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Enhancing the Radiata Pine and Spotted Gum Coating Performance against Weathering using UV Absorber

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Abstract
Wood coatings play a significant role in enhancing the durability and overall aesthetic appeal of wooden products. This study investigates the performance of coatings applied to two wood species—Radiata Pine (Pinus radiata) and Spotted Gum (Corymbia maculata)—under various weathering conditions over one year. A total of 320 samples were analysed to study the effects of natural exposure and accelerated weathering (QUV) on both solid and clear coatings. The incorporation of UV absorbers into coating formulations demonstrated significant improvements in stabilising wood colour, with Radiata Pine benefiting most from UV absorption, while Spotted Gum performed better when untreated. The findings indicate that strategic use of UV absorbers is critical in extending the lifespan of wooden products.

Keywords: Wood Coating, UV Absorber, Weathering, Radiata Pine, Spotted Gum

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1.0 Introduction

Wood, touted for its aesthetic and functional benefits, is inherently hygroscopic due to the abundance of hydroxyl (OH) groups throughout its structure, particularly in the cellulose and hemicellulose fractions. These hydroxyl groups facilitate the attraction and retention of water molecules via hydrogen bonding. While these properties contribute positively to the wood's ecological footprint, they also render unprotected wood surfaces highly susceptible to environmental factors, leading to significant weathering. Weathering, as defined by William (2005), refers to a series of physical deteriorations, including colour changes, surface roughening, cracking, and irreversible damage to the wood microstructure.

This study aims to investigate the mechanisms of wood deterioration under weathering and to explore protective coating treatments that mitigate these effects. Specifically, the effects of ultraviolet (UV) radiation on wood must be understood comprehensively, as it is a major contributor to wood degradation. The breakdown of lignin and other wood constituents by UV radiation, coupled with the removal

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of water-soluble degradation products via precipitation, accounts for the surface-level deterioration observed in wood exposed to natural outdoor conditions.

1.1 Weathering

Weathering encompasses gradual surface deterioration, where external environmental conditions induce observable changes in appearance (e.g., gloss and colour), alterations in surface roughness, and the emergence of surface checks. The superficial layer of wood changes primarily due to lignin degradation and the disintegration of other structural constituents by ultraviolet radiation. This degradation is often exacerbated by moisture, as rain leaches away water-soluble degradation products, further compromising the wood's structural integrity and aesthetic appeal.

Understanding the weathering process is crucial to developing more effective protective measures. Traditional coatings have often fallen short in prolonging the service life of wood products when exposed to the elements. Thus, the need arises to investigate innovative protective technologies that offer improved durability and aesthetics, particularly in light of increased awareness of sustainability and the longevity of wooden products.

1.2 Coatings Durability

Coating durability in wood protection has evolved, and is currently defined by several key criteria, including:

1. The length of exterior exposure during which the coating retains an acceptable appearance, protects the substrate, and requires no maintenance beyond routine cleaning.
2. The extent to which coating systems resist the destructive impacts of weather, thereby ensuring the longevity of the underlying wood structure.
3. The ability to reliably provide its intended functionality over an extended service life under typically anticipated conditions of use (Graystone, 2013).

These criteria highlight the need for interventions that enhance the performance of wood coatings against the dual threats of weather-induced deterioration and aesthetic compromise, paving the way for advances in protective technologies.

1.3 Research Objectives

The primary objective of this study is to assess the performance and longevity of wood coatings by examining colour changes on wood surfaces over time under both natural light and artificial weathering conditions. This study aims to explore how incorporating ultraviolet absorbers can shift the performance paradigm for coatings on radiata pine and spotted gum, two species widely used in outdoor applications.

The specific objectives of this research are as follows:

1. To evaluate the effects of UV radiation on the colour stability of radiata pine and spotted gum in outdoor conditions.
2. To determine the extent of surface roughness changes over time in wood samples subjected to weathering processes.
3. To assess the protective capability of selected UV absorbers when incorporated into wood coatings.
4. To compare the performance of coatings with UV absorbers against standard coatings without these enhancements in terms of aesthetic retention and physical integrity over time.

