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Semi-destructive in situ tests as support to the assessment of a conservation process

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HIGHLIGHTS

- Efficiency assessment on site by of a conservation process.
- SDT methods of drill resistance and penetration resistance.
- Structural and non-structural scots pine wood (*Pinus sylvestris* L.) elements in service.
- Mechanical characteristics of wood degraded by fungi after treatment and consolidation.
- This SDT methods showed good sensitivity to the conservation process.

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ABSTRACT

This paper refers to the assessment on site by semi-destructive testing (SDT) methods of the consolidation efficiency of a conservation process developed by Henriques (2011) for structural and non-structural pine wood elements in service. This study was applied on scots pine wood (*Pinus sylvestris* L.) degraded by fungi after treatment with a biocidal product followed by consolidation with a polymeric product. This solution avoids substitutions of wood moderately degraded by fungi, improving its physical and mechanical characteristics.

The consolidation efficiency was assessed on site by methods of drill resistance and penetration resistance. The SDT methods used showed good sensitivity to the conservation process and could evaluate their effectiveness.

1. Introduction

This conservation process was developed in order to help keeping the timber in buildings that lies slightly deteriorated but yet has strength capacity determined on site. In those cases it is essential to recover or try to improve the physic-mechanical characteristics so that the timber continues to fulfil its structural and decorative functions [2]. The process of consolidating degraded timber by impregnation consists of forcing a specific fluid material into it, which when hardened will restore its integrity and improve the physical and mechanical characteristics [3–5].

In addition to strengthening the wood structure, the materials used may also provide some protection against biological pests [6,7]. However it was found that synthetic consolidants, including epoxies, do not significantly increase the resistance of wood against fungi [6–8]. So the application of biocides before or with the consolidant became necessary and the use of boron was a possibility because of its good fungicide and insecticide properties [9,10].

In situations where it is as important to apply a wood preservative as a consolidant, it is necessary to know their combined performance. That goal was achieved by Henriques [1] who studied in laboratory the combination between seven acrylic and epoxy consolidants with three biocide products. The pair of products which showed the best mechanical results was an epoxy consolidant (EPO 155) and a boron-based biocide (Bora-care) [11–13]. In this study were obtained increases in bending strength in the order

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of 40% for 35% of MOE loss and 80% for 70% of MOE loss with this pair of products [11–13]. Also in axial compression testing and static hardness testing, the mechanical strength was increased in the order of 30% and 60% respectively to 10% of mass loss and 40% and 110% respectively to 20% of mass loss [12].

After that it was necessary to evaluate the efficiency of the method in wooden elements in service [11]. This evaluation was done using the SDT methods of drill resistance and of penetration resistance due to the superficiality of the consolidation (up to 15 mm) and to the necessity of some tools sensitive to that.

The drill resistance device has been seen as a reasonable tool to evaluate mechanical characteristics of timber, even though that was not its original objective [14], nor its most usual application field. Due the sensibility of the tool several authors have recently been evaluating wood properties like the density of some species with the drill resistance device in laboratory conditions to estimate this characteristics in timber applied on site [11,15–17,18]. The mechanical strength and modulus of elasticity have also been correlated with the drill resistance results [15–17]. The penetration resistance technique is also applied to evaluate the surface physic-mechanical characteristics of timber as well as the level of damage of the timber, which depends on its surface hardness and density [11,16,19]. It is based on the principle that each solid material will have an inner resistance against an exterior loads. The Pilodyn is the commonly applied measurement device [19].

Both techniques can be used to evaluate the level of wood decay by fungi, but it is necessary to have a zone not damaged in the same element to obtain the reference values and to estimate the loss of strength. The irregularity of the decay along the section can be analysed on the drill resistance profile. The penetration resistance method is more limited because offers just surface informations. These are processes of approach and must be accompanied by laboratory tests.

2. Case study

This case study presents the in situ experimental conservation process performed on six degraded sections of structural timber elements from a XIX century palace: three floor beams, a staircase, a wall and a roof beam.

