Progress in Organic Coatings 95 (2016) 54–63

Contents lists available at ScienceDirect

Progress in Organic Coatings

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

Application and artificial weathering performance of translucent coatings on resin-treated and dye-stained beech-wood

Bodo Caspar Kielmann, Carsten Mai*

Wood Biology and Wood Products, Georg August University of Göttingen, Büsgenweg 4, 37077 Göttingen, Germany

ARTICLE INFO

Article history:
Received 2 October 2015
Received in revised form 10 February 2016
Accepted 15 February 2016

Keywords:
Wood modification
Thermosetting resin
Colouring agent
Coating
UV absorbers
Radical scavengers

ABSTRACT

Beech wood boards (*Fagus sylvatica* L.) modified with thermosetting *N*-methylol melamine (NMM) and phenol-formaldehyde (PF), partly with a dye added (NMM-dye, PF-dye), were coated solely with a translucent water-borne acrylic binder and a formulation containing the same binder and UV-protective agents (UV-PA: UV absorbers, HALS). The aim was to improve the weathering performance and to maintain the colour stability of the modified wood. The applicability of the coating on the modified boards was similar to that of untreated control boards, but the drying times were prolonged. Capillary water uptake of modified, uncoated and coated boards was clearly lower than that of respective controls. Dry and wet adhesion of the coating film and the proportion of wood fracture were higher on the modified substrates than on the controls, but no clear difference was observed among the modified boards. The colour stability during weathering depended in the modification and coating. Untreated and NMM modified samples became lighter, while PF-modified boards turned darker. The weathered coating on the modified boards, particularly with PF resin, showed less blistering, flaking and cracking than that on the controls. The coating on all resin-modified boards maintained higher adhesion during weathering than the controls. UV-PA stabilised the colour and adhesion on all boards compared to the single binder formulation. The study shows that wood modification with NMM and PF improves the weathering performance of wood coated with acrylic coatings. Combined modification with staining can diversify the optical appearance of wood coated with translucent finishes.

1. Introduction

Wood exposed under exterior conditions needs to be protected from abiotic erosion and biological decay. The traditional methods of slowing down the degradation process and to prolong the service life of wood include preventive biocidal preservation and surface coating. Environmental concerns associated with the use of conventional wood preservatives, however, have increased interest in non-biocidal wood modification approaches [1]. A variety of wood modification methods (thermal, chemical, impregnation) have shown good potential in reducing water absorption and deformation, increasing biological resistance and enhancing weathering performance [2]. Chemical and impregnation modification, e.g. with linear anhydrides, aldehydes, furfuryl alcohol, 1,3-dimethylol-4,5-dihydroxyethyleneurea (DMDHEU), phenolic or melamine resins, belong to the most effective treatments to enhance the performance of wood during service life [2,3]. Impregnation modification with *N*-methylol melamine resins (NMM) has been studied widely and brings about considerable improvements, such as reduced water uptake and increased dimensional stability, increased hardness and bending strength, decay resistance, and resistance to weathering and colour changes [4–15]. NMM resins penetrate and polymerise in the cell wall resulting in cell wall bulking [4], but a major proportion is also located in the cell lumens [16]. The resin is fixed in the wood by formation of a 3-dimensional NMM-network rather than by covalent bonding to the wood matrix [7]. Impregnation modification with low molecular weight phenol-formaldehyde (PF) resin proceeds in a comparable way, but PF penetrates the cell wall to a greater extent and thus causes greater cell wall bulking than NMM modification [17–20]. PF modification enhances surface hardness, dimensional stability, decay resistance and the weathering performance [18,19,21–24]. PF-resins are considered to be strong absorbers of ultraviolet (UV) light; PF modification of pine wood has induced a better performance of translucent (clear) finishes during exposure to accelerated weathering than unmodified, coated controls [24,25]. Recent studies have reported on the combined staining of wood with thermosetting resin and a metal–complex dye to enhance the

---

* Corresponding author. Fax: +49 551 399646.
E-mail address: cmai@gwdg.de (C. Mai).

http://dx.doi.org/10.1016/j.porgcoat.2016.02.019
0300-9440/

Table 1
Characteristics of the applied coating formulations.

Coating	Coating formulation	Solid content (w/w) [%]	Wet amount [g/m^2]	Dry film thickness [μm]
Primer	Acronal® LR 9014	10.7	80	10
Binder	Acronal® LR 9014	32.8	300	80–100
Binder + 3% UV-PA	Acronal® LR 9014 + 3% Tinuvin®5333-DW	34.3	300	80–100
Binder + 6% UV-PA	Acronal® LR 9014 + 6% Tinuvin®5333-DW	34.8	300	80–100

aesthetic quality of the whole beech substrate [12–14]. It was previously shown by means of UV-micro-spectrophotometry and X-ray micro-analysis that condensation of NMM causes fixation of the water-soluble dye [13].

