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Full Length Article

Surface properties of thermally treated composite wood panels

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ABSTRACT

Composite finger-jointed spruce and oak wood panels have been thermally treated under standard pressure and oxygen content conditions at two different temperatures, 180 °C and respectively 200 °C for short time periods (3 and 5 h). Due to the thermally-aided chemical restructuration of the wood components, a decrease in water uptake and volumetric swelling values with up to 45% for spruce and 35% for oak have been registered, comparing to the reference samples. In relation to water resistance, a 15% increase of the dispersive component of the surface energy has been registered for the thermal-treated spruce panels, which impedes water spreading on the surface. The thermal-treated wood presents superior resistance to accelerated UV exposure and subsequently, with up to 10% higher Brinell hardness values than reference wood. The proposed thermal treatment improves the durability of the finger-jointed wood through a more economically and environmental friendly method than traditional impregnation, with minimal degradative impact on the structural components of wood.

1. Introduction

Wood represents one of the most lightweight and sustainable construction materials, due to its renewability, low carbon footprint, cost efficiency and ease of use [1–3]. The main disadvantages of wood are represented by its low dimensional stability to moisture, coupled with high susceptibility to biological attack and to outdoor UV-photodegradation [4,5]. Various energy intensive industrial processes currently employed for improving the durability of wood such as coating and/or impregnation make use of toxic monomers, resins, solvents and preservatives [6,7]. Several milder processes, with limited industrial applicability have been described up to date, such as impregnation with natural compounds (plant extracts, polymerizable natural unsaturated oils [8], biopolymers such as chitosan or zein [9,10]). Thermal treatment is one of the most cost-efficient and ecologic methods for wood durability improvement, through which higher fungal decay and UV degradation resistance, reduced hygroscopicity, improved dimensional stability and surface hardness could be imparted to wood.

Various technological processes have been implemented over time (ThermoWood, Perdure, and so forth), employing heating wood at temperatures ranging from 160 to 260 °C in different environments such as air, vacuum, nitrogen, argon, steam or oil [11–14]. Under these conditions, supplementary crosslinks could be formed between lignin molecules, or between cellulose/hemicelluloses and the extractive compounds, which stabilize the cellulose microfibrils through interfering with their expanding and water absorption [14].

One of the most often used engineered wood products are finger joint laminated boards, which bear satisfactory mechanical resistance due to cross-graining, but still relatively low performances in outdoor conditions use (dimensional stability, UV radiation resistance) [15].

Typical softwoods (spruce, fir, pine and so forth), often used in wood engineering applications are among the least durable wood species and through thermal treatment, their biological and dimensional resistance are improved to resemble the properties of more expensive species [16,17]. Hardwoods, while proving more durable than softwoods, could still be made more dimensionally and chemically stable by the supplementary polymerization of extractives (for example tannins) and lignin in their structure [18].

Most of the studies from reference literature describe the modifications in the engineering properties of thermal-treated wood

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(roughness, color, mechanical properties, wetting and so forth), without correlating them to the operational parameters of the thermal treatment regime, and to the morphology and chemistry of the material [17,19]. Moreover, most of the studies report only a singular thermal treatment regime of wood, and the use of vacuum or inert gases (Ar, N_2) as means of avoiding degradation of the wood constituents [20,21]. While proving more efficient in terms of wood chemistry and mechanical properties preserving, heating in vacuum or inert gases is more energy demanding and expensive.

The novelty of this paper consists in the comprehensive study about the influence of four distinct thermal treatment regimens on both the surface properties (surface energy, wettability, hardness, resistance to UV exposure, wear resistance, friction coefficient) and bulk properties (mass and volume uptake of water, impact resistance) of spruce and oak finger-jointed panels. The modifications in the surface properties due to heat treatment have been correlated to the surface and bulk characteristics of the material (modification of wood anatomical features size and distribution, roughness and surface chemistry). Two temperatures, 180 °C and 200 °C and two short heat treatment durations, namely 3 and 5 h were employed, aiming a cost-efficient balance between durability increase and possible chemical degradation of lignin and hemicellulose, which occurs at temperatures above 200 °C and at longer heat treatment durations (7–12 h) [22].

This paper could serve as a bridge between the studies focused on the engineering properties of thermal-treated wood and those which treat unilaterally the chemical and structural aspects of wood heat treatment. A thorough understanding of the mechanisms involved in wood properties modification through thermal treatment is of upmost importance to the use of this resource more effectively and efficient for the manufacturing of value-added products.

