

CODE 319

OUTDOOR WOOD WEATHERING AND PROTECTION

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ABSTRACT

This paper deals with the wood durability when applied in the building façades and outdoor subject to aggressive environmental agents and its means of protection. This study is justified since wood outdoors is an important part of the built heritage that needs to be preserved. The aim of this work was to obtain the relationship between the performance of wood surface protection products and different service situations. It was evaluated its coating ability to the environmental aggressions, simulating an application above ground and exposed to the weather (use class 3.2 - EN 335-2:2013) and to the attack by fungi simulating an application in direct contact with soil (use class 4.1). The long-term goal of this work is to contribute for the creation of a results network making easier for the user to protect wood from external aggression. Four different environmental conditions were chosen: next to the coast (saline); urban centre (pollution); interior of the country (high thermal amplitude); soil contact (fungi and moulds) and building interiors (control). Three commercial water based products were chosen due to its characteristics: WRN - water resistance assured by nanotechnology; WAC - weatherproof acrylic copolymer; ART - acrylic resins with Teflon®.

This work showed that the most aggressive environment was the one with high thermal amplitudes. Comparing the performance of tested products: WRN exhibits the lowest protection levels, only antifungal function was comparable to the other products, in this formulation instead of sealing the pores, nanoparticles "dress them", assuring that water is effectively repelled by chemical forces; WAC and ART were very similar since both form a protective film increasing the surface resistance; ART presents the best performance with respect to coating integrity with very positive influence against the development of cracks.

1. INTRODUCTION

Wood is a biological, biodegradable and renewable material. It has an indelible presence in the construction creating calm and pleasant environments, allowing bold forms in modern architecture and affirming itself as one of the materials with greater presence in the built cultural heritage. However, when exposed to outdoor environments, both urban and rural, the wood is subject to a sequence of surface degradation reactions, induced by different environmental factors [1, 2]. The changes in the surface layer of the wood under these conditions are mainly due to the breakage of lignin and other constituents of the wood by the ultraviolet rays and their

subsequent removal by the rain associated with the rapid loss of extractives soluble in water [1]. Prolonged exposure to atmospheric agents leads to discoloration, either by the loss of the natural color of the wood or the accumulation of dirt, as well as the eventual growth of fungi on the surface. On the other hand, repeated variations in temperature and humidity of the ambient air cause successive cycles of wetting and drying of the wood, with consequent expansion and retraction, leading to the opening of cracks. These potentiate, in turn, the exposure of the underlying layers of wood to the atmospheric agents and the progression of the process to its interior [3].

If to date, reducing carbon emissions and sustaining resource use have been the environmental factors that have most driven the increase in the use of wood, climate change has emerged today as another issue of recognized implications. Faced with this growing aggressiveness, wood protection technologies are increasingly seen as an essential development object. So, this scientific study aims at the study and development of methodologies of surface protection of wood based on the application of products that enhance an effective defense against the most severe environmental actions felt in the south of Portugal [4]. The environmental factors to be considered are of physical, chemical and biological nature, together with duration, intensity and frequency of action. Twenty sets of test pieces will be treated with four protection products with distinct characteristics and exposed to the following typified environments: maritime (MAR), industrial (IND), rural (RUR) and soil (SOIL) (Figure1). The analysis of results has the objective to maximize the efficiency and to adjust the treatment to the preponderant aggressions. This text refers to a study ongoing. Part of the results presented are preliminary and obtained by [4] in a master work guided by the authors.

Protective solutions should enhance formulations with penetration into the wood surface layer that provide alteration of their properties, retarding degradation by action and UV radiation, and promoting long-lasting hydrophobic properties. The effectiveness and efficiency of the protection will be studied by evaluating the physical, colorimetric and chemical degradation characteristics of the samples. Issues related to the durability of wood when exposed to outdoor environments have been the subject of several scientific studies. However, the toxicity and carcinogenicity of some solvents and products, the presence of heavy metals and VOCs make some of these solutions harmful to the environment and human health and incompatible with environmental and sustainability concerns [5,6]. Although there are still no satisfactory solutions, the causes that contribute to the surface degradation of natural wood exposed to solar radiation and rain are progressively being understood [1, 7].

