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Article

Investigation into Adhesion of Coatings and Adhesives of Eucalyptus and Grey Poplar for Building Applications

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Abstract: This study investigated the bonding strength and chemical composition (as an influencing factor of adhesion) of red eucalyptus (*Eucalyptus camaldulensis*) (EUW) and grey poplar (*Populus canescens*) (GPOW) wood surfaces, comparing their suitability for indoor and outdoor wood-building applications. The research focused on adhesion strength using different coatings and adhesives, including lasure and 2K lacquer. The results showed that whilst both wood species had a conveniently high cellulose content, GPOW had a higher cellulose content (48.21%) than EUW (45.18%). However, EUW demonstrated superiority in tensile shear strength tests when using structural adhesives. Additionally, EUW exhibited stronger pull-off adhesion with 2K lacquer (5.25 MPa) compared with GPOW (3.42 MPa), suggesting that whilst both reached the expectations, EUW was more appropriate for high-stress indoor applications like flooring or wall cladding. EUW and GPOW performed well with lasure, achieving comparable adhesion strengths. EUW had a density of 1020 kg/m^3 vs. 575 kg/m^3 for GPOW and stronger bonding capabilities than GPOW, which suggests that it is equally suitable for wood applications inside and outside buildings. The study concluded that whilst both wood species met expectations and proved to be suitable for doors, windows, and other wood-building product applications, GPOW was suitable for the production of cellulose-based products, while EUW was worth relying on for its excellent adhesion to coatings and adhesives.

Keywords: red eucalyptus; adhesion; lacquer; lasure; grey poplar; cellulose and lignin contents

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1. Introduction

Researchers have shown a growing interest in addressing the issue of climate change and assessing the environmental impact of various industries, with the aim of reducing greenhouse gases that harm the atmosphere and contribute to global warming [1–4]. In the construction sector, increasing attention has been focused on studying and using sustainable materials of natural origin. Wood, as a natural, forest-derived material, is known for being suitable for constructing both large- and small-scale structures [5,6]. Ramage et al. (2017) [7] studied the use of timber in general for wood products and highlighted its historical role and the renewed interest in wood construction. Numerous studies have explored the role of wood in sustainability and the use of wood in both structural and non-structural construction across various wood types. However, certain wood types specific to regions remain under-researched and underutilized despite possessing unique and distinctive characteristics [8]. Wood is a renewable and biodegradable engineering material that is lightweight and has good strength characteristics. It has been used since ancient times. GPOW and EUW are distinct wood species; grey poplar is among the fastest-growing wood species in Europe, whilst eucalypts are recognized as some of the fastest-growing trees in the world [9]. Eucalyptus is the most abundant Australian tree species commercially planted in warmer tropical and temperate climates. These regions include America, Brazil, Europe, Africa, the Mediterranean Basin, the Middle East, China, and the Indian subcontinent, where it is increasingly cultivated. Countries like Iraq and Saudi Arabia utilize it due to its oil's health benefits [10,11]. The rapid expansion of global forest cultivation and its significance as a source of raw materials underscores the growing demand for fast-growing species in various applications [12].

In the case of POW, the cellulose (holocellulose and alpha-cellulose) content is usually higher than the lignin content [13]. These characteristics allow it to be utilized in various industrial applications, including furniture making and paper production. POW is used for construction-grade lumber and plywood, as it is economical, thick, and long-lasting. Owing to its straight grain, even structure, and capacity to adhere to stains and paints, it also finds applications in interior works. However, over time, POW tends to warp and become discolored. Its greater strength-to-weight ratio and ease of processing also make it applicable for structural engineering [14]. Because of its good mechanical properties, EUW is also appropriate for use in structural members such as beams or columns of buildings [15] or non-structural applications like bio-based insulation panels [16], but it has shortcomings. EUW raises concerns regarding its durability, environmental factors, and resistance to moisture and insects [17]. Other than that, EUW is worth investigating as an alternative to traditionally used timber. Due to its rapid growth and availability, it is indeed a sustainable material [18]. Grey poplar is obtained from different species of the genus Populus, which is very flexible, easily available, and has suitable mechanical properties. GPOW is very much understudied and even underutilized compared with its available stock. Limited research results concerning grey poplar are available for Hungarian forests, which has proved to be a species resistant to climate change, spreading in forests even by itself without being planted.