2. Experimental

2.1. Materials

Norway spruce (*Picea abies*) and oak (*Quercus robur* L.) finger joint laminated wood boards bonded with phenolic resin were bought from Silvarom Co. Bucharest, Romania.

The wood boards have been thermally treated and sampled for morphostructural tests performing, according to the procedure mentioned in Section 2.2.1

2.2. Testing procedures and characterization methods

2.2.1. Thermal treatment of composite wood boards

The heat-treatment of the spruce and oak wood panels has been performed in a drying stove employing two distinct steps, as depicted in Fig. 1a. In the first step, the wood panels have been dried for 5 h at 105 ± 2 °C to eliminate the free water and volatile extractives. In the second step, the wood panels have been heated at the two selected temperatures, namely 180 °C and 200 °C, for 3 and respectively 5 h, under normal pressure conditions (756 mmHg) and atmospheric oxygen content.

The codification of the heat-treated and reference samples is given in Table 1.

The mass loss of the samples due to thermal treatment (Δm, Fig. 1a) are ranging from 4 to 8%, as illustrated in Table 1.

The apparent density of the wood samples (d_{ap}, Table 1) has been determined with the help of a Radwag analytical balance density determination kit, model WX-002-0001, using toluene as non-swelling immersion fluid (22 °C).

The relative standard errors for both mass loss and apparent density (RSE) are given in Table 1.

Samples with dimensions of 100 × 20 × 10 (mm) have been band-saw cut for impact resistance tests, with the corresponding wood sections as marked in Fig. 1b. For accelerated UV exposure and water stability tests, samples with dimensions of 40 × 20 × 10 (mm) have been used. Since the surface of the panels corresponded to the radial section of spruce and oak wood, this section has been studied in terms of color and structural modifications related to UV-exposure. The longitudinal section of the thermal treated wood, corresponding to the bulk of the panels, has been analyzed in comparison with that of reference wood, to assess the differences in morphology.

Prior to any testing, the thermal treated wood samples were equilibrated for 7 days at 55% ± 2% relative humidity and 24 ± 2 °C ambient temperature conditions (equilibrium moisture contents-EMC- values are given in Table 1).

2.2.2. Accelerated UV-exposure

The accelerated UV-resistance tests have been performed in a closed-cabinet setup containing a 400 W high-pressure mercury-vapor lamp (SYLVANIA 69450 model, with 40% of the total emitted light being in the UV domain) placed at 20 cm distance from the surface of the samples, so as the light intensity at the sample surface to be 400 lx. The testing conditions were 55% ± 2% relative humidity and 24 ± 2 °C ambient temperature. A continuous irradiation time of 24 h has been used in this setup, followed by morphological and structural analysis. A minimum of 3 samples of each type have been submitted to accelerated light exposure tests, for comparison and reproducibility purposes.

The color modifications ΔE occurring due to changes in the surface chemistry of the panels have been assessed through the image analysis method, as described in our previous work [23] using the CIELab color space (L, a, b parameters).

2.2.3. Microscopy analysis

The surface and cross-sections of the wood panels have been analyzed through reflectance-mode optical microscopy (Omnimet-Buehler structural analysis system, with Nikon Eclipse MA 100 optical microscope) and scanning electron microscopy SEM (A QUANTA 200) at different magnifications.

The average roughness (Ra) has been computed with the help of ImageJ software (SurfaceChJ 1q plugin), based on the pixel illuminance distribution. In 8-bit images, a higher pixel value-closer to the observer produces a brighter pixel (pixel values of 255 are perceived as white), while a more in-depth pixel presents lower value (0 is perceived as black) [24].

To comparatively assess the structural modifications occurring due to thermal treatment, the radial surface Ra values (expressed as pixels) have been determined through photographic image analysis of the samples surface (converted to 8 bits with ImageJ), obtained at identical sample-camera distances and illumination conditions (source photographs embedded in Fig. 6).

The porosity (percent of open pores in the longitudinal section of wood) has been determined through 8-bit-converted SEM micrographs thresholding with the help of ImageJ software. The darker areas of the thresholded micrograph stand for the foreground (pores), while the lighter areas represent the cell walls (lumens) and is considered as background. The porosity ratio (P) has been calculated through reporting the total area occupied by the pores to the total area of the image (expressed in μm^2) [25], considering as basis a region of the micrograph with 50 × 50 μm. The mean values of cell wall thickness have been determined through arithmetic averaging of 50 measurements from different regions of the micrograph, with the help of the SEM instrument's software.