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Chestnut wood in compression perpendicular to the grain: Non-destructive correlations for test results in new and old wood

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Abstract

This paper addresses the evaluation of the compressive properties of chestnut wood under compression perpendicular to the grain, using destructive and non-destructive methods. Three non-destructive methods (ultrasonic testing, Resistograph and Pilodyn) are proposed and the possibility of their application is discussed based on the application of simple linear regression models. Timber specimens were tested up to failure, divided in two different groups for assessing a possible load history related degradation, namely New Chestnut Wood (NCW), never been used structurally, and Old Chestnut Wood (OCW), obtained from structural elements belonging to ancient buildings. The specimens were also divided into four groups according to the orientation of annual growth rings towards load and wave propagation direction. The results show, in general, good correlations between compression strength and stiffness with non-destructive techniques via ultrasonic testing, Resistograph and Pilodyn. However, the orientation of the loading direction with respect to the annual growth rings must be taken into account. This conclusion, and the observation that NCW and OCW shows correlations and regression models usually different, add additional complexity to the quantitative use of non-destructive evaluation techniques for the assessment of the mechanical behaviour of timber elements.

Keywords: Chestnut wood; Compression perpendicular to the grain; Non-destructive methods; Ultrasonic testing; Resistograph; Pilodyn; Ancient structures

1. Introduction

Timber is an anisotropic material showing significant mechanical properties differences when loaded parallel or perpendicular to grain. A ratio between parallel and perpendicular strength of 30:1 in tension and 5:1 in compression is generally found for hardwoods species. In the case of traditional timber buildings, given the marginal strength of wood in tension perpendicular to grain, the structural system is usually conceived in such a way that any load transferred perpendicular to grain must be in compression. Therefore, wood compressive behaviour perpendicular to the grain is of crucial importance for design and safety assessment purposes.

In rehabilitation works of ancient timber structures, in situ inspection and evaluation of mechanical properties represent a first step towards diagnosis, structural analysis and possible remedial measures. Structural assessment comprises the need for answers regarding strength of sound timber elements, as well as regarding the effect of local damage due to biological attack (usually associated with excessive moisture). Non-destructive evaluation (NDE) plays a key role here, usually adopted for qualitative evaluation. Gradual steps towards quantitative evaluation have

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been made recently since the removal of samples and their destructive testing is time-consuming, unpractical and, often, even not feasible.

The efficiency and reliability of NDE methods can be increased if extensive laboratorial tests are used to provide correlations with the mechanical characteristics of wood [1,2]. In particular, the last decades witnessed developments in the NDE techniques, equipments and methods that allow increasing their accuracy. NDE can be grouped in Global Test Methods (GTM) and Local Test Methods (LTM) [3,4]. The former includes e.g. the application of the ultrasonic and vibration methods [5,6]. The latter plays usually a leading role in the support of visual inspection, being the Resistograph [7] and the Pilodyn [8] the most common techniques. The general characteristic of all methods is their easy usage and transport, plus the fast in situ application.

The most relevant material properties when dealing with compression perpendicular to the grain are the compressive strength and the elasticity modulus. Experimentally, these properties can be obtained according to different standards, being the Brazilian Standard NBr 7190 [9] adopted in the present paper. Wood micro-structure leads to behaviour in compression perpendicular to the grain characterized by an absence of a clear failure of the material associated with very high strains. In addition, the loading direction with respect to the annual growth rings leads to very different stress–strain diagrams. In fact several authors consider the loading direction more important than the differences between wood species [10,11].

Some authors pointed out that wood behaviour in radial compression is strongly dependent on its anatomical features [10,12,13], but others authors believe that elastic behaviour is more dependent on density than on anatomical characteristics [14,15]. In practical situations, the influence of the loading direction seems less relevant due to the difficulties of finding, in a real structure, timber elements exhibiting a particular orientation. Therefore, tests should be made using random loading directions. It must be also taken into account that the failure mode observed for a 45° slope, which provides the lowest strength values for transversal compression [16], is common in prismatic standardized specimens without apparent defects, but it is rarely observed either when structural dimensions specimens are used or in engineering applications.

The testing set-up and procedure also seems to have direct influence on the derivation of strength and elastic properties. Depending on shape and dimensions, thickness and stressed area, different relations between strength and elastic properties of wood may be obtained [17,18].

The impact of load history and time over strength and stiffness of structural timber elements has raised some discussions but generally, if no damaging action occurred, there is no loss of mechanical properties. This observation is also due to the large range of strength values generally obtained for each wood species and grade (coefficient of variation around 20–40%). Usually, inspection of old timber structures show that large deformations, that could possibly have been linked to exceptional loading conditions, are often the result of using green round or square elements and excessive moisture conditions during the history of the structure.

The objective of this paper is to discuss the possibility of using NDE methods for the evaluation of strength and stiffness of chestnut wood (*Castanea sativa* Mill.) in compression perpendicular to grain. This wood is usually present in historical Portuguese buildings, given not only its mechanical and durability properties, but also its aesthetic characteristics. The effect of annual rings orientation towards load direction and the effect of age-related degradation are taken into account. Regression analyses are carried out in order to obtain correlations between mechanical properties and density and non-destructive methods.

2. Test specimens

The average size of the specimens adopted in the testing program was originally $50 \times 50 \times 300$ mm^3. Ultrasonic tests were carried out in these specimens and, afterwards, each specimen was cut in three smaller samples of $50 \times 50 \times 100$ mm^3: two specimens were tested in laboratory up to

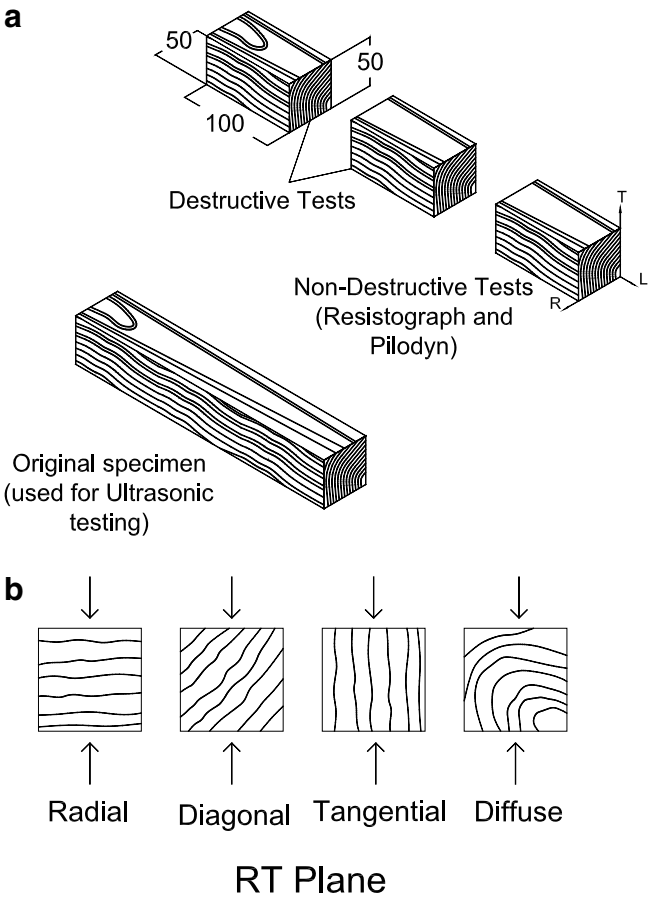

Fig. 1. Specimens used in the testing program: (a) nominal dimensions in mm and (b) annual growth rings orientation with respect to the loading direction.