This research intended to determine the bonding strength of GPOW compared with EUW and examined surface coatings' adhesion strength, involving lasure (for external surfaces) and 2K lacquer (for internal use). The chemical properties of both species were also investigated to reveal the influence of these internal factors on bondability and adhesion, as synthetic resins are supposed to be influenced by the chemical status of the wood surface and have an effect on the quality of the engineering applications. The suitability of EUW for enhanced structural applications has been studied only occasionally, even for new techniques such as non-destructive testing [19], whilst GPOW is not a focus of research attention. The choice of these two wood types was driven by the fact that they both are abundantly available, but underutilized in their countries of origin. At the same time, they have unique characteristics in addition to the limited availability of academic resources on their properties, particularly in building applications.

Iraqi eucalyptus wood, for instance, is abundant, and there are studies promoting its further plantation when developing strategic plans to address the problems of afforestation and forests, and to revive artificial forests or green-belt forests by selecting trees suitable for the climate of Iraq. Eucalyptus was ranked as the most suitable wood species; it was considered ideal for creating green-belt forests around cities, as, in addition to their tolerance to high heat, salinity, and lack of watering, they grow easily and can be utilized in several areas, including beekeeping (which results in the best type of honey in the world) [20]. Although it is recognized as a resistant wood species, it is underutilized, with minimal scientific research available to explore its potential.

Grey poplar, on the other hand, is available in Hungary in large stocks, but has a lack of academic exploration regarding its material properties and technology knowledge, and its utilization remains sparse. This makes it an intriguing subject for further research, particularly in understanding its coatability and bondability.

By studying these two species, we sought to establish a comparative understanding of their behavior and potential, connecting two distinct regions—one in the Middle East and the other in Europe—by focusing attention on two underutilized wood species.

As wood is a renewable material, it is a luxury to omit some wood species from production just because they are not part of the usual business and are not fashionable. The trends can be changed. The first steps are to reveal the properties of the wood species in question and to make utilization suggestions for the wood industry. Wood can only store CO_2 if it is not decomposing. If some wood species are left to decay in the forest (which already happens with large stocks of grey poplar in Hungary and with eucalyptus in Iraq), instead of storing carbon in the form of wood products, the decomposing wood starts emitting CO_2 and becomes responsible for further CO_2 emissions. Committed to sustainability, our paper investigated two underutilized wood species to contribute to their broader utilization, as any further utilization leads to carbon storage. By focusing on this species, we aimed to fill a critical gap in the literature and highlight the suitability of GPOW and EUW for construction purposes, thereby contributing to their larger utilization with scientific knowledge.

2. Materials and Method

2.1. Materials

2.1.1. Lasure

Lasure is a versatile, biocide-free, and protective coating, which is ideal for outdoor wood surfaces (but also suitable for indoors), offering enduring protection against weathering while accentuating the natural beauty of the wood grain with high-quality, non-fading earth pigments. It is suitable for various applications, including windows, doors, facades, and garden furniture, ensuring longevity and easy maintenance. This materialwas purchased from OBI Hungary (Sopron, Hungary), has a density of 1300 g/L, and contains binders (linseed oil and acrylic polymers), pigments (iron oxides and titanium dioxide), solvent, or aqueous phases for application. It allows water vapor diffusion, but has high resistance to soaking in water.

2.1.2. 2K Lacquer

2K lacquer is an acid-curing, alkyd, and amino-resin-based experimental lacquer, requiring phosphoric acid as a hardener. The lacquer has high gloss (80–100 gloss units per DIN 67530 [21]; 60°), and is resistant to UV radiation, mechanical stress, and heat up to 150 °C. Mixing requires resin and hardener, with a mixing volume ratio of three parts of component “A” to one part of component “B”. The mixture dries at 20 °C for 3 h. The recommended amount for lacquering is 100 g/m^2 per layer.

2.1.3. Pattex Wood Express (D2)

Pattex Wood Express (D2) adhesive (Henkel Ltd., Budapest, Hungary) was used, which quickly bonds wood. It is a white, synthetic adhesive based on PVAC resin. It is an adhesive for wood and laminates, it is fast-setting, and it is ideal for indoor assembly, joint, and surface-bonding applications. Joints bonded with Pattex Wood Express resist short-term soaking in water and fulfill D1 and D2 classes according to EN 204:2016 [22]. The adhesive’s final strength is greater than the cohesion of the bonded wood. The required amount is approx. 150 g/m^2, depending on the substrate’s absorbency.