2.0 Literature Review

Wood is inherently a strong light absorber due to the presence of various chromophores, including phenolic hydroxyl groups, aromatic skeletons, double bonds, and carbonyl groups. When exposed to outdoor conditions, wood undergoes a complex interplay of chemical, mechanical, and energy factors known as weathering. The primary agents contributing to wood weathering include ultraviolet (UV) irradiation and moisture. Among wood polymers, lignin stands out as the most effective absorber of UV light, thanks to its chromophore functional groups that absorb a broad spectrum spanning 250–400 nm (Sadeghifar et al., 2020). The phenolic hydroxyl groups in lignin react with UV radiation to generate aromatic free radicals (phenoxy radicals), which subsequently react with oxygen to form quinoid structures responsible for the yellowing of wood (Pandey, 2005). Photodegradation affects a thin surface layer of wood due to its limited penetration. Previous studies suggested that UV light penetrates wood to approximately 75 μm; however, recent investigations have shown that this penetration depth can reach up to 150 μm (Volkmer et al., 2016). Not only UV light but also visible light, particularly in the violet region, contributes to surface discolouration (Živković et al., 2014). Weathering processes induce notable changes in the wettability of wood surfaces (Cademartori et al., 2015), impact the surface layer strength (Turkulin et al., 2001), alter the chemical composition (Kanbayashi et al., 2018), and modify the microscopic structure of the wood surface (Sandak et al., 2021). While weathering primarily manifests at the surface, it significantly affects the appearance, service life, and coating performance of outdoor wood products. Colour change, the first indicator of conflicting chemical reactions in weather-exposed wood, is instigated by solar radiation, chiefly the UV component. UV radiation possesses substantial energy, causing bond breakage in the polymeric molecules of wood and leading to photochemical reactions that depolymerise lignin and cellulosic polymers in the wood cell wall. Together with moisture, temperature fluctuations, and oxidative agents such as oxygen and ozone, UV radiation facilitates the degradation of lignin and cellulose, which, in turn, adversely affects a range of physical, chemical, and biological properties of wood.

2.1 Protection with Coatings

To protect wood from the detrimental effects of weathering, various coatings—such as paints, varnishes, stains, and water repellents, are commonly employed (Evans et al., 2020). The primary objective of applying these coatings is to protect the wood from UV radiation and moisture while preserving its appearance. Recent advancements in coating technology have emphasised the development and modification of coatings to enhance their protective efficacy (Mishra et al., 2021). The performance evaluation of coatings typically hinges on changes in colour, gloss, adhesion loss, brittleness, chalking, peeling, blistering, and structural alterations in the coating (Miklečić, 2020). Selecting the appropriate coating presents challenges, particularly in maintaining the natural appearance of wood, ensuring surface protection, and adhering to increasingly rigorous environmental regulations (Saha et al., 2020). Weather conditions negatively affect both the physical and mechanical properties of coatings by inducing new functional groups or fragmenting cross-linked macromolecules (Pospíšil et al., 2021). Furthermore, the absorption of UV radiation by coatings and the underlying wood can initiate complex chemical reactions, leading to degradation of the protective function and deterioration of both the coating and the substrate (Miklečić et al., 2021).

To prolong the service life of wood and preserve its natural aesthetic, the development of eco-friendly clear coatings has become paramount in wood finishing (Miklečić, 2020). While clear coatings can enhance the visual appeal of wood surfaces, they also allow harmful solar radiation to penetrate, inducing surface alterations (Miklečić et al., 2021). Numerous clear coatings degrade after as little as one to two years of outdoor exposure, depending on climatic conditions (Evans et al., 2020).

Three core methods to fortify wood coating systems against harmful solar irradiation involve: (1) reflection (using pigments), (2) suppression of reactions by eliminating free radicals using hindered amine light stabilisers (HALS), and (3) absorption of UV radiation preemptively to hinder free radical formation, utilising UV absorbers (Miklečić et al., 2021). Pigments are insoluble fine particles that enhance the performance of coatings through light interaction, but they can obscure the wood's natural texture and colour (Wicks, 2018). Organic UV absorbers, introduced into coatings to defend wood from detrimental UV radiation, include substances such as benzophenone, benzotriazole, triazine, malonate, and oxalanilide (Miklečić, 2020). Benzotriazole is particularly noteworthy for its high UV absorption and low visible light absorption, making it valuable for clear coatings (Rao et al., 2021). However, the relatively low molecular weight of organic UV absorbers raises concerns regarding their potential migration to the coating's surface and susceptibility to degradation (Lowry et al., 2020).

