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Original article

Consolidating preservative-treated wood: Combined mechanical performance of boron and polymeric products in wood degraded by *Coniophora puteana*

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ABSTRACT

When timber elements in heritage buildings are moderately degraded by fungi and assuming underlying moisture problems have been solved, two actions can be taken: i) use a biocide to stop fungal activity; ii) consolidate the degraded elements so that the timber keeps on fulfilling its structural and decorative functions. The aim of this work is to investigate the mechanical performance of maritime pine wood degraded by fungi after being treated with a biocide followed by impregnation with a polymer product. Three commercially available products were used: a boron water-based biocide, an acrylic consolidant and an epoxy-based consolidant. Treated and consolidated specimens were subjected to mechanical tests: axial compression test (NP 618), static surface hardness (ISO 3350) and bending test (NP 619). Sets of replicates were subjected to an evaporation ageing test (EN 73) after application of the products and also tested for mechanical behaviour. An increase in mechanical strength was observed for both consolidants with no significant influence from the previous use of biocide product. The specimens subjected to ageing showed a slightly better general mechanical performance.

1. Research aims

The objective of the study was to investigate the mechanical performance of maritime pine wood degraded by fungi (with mass loss of less than 20%) when treated with a biocide product followed by consolidation through impregnation with a polymeric product.

2. Experimental

2.1. Introduction

Wood is a natural biodegradable product but humans have always tried to prevent wood decay and destruction by climate, pests and fire [1]. In fact, once wood is in service and protected it can last centuries, as long as the protective conditions remain stable [2–4]. Building quality and durability are a priority and therefore, solutions that increase and preserve the physical and mechanical integrity of constructions are needed, and this is more demanding when the building has historical value [5,6]. Accordingly, the option of keeping the original timber elements (even though deteriorated) in the building has been gaining importance, because removing them detracts from the building's historical identity. Extensive replacement of elements is both expensive and often also unnecessary; it may change the characteristics of the structure, and it disrupts the normal use of the building [7]. Furthermore, the sustainable use of forest resources means that timber must be used more efficiently and its life in service increased, hence, a greater use of protection technologies [8].

When timber elements are moderately degraded by fungi, and assuming that underlying moisture problems have been solved [3], it is essential to recover or try to improve the physico-mechanical characteristics so that the timber continues to fulfil its structural and decorative functions [6]. 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 [9–12]. In addition to strengthening the wood structure, the materials used may also provide some protection against biological pests [1,13]. However, it was found that synthetic consolidants, including acryloids and epoxies, do not significantly increase the resistance of wood against fungi [1,13,14], and may even be themselves used as a substrate [15]. Several authors, when analysing the influence of various synthetic consolidants on the degradation process of spruce (*Picea abies* Karst.) and other species, also found that they do not improve

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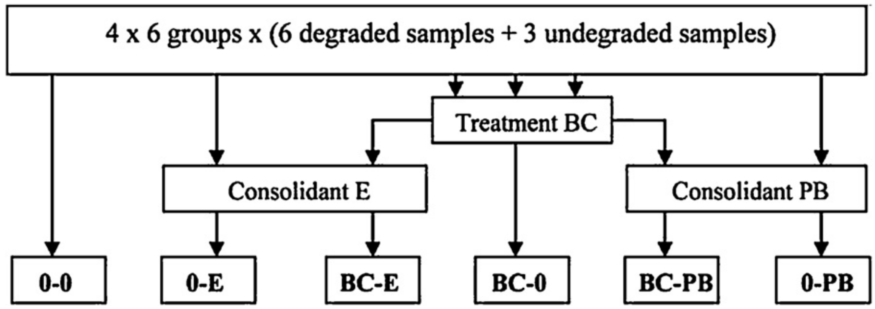

Figure 1. Application scheme of treatment and consolidation products.

resistance to brown rot [13,16,17]. In 1986, Nakhla recommended that a fungicide should be applied whenever the use of synthetic resins was required in wooden works of art [13], and application of biocides became a routine practice in the conservation of art works [14], even though studies about compatibility of different products are scarce.

In the last 20 years of the 20th century environmental concerns, disposal issues and the general public's perception questioned the use of traditional active substances [18–20]. Currently, when the risk of leaching is not a conditioning factor, one possibility is to use boron because of its characteristics: low toxicity to mammals and good fungicide and insecticide properties [21,22]. Laboratory and field tests have demonstrated that timber treated with boron withstands brown and white rot as well as insect attack [23,24]. Boron treatment may also provide fire resistance and it is cheap and easy to handle [25].