2.1.4. Pattex Wood Express (D3)

Pattex Wood Express (D3) adhesive (Henkel Ltd., Budapest, Hungary) was also used, which is suitable for indoor and outdoor applications. It can be used for joints, solid wood bonding, and large surfaces. The adhesive film is white and transparent. The adhesive forms a water-insoluble layer that can be mechanically removed. The D3 adhesive is manufactured according to EN 204:2016, with a suggested application amount of 140–200 g/m^2, depending on the wood substrate's absorbency.

2.1.5. JOWAPUR 681-60 Structural Adhesive

JOWAPUR 681-60 structural adhesive (Jowat SE Co., Detmold, Germany) was also used. This is a joint-filling, fiber-reinforced, one-component polyurethane adhesive for load-bearing wood structures. This adhesive is recommended to be applied on wood surfaces at an amount of 120–160 g/m^2.

2.2. Method and Wood Materials

The GPOW material was obtained from KEFAG Ltd. (Kecskemét, Hungary), and the EUW was collected in Iraq by author. The GPOW samples, as shown in Figure 1, were characterized by a measured density of 510 kg/m^3 and an average moisture content of 12.65%. The wood species' indicative mechanical properties were reported based on the literature as follows: a bending strength of 67.5 MPa, a tensile strength of 82.3 MPa, a shear strength of 7.8 MPa, and a compressive strength of 38.3 MPa, as reported by Molnár and Bariska (2002) [23].

On the other hand, the EUW samples, as shown in Figure 2, had a significantly higher density of 1020 kg/m^3 and an average moisture content of 12.8%, with an indicative compressive strength of 88 MPa and a tensile strength of 60 MPa, as documented in related studies [24].

Figure 1. Digital photographs of GPOW samples.

Figure 2. Digital photographs of EUW samples.

The wood surfaces were planed and adequately sanded with a grit size of 150 using a contact sanding machine (with simultaneous dust exhausting).

The surface topography of the machined surfaces was recorded using a topography module integrated with a OneAttension Theta tensiometer (Biolin Scientific AB, Gothenburg, Sweden) as shown in Figure 3. During the procedure, a digital camera recorded fringe patterns, which were used to reconstruct the surface shape of the machined sample surfaces by replicating the surface profile through a structured light technique known as phase-shifted fringe projection. Both 2D and 3D measurements were obtained in accordance with the procedure described in the Biolin company manual [25,26]. The data were taken with a 1.1 μm × 1.4 μm resolution in the XY direction, with a measuring range of 60 μm along the Z-axis.

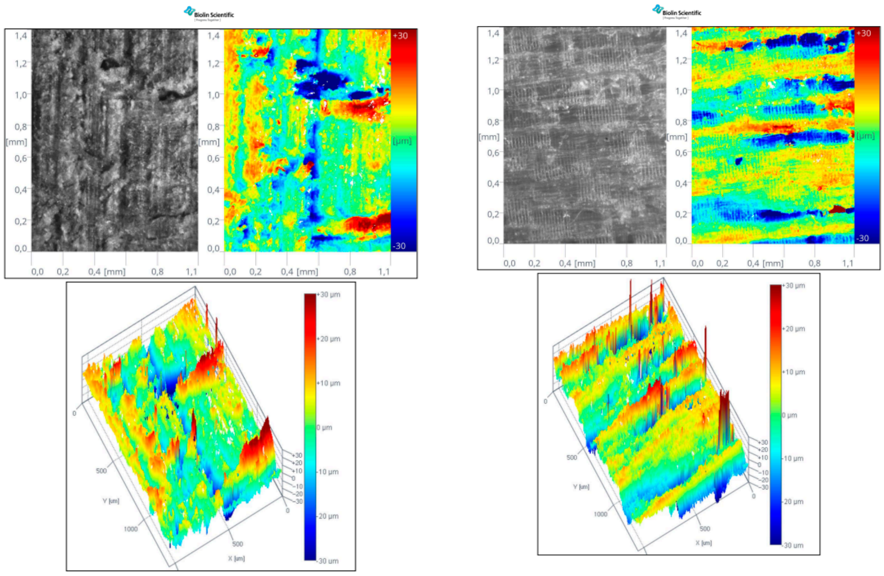

Figure 3. Microscopic photos for EUW (**left**) and GPOW (**right**).