Recent findings indicate that adding organic UV absorbers effectively mitigated wood discolouration during initial phases of artificial weathering (Allen et al., 2021). However, protection can diminish over time as absorbers migrate and degrade during weathering. In outdoor coatings, organic UV absorbers are typically applied at concentrations of 1–5%, though this can reduce coating transparency (Allen et al., 2021). The efficacy of benzophenone in providing weathering protection is noteworthy, as evidenced by Rao et al. (2021), who demonstrated superior photodegradation resistance in bamboo compared to coatings with ZnO nanoparticles. Despite these benefits, Akbarnezhad et al. (2020) found that benzophenone-modified acrylic coatings failed to mitigate the effects of natural weathering on beech wood. Incorporating inorganic UV absorbers, such as TiO2, ZnO, CeO2, and iron oxides, extends UV protection without degradation over time; however, they may alter the coating's colour. Recent studies by Forsthuber and Grüll (2021) confirmed that TiO2 microparticles effectively reduce wood discolouration. Increasingly, the integration of nanoscale inorganic UV absorbers in tandem with HALS and organic UV absorbers has shown promise, as these nanoparticles can protect coatings without significantly compromising transparency (Sun et al., 2021). Nevertheless, research remains imperative to assess the safety of nanomaterials for human health and the environment before their widespread application in wood treatment technologies (Wiesner et al., 2020).

3.0 Methodology

3.1 Preparation of Samples

The wood samples utilised in this study were sourced from two distinct species: Radiata Pine (*Pinus radiata*) and Spotted Gum (*Corymbia maculata*). The selection of test samples was meticulous; only samples free of knots, cracks, blue staining, or other indications of fungal infection were included to maintain uniformity and reduce data variability. To ensure that the wood samples had a consistent starting point for experimentation, they were conditioned in a controlled environment room in accordance with ISO 554:1976. This environment was maintained at a temperature of 20 ± 2 °C and a relative humidity of 65 ± 5%. The samples were allowed to equilibrate until they reached a constant mass, corresponding to an equilibrium water content of 11%. This conditioning step is crucial, as it ensures that subsequent tests on the samples reflect the wood's inherent properties rather than fluctuations in moisture content.

3.2 Formulations of the Coating Systems

To assess the impact of light stabilisers on the coatings' durability, the study implemented two primary types of stabilisers:

1. UV Absorbers: These compounds serve as filters for ultraviolet radiation, which is known to degrade coating materials and negatively impact their aesthetic qualities.
2. Radical "traps": Specifically, sterically hindered amines (HALS) are utilised not to absorb UV radiation, but to limit radical formation that occurs during the photolysis process.

The inclusion of these stabilisers is critical, as they play a significant role in preserving the colour integrity and mechanical properties of coatings, thereby enhancing their longevity when exposed to environmental stressors. Additionally, this study aims to investigate whether the addition of colourants influences the efficacy of the UV absorbers. For this purpose, coatings were formulated in two variants: solid colors (e.g., white) and clear (transparent) coatings, with and without UV absorbers. Each coating variant was assessed with three different graft molecules, characterised by small, medium, and large molecular weights, enabling a comprehensive evaluation of the stabilisers' performance across various formulations. An updated schematic diagram of the experimental design is presented in Figure 1, which now clearly indicates all major stages, materials, and flow directions for better comprehension.

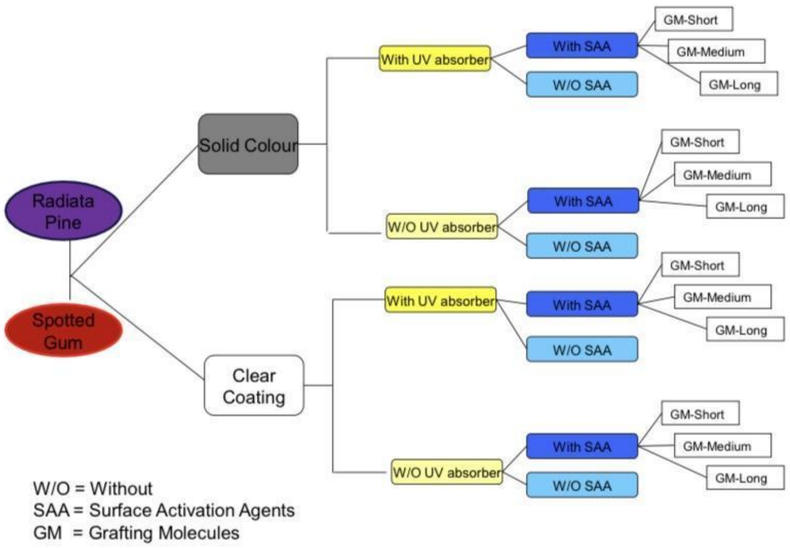

Figure 1: Schematic diagram of experimental design.

