing the mechanical behaviour of self-tapping screw connections on two different wood species: Maritime pine and Iroko. Table 1 sums up the tests that were made.

Besides the connections themselves, the parameters that influence their load bearing capacity were also considered. Thus, embedment strength of timber in presence of metallic dowel and screw withdrawal tests for the three main directions (longitudinal, tangential and radial) of structural timber if approximated as continuum with linear elastic orthotropic properties, and different penetration depths were made, as well as the analysis on the headside pull-through strength.

Table 1
Experimental campaign.

Test			Number of tests	
Embedment strength EN 383:2007 (with metallic dowel)	Direction		Maritime pine	Iroko
	Parallel to the grain		49	49
	Perpendicular to the grain		49	49
Screw withdrawal UNI EN 1382:2002	Direction	Penetration		
	Tangential	8d	7	7
		10d	7	7
		12d	4	5
	Radial	8d	7	7
		10d	7	7
		12d	2	5
	Parallel	8d	8	8
		10d	4	4
		12d	4	4
Screw headside pull-through UNI EN 1383:2002			22	24
Simple shear of screwed connections UNI EN 26891:2001			20	21