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Effect of artificial weathering on the properties of heat treated wood

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ABSTRACT

This study aims to investigate the change in chemical composition, surface characteristic and mechanical properties of heat treated four wood species (ash, iroko, Scots pine and spruce) during artificial weathering from 400 h to 1600 h in relation to their color changes, surface roughness, compression strength, modulus of elasticity, modulus of rupture and surface composition. Original color of wood species was significantly changed by heat treatment and artificial weathering. Artificial weathering decreased color change of heat treated wood samples except for iroko. Color change significantly increased with longer weathering exposure for heat treated wood samples however similar trend was not observed for control samples exposed to weathering factors. In general, heat treatment alone did not have a considerable effect on surface roughness of wood. Heat treatment seemed to protect wood surface to become rougher after weathering for softwoods. Compression strength and MOR of samples decreased while MOE increased during heat treatment. Compression strength, MOR and MOE of samples decreased considerably with longer weathering exposure both for heat treated and control samples. Softwood species seemed to be more affected by heat and weathering than hardwood species did with respect of loss on the strength properties. Severe delignification and hemicellulose degradation occurred in heat treated and control samples for all wood species during weathering from 400 h to 1600 h evident from rapid decrease at 1504/1508 cm^{-1} and 1730 cm^{-1}, respectively. Heat treatment did not fully protect hemicellulose degradation and delignification occurred by weathering with longer exposure periods.

1. Introduction

Wood surface exposed to degradative outdoor conditions undergoes a complex set of physical and chemical changes which mainly cause a loss of original color and surface fibers, and graying [1]. Following to color changes in wood, mildew growth, checking, splitting, and warping occurs in a wood surface in extended outdoor exposure [2]. The degradation mechanism depends on the wood species and combination of factors found in nature such as sunlight, moisture, temperature, oxygen, atmospheric pollutants, chemicals, heat/cold, abrasion by windblown materials, and biological agents [2,3]. Ultraviolet (UV) irradiation and water are thought to be the main factors on wood weathering [3–7]. The change in wood color is believed to be due to the UV component of sunlight acts in combination with moisture, temperature as well as oxidative agents such as oxygen and ozone to depolymerize lignin and carbohydrates in wood cell wall [2,6]. Degradation in wood by weathering primarily affects wood components, significantly reduces esthetic appearance, and causes some decrease on physical, mechanical and biological properties of wood [2].

Treatment with wood preservatives especially formulated by chromium and/or copper compounds improves the durability of wood surfaces against UV irradiation and weathering factors [3,5,6]. In the recent years, heavy duty wood preservatives are being questioned because of their toxicity effect on the environment and human. In this aspect, thermal modification of wood can be considered as an alternative method for protecting wood against most basidiomycetes. Heat treatment modifies wood structure without using any harmful chemicals therefore, it is commonly accepted as a cheap and an environmentally-safe method compared with the other modification and/or impregnation techniques. Heat treatment reduces equilibrium moisture content and in many cases also the water absorption, shrinking and swelling of wood, and wettability of wood, and increases biological resistance [8–11]. However, mechanical strength decreases in relation to the intensity of the heat treatment [10,12–14]. It is reported that heat treatment makes the wood more resistant to biodegradative effects in outdoor conditions compared with un-treated (control) wood [10,15–18]. The effectiveness of heat treatment on North American wood species (jack pine, aspen, and birch) against artificial

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weathering factors and UV irradiation was recently studied by Huang et al. [11,19] and Huang et al. [20].

Heat treated wood is being used as a commercially available product in many indoor and outdoor usages without ground contact in nowadays although, the effects of weathering on heated wood species are not well known. It is possible to maximize the service life of heat treated wood products in any type of climatic conditions by understanding and predicting the protection mechanism against weathering factors. The aim of this study was to investigate several properties of heat treated wood during artificial weathering exposure of 400 h, 800 h and 1600 h: color change, surface roughness, compression strength, modulus of elasticity, modulus of rupture and surface composition. Results of two hardwood species (iroko and ash) and two softwood species (Scots pine and spruce) could serve as the basis for the performance of heat treated wood in outdoor conditions. Furthermore, parallel work involving natural weathering in above ground contact field test of these wood species helps in predicting more realistic outdoor performance is under progressive by the authors.