The total number of wood samples used for the study was 320 samples: two types of species (Radiata Pine and Spotted Gums), two types of weathering (Natural Exposure and QUV), and two types of coating systems (solid colour and clear), three different graft molecules (short, medium and long).

3.3 Application of Paint

After a 30-minute drying period for the graft molecules, each sample underwent a rigorous painting process with designated coats of clear and solid water-based paints sourced from Dulux Australia. The application was performed meticulously using a roller brush on the top surfaces of each sample. To achieve the recommended coating thickness of at least 60 microns per layer, three coats of paint were systematically applied. The coating thickness was monitored with a thickness gauge to ensure compliance with the required standards. After each coat application, the samples were placed in an oven to expedite drying—a crucial step to control drying conditions and minimise variability in adhesion performance among samples.

Furthermore, the sides and edges were coated three times with the same paint using a painting brush to ensure comprehensive sealing, which is vital for preventing moisture ingress and ensuring the reliability of adhesion tests. After completing the paint application, the samples were allowed to cure for approximately one week. This curing period is essential for the subsequent adhesion and performance testing, as it allows the coatings to reach their optimal physical and chemical properties.

3.4 Colour and colour shift measurement

Subsequent to conducting the initial cross-hatch tests, colour measurements were systematically recorded for each sample using a colourimeter, ensuring accuracy through three readings per sample. The changes in colour due to UV exposure were evaluated using the CIE L*a*b* method with a CIE spectrometer. This method was employed to determine shifts in lightness (L*), redness (a*), and yellowness (b*), enabling the calculation of the total colour shift, ΔE, as per established equations. Subscript 1 denotes values obtained before UV exposure, while subscript 2 refers to values recorded post-exposure. This dual measurement approach reinforces the robustness of the study by quantifying the effects of weathering on the coatings applied to the wood samples.

Figure 2: Colourimeter

The colour change during UV exposure was determined by the CIE L*a*b* method using a CIE spectrometer. The changes of lightness (L*), redness (a*) and yellowness (b*) were used to calculate the total colour shift, ΔE, by the following equation:

$$\Delta E = \sqrt{(L*_2 - L*_1)^2 + (a*_2 - a*_1)^2 + (b*_2 - b*_1)^2}$$

Subscript 1 denotes the values before UV exposure, whilst subscript 2 denotes the values after exposure.

3.5 Limitations

While this study provides valuable insights into the weathering performance of coated wood species, several limitations should be explicitly acknowledged.

1. Sample Size: The analysis was conducted on a limited number of samples. This narrow scope might affect the generalizability of the results, as larger sample sizes would provide a more robust representation of the weathering effects across different environmental conditions.
2. Method Constraints: The methodology employed for measuring colour change was primarily observational and did not utilise advanced imaging techniques or colourimetric analyses. Such methods would offer more precise quantification and validation of colour changes over time.
3. Measurement Issues: The parameters for measuring surface damage were somewhat subjective and may lack precision. A more objective and quantifiable approach to assessing the degree of coating erosion would yield more reliable data.
4. Short-term Study Duration: The maximum exposure duration of nine months, while revealing significant trends in coating longevity, was not sufficient to draw comprehensive conclusions about the long-term durability of the coatings, especially under varying environmental conditions.

4.0 Results and Discussion

4.1 Colour Change Measurement

The colour change during UV exposure was determined by the CIE L*a*b* method using a CIE spectrometer. The changes of lightness (L*), redness (a*) and yellowness (b*) were used to calculate the total colour shift, ΔE, by the following equation:

$$\Delta E = \sqrt{(L*_2 - L*_1)^2 + (a*_2 - a*_1)^2 + (b*_2 - b*_1)^2}$$

Subscript 1 denotes the values before UV exposure, whilst subscript 2 denotes the values after exposure.