Wood is a polymer complex composed essentially of cellulose, hemicellulose and lignin. Cellulose is a long linear polymer. Hemicelluloses are polysaccharides consisting of different chemical constitutions, depending on their origin. Lignin is a cross-linked polymeric structure made up of phenylpropane units containing chromophore groups with conjugated aromatic rings and carbonyl groups. The interaction of these groups with UV and visible radiation in the presence of oxygen is the main cause of photo oxidation of wood, while the contribution of cellulose and hemicellulose is minimal. Photo-oxidation of lignin is a process of successive chemical changes that results in its decomposition with the production of colored by-products. These surface modifications cause changes in physical and mechanical properties of the wood structure, increasing its sensitivity to water, washing and cracking of the surface layer. UV radiation causes changes in the chemical properties of lignin, gradually destroying the polymer chain and allowing its solubilization in water. After sufficient time to change the structure of the lignin, the direct effect of the water, little by little the removal of the lignin is given. With the entrainment of the lignin are the cellulose fibers disaggregated from each other, losing resistance properties. A very visible effect from the beginning is the change in the natural color of the wood to the shades of gray. In a climate with high solar radiation, the effect of discoloration to gray is very rapid, starting at about six months, if the radiation and water contributions are combined in the ideal sequence (radiation, followed by wetting). The solutions to be proposed should potentiate the formulations with penetration in the superficial layer of the wood and prolonged alteration of its superficial properties, fomenting properties of hydrophobicity of long duration. In this way, it will be possible to avoid the alteration of wood properties, keeping it dry and reducing surface movements and with water repellency, not only to avoid adhering to dirt and chemical contaminants, development of micro-organisms that depend on small pockets of moisture. The study of the surface microstructure changes that maximize properties of hydrophobicity, UV

resistance and improvement of the resistance to biological agents, without occurrence of adhesion or leaching loss, using products of low toxicity and low VOCs emission is presented.

2. MATERIALS AND METHODS

2.1. Wood specimens

A sample of 140 softwood specimens with 10 x 95 x 150 mm was used. The specimens from species of pinus (pine) and picea (spruce) presented sapwood and heartwood, several ring arrangements and some of them had knots. The test pieces with the least visible defects were selected. The specimens were obtained from wall wood paneling to simulate real cases of use. For that reason, their dimensions were different from the standards. These specimens were grouped into five groups, one for each environment. Each group is, in turn, composed of four batches corresponding to each protection product, seven times replicated. One of the batches was left untreated in the conditioned room as a control lot. Any irregularities were recorded, and the mass of each test specimen was recorded.

The specimens were then placed in a conditioned environment of $65 \pm 5\%$ RH and $20 \pm 2^\circ\text{C}$, and periodic weighing was carried out until their water content was stabilized, taking as reference the standard NP 614:1973 [8]. When all samples were stabilized by application of [8], a sample of five test pieces was dried in an oven and the actual value of the water content was determined, from which it was accepted that all other test pieces would have the same content. In this way, a water content of approximately 14% was obtained for the test pieces. The density determination based on the water content of the wood was made based on NP 616:1973 [9] standard. The density of the test specimens was $467 \pm 75\text{ kg/m}^3$ [4].

2.2. Coating products

To evaluate the performance of different coatings and wood protectors for exterior use, three commercial water-based exterior stains or lasures were selected according to criteria of low toxicity for mammals, low VOCs emission, ease of application, good absorption capacity and permanence in outdoor timber. For these products it was intended to evaluate its weatherability (simulating exterior walls without contact with the soil) and the attack by fungi (simulating the exterior walls in contact with the soil). Characteristics are presented in Table 1.