Moderately fungi degraded timber elements were subjected to consolidation by impregnation with an epoxy-based product preceded by the application of a biocide product. In every case the degradation was located in a small part of the element with an extent generally lower than 80 cm. The laboratorial development of the process considered it applicable to wood degraded by fungi, with mass losses lower than 20% or MOE losses lower than 70%. This value is regarded as a limit for the intervention success once the ratio of strength and weight loss due to brown rot decay was approximately 4:1 [1,12,20]. For higher values of mass loss, laboratory tests indicated that the resistance was lower than the minimum structural class of Scots Pine [1,21].

The evaluation of the local timber elements condition was made with a drill resistance device and with a penetration resistance equipment before and after the treatment and consolidation application. The main goals of the use of non/semi-destructive techniques in situ were the evaluation of the local degradation condition [21,22] as well as a physical/mechanical efficiency evaluation of the applied treatment and consolidation products.

The experimental campaign was developed at Ribeiro da Cunha palace in Principe Real in the center of Lisbon city.

The building has wood as a material of excellence, combining the rigorous construction and expert details with the historical and artistic values (Fig. 1). The palace was built in 1877 initially for residential purposes. It has four floors, with structural timber horizontal elements, staircases and roof beams (generally made of *Pinus sylvestris* L.) and with the constructive characteristics of "gaiola pombalina" [23].

Over time the building assumed many uses and some infiltrations of water in the most sensitive points occurred, which led to brown rot situations, as identified in Fig. 1f.

3. Materials and methodology

3.1. Treatment and consolidation

The process consists on an initial application of a boron-based aqueous biocide (Bora-care® – Nisus Corporation). On a second stage, and after the stabilization of the water content, the two component consolidation product is applied (EPO 155® + K 156® – C.T.S. Srl.). This is a product based on solvent-free fluid epoxy resins, cold crosslinkable under a hardener action. This pair of products was selected among others with a similar individual efficiency, because they proved to have the best joint mechanical efficiency [1,12,13].

Both products were applied on the timber elements by brush (Fig. 2). It is also possible to resort to injections whenever it is justifiable [11].

3.2. Evaluation tools

Aiming to identify local timber elements condition, drill resistance equipment (IML Resi-B-1280® regulated to a penetration speed of the needle of 20 cm/min) and penetration resistance equipment (Pilodyn® 6 J) were used. To assess the increase of mechanical strength after applying the proposed method, the mentioned devices were used before and after the treatment and consolidation application. As verified by Henriques [1], the penetration depth of consolidation product is in the order of 10–15 mm. Therefore, the drill resistance measure was determined in an extension of 10 mm for non-structural elements and 15 mm for structural elements, always excluding the initial 2 mm, considered as a perturbation zone. For that, was used the Resistance Measure, RM, given by the quotient between the integral of the area of the Resistograph chart and the referred penetration depth of the nail in the specimen, Eq. (1) [17]:

$$RM = \frac{\int_0^{depth} Area}{depth} \quad (1)$$

It was verified that drill resistance equipment allowed the identification of strength increase through the density profiles analysis [21].

By a comparative analysis penetration resistance equipment also allows the identification of strength increases, identified by a reduction of the penetration depth.

3.3. Methodology

The experimental campaign was developed according to the methodology below:

- Selection of 6 timber test elements by visual analysis and simple cutting instruments;
- In each element to be analyzed, three analysis zones were determined: in sound wood (Zone C), to control, moderately degraded by fungi (Zone A) and heavily degraded by fungi (Zone B), for comparison;
- Testing each zone with drill resistance device in seven different points and penetration resistance device with ten measurements;
- Moisture content measurement in sound elements (by contact MC meter) in all steps of the method with seven measurements in each zone;
- Application of the treatment and consolidation process;
- New tests with drill resistance and penetration resistance approximately in the same points, in order to assess the consolidation effect.

4. Results

The results are presented in Table 1 through medium values comparing the situation before and after treatment and consolidation, property variation (%), in each timber element moderately degraded by fungi. It is presented the medium value and standard deviation of the measurements obtained.

Comparing C and A zones it was possible to get a rough idea of timber decay levels through both drill resistance and penetration resistance methods, but it was not possible to quantify it because of the great variability of results obtained [11,19].

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