2. Materials and method

Samples 50 mm (radial) × 100 mm (tangential) × 800 mm (longitudinal) were machined from the air-dried sapwood of Scots pine (*Pinus sylvestris* L.), spruce (*Picea orientalis* L.), iroko (*Chlorophora excelsa*) and ash (*Fraxinus excelsior* L.) lumber, and were subjected to the heat treatment in an industrial plant (Nova Wood, Gerede, Turkey) under steam atmosphere. Softwoods were subjected to the heat treatment at 212 °C for 90 min while hardwoods were heated at 190 °C for 90 min. Heat treated timbers were then cut in parallel to grain directions and sawn into samples with dimension of 20 mm (tangential) × 20 mm (radial) × 300 mm (longitudinal) at both ends. Sample preparation is shown in Fig. 1.

In Fig. 1, sample parts with gray color were removed, and test samples were carefully chosen for being heat treated equally and for having the similar new cut surfaces. Twelve samples with the final dimension were obtained from one heat-treated 50 × 100 × 800 mm sample. Then samples were divided into four groups. First group was the heat treated samples; second group was the heat treated and weathered samples; third group was the un-treated (control) samples; fourth group was the un-treated and weathered samples. Five replicate samples were used for each treatment group and wood specie. The color, surface roughness and FT-IR analysis were measured at the same points on the exterior tangential face of the oven-dry samples before and after artificial weathering. Samples were oven dried at 70 °C for 4 days until they reached unchangeable weight to avoid a cause of moisture content variability between the treatments since the moisture content was an important parameter affecting the properties of wood.

2.1. Artificial weathering test

Heat treated and control samples were subjected to an artificial weathering by exposing to 340 nm fluorescent UV lamps in the QUV accelerated weathering tester (V-230) during the periods of 400 h, 800 h and 1600 h. The weathering cycle involved a continuous light irradiation of 1 h followed by a water spray for 10 min. The average irradiance was 0.85 W/m^2 at 340 nm wavelengths with a constant chamber temperature of 60 °C [21].

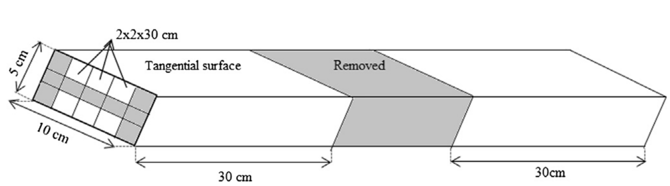

Fig. 1. Sample preparations and cutting plan of samples.

2.2. Color measurements

The color measurements were carried out using a Minolta CM-2600d spectrophotometer, equipped with an integrating sphere according to the CIE $L^*a^*b^*$ system [22]. Measurements were made over an 8 mm diameter spot with 10° observer angle. Four measurements were recorded at the same points on the tangential surface of the each sample before and after weathering.

2.3. Surface roughness

Surface roughness was measured using a Mitutoyo SJ-301 instrument according to DIN 4768 standard [23]. R_z is arithmetic mean of the 10-point height of irregularities. Roughness was measured with a sensitivity of 0.5 μm. Measurements were carried out perpendicular to the fiber direction. Four measurements were recorded at the same points on the tangential surface of the each sample before and after weathering.

2.4. Fourier transform infrared spectroscopy (FT-IR)

The FT-IR spectra were recorded with a Perkin–Elmer Spectrum 100 with a Universal ATR sampling accessory. Four accumulated spectra with a resolution of 4 cm^{-1} were obtained from the tangential surface of samples between wavenumbers of 4000 and 650 cm^{-1}.

2.5. Mechanical tests

Modulus of rupture (MOR, N/mm^2) and modulus of elasticity (MOE, N/mm^2) were determined by 3-point bending according to TS 2474 [24] in a Universal Testing Machine. Loading was done at the tangential direction of the five replicate samples. The distance between the centers of the two supports was 240 mm free span, and the crosshead speed was 1.1 mm/min.

Compression strength parallel to grain (CSPG, N/mm^2) was determined according to TS 2595 standard [25] using a Universal Testing Machine. The crosshead speed was 1.1 mm/min. Conditioned samples used for MOR and MOE determinations were then cut into 20 mm (tangential) × 20 mm (radial) × 30 mm (longitudinal) at the both ends of the samples. Ten replicates were tested for each treatment group.

2.6. Statistical analysis

The effect of artificial weathering exposure periods on color change, surface roughness, compression strength, MOR and MOE of samples in comparison with controls was analyzed by One-Way ANOVA test using with SPSS 18.0 program. The significance ($P < 0.05$) between the treatments was compared with Duncan homogeneity groups. Different letters given along with the average values of tested parameters indicated significant difference by Duncan's homogeneity groups.

3. Results and discussion

3.1. Chemical composition

The FT-IR ATR spectra of heat treated and control samples before and after weathering are shown in Figs. 2 and 3 for Scots pine and