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Densified wooden nails for new timber assemblies and restoration works: A pilot research

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HIGHLIGHTS

- Densified wooden nails have been developed.
- Compression tests analyze buckling of nail and damage of board during nail driving.
- Push-out tests analyze joint behaviour.
- Joint ductility depends on limitation of damage and flaws during installation.

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ABSTRACT

The use of wood-based connectors as a possible substitute of metal fasteners, for specific applications, in modestly loaded and moderately dense timber components, in new timber assemblies as well as for restoration works, is discussed. The densification technique has been used to obtain a wood-based material with higher mechanical performance with respect to the natural wood. A dedicated research has been carried out to monitor the compression behaviour of the wooden nails. The progress of pushing force during insertion of the wooden nails into wood samples was analysed and served for insertion process control. 600 compression tests were carried out to evaluate the mechanical behaviour of densified wooden nails, obtained from four different hardwood species and with different densification ratios. Beech, densified at 0° ring angle, 60% densification ratio, was selected for the further experimental campaign on the joints.

Ten push-out tests have been performed on timber-to-timber joints. Results in terms of rigidity, resistance and post-elastic behaviour are discussed. The observed variability (slip modulus CoV = 26.7%, maximum load CoV = 23.7%) is mainly dependent on the occurrence of geometric flaws during nail insertion. Ductility exhibited by a group of joints was given by nail embedding into the wood before failure as well as by the bending resistance of the nail. The choice of an optimized technology for wood densification and for nail insertion is considered as a key factor for the optimal employment of the novel connectors.

1. Introduction

Nails represent the easiest and fastest method to connect timber members. Nails are also the oldest metal fastener type, as evidenced by Egyptian findings dating back to ca. 3400 BC [1]. However, nails were initially used with wood not to fix structural members together, but rather to attach cladding, veneering, plating, etc. The extensive use of nails in building constructions appeared during antiquity in connection with the use of wooden shuttering for Roman Concrete [1].

Hardwood connectors, such as a nails and pegs, were used in the past, instead of metal fasteners, for timber constructions exposed to wet environments. This is the case of the so-called treenails or trunnels, typically used in shipbuilding, in timber framing, such as in bridges or watermills, and to secure rail-support chairs to wooden sleepers [2]. These had the advantage of avoiding the occurrence of decay concentration around metal fasteners, so-called "nail-sickness". Moreover, increased water content causes wood to expand, so that trunnels gripped the assembly tighter as they absorbed water. Similarly, wooden nails were used to fix laths to ceiling or walls, being more compatible than iron nails with the gypsum or lime plaster. Wooden connectors in the form of wedges, dowels and pegs are often present as reinforcement of carpentry joints, in particular for scarf joints. For this

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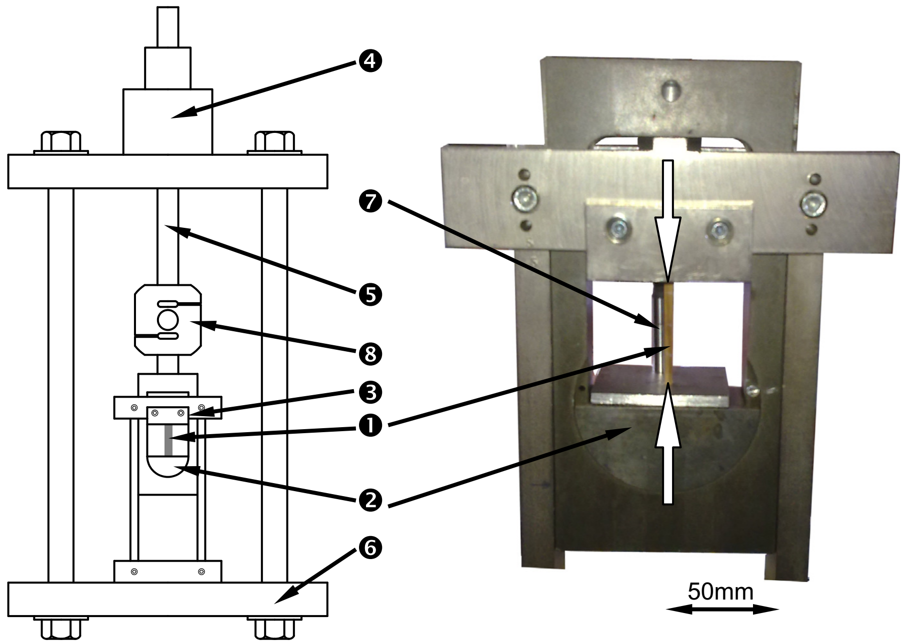

