Progress in Organic Coatings 119 (2018) 145–154

Contents lists available at ScienceDirect

Progress in Organic Coatings

journal homepage: www.elsevier.com/locate/porgcoat

Weathering resistance of thermally modified wood finished with coatings of diverse formulations

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ARTICLE INFO

Keywords:
Weathering
Thermal modification
Hyperspectral imaging
Visual appearance
Wettability

ABSTRACT

Thermal modification processes significant affect the chemical configuration of the wood matrix improving moisture-related properties and material durability. In addition, the distinctive dark tones of heat-treated timber increase the economic value of several light-colored species. However, these treatments alter the substrates and it could influence the performance of coating products, necessary to maintain the surface features in certain end-use sectors. Ash wood (*Fraxinus excelsior* L.) samples industrially treated at 192 °C, 202 °C and 212 °C were coated with decorative waterborne polyurethane and industrial UV-hardened coatings. Afterwards, the samples were subjected to accelerated weathering. The resulting surface topography was assessed with a 3D scanner and a profilometer, revealing slight changes in the texture. Color changes were quantified with hyperspectral imaging by generating surface color maps in CIE Lab coordinates. The results indicate acceptable photostability of thermally modified wood. Changes in wettability, surface free energy, work of adhesion and cohesion were determined by contact angle. Higher hydrophilicity after weathering was observed, but with an acceptable overall performance. At the same time, polar and dispersive shares were redistributed depending on the applied coating. It was demonstrated that heat-treated wood could be an optimal substrate for innovative wood-based products, suitable for use outdoor and exposure to changing weather conditions.

1. Introduction

Darkening the color of diverse light-colored wood species without using stains is one of the most appreciated effects of thermally-treating wood. Thermally modified products are provided with an attractive "exotic wood appearance", which in certain end-use sectors is highly appreciated [1]. Besides color changes, the treatment diminishes the hygroscopic affinity of wood allowing its use in outdoor or wet environments, therefore increasing the service life of wood-based materials [1,2]. Conversely, the visual appeal of modified wood surfaces exposed during service may be rapidly diminished by weathering and/or biological decay [3]. Finishing wood surfaces with coating products has been proven as a good solution to diminish the weathering effects and to maintain the aesthetical features when the material is exposed outdoor in different directions or designs.

The range of coating products recently used in the European market is dominated by water-borne systems [4]. These products (pigments or binders) are dispersed or dissolved in a continuous phase, consisting mostly of water. Decorative coatings are usually applied by hand and are air-dried. To the contrary, industrial products use much wider range of application techniques and frequently require heat or radiation curing [4,5]. An important consideration when applying any coating product is to avoid or substantially decrease emissions of air polluting volatile organic compounds [6]. Waterborne coatings consist in up to 40% solid content and its liquid fraction is mostly water, the radiation curing (radcure) coatings are often converted 100% to solid state during the curing process. Most frequently, ultraviolet (UV) or electron beam (EB) radiation is used for curing [4].

The altered surface characteristics of heat-treated wood may have an influence on the performance and interaction between finishing products and the modified-wood surfaces. Wood-surface acidity and hydrophobicity changes have previously been studied, showing that wood-coating adhesion and the penetration are not strongly affected when water-based coatings are used [7].

An essential effect of the heat-treatment is the reduction of the hygroscopicity of the material, which in turn contributes to higher dimensional stability. After treatment, the wood specimens present a progressive decrease of volumetric shrinkage with stable values of

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https://doi.org/10.1016/j.porgcoat.2018.02.015
Received 24 May 2017; Received in revised form 9 January 2018; Accepted 19 February 2018

dimensional change close to 1%. The influence of heat-treatment on the wood hygroscopicity is therefore highly positive, especially for outdoor applications, where wood is exposed to cyclic weather and moisture variations [8]. Nevertheless, it has not been reported if any drawback appears during the service life when coated surfaces undergo the weathering/aging process.

Weathering is defined as the slow decomposition of materials subjected to weather factors [9]. Depending on the wood specie or treatment, aging effects can be visible in hours, months or years. Despite the fact that natural weathering is usually a relatively slow process, artificial weathering plays an important role in evaluating coatings by obtaining performance assessments in much shorter time than natural weathering. Even though artificial weathering methods do not fully represent actual material changes at specific weather conditions, these are commonly considered as a highly useful tool for estimating surface resistance and future product performance [10,11].

The goal of this study was to examine the response to artificial weathering of *Fraxinus excelsior* L. wood, which was heat-treated at different temperatures and surface coated with water-based or solvent products. The challenges were to understand changes to the physical and surface properties during the weathering in order to identify differences induced by the thermal treatment intensity and to find appropriate markets for the end-use products.

2. Experimental methods

2.1. Wood material and industrial-scale treatment

European ash (*Fraxinus excelsior* L.) wood was thermally modified according to the state-of-the-art industrial production standards at 192 and 202 °C (Thermo-Drewno®, Tartakstefan, Włoszakowice Poland) and 212 °C (Termogenik®, Torrebaso, Orozco, Spain). The lumber was plain sawn, as this is the most common way to manufacture lumber products in Spain. The annular rings were 30 ° to the face of the board (tangential grain). Consequently, the typical grain pattern was visible on the investigated surfaces.