The moisture content of the wood samples was tested and an average moisture content of 12.65% for GPOW and 12.8% for EUW was registered. All wood material was kept in an air-conditioned environment at 21 + 1 °C and 65% RH for 2 weeks prior to sample preparation and during testing.

Samples were prepared as shown in Figure 4, for shear tensile adhesive strength after being bonded with the following three types of adhesives: structural and non-structural, the latter with different watertightnesses of D2 and D3. For tensile shear strength testing, samples were made from both GPOW and EUW wood by bonding panels with dimensions of 150 × 150 mm and a thickness of 10 mm together.

From five samples of EUW and GPOW, two panels of 180 mm × 180 mm and 10 mm thickness were prepared according to EN 205:2003 [27]. Each of the two panels was bonded with D2- and D3-type PVAC and a PUR structural adhesive.

As the producers of the adhesives recommended wide boundaries for the applied amount of adhesive, several preliminary tests were performed to find the convenient amount of adhesive to be used. The wood samples were coated with adhesive on both sides and pressed together, and observations were made on how much the wood surfaces absorbed the adhesive. After several trials, the convenient amount to be applied was set to be 155 g/m^2 applied on one side of the assembly for the water-based PVAC dispersion adhesives and 85 g/m^2 for the structural adhesive, also one per surface of the assembly. The even distribution of the resins was checked using an Elcometer (Manchester, UK) wet film thickness comb.

The bonded samples were pressed together in a laboratory small press under 0.8 MPa for both wood species.

After the curing of the adhesives, strips of 20 mm width and 150 mm length were cut along the grain from each bonded assembly, resulting in 7 sample strips for each type of adhesive. A flat bottom crosscut of 2 mm width was performed in the bond section across the grain so that an overlap between the two cuts on the two sides of the sample equaled 10 mm, resulting in a 200 mm^2 bonded surface for shear strength testing on each sample strip. Samples were shear-tested using an INSTRON 5566 test machine (Illinois Tool Works Inc., Norwood, MA, USA), and the ultimate force was computerized and recorded.

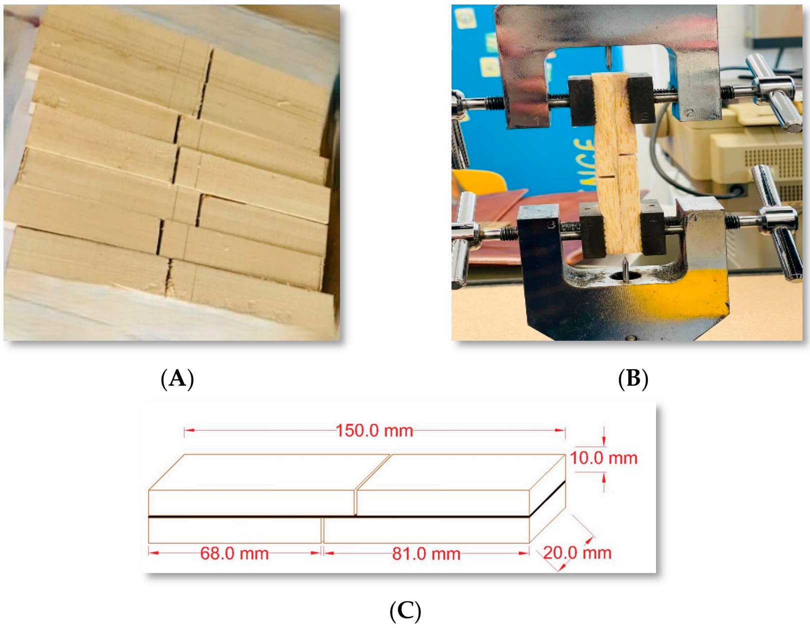

Figure 4. Wood samples prepared for shear tensile adhesion strength testing (**A**); in INSTRON machine (**B**), and their dimensions (**C**).

For pull-off adhesion testing, samples were coated with outdoor lasure and indoor lacquer. As shown in Figure 5, the pull-off tests were performed using metallic dollies of 20 mm diameter and bonded with an epoxy resin to the lacquered/lasure surface of both the EUW and GPOW samples according to ISO 4624:2002 [28] to compare EUW's and GPOW's adhesion properties. After curing and 14 days of conditioning, the dollies were pulled using a POSITEST AT-A PosiTest automatic adhesion tester (DeFelsko Corporation, Ogdensburg, NY, USA). The device automatically measured and displayed the adhesion pull-off strength.

