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# An experimental comparison of strengthening solutions for dowel-type wood connections

Cristóvão L. Santos [a], Abílio M.P. de Jesus [b,*], José J.L. Morais [c], Bruno F.C. Fontoura [c]

[a] Engineering Department, School of Sciences and Technology, University of Trás-os-Montes e Alto Douro, Quinta de Prados, 5001-801 Vila Real, Portugal
[b] IDMEC/Engineering Department, School of Sciences and Technology, University of Trás-os-Montes and Alto Douro, Quinta de Prados, 5001-801 Vila Real, Portugal
[c] CITAB/Engineering Department, School of Sciences and Technology, University of Trás-os-Montes and Alto Douro, Quinta de Prados, 5001-801 Vila Real, Portugal

## HIGHLIGHTS

- A comparison of reinforcing techniques is proposed for doweled wood joints.
- Glued metallic inserts are compared with CFRP laminates using static tests.
- The CFRP laminate eliminate the brittle failure modes in doweled joints.
- The metallic insert increase significantly the stiffness of doweled T-joints.
- The metallic inserts were not able to eliminate the brittle collapses.

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## ABSTRACT

This paper presents an experimental investigation of the development of adhesively bonded reinforcing techniques for dowel-type wood connections. One of the proposed techniques is based on the application of carbon fiber reinforced plastic (CFRP) laminates (glued with epoxy adhesives) in the areas surrounding the holes of the wood members. The other technique is based on a novel reinforcing procedure involving the application of steel inserts that are glued to the holes of the timber members. For this latter technique, two distinct commercial epoxy adhesives were investigated. Both techniques were demonstrated for maritime pine wood. The experimental program comprised embedding tests, carried out according to the procedures of the EN 383 standard, with and without reinforcements, and included both parallel- and perpendicular-to-grain quasi-static loading. The embedding strength and foundation modulus were determined and compared between the non-reinforced and reinforced solutions. Furthermore, three series of single dowel T-connections were tested, one without reinforcement and two series reinforced with metallic inserts and CFRP laminates, respectively. The analysis of the experimental results showed the improved performance of the strengthening solutions. Additionally, it is important to emphasize that the reinforcement based on CFRP laminates was more effective in eliminating brittle failure modes in the wood members.



## 1. Introduction

Connections are often the weakest points in timber structures. The loss of perfect continuity in the structure, which is caused by the presence of connections, will result in a reduction of the global strength that requires an increase in the dimensions of the assembled elements. Approximately 80% of structural failures originate at connections [1]. Dowel-type connections are the main fastening technique used worldwide in timber structures. The singular approach to wood connections can be attributed not only to the effectiveness of combining different materials, such as wood and steel, but also to the highly anisotropic behavior of wood. Fundamental to an efficient utilization of dowel-type connections is the understanding of their mechanical behavior under loading (e.g., load-slip behavior, stress distributions, ultimate strength, and failure modes). The mechanical behavior of wood connections is a complex problem governed by a number of geometric, material, and loading parameters (e.g., wood density, fastener slenderness, end distances, edge distances, spacing and number of fasteners, fastener/hole clearances, friction, and loading configuration).

According to the widely accepted design rules [2,3], the calculation of mechanical timber connections is based upon Johansen's theory, which is known as the European Yield Model (EYM) [4].

* Corresponding author. Tel.:/fax: +351 259 350 356.
*E-mail addresses:* clsantos@utad.pt (C.L. Santos), ajesus@utad.pt (A.M.P. de Jesus), jmorais@utad.pt (J.J.L. Morais), bruno-fontoura@hotmail.com (B.F.C. Fontoura).

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In this model, the embedding strength of wood is a material parameter governing the failure of wood members. The EYM only predicts the ultimate loads associated with ductile failure modes; brittle failure modes (e.g., shearing out, splitting perpendicular to grain) are not foreseen [5]. Because the EYM does not allow modeling of brittle failure modes, design codes prescribe empiric minimum dimensions for connections (e.g., dowel holes to end member distances) to avoid the brittle failure modes, which compromise structural safety. In addition to the minimum distances suggested by EC5, the fastener slenderness may be controlled to allow ductile failure modes.

The reinforcement of dowel-type connections for the purpose of improving the mechanical performance of the connection, including the reduction of brittle failure modes, is challenging. Reinforcing techniques may be used to increase the reliability of the dowel-type connections and to contribute to an efficient use of materials. Several reinforcing techniques have been proposed to improve the stiffness, strength, and ductility characteristics of connections (e.g., resin-injected dowels, expanded tube connections, shear plate connectors, glued composites such as glass fiber reinforced plastics (GFRP), and bonded textile reinforcements) [6–9].