Fig. 1. Experimental setup for compression test: ❶ sample, ❷ bottom bearing block, ❸ upper bearing block, ❹ hydraulic piston, ❺ acting arm, ❻ machine frame, ❼ LVDT, ❽ load cell, *Note:* white arrows indicate the loading direction.

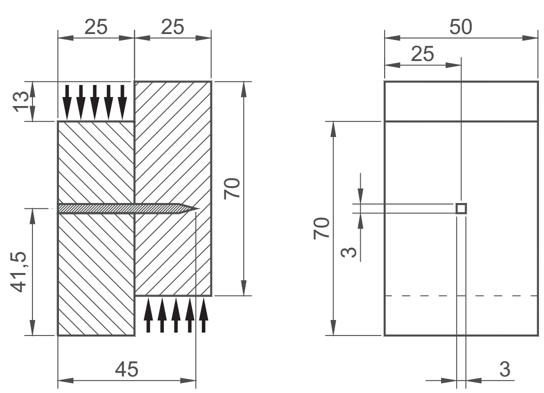

Fig. 2. Specimen geometry (dimensions in millimeters).

application, dense hardwood species, such as read oak (*Quercus rubra* L.), European ash (*Fraxinus excelsior* L.) and black locust (*Robinia pseudoacacia* L.) are typically chosen.

Nowadays, wood can be modified with technologies such as densification, in order to achieve increased density, decreased porosity and improved material strength, hardness and dimension stability. Densification belongs to the family of hydro-thermo-mechanical modifications of wood. Most authors date back initial development of wood densification technologies to early 1900s [3]. However, an interesting pioneering use of densified wood was proposed in England already in 1841 as a development of the treenails used to fasten the railway chairs [4].

As in the application reported, modification of densified wood is not stable, if the material is not post-processed after the densification. In fact, the wood tends to undergo irreversible "springback" or recovery from compression when exposed to moisture. In some applications, this was however a desired effect, increasing the tightness of the connection. Nowadays, technological developments permit to obtain densified wood with enhanced mechanical properties and stabilised dimensions. In the past few years, there have been many studies on mechanical properties of densified wood (see e.g. in [5]). Several attempts have been reported, also, to develop wood-based dowel-type fasteners, using densified wood (e.g. 5–9). The cited researches give an interesting overview of the possibilities given by wood densification, for the production of different types of connections, such as nails, bolts and rods. One of the motivations of these studies is the environmental advantage of using engineered wood-based fasteners, which improve recyclability and reuse rate of wood resources, in case of disassembly. Additional characteristics of wood-based connectors are light weight and compatibility with the assembled material, which is an advantage in both new constructions and restoration works.

In the research reported in this paper the possibility to rely on enhanced mechanical and technological properties of densified wood, for the production of wooden nails, is discussed, and some preliminary results are presented.

2. Materials and methods

2.1. Technology of wooden nails

In the experimental campaign reported in a preceding publication [10], four hardwood species were chosen to produce the densified wooden nails to be tested: European beech (*F. sylvatica* L.), European aspen (*P. tremula* L.) commonly called poplar, European ash (*F. excelsior* L.) and black locust (*R. pseudoacacia* L.) [10]. The latter two species were traditionally used for wood connectors. Samples of non-modified wood were also tested for comparison.

The material to be densified was prepared in the form of boards, selecting timber devoid of macroscopic heterogeneities such as knots, splits and pith. The initial moisture content of the boards was approximately 12%. The densification process was performed at the CNR-IVALSA laboratories, using an open system (i.e. atmospheric pressure) hot press. The hot press temperature was set to 180 °C. The densification cycle followed the literature references and was composed of: 10 min pre-heating (plasticization), 10 min densification, 5 min post treatment and 5 min cooling. Samples were clamped during cooling, to limit distortions. The densified wood was not post-treated.