Table 1: Characteristics of tested products [adapted from 4].

	Acronym	ART	WAC	WRN
	Chemical designation	Acrylic resins with Teflon	Weatherproof acrylic copolymer	Water resistance assured by nanotechnology
Characteristics	Solvent ⁽¹⁾	aqueous	aqueous	aqueous
	Surface film forming	thin	very thin	none
	Final color ⁽¹⁾	colorless	colorless	colorless
	Fresh color product	white	white	colorless
	Gloss	semi-gloss	semi-gloss	matt
	Odor Intensity ⁽²⁾	medium	medium	soft
	Density ⁽¹⁾	1,03	1,04	0,98
	Drying to touch (min) ⁽¹⁾	30	60	n.a.
	Drying for use (h) ⁽¹⁾	12	12	24

n.a. – not applicable; ⁽¹⁾ Manufacturer Information; ⁽²⁾ Estimated by observation under test ($21 \pm 2^\circ\text{C}$)

After stabilization all test pieces were cleaned and degreased prior to the application of the product, then the products were applied to the exposed face and the density of the wood and product set measured.

2.3. Exposure environments

Four different environmental conditions were chosen: **MAR**-maritime, next to the coast (saline). Classified by [10] as severe; **IND**-industrial, in urban centre (pollution). Classified by [10] as high severe; **RUR**-rural, interior

of the country (high thermal amplitude and high radiation). Classified by [10] as soft; **SOIL**-soil contact (fungi and moulds) **CNTR** -building interiors (for control).

2.4. Natural weathering

Plates containing seven replicates of test specimens treated with each of three products and seven replicates of test specimens (control) were then be assembled [4]. The seven specimens treated with each of the three products and the seven control specimens were exposed to each of the standard environments for six months, between April and September 2014. This six-month period covers the more rigorous months of heat in Portugal (July and August).

2.5. Soil degradation

Soil degradation of the specimens was achieved by exposing them to a natural environment (a calibrated vegetable soil mixture) in boxes with ventilated lids according to a methodology developed by the author [6, 12]. The mixture was prepared according to Standard DD CEN/TS 15083-2:2005 [11] and the degradation process was run for 6 months in a conditioned room at 25 ± 2 °C temperature and $80 \pm 5\%$ 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

2.6. Physical assessment

At the end of this exposure period, the specimens were stabilized in a conditioned room and submitted to physical and chemical tests for evaluation of properties related both to appearance and to performance of wood and coating: mass loss; loss of gloss; color change; film adherence; resistance to natural aging; water permeability.

2.7. Chemical assessment

This scientific study, using FTIR and other image and chemical technologies is ongoing.

3. RESEARCH METHODOLOGY

The model of this research process is illustrated by diagrammatic representation in Figure1.

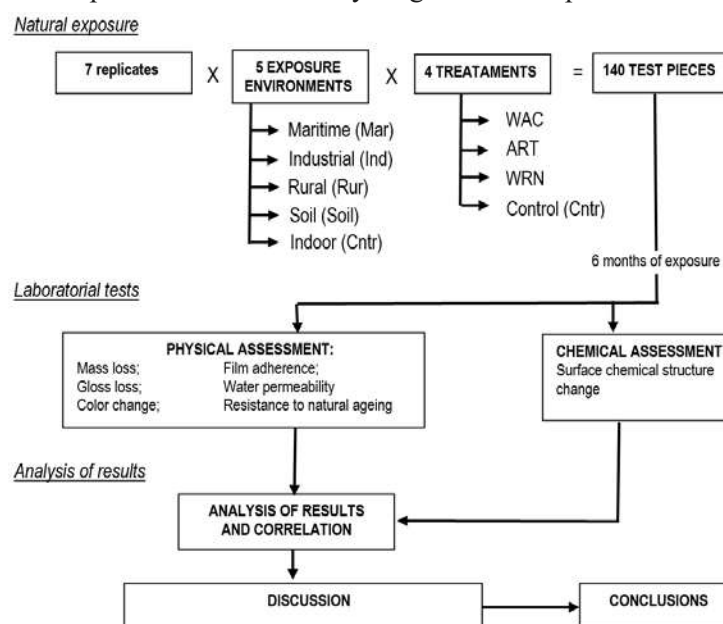


Figure 1: Research flowchart.