Figure 5. The PosiTest instrument with the metallic dollies adjusted for the pull-off adhesion test.

The amount of adhesive/lacquer/lasure applied onto surfaces is reported in Table 1. Adhesives were applied using a glue-applicator handheld roller, whilst the lasure and the lacquer were applied using a lacquer roller coating machine. The glue applicator was similarly adjusted to apply the adhesives and the applied amount was checked for similarity using a weight measurement.

Table 1. The applied amount of adhesive/lacquer/lasure.

Wood Type	Wb PVAC D2 g/m^2	Wb PVAC D3 g/m^2	PUR Structural g/m^2	Lasure g/m^2	Lacquer g/m^2
EUW	310	310	170	300	180
GPOW	310	310	170	300	180

3. Results and Discussion

3.1. Mechanical Properties

The pull-off adhesion strength and tensile adhesion strength measured according to EN standards EN 204:2016, EN 205:2003, EN 301:2017 [29], EN 302:2004 [30], and ISO 4624:2002 [28] demonstrated differences in bonding performance between EUW and GPOW, which were primarily attributed to their different densities, microstructures, and wood material's chemical properties. The test results are shown in Figures 6 and 7.

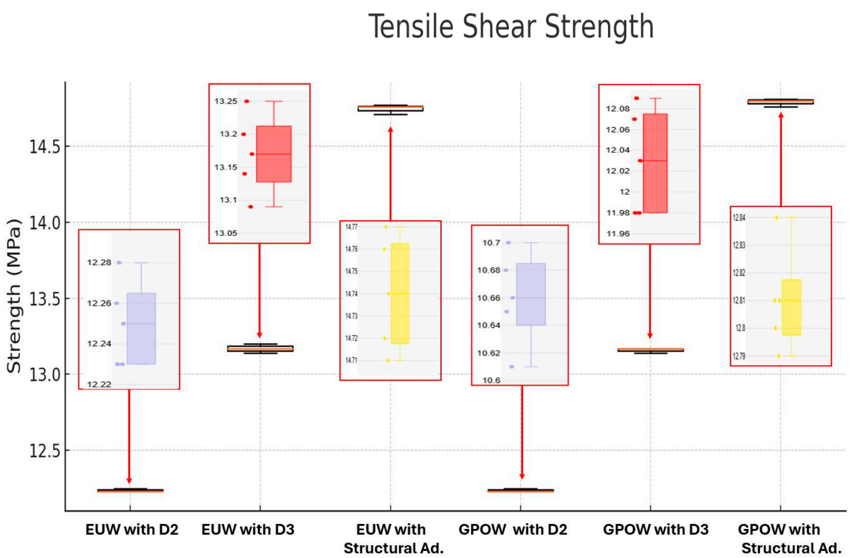

Figure 6. Tensile shear strength results for EUW and GPOW.

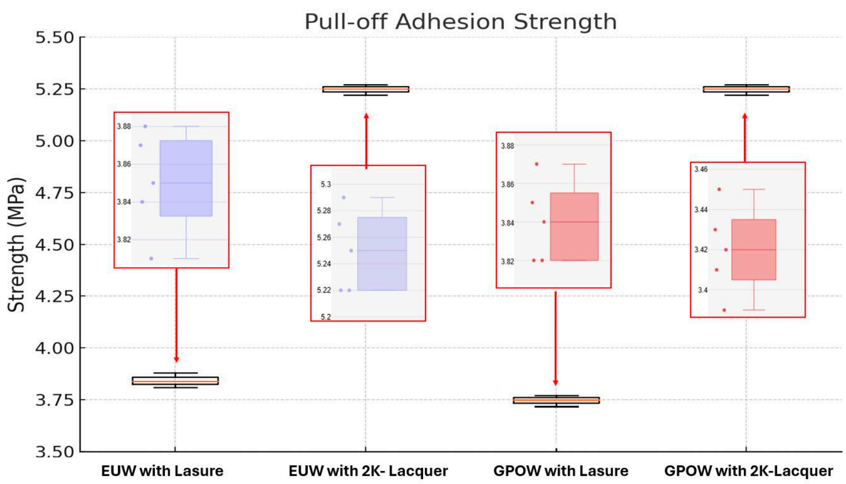

Figure 7. Pull-off adhesion strength for EUW and GPOW.