The colour change was calculated through the values of L*, a* and b*. Each of these parameters was obtained from an average of 3 readings from each test area on the samples of Radiata Pine and Spotted gum, and then from the average of the three samples for each formulation. Good results were obtained when measuring the parameters in the same samples during the weathering. But when comparing different formulations, some deviations in the global behaviour were detected between the two species of each formulation. In hindsight, it would have been useful to have more test specimens for each coating formulation. It can also be seen that a statistically significant difference between the adhesions of the two types of coatings existed only on the different chemical grafts (low, medium, and high). A colour change was always observed with ageing. Table 4.1 showed that the colour change due to different UV exposure duration during natural weathering based on sample groups, wood species and coating types. The results showed that the exposure duration had a significant effect on the colour change of the sample groups which were exposed to natural weathering.

Table 4.1: Mean colour change values during natural weathering, comparison in wood species and coating types.

Exposure Duration	Group	Treatment					
		Natural Weathering					
		Wood Species		Coating			
		Radiata Pine (%)	Spotted Gum (%)	Clear (%)	White (%)	Clear UV (%)	White UV (%)
0 month *ΔE	Brisbane	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Melbourne	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	QUV	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
3 months *ΔE	Brisbane	1.4 (1.26)	1.36 (0.71)	1.71 (1.09)	1.06 (0.82)	1.54 (1.17)	0.81 (0.45)
	Melbourne	4.3 (3.33)	3.51 (2.32)	6.25 (2.22)	1.55 (0.31)	6.25 (1.42)	1.48 (0.28)

	QUV	9.07 (8.85)	5.23 (4.31)	12.75 (5.69)	1.54 (2.31)	11.23 (4.7)	1.27 (1.11)
6 months *ΔE	Brisbane	5.5 (3.2)	4.08 (1.78)	6.58 (2.66)	3 (0.75)	6.13 (2.45)	2.89 (0.87)
	Melbourne	5.08 (1.52)	4.39 (1.26)	4.81 (1.95)	4.66 (0.58)	5.16) (2.01)	4.83 (0.49)
	QUV	8.77 (8.57)	5.5 (4.19)	12.68 (5.14)	1.59 (2.18)	10.86 (2.46)	1.09 (0.39)
9 months *ΔE	Brisbane	6.71 (3.15)	5.3 (2.28)	7.92 (2.73)	4.09 (0.95)	7.71 (3.57)	4.57 (1.08)
	Melbourne	6.32 (3.49)	5.73 (3.28)	7.61 (4.14)	4.44 (0.79)	8.65 (4.65)	4.74 (0.68)
	QUV	9.29 (8.96)	5.32 (4.38)	13.14 (5.5)	1.47 (2.25)	12.17 (2.75)	0.98 (0.43)

*Values in parentheses are the standard deviation.

All exposure durations gave significant effects to the sample groups exposed to the natural weathering, except the 0-month and 9-month groups. The percentage of colour change increased in parallel with the increase in exposure duration. The change of colour was expected due to the exposure to UV, which is known as colour fading. Colour fading is defined as the loss of colour of one or more of the colour pigments within the paint (in this case, coating). This fading is also known as paint degradation. The fading occurs when a substrate coated with the paint is exposed to sunlight (the source of UV) and the hot and cold cycles of the surrounding environment (Dulux, 2023). When comparing by species, it was clear that Radiata Pine had slightly higher mean colour change values for all exposure durations compared to those of Spotted Gum. The results for Radiata Pine ranged from 0 to 9.29%, and Spotted Gum ranged from 0% to 5.73%. Radiata Pine is known to have lower durability compared to Spotted Gum, and perhaps this characteristic has accelerated a higher colour change rate on the surface of Radiata Pine. The other fact that needs to be taken note of is that Spotted Gum has a darker colour compared to Radiata Pine, thus the colour change on the surface of Spotted Gum was not as prominent as that of Radiata Pine (Wood Solutions, 2018). Both species showed colour change only after they had been exposed to natural weathering for more than 3 months. The coating type was also found to have an influence on the colour change rate. Both coatings were effective in the prevention of UV photodegradation. Similar results patterns were found from samples coated with Clear UV and White UV. The colour change occurred after the samples were exposed to natural weathering for more than 3 months. No changes were recorded before that exposure duration. These compelling results underscore the necessity of incorporating specific guidelines for wood treatment within industry standards, particularly concerning Australian timber species like Radiata Pine and Spotted Gum. The findings suggest that coatings infused with UV absorbers should be recommended in applications where these species are utilised to enhance their longevity and aesthetic appeal. Furthermore, future research should investigate optimally tailored formulations and long-term performance evaluations across different climatic conditions to ascertain their effectiveness comprehensively.