The performance of translucent coatings on wood is mainly affected by the wood material itself (e.g. content of extractives, cell structure) and by environmental factors such as temperature, relative humidity and moisture content [26,27]. Deterioration of the wood substrate at the wood-coating interface (e.g. through photodegradation, colonisation by staining fungi, high moisture content), can shorten the renovation intervals of coatings and bring about additional maintenance costs during service life [28]. Translucent coatings can protect the wood in two ways: by preventing water from leaching UV degradation products and by absorbing UV light [29]. UV light penetrates through transparent coating films and degrades the timber directly underneath, thus forming a weak connection interface under the finish [29,30]. Pigmented finishes and clear finishes with additives, such as UV absorbers and hindered amine light stabilizers, (HALS) are the most effective formulations which prevent the degradation through UV light and the following erosion of the wood substrate [27,31–33]. Williams et al. [30] described three main consequences of the failure in the interface between wood and coating: (a) the coating film can be deboned in a short period of time, (b) cracks can occur on the substrate, and (c) the coating film might peeled off. Sorption of moisture and liquid water by wood causes stress development in the coating due to dimensional changes of the substrate; this leads to cracks in the coating film [34]. Chemical or thermal modification can reduce these stresses by enhancing dimensional stability. In addition, some types of modification reduce the susceptibility to photo-degradation and microbial decay [29,35–39]. Nowadays, most wood finishing formulations are water-borne, due to environmental concerns and occupational health considerations [40]. Thus, hydrophobation due to chemical modification may lead to problems in the application of such water-borne finishes. Modification of wood with DMDHEU did not negatively affect the application of water-borne finishes [35], probably because the condensation product of DMDHEU in wood is polar and hydrophilic. Acetylation of wood improved coating performance regarding adhesion and weathering without displaying negative effects on the drying features [29]. The aim of this study is to investigate how different modifications of beech wood with thermosetting resins, partly combined with a dye, influence the application and performance of water-borne coating formulations compared to the untreated beech wood. The topcoats consisted solely of an acrylic binder, or of the binder combined with a UV absorber and a HALS.

2. Materials and methods

2.1. Wood specimens and chemicals

Wood specimens: Boards of beech wood (*Fagus sylvatica* L.) measuring 74 ± 1 × 18 ± 1 × 150 ± 2 mm^3 (r × t × l) were prepared according to EN 927-6 [41]. The mean density of the samples was 690 kg m^{-3} at 12% moisture content. The specimens were oven-dried at 103 ± 2 °C for 48 h and weighed. Prior to chemical modification, the dried wood specimens were conditioned at 20 °C ± 1 °C and 65% ± 5% relative humidity (RH). The *N*-methylol melamine (NMM) resin was Madurit MW840/75WA (Ineos Melamines GmbH, Frankfurt, Germany), an aqueous formulation with approx. 75% solid content, 1.245–1.260 g ml^{-1} density at 23 °C, 430 mPa s dynamic viscosity and pH of 9.3 (all values at 25 °C). The low molecular weight phenol formaldehyde (PF-) resin Phenoplastharz P554 (Surfactor GmbH, Schöppenstedt, Germany) is an aqueous formulation with approx. 59% solid content, 1.15–1.25 g cm^{-3} density and pH of 8.4–8.8 (all values at 23 °C). The metal–complex dye Basantol® Brown 269 liquid (BASF SE, Ludwigshafen, Germany) is an aqueous formulation with 30% solid content, 1.15 g cm^{-3} density, and pH 7.0–7.5. Triethanolamine was purchased from Th. Geyer GmbH & Co. KG (Hamburg, Germany).

All coating components were obtained from BASF SE (Ludwigshafen, Germany). The water-borne formulation, Acronal® LR 9014, is an aqueous anionic dispersion of a copolymer of 2-ethylhexyl acrylate and methyl methacrylate with approx. 33% solid content, 1.04 g cm^{-3} density at 23 °C, 100–400 mPa s dynamic viscosity and pH of 7.5–8.5. The light stabilizer blend containing UV absorbers (UVA) and hindered amine light stabilisers (HALS) was Tinuvin®5333-DW with approx. 62% solid content, 1.05 g cm^{-3} density at 23 °C, 69 mPa s dynamic viscosity and pH of 6.0–9.5.

2.2. Modification of wood

The wood boards were treated with 25% (w/w) aqueous solutions of NMM and PF as well as with respective resins solutions containing 1.5% (final concentration) dye as described previously [16]. The conditioned specimens were impregnated using a vacuum–pressure process at 5 kPa (1 h) and 1200 kPa (2 h). Drying and curing included 72 h air drying followed by continuous temperature increase 30, 40, 60, 80, 100 °C (24 h each), 120 °C (48 h), 103 °C (24 h). Solution uptakes (SU) after impregnation and the weight percent gain (WPG) after modification were related to the dry mass of untreated beech wood. Untreated wood blocks served as control specimens.

2.3. Coating application

Prior to coating, all samples were conditioned at 20 °C and 65% RH for one week and sanded with a 240-grid paper and subsequently a 400-grid paper. To apply the coatings, all specimens were coated on one of the radial sides with Acronal® LR 9014 as primer on the sanded surfaces (all other sides were left uncoated) using a spay gun with a nozzle tip of 1.0 mm at 2 bar. Then, three topcoat formulations were respectively applied twice in the same manner. The topcoat formulations were (a) Acronal® LR 9014, (b) Acronal® LR 9014 and 3% (of stock solution) Tinuvin® 5333-DW, and (c) Acronal® LR 9014 and 6% Tinuvin® 5333-DW. The amount of the freshly applied coating was calculated by weighing each sample before and after each spray application (Table 1). After each coating step, the finishes were dried at 25 °C ± 1 °C. After coating, all samples were conditioned to constant weight in the climate chamber (20 °C ± 1 °C, 65% ± 5% RH) according to ISO 554 [42]. The thickness of the cured coating was determined according to EN ISO 2808 [43]. Two pieces (10 mm) were cut from each coated samples: one from