3.2. Chemical Properties

Approximately 200 g of samples from EUW and GPOW were ground in a hammer mill and sieved. The fraction resulting from the 0.2–0.63 mm sieve was selected for chemical analyses. Particles were stored at 20 °C and 65% relative humidity until a constant weight was achieved. Chemical analyses for ash, holocellulose, hemicellulose, lignin, and extractive content determination were performed; furthermore, the pH and buffering capacity were also registered in triplicate using methods detailed in the authors' previous works [31]. Table 2 shows some selected chemical properties of the EUW samples.

Table 2. Selected chemical properties of EUW.

	Ash (%)	Holocellulose (%)	Alpha-Cellulose (%)	Lignin (%)	Total Extractives (%)	pH	Buffering Capacity (mg/g)
EUW	0.42	71.15	45.18	24.00	5.39	4.85	1.23
St. dev	0.08	0.42	0.58	1.44	0.2	/	/

Note: Tests conducted by the authors.

Table 3 shows some selected chemical properties of the GPOW samples.

Table 3. Selected chemical properties of GPOW.

	Ash (%)	Holocellulose (%)	Alpha-Cellulose (%)	Lignin (%)	Total Extractives (%)	pH	Buffering Capacity (mg/g)
GPOW	1.13	77.87	48.21	16.27	4.89	5.58	0.45
St. dev	0.06	0.37	0.49	1.75	0.25	/	/

Note: Tests conducted by the authors.

3.3. Discussion

3.3.1. Ash Content

GPOW (1.13%) showed a higher ash content than EUW (0.42%), which indicated potentially higher mineral contents or impurities than EUW. This result conformed with Marques et al. (2009) [32] and Yusiharni and Robert (2012) [33].

3.3.2. Holocellulose Content

The holocellulose content was 71.15% for EUW and 77.87% for GPOW. Holocellulose is composed of cellulose and hemicellulose, the primary constituents of wood. GPOW exhibited a slightly higher holocellulose content than EUW. This result conformed with Vieira et al. (2021, 2023) [34,35].

3.3.3. Alpha-Cellulose Content

The alpha-cellulose content was 45.18% for EUW and 48.21% for GPOW. GPOW contained slightly more alpha-cellulose than EUW, indicating a marginal difference in the cellulose purity in favor of GPOW.

3.3.4. Lignin

Lignin can contribute to mechanical strength by reinforcing cell walls, enhancing rigidity, and resisting compressive forces. However, its hydrophobic nature can reduce adhesive strength [36], thereby limiting bonding with hydrophilic cellulose and hemicellulose. Despite EUW's higher lignin content, it showed superior adhesion in both pull-off adhesion strength and tensile shear adhesion strength tests. This might lead to the conclusion that the holocellulose and alpha-cellulose contents were high enough to promote good adhesion to overcome the adhesion-blocking effect of the lignin. However, at the same time, it must be also considered that, in contrast, GPOW's lower lignin content and higher holocellulose content did not lead to an increased adhesion, as was expected.

GPOW had a 1.61 times higher holocellulose/lignin ratio than EUW (4.7 compared with 2.96). Our results did not support the conclusion that a lower lignin-to-holocellulose ratio promoted adhesion. The sum of the components for EUW was 100.96% and for GPOW it was 100.16%. Although the value in both cases was higher than 100%, this was due to a measuring error, which was accepted as it was under 5% and coped with data published earlier based on this method [37,38] and also based on another method [39].

3.3.5. Extractive Content

The extractive content was 5.39% for EUW and 4.89% for GPOW. The extractive content included resins, oils, and other organic compounds. EUW showed only a slightly higher extractive content than GPOW, indicating that GPOW balanced its minor odor, which is typical for EUW (well known for its oil content) [40], with extractives contributing to color [41] and natural durability [42,43].