4. LABORATORIAL TESTS

After the periods of degradation (Figure 2) and after stabilization of all specimens, which took approximately one month, a comparative study was started. For all the tests described, the rules according to which they were to be carried out are presented, since it was not always possible to have access to the appropriate equipment for carrying out the tests according to the norms. For this reason, all results of visual inspection were done to obtain a quantitative conclusion, considering for this a percentage scale from 0% to 100%, not the scale of 0 to 5 (more qualitative), as suggested in Annex E of standard EN 927-3: 2000 [13]. Figure 2 shows the sample exposure.

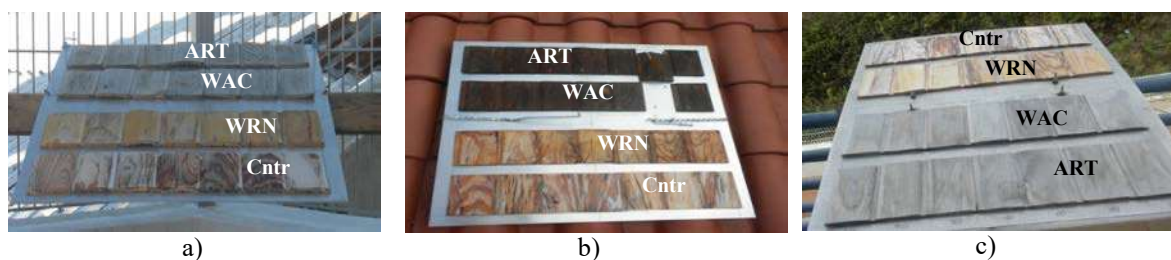


Figure 2: Samples exposure to the environments: a) Industrial (Ind); b) Rural (Rur); c) Maritim (Mar) [4]

4.1. Properties related to appearance

4.1.1. Gloss

The brightness classification is based on the determination of the specular brightness of the film resulting from the application of the paint product to a frosted glass base. It should be used an aperture of 150 μm and the brightness shall be determined in accordance with standard ISO 2813:2014 [16], using the angle of incidence of 60°. This is a characteristic that can only be evaluated for ART and WAC products since the WRN product is matt. In the present evaluation, it was decided to make an assessment, with the naked eye, about the loss of the initial brightness (when applied) in comparison with the various samples exposed, thus evaluating their wear. A percentage scale was considered, with 100% the brightness obtained after application of the product and 0% the total loss of brightness visible to the naked eye.

4.1.2. Color

Regardless of the location of exposure, the control specimens protected with WRN were greyish colored, while those protected with ART and WAC were derived to yellowish tones. In addition, the ART-protected products had white or whitish spots on the specimens. Coloring can be measured with the aid of a colorimeter, following ISO 7724-2: 1997 [17]. In the present case a visual comparison was made between a non-degraded specimen and the various specimens exposed to wear.

4.2. Properties related to performance of coating and wood

4.2.1. Film adherence

The loss of integrity of a coating can be directly related with film adherence and may be in various forms such as blistering, peeling or disappearance of the coating itself. The standard [13] recommends the evaluation of the anomaly density in each sample exposed through the ISO 4628-2: 2003 [18] standards for bubble formation, ISO 4628-5: 2003 [19] for the formation of peeling and ISO 4628-4: 2003 [20] for coating cracking. By the analysis of the test pieces after their degradation periods, it was found that the loss of integrity of the coating is essentially due to the formation of cracks. In some areas, the loss of coating may be due to the formation of bubbles that have subsequently been broken down, making the evaluation more complex. In this way, it was decided to visually determine the percentage of coating loss versus the total area of the specimen.