In situations where it is as important to apply a wood preservative and a consolidant, it is necessary to know their combined performance. This study set out to ascertain the mechanical performance of maritime pine wood degraded by fungi (with mass loss of less than 20%) after treatment with a biocide product followed by consolidation through impregnation with a polymeric product.

2.2. Materials and methods

Specimen preparation was divided in two phases: cutting, selection, and fungal degradation of wood in laboratory conditions. The biocide treatment (BC) was then applied, as were the two consolidation products (E and PB), and mechanical tests were conducted (Fig. 1).

Table 1 presents a distribution matrix of products *versus* specimens and mechanical tests, together with the density groups they belong to. Two control series were tested for each density group. The mechanical properties of the specimens treated and/or consolidated are analysed by density group and the results are interpreted through comparison with the respective control series.

2.2.1. Specimens

Maritime pine (*Pinus pinaster* Ait.) dry wood was cut into two sizes: 15 × 25 × 50 mm (SHORT specimens) and 20 × 20 × 340 mm (LONG specimens). The wood was taken from different trees, and specimens were grouped by similar densities. The selection of SHORT specimens for testing was in accordance with the physical characteristics specified in European Standard EN 113 [26]: exclusively sapwood, free from defects, maximum dimensional deviation of 0.5 mm in any of the dimensions, annual growth rings between 2.5 and 8 per 10 mm, proportion of late wood in the annual rings not exceeding 30% of the whole. SHORT specimens were subjected to axial compression testing, according to the Portuguese Standard NP 618 [27] and static surface hardness test (ISO 3350) [28]. The size of LONG specimens was established according to the Portuguese Standard NP 619 [29], since these specimens were to undergo the static flexural test.

2.2.2. Wood degradation

The SHORT specimens were exposed to brown rot fungi *Coniophora puteana* (Schumach.) P. Karst, for periods of 4, 8 and 12 weeks. Different levels of degradation of the specimens were obtained. Mass loss was determined as a percentage of the ratio between the mass loss and the initial mass of the non-degraded specimens. Before and after the degradation process, the specimens were placed in a conditioned room at 20 ± 2 °C temperature and 65 ± 5% relative humidity (RH); weighing was performed after mass stabilisation. Mass loss levels between 3% and 23% were obtained.

Degradation of the LONG specimens was achieved by exposing them to a natural environment (a calibrated vegetable soil mixture) in boxes with ventilated lids. The mixture was prepared according to British Standard BS15083-2 [30] and the degradation process was run for 6 to 9 months in a conditioned room at 25 ± 2 °C temperature and 80 ± 5% RH. The test specimens were placed inside the boxes such that the outer 50 mm of the specimens were never in direct contact with the moistened soil (Fig. 4(a)). The degradation level was assessed by the modulus of elasticity (MOE) loss. The MOE parallel to the fibres was measured at intervals during the degradation process. This method resulted from the adaptation of two standards [29,30].

2.2.3. Treatment product

The treatment products were selected according to the criteria of low toxicity for mammals, easy application, good absorption capacity and permanence in indoors timber, and biocide efficiency. A boron-based aqueous solution was selected [21] that met these criteria. The impregnation depth achieved when this solution was applied to timber from an old building previously treated with an unknown product was studied by the same authors, with satisfactory results [12]. The active biocide substances of the product (BC) were sodium oxide (14.7%) and boric oxide (67.1%), with water as solvent.

2.2.4. Consolidants

Consolidants were selected for the following characteristics: penetration capacity in the wood, mechanical strength, durability, hardening without shrinkage, easy application, low toxicity, good aesthetics, low price, and ease of acquisition [13,31,32]. Two commercial consolidants were used (E and PB), after selection tests performed by the same authors [33].

Consolidant E (EPO 155® + K 156® – C.T.S. Srl.) is a thermo-hardening epoxy-based product. The resin component is based on diglycidyl ether of bisphenol A (DGEBA) and the hardener is made of aliphatic and cycloaliphatic amines. A pot life of 40 min at 22 °C was obtained.

Consolidant PB (Paraloid B72® – Rohm and Haas) is a thermoplastic acrylic-related product currently used as an adhesive and