3.3.6. pH

The pH was 4.85 for EUW and 5.58 for GPOW. The pH of wood surfaces influences the curing process of adhesives; if the wood pH significantly deviates from the adhesive's optimal pH range, adhesives may cure too quickly or too slowly, affecting the bond's mechanical integrity [44]. The lower pH of EUW indicated higher acidity, which enhanced the interaction between the wood surface and acid-curing coatings or adhesives. This explained the superior performance of the "2K lacquer" in the adhesion tests and the pull-off tests (5.25 MPa for EUW vs. 3.42 MPa for GPOW). For GPOW, the higher pH indicated a less acidic surface, reducing the adhesive interaction and resulting in a lower performance in the acid-curing 2K lacquer bonding tests. At the same time, EUW achieved a higher mechanical strength in the tensile shear tests of up to 14.74 MPa with the PUR structural adhesive, but this was interpreted to be due to its higher density rather than the acidity of the surface as in the case of the tested PUR adhesive, the moisture activated the curing process.

3.3.7. Buffering Capacity

The buffering capacity was 1.23 mg/g for EUW and 0.45 mg/g for GPOW. Wood species with a high buffering capacity resist better to changes in their surface pH during adhesive applications. This stability helps maintain the adhesive's curing process within its optimal range, leading to stronger adhesion and a better pull-off strength. Conversely, wood species with low buffering capacity may experience pH fluctuations that disrupt adhesive curing, weakening the bond [44]. A higher buffering capacity made EUW more resistant to pH changes when applying coatings or adhesives, ensuring better adhesive interactions and a reduced risk of adhesion failure due to pH fluctuations. The lower buffering capacity of GPOW meant it was somewhat more sensitive to pH changes. The differences in their shear strength measured with an acid-curing 2K lacquer supported this hypothesis.

The measured shear test data showed a correlation with the pH of the tested samples. Whilst the pH of GPOW is considered to be moderately acidic according to the general pH range categorization, this is more accentuated in the case of EUW, which can be considered to be very strongly acidic with its pH of 4.85. The slightly lower pH of EUW explained the different chemical composition and concentration of the extractives. A lower pH was accompanied by 3-fold higher levels of buffering capacity compared with the GPOW sample, which could be attributed to the presence of resin acids and polyphenolic substances in the EUW sample, both of which were either absent or present in low concentrations in the GPOW samples. This result conformed with Hofmann and Pozsgay (2024) [31].

This led to the conclusion that in the case of the measured samples, pH was likely to be a stronger influencing factor of adhesion than lignin and/or the cellulose content and their ratio. The increased acidity of the tested EUW and GPOW samples correlated with increased adhesion of some most typical coatings and adhesives, especially when coated with 2K lacquer.

The chemical properties, such as a low ash content and pH levels, combined with high levels of lignin contents, the buffering capacity, the extractive content, and the measured levels of holocellulose and alpha-cellulose contents, distinguish EUW when compared with GPOW. These properties established a strong correlation between the higher density of EUW and its superior performance in adhesion tests such as tensile and pull-off test results. To substantiate this correlation, a detailed statistical analysis was performed.

The Pearson correlation coefficient between the density and pull-off adhesion strength was found to be 0.92 for EUW and 0.91 for GPOW, indicating a very strong positive relationship. Additionally, the correlation coefficient between the density and tensile shear adhesion strength ranged from 0.92 to 0.98 for EUW and 0.91 to 0.96 for GPOW, confirming the strong correlation between the density and adhesion properties. This unique combination of properties underscores the potential of EUW as a remarkable wood type, meriting further research efforts to enhance our understanding of its characteristics and areas of utilization. Such studies are crucial for evaluating its potential use in timber building works, particularly in cross-laminated timber (CLT) applications and door and window production. These results were consistent with the work of Bao et al. (2021) [45]. Although GPOW showed, in some cases, inferior performance compared with EUW, this did not lead to the conclusion that its performance did not suit the needs of construction wood-product manufacturing. A comparison of its potential with a species of similar density, traditionally used in the wood industry, is the target of future research.

As shown in Tables 2 and 3, there were notable differences in the cellulose content of the two wood species, which, based on literature data, is supposed to influence their shear strength and adhesion properties. The literature reports that the cellulose content impacts the elongation behavior of the same fibers [46]. When testing solid wood samples, it was found that a lower cellulose content was associated with superior elongation-to-break characteristics [47,48].

3.3.8. Density and Moisture Content

EUW had a higher density and a lower moisture content than GPOW. The higher density of EUW indicated greater mechanical strength.