4.2.2. Mass loss

Although visual inspection is a good indicator of the appearance degradation of a specimen, it is difficult to know to what extent it has been structurally affected. Thus, a method of comparison of test pieces is the verification of the mass loss by effects of the degradation. Before and after the exposure process, the treated specimens were conditioned in an environment with 20 ± 2 °C and $65 \pm 5\%$ RH, and weighing was performed only after mass stabilization (wood + dried product). Mass loss levels between 0,5% and 10% were obtained for almost the whole sample, except for the control specimens exposed to the marine environment, which had mass gains.

4.2.3. Water permeability- Karsten Tube Test

The Karsten tube test is widely used in the measurement of permeability to water under low pressure in various inorganic type building materials, such as tiles and mortars, allowing to evaluate of the waterproofing properties of the coatings. The use of this device in wood coatings is innovative, and adapted, to comparatively evaluate the impermeability conferred to the surface by the treatment product used. This method permits carrying out tests both in situ and in the laboratory and not only the evaluation of the permeability of a coating but also the degree of degradation by comparing results with their original state.

4.2.4. Resistance to natural aging

The test is performed according to EN 927-3 [13] and the test pieces are prepared as indicated in its section 6. After visual observation the defects are evaluated on a scale of 0 to 5. In this work the resistance to natural aging was empirically evaluated combining the results obtained before and after aging in the different environments for all samples making joint analysis of the results obtained to film adherence, stain development and cracks development. Results are presented in percentage.

5. RESULTS AND DISCUSSION

The conclusions obtained from this study can be divided into before and after exposure and tests. Before exposure: after applying the product to the three specimens it is possible to see that: the application of WRN is perfectly imperceptible to the naked eye, unlike the WAC and ART products that leave a satiny appearance. WAC is the product that gives the most gloss to the wood. After the exposure period it is possible to observe significant differences between panels. The panel that presented the least degradation was the one exposed to industrial environment, being the other two in worse conditions (Figure 2).

The laboratorial analysis of the surface appearance was taken by comparison with the samples in the environment “indoor” as the control. Results are presented in percentage of loss: colour, gloss and adherence. Since neither the control nor the WRN had film or brightness the results for these parameters are null.

There is a very evident loss of surface appearance in the WRN-treated specimens, at levels like control specimens, for all environments (Figure 3). Comparing WAC products with ART, similar performances are found for all environments, but ART generally has better performance (Figures 3 and 4). About the environments there is an increasing loss of physical properties in the sequence of aggressiveness from Maritime to Industrial and Rural. This runs counter to the BS 6150 [10] sequence in which the harshest environment is industrial and the least severe is rural. The rural environment is worth mentioning, because despite the absence of chemical pollution, the test pieces were exposed to very high daily and seasonal temperature ranges (close to 30°C) and the average values of radiation is very high. Loss of color, gloss and loss of film higher than that of specimens exposed to the other two atmospheres (Figures 2 (b), 3 and 4) should be taken seriously in what is considered a mild exposure environment. The standard [10] does not establish the soil contact environment. It is verified that the physical loss is quite severe with all applied products and for all the characteristics studied.