One of the most widely used reinforcing techniques involves applying high-strength, stiff materials on the side faces of wood members, around the holes. Typical reinforcing materials include high-density wood, transformed wood-based products (e.g., densified wood), metallic plates, and fiber-reinforced composites (FRP). The reinforcements may assume various shapes, such as rectangular plates or reinforcing rings, and may be glued or simply nailed to the wood members. These types of reinforcements aim at increasing the perpendicular-to-grain failure resistance and increasing the embedding strength [6,8].

Resin injection dowels have also been used to increase the connection stiffness. The resin fills the clearance between the dowel and the holes, allowing a better stress distribution around the holes, increasing the ultimate strength of the connection, and improving the immediate load take up of the connection [7].

Larsen and Jensen [6,10] proposed the use of semi-rigid connections made of expanded tube fasteners replacing the solid dowels to increase the ductility of the connection and, consequently, the energy dissipation capacity.

A new reinforcing solution based on bonded metallic inserts has been proposed for high-performance composite materials [11,12]. This paper proposes the extension of this technique to dowel-type wood connections. Based on an experimental approach, the authors demonstrate the potential of this reinforcing technique. Embedment tests were carried out on unreinforced and reinforced series, according to the procedures of the EN383 standard [13]. The embedment tests were carried out on maritime pine wood (*Pinus pinaster* Ait.) for both the parallel-to-grain (longitudinal) and perpendicular-to-grain (radial) directions, allowing the comparison of the embedding strengths and foundation moduli.

Additionally, this paper assesses an alternative reinforcing technique based on the application of CFRP laminates glued with epoxy resin to the side faces of the wood members and surrounding the holes made for insertion of the dowels. The performance of this reinforcement is also demonstrated using embedment tests, according to the procedures of the EN 383 standard, along the longitudinal and radial directions of the wood.

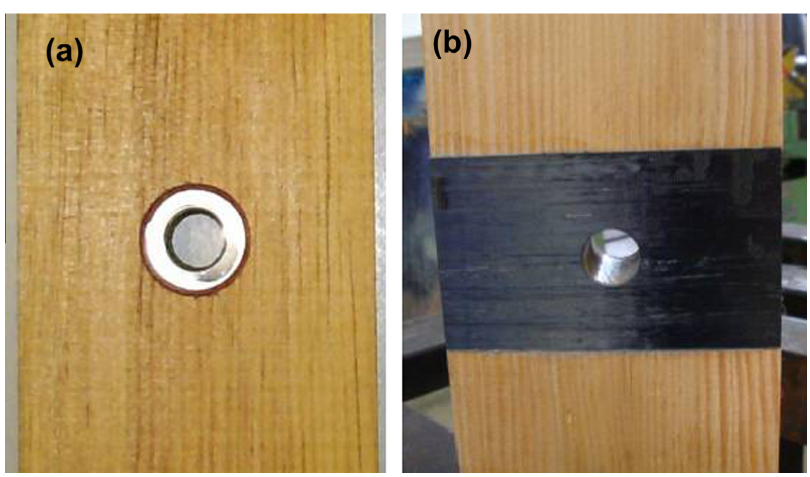


**Fig. 1.** Reinforcing techniques: (a) bonded metallic inserts; (b) bonded CFRP laminates.

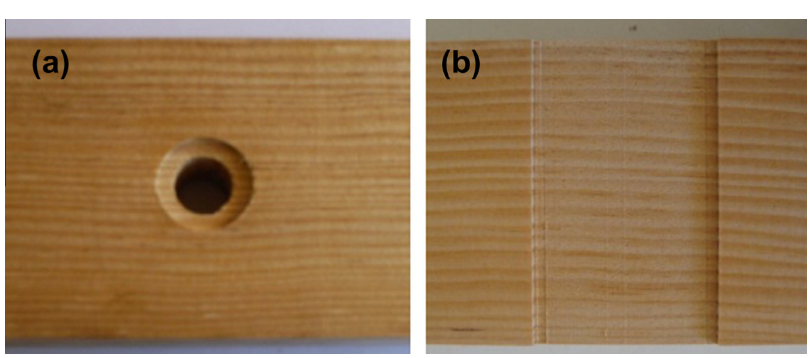


**Fig. 2.** Preparation of wood members for: (a) metallic insert application; (b) CFRP laminate application.