5.0 Conclusion and Recommendations

In conclusion, the application of UV absorbers significantly enhances the coating performance of Radiata Pine and Spotted Gum against weathering effects. The primary visual alteration noted during the initial quarter of outdoor exposure was discolouration, with the degradation domino effect influenced predominantly by UV radiation exposure. Initially, the wood substrate's influence on weathering was minimal; however, observable changes began to manifest notably after six months of exposure, characterised by mild erosion and superficial damage to the coating layers. A critical assessment of the colour change revealed that it was directly correlated to the duration of UV exposure across different wood species and coating types. Notably, significant discoloration commenced after three months of exposure, with the colour variation being relatively modest between Radiata Pine and Spotted Gum. The post-weathering samples displayed a darker hue relative to their control counterparts, emphasising the enduring impact of UV degradation on aesthetic qualities even when protective coatings are employed.

Based on the limitations outlined in the methodology section, several actionable recommendations are proposed for enhancing future research endeavours: 1. Broaden Sample Scope: Future studies should include a wider variety of wood species and coating formulations to establish a more comprehensive understanding of their behaviour under varying exposure conditions. This could involve a comparative analysis of domestic and exotic wood species and synthetic versus natural coatings. 2. Implement Advanced Measurement Techniques: Utilising advanced technologies such as spectrophotometry for colour measurement, drone imagery for surface analysis, or even real-time monitoring systems could enhance the accuracy and depth of the research findings. 3. Long-term Performance Assessments: Extending the duration of exposure beyond two years would provide critical insights into the long-term performance of coatings. This would allow researchers to analyse the interactions between environmental variables, UV exposure, and coating performance over extended periods. 4. Incorporate Mechanical Testing Methods: In future investigations, it is recommended that mechanical testing be integrated to evaluate the sustained structural integrity of the wood species under weathering stresses. This could include assessments like density, moisture content (MC), modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) under various exposure conditions. 5. Investigate Engineered Wood Applications: Future research should also explore the transformation of Radiata Pine and Spotted Gum into engineered wood products, such as particleboard, plywood, or laminated profiles, assessing their performance under weathering conditions typically faced in structural applications.

Finally, a concerted focus on new variables and advanced technologies could pave the way for significant advancements within this field. Areas for further exploration may include: 1. Environmental Variability: Studying the effects of different climatic conditions on the weathering performance of coated wood, including variations in temperature, humidity, and UV intensity, could yield essential insights for practical applications. 2. Chemical Interactions: Investigating potential interactions between UV absorbers and different coating chemistries may also unveil innovative approaches to optimising coating formulations for enhanced durability. 3. Sustainability Considerations: Future research should also take into account the sustainability of various wood species and coatings, focusing on biodegradable options or eco-friendly treatments that provide protective qualities without impacting environmental health.

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Paper Contribution to the Related Field of Study

This study presents a significant advancement in the field of wood treatment and protective coatings, particularly focusing on Radiata Pine and Spotted Gum. The primary contribution lies in our introduction and evaluation of a novel UV absorber specifically designed to enhance the weathering resistance of these wood species. By systematically investigating the interaction between the coating formulations and the UV absorber, this research provides new insights into optimising coating formulations for improved durability, thus addressing a prominent issue within the Coating Industry. The findings reveal that the application of the UV absorber leads to a marked improvement in the longevity of the coatings when exposed to various weathering conditions. This advancement is pivotal, as it not only extends the life cycle of wooden products but also contributes to sustainability efforts by reducing the frequency of re-coating and maintenance. The implications of this study extend beyond theoretical contributions to encompass practical applications in wood preservation, thereby meeting the industry's increasing demand for environmentally friendly and efficient solutions. In contrast to previous research, which may have focused predominantly on conventional coating materials without considering the role of UV absorbers, our work underscores the importance of integrating such additives into wood coatings. Previous studies have often noted the detrimental effects of weathering on wood, highlighting the need for improved formulations. However, this research goes a step further by offering a tangible solution that enhances both the aesthetic quality and protective attributes of wood surfaces. Moreover, the methodology sets a precedent for further exploration within the coating industry. The standardised techniques we employed not only allow for reproducibility but also pave the way for future studies to build upon our findings. By elucidating the mechanisms through which UV absorbers interact with wood coatings, our study lays the groundwork for subsequent investigations into optimising treatment strategies for different wood species and environmental conditions.

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