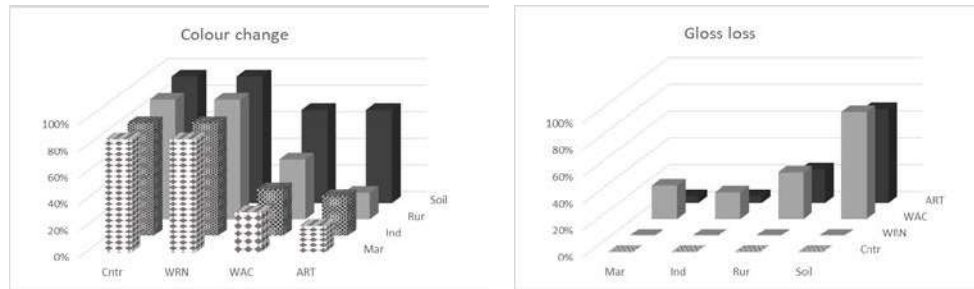


Figure 3: Loss of physical properties related to appearance

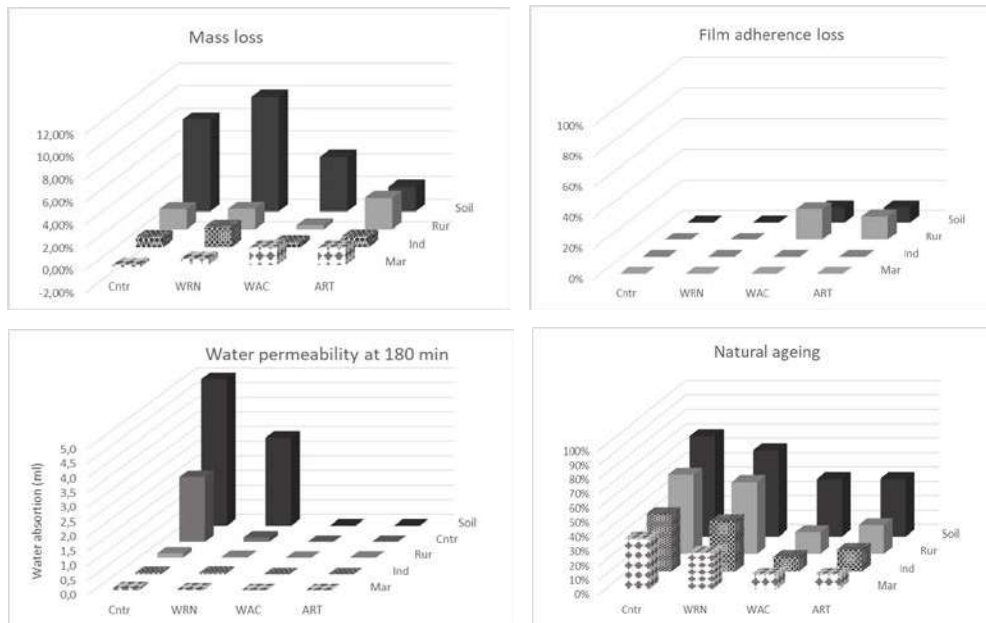


Figure 4: Loss of physical properties related to performance of coating and the wood

6. CONCLUSIONS

This work allows to conclude that the effectiveness of protection depends fundamentally on the aggressive conditions of the environment. In the case of Portugal, the interior zone, although rural poorly polluted, presents levels of aggressiveness that can be considered as severe considering the results obtained. The wood presents a porous and hygroscopic structure and the mass gain observed after exposure in the marine environment can be attributed to the crystallization of salts in the interior.

Portugal is in a latitude range between 30° N and 42° N, and for that reason it has considerable solar radiation values, which are considerably higher than those observed in most European countries. Solar radiation in our country therefore increases from north to south and from the coast to the interior. Considering the average values of radiation recorded for Continental Portugal: the area of Alto Alentejo - South-east (rural environment) has average irradiance values between 200-250 kWh / m² in the summer and 120 kWh / m² in winter, whereas for the Lisbon area (industrial environment) and Ericeira (maritime environment) in the range 150-160 kWh / m² in summer and about 100 kWh / m² in winter [21]. Thus, we can consider that the samples exposed in rural environment suffered a more pronounced surface degradation because of the more severe action of the incident UV radiation presenting. It is also concluded that the strict compliance of the standards can lead to situations of under-protection of the exterior exposed wood.

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