3.3.9. Adhesion Test Results

All samples exceeded the minimum dry adhesion strength of 10 MPa in this test as required by EN 205:2003 and EN 301:2017. The EUW samples bonded with D2 adhesive achieved a dry bonding strength of 12.25 MPa, surpassing GPOW's adhesive strength by approximately 15% as GPOW was recorded as 10.66 MPa. With the D3 adhesive, EUW exhibited a bonding strength of 13.17 MPa, while GPOW reached 12.03 MPa. Although it was smaller with the D3 adhesive, EUW still demonstrated superior dry bonding strength, underscoring its potential in applications requiring strong bonds. When bonded with a fiber-reinforced structural adhesive, EUW achieved an adhesion strength of 14.74 MPa compared with GPOW's 12.81 MPa. This significant performance with structural adhesives suggested that both EUW and GPOW could satisfactorily be bonded for applications demanding high structural adhesion.

3.3.10. Pull-Off Test Results

EUW and GPOW surfaces were coated with lasure to evaluate their suitability as wood types for outdoor applications and to test their pull-off adhesion strength according to EN 12004-1 [49]. All the results exceeded the minimum requirement of 1.5 MPa as prescribed in EN 12004-1. EUW achieved a pull-off strength of 3.85 MPa. GPOW also performed well, with a pull-off strength of 3.84 MPa, demonstrating similar adhesion capabilities. Both kinds of wood were suitable for outdoor use when coated with lasure, meeting industry standards for window manufacturing.

EUW and GPOW were also coated with 2K lacquer, used for indoor applications, and the adhesion strength was evaluated using pull-off tests. EUW exhibited a pull-off strength of 5.25 MPa compared with GPOW, which was 3.42 MPa. This indicated that EUW provided better adhesion strength when coated with 2K lacquer, but both species performed satisfactorily, demonstrating their suitability for indoor applications like flooring or wall claddings where high adhesion is required. EUW and GPOW demonstrated good performance when coated with the chosen lasure and 2K lacquer. EUW outperformed GPOW, especially with 2K lacquer, but both species were found to be suitable for indoor and outdoor building usage.

4. Conclusions

- The difference in cellulose content between EUW and GPOW was approximately 3.03%, with the cellulose content of GPOW being higher than that of EUW at 45.18%; EUW had a higher lignin content (24.00%) than GPOW (16.27%). Despite the general assumption that a lower lignin content enhances adhesion strength, the results demonstrated that EUW exhibited superior adhesion properties in both pull-off and tensile shear adhesion strength tests. The actual test results led to the conclusion that whilst the pH of the samples correlated with the adhesion of the tested (most frequently used) wood adhesives and coatings, the lignin/holocellulose ratio did not. It was posited that the pH was a stronger influencing factor of adhesion than the chemical composition of the surface with regard to lignin and the lignin/holocellulose ratio. The balanced content of cellulose, hemicellulose, and lignin in EUW contributed to its superior bonding performance; EUW achieved a tensile shear strength of 5.25 MPa with 2K lacquer, outperforming GPOW, which only reached 3.42 MPa. Similarly, pull-off adhesion strength tests showed that EUW surpassed GPOW, achieving a value of 14.74 MPa, while GPOW reached 12.81 MPa, but, at the same time, both wood species outperformed the expected minimum of 10 MPa. The lower pH of EUW, i.e., higher acidity, promoted the curing of adhesives and enhanced the interaction between the wood surface and adhesive coatings, further contributing to its superior adhesion performance.
- EUW showed a significantly higher buffering capacity (1.23 mg/g) than GPOW (0.45 mg/g), which helped to stabilize the wood's surface pH during the adhesive application. This stability ensured better adhesive curing conditions, leading to stronger bonds and a higher mechanical strength in the EUW adhesion tests.
- The correlation coefficient between density and the tensile shear adhesion strength ranged from 0.92 to 0.98 for EUW and 0.91 to 0.96 for GPOW, confirming the strong correlation between density and adhesion properties. At the same time, the higher density of EUW (1020 kg/m^3) was an advantage for adhesion compared with GPOW, even though GPOW's adhesion strength met the usage expectations for structural bonds and indoor and outdoor coating applications with the tested lacquer and lasure, respectively.

Author Contributions: Conceptualization: C.C.; Methodology: O.S.Z., C.C. and T.H.; Formal Analysis and Investigation: O.S.Z. and T.H.; Writing—Original Draft Preparation: O.S.Z.; Writing—Review and Editing: C.C. and O.S.Z.; Funding Acquisition: C.C.; Resources: C.C., Supervision: C.C. All authors have read and agreed to the published version of the manuscript.

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