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Application of instrumented micro-indentations to 'in situ' mechanical characterization of wooden structures: Part I—Analysis of highly selected and decayed pinewood samples

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Abstract

The need for an experimental protocol, which allows determining overall mechanical properties of wooden structures by using a local, non-destructive and 'in situ' implemented testing procedure, has pushed towards the definition of several methodologies.

In this work, an application of an instrumented micro-indentation, based upon a flat punch, is investigated, aimed at defining a technique less affected by typical discontinuities, defects and alterations of wooden materials, which, severely, jeopardize the reliability of all the other available testing procedures.

First, a calibration of the experimental procedure is carried out, taking care of the influence on the collected data of the actual samples dimensions, their weight, number of growth rings, growth rings width, distance between indentation location and latewood layer and depth along indentation axis. Then, an application of testing procedure on pinewood is performed and strict criterion in executing experiments and choosing wooden specimens is defined to improve the reliability of results. At last, the capability of instrumented micro-indentations in detecting overall mechanical properties of new and decayed samples is checked out, stating the high sensitivity and effectiveness of the procedure.

Keywords: Micro-indentation; Pinewood; Testing procedure

1. Introduction

The mechanical properties of wood are generally obtained from extensive testing and analysis procedures of small "clear" and "straight grained" wooden samples because they do not contain characteristics such as knots, cross grain, checks, and splits [1]. Moreover, these samples need have anatomical characteristics such as growth rings that occur in consistent patterns within each piece, giving rise to a sort of 'homogeneous' material.

Variability, or variation in properties, is common to all materials. Because wood is a natural material and the tree is subject to many constantly changing

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influences (such as moisture, soil conditions, and growing space), wood properties vary considerably, even in clear material. The effects of growth features, such as knots and slope of grain, definitely influence the overall mechanical properties of woods varying their specific gravity as well as natural defects, which may occur as a result of biological or climatic elements influencing the living tree. These aspects must be taken into account in assessing actual properties or estimating the actual performance of wood products.

The decay can also affect the wood strength. Early stages of decay are virtually impossible to detect. For example, brown-rot fungi may reduce mechanical properties in excess of 10% before a measurable weight loss is observed and decay is visible [2]. When weight loss reaches 5–10%, mechanical properties are reduced from 20% to 80% [2]. Decay has the greatest effect on toughness, impact bending, and work to maximum load in bending, the least effect on shear and hardness, and an intermediate effect on other properties. Thus, when strength is an important issue, adequate measures should be taken to prevent decay before it occurs, control incipient decay by remedial measures, or replace any wood member in which decay is evident or believed to exist in a critical section. No method is known for estimating the amount of reduction in strength from the appearance of decayed wood [3]. Therefore, the safe procedure is to discard every piece that contains even a small amount of decay.

2. Background

Different methods, essentially based on the micro-seismic excitations, like ultrasonic wave propagation, are available and proposed with reliable procedure for quality control of the wood [4–6]. However, the application of the micro-seismic survey techniques to non-isotropic, non-homogeneous or composite materials presents a relevant number of concerns and doubts. For instance, decayed wood, with the presence of hidden micro-voids, is not well suited for ultrasonic wave propagation. In fact, the interpretation of results is too much affected by the problems of reflection and refraction of the elastic wave at the border of the two different media [4]. Moreover, from the physical point of view, ultrasonic frequencies and in particular the lowest, like those used for concrete, are characterized by a wave propagation front very spread and therefore not well suited to sharply catch the presence of micro-voids [5,6]. On the other hand, different kinds of discontinuity in the texture of the material, a common feature of decayed old wooden structural elements, which may deeply affect the residual and actual resistance capacity [7,8], are almost impossible to detect with such techniques [9].

Methodologies based on mechanical tests seem to have parameters, which can be handily calibrated and taken under control, when testing wooden structures and estimating the decay, in a more reliable way than other techniques [3]. Among mechanical testing procedures, ‘in situ’ penetration test seems to be a very promising technique in assessing wood properties and decay [10]. It is supposed to work on the basis of the number of blows necessary for the wood penetration, centimeter after centimeter, of a graduated rod, connected to a constant energy rebound hammer. However, even in this technique, the variation of the number of blows is not only a function of the overall wood mechanical properties or decay [10]. It is affected, at a large extent, by several parameters as the geometry of the graduated rod and of the tip, to avoid, or at least to minimize, instability and friction problems and the hardness and compactness properties of wood fibers, which are strictly linked to the specific wood species, fiber direction and water content [10]. As well known, other defects, such as knots, resin pockets and ring growth irregularity, can also have a great influence on measures, even if the effects are essentially localized [10]. Moreover, the relevant size of the hole and stress on structure produced by this procedure make such technique not so effective in evaluating wooden properties.

In such context, as an alternative to ‘in situ’ penetration technique, an instrumented micro-indentation, using a flat punch, is arisen. The main advantage of the micro-indentation is connected to the small sizes of indenter diameter (generally 1 mm, but smaller sizes are acceptable) [11]. Besides, this technique is characterized by low friction phenomena between indenter and substrate during the indentation, low depth of indentation (also few hundreds of micron or less), sensitiveness of procedure, which makes use of high precision load cells as well as by the absence of impact between indenter and substrate [11,12]. In addition, the possibility of performing tests on highly selected small pieces of wood not affected by defects or alterations, which could determine less reliability of experimental results, and the practically non-destructive characteristic of testing procedure represent further relevant returns.