The treatment was conducted in presence of saturated steam in dedicated heat-treatment processors. The treatment period was set between 60 and 70 h following the schedules of industrial processes. Technical details regarding the modification procedures implemented have been presented in detail elsewhere [12,13]. An additional set of untreated ash samples (*A0*) and coated with the same products as the thermally modified samples was used as a reference. The abbreviations of the treatments are defined as follows: *A192* (wood modified at 192 °C), *A202* (wood modified at 202 °C) and *A212* (wood modified at 212 °C). All samples were conditioned before coating applications and after the weathering process in the climatic chamber at 23 ± 2 °C and 60 ± 5% relative humidity.

2.2. Wood finishing

All the wood surfaces were sanded with an orbital sander before coating in a sequence of sanding paper gradation from P150 to P320 to assure minimal surface roughness and improve adhesion with the coating. Two coating systems were used for this research including:

- an industrial UV-hardened coating (C) by using industrial rollers and a hybrid line mix of LED and arc lamps performed in the technical center of the Sherwin-Williams Company (Poland). Product name: Beckry clear 100% UV, Sherwin-Williams Company, USA.
- a decorative 2 K waterborne polyurethane coating, (W) using a brush in laboratory conditions (Poznan University of Life Sciences, Poland). Product name: OLI-AQUA, Oli lacked Company, GMBH, Germany.

Table 1
Chemical composition and features of wood coatings systems [13].

Coating System[a]	Product Target	Main composition	Dry mass rate [%]
C	1.Clear sealer	TMPTA ($C_{15}H_{20}O_6$)	12.5–15
		Acrylate oligomers	14–35
	2.Clear coat	EO-TMPTA ($C_{21}H_{32}O_9$)	7–20
		Photoinitiator: HMPP ($C_{10}H_{12}O_2$)	2.5–5
	3.Topcoat	UV-absorber: Benzophenone ($C_{13}H_{10}O$)	1–2.5
W	1.Primer	Naphtha	50–55
		MEKO (C_4H_9NO)	0.1–0.9
		2- Ethylhexanol ($C_8H_{18}O$)	0.1–0.9
	2.Topcoat	Water-based PU's	32–55
		BDG ($C_8H_{18}O_3$)	1–5
		BIT (C_7H_5NOS)	1–3
		MIT (C_4H_5NOS)	0.1–0.9
	3.Hardener	MPA (C_6 H_{12} O_3)	25–35
		IPDI ($C_{12}H_{18}N_2O_2$)	20–25
		HDI ($C_8H_{12}N_2O_2$)	20–25
		Blocked Isocyanate	10–15
		Xylene (C_8H_{10})	5–10
		EB ($C_6H_5CH_2CH_3$)	1–3

[a] C: Industrial UV-hardened coating; W: Decorative 2 K waterborne polyurethane coating.

Both −coating systems (UV-hardened solvent-free and water-borne PU) were selected based on their different characteristics regarding appearance (medium film build and high film build), chemistry (acrylates and polyurethanes) and technology (Industrial UV curing and decorative water-borne). Both coatings were applied following supplier recommendations on one lateral face of the wood sample. Further details concerning the coating systems composition and application are summarized in Tables 1 and 2 . All the samples were stored in a climatic chamber for two weeks before any further action in order to assure complete curing of the coating system.

2.3. Accelerated artificial weathering

Coated wood samples were exposed to the accelerated weathering test after finishing and conditioning in order to simulate a combined effect of temperature, solar radiation and precipitation on surface properties. The test was performed in a light exposure test apparatus (SOLARBOX chamber M/S Erichsen model 522/1500, Hemer, Germany) following the UNE-EN ISO 11507:2007 standard procedure [14]. Sample surfaces were cyclically exposed to 112 min of ultraviolet radiation (UVA-340 lamps) at 70 °C (temperature on black panel), after which the samples were periodically wetted to simulate precipitation by soaking in water for 18 min. The total duration of the weathering test was 2000 h, which corresponded to 923 weathering cycles. According to the technical specifications, the SOLARBOX chamber emits an average energy of 50.4 MJ/m^2 during a one-hour test exposing samples to wavelengths between 295 and 800 nm.

2.4. Assessment of wood surface

2.4.1. Three-dimensional surface topography

A coated surface roughness map was generated by means of a depth-of-field scanner developed at CNR-IVALSA, San Michele All'adige, Italy. The surfaces of experimental samples were photographed using a high-resolution CCD camera (PL-A782, Pixelink, Ottawa, Canada), a zero distortion multi-configuration macro lens (MC3-03X, Opto-engineering, Mantova, Italy) and diffused white light. The sequence of images was acquired by the camera while changing the distance between measured surface and the focusing lenses, with a resolution of 3000 × 2208 pixels. A stack of 40 images was collected from each sample; the