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EVALUATION OF BONDING CHARACTERISTICS OF GREY POPLAR (*POPULUS X CANESCENS*)

Csilla Mária Csiha

ABSTRACT

Coniferous forests are drying out due to climate change, creating a need for alternative species. Grey poplars (*Populus × canescens*) are underutilized in Hungary, with about 12 million m³ reaching harvesting age by the end of 2026 and decaying due to limited industrial use. The bondability of grey poplar with structural polyurethane (PUR) and nonstructural polyvinyl acetate (PVAc) adhesives, comparing it with Scots pine (*Pinus sylvestris*) and beech (*Fagus sylvatica*) under both dry and wet conditions, in accordance with EN standards is evaluated in the study. Beech met the minimum dry tensile shear strength requirements for both adhesives, whereas grey poplar and Scots pine did not. Grey poplar bonded with PVAc showed higher dry strength than Scots pine, while Scots pine with PUR outperformed grey poplar. Despite its higher density, grey poplar heartwood exhibited lower strength than sapwood. Overall, grey poplar's adhesive performance was comparable to Scots pine, suggesting it could serve as a viable alternative to coniferous species in both load-bearing and non-load-bearing applications.

Keywords: grey poplar; shear strength; PVAc; PUR structural adhesive, CLT panel.

INTRODUCTION

Due to climate change, the composition of forests in Hungary is changing. The population of traditionally used pine species is decreasing, and many coniferous forests are drying out (Borovics *et al.,* 2025). Therefore, the wood industry requires new, alternative tree species that tolerate changing environmental conditions and could replace pine species, either in their current form or after suitable modification. In recent decades, the timber industry has mainly worked with coniferous species, while many deciduous tree species have remained underutilized (Király *et al.,* 2024), including grey poplar. Grey poplar (*Populus × canescens*), a natural hybrid between white poplar (*Populus alba*) and common aspen (*Populus tremula*), was historically described as a variety of P. alba by Aiton (1789) and later recognized as a full species by Smith (1804). It is intermediate between its parents, with a thin, grey, downy coating on the leaves, which are less deeply lobed than those of P. alba. A vigorous tree with marked hybrid vigor, it can reach 40 meters tall and 1.5 m trunk diameter (Populus × canescens, 2025). The visually appealing grey poplar (white bark, silvery leaves, Figure 1) grows well on sandy soils of the Hungarian Great Plain (Alföld) and tolerates extremely dry sites. It belongs to the South Eurasian flora, found in Europe and Asia between 25° and 52° latitudes. The stem usually contains false heartwood (Figure

2), and ring shakes are frequent. Molnár and Bariska (2002) reported that research at the time aimed to propagate grey poplar hybrids developing colorless heartwood. They also highlighted key physical properties of grey poplar, noting that density strongly influences dry matter content and, consequently, strength and flexibility. Grey poplar was classified into the third density category ($\rho > 401$ kg/m^3), among the highest for poplar hybrids. While there is extensive literature on hybrid and plantation poplars, research specifically on grey poplar remains limited (Kánnár and Csiha, 2021).

Fig. 1 Grey poplar tree.

Fig. 2 Heartwood and sapwood of grey poplar.

In November 2024, the Council of the European Union announced the "EU Carbon Removal Certification Framework" (2025), promoting durable goods, including wood-based construction materials, to enhance long-term carbon storage. Increasing the use of wood as an alternative to conventional materials such as concrete or brick offers the potential to sequester carbon for over 100 years. Prefabricated cross-laminated timber (CLT) panels are currently the most advanced wood building materials, with European CLT production relying primarily on spruce and pine in mid-layers, followed by larch and Douglas fir. Hardwoods such as beech and birch are rare in commercial CLT, typically below 5% and mostly limited to experimental or niche applications (Illgin et al., 2023).

Although CLT production focuses on coniferous species, forecasts from the Hungarian Forest Research Institute predict a decline in coniferous availability due to climate change. Industrial processing is also optimized for long, straight logs, whereas grey poplar naturally develops strong lateral branches, resulting in shorter trunks if unpruned. Other industrial limitations related to its appearance are documented by manufacturers (Types of Poplar wood, 2025). Given the European Commission's recommendations to increase wood use for long-term carbon storage and considering the 12 million m^3 harvestable stock of grey poplar in Hungary and its extreme drought tolerance, research into this species is highly warranted.

Processing parameters for grey poplar require thorough investigation, as many criticisms can be addressed by optimizing kiln drying and handling.

This study focuses on the bondability of grey poplar using two major adhesives: structural polyurethane (PUR) adhesives for loadbearing applications, and non-structural polyvinyl acetate (PVAc) adhesives typically used for doors and windows. The main objective of the study was to determine whether grey poplar can serve as a suitable substitute for Scots pine as a representative of coniferous species in terms of bonding performance. Clarifying its bonding behavior provides essential technical data for evaluating its processing potential and integration into wood construction. Simultaneously, this research addresses the broader need to diversify the raw material base and promote sustainable use of available wood resources, thereby assessing grey poplar's suitability and justifying its potential role as an alternative construction material.

MATERIALS AND METHODS

Tree species: grey poplar (*Populus x canescens*), Scots pine (*Pinus sylvestris*), and beech (*Fagus sylvatica*) wood specimens were prepared. Grey poplar wood was sourced from KEFAG Zrt. (Hungary) as kiln-dried boards of 3000 mm × 150 mm × 24 mm, while beech and Scots pine were provided by Németh-Fa Ltd. (Hungary) in kiln-dried boards of 900 mm × 1300 mm × 24 mm.

Adhesives: two types were used: a non-structural D3 water-based PVAc Technobond 3000 by Szolvegy Ltd. (Hungary) and a close-contact structural polyurethane (PUR) adhesive, Jowapur 686.20, by Jowat (Germany). The applied amount of structural adhesive for the tested tree species is not specified by the adhesive producer; only a general recommendation is available between 100 – 230 g/m^2, with a pressure recommended between 0.3-1.2 N/mm^2, and an open time of 10 minutes.

For the non-structural adhesive, the general recommendation of the manufacturer on the applied amount is between 120-180 g/m^2, with an open time of 5 minutes and pressure recommended between 0.2 – 0.8 N/mm^2. For complete curing of the adhesive, 24 hours are necessary.

Adhesive application: Prior to the current tests, it was observed that grey poplar specimens tended to absorb more adhesive from the bond line than beech wood. This observation aligns with previous research, which reported that lower-density wood specimens/species allow for greater adhesive penetration (Konnert *et al.,* 2008; Follrich *et al.,* 2008; Hass *et al.,* 2012). Given the broad range of the manufacturer's recommendations and the varying densities of the wood specimens—which required different adhesive amounts to achieve comparable bond line thicknesses—both adhesives were applied in excess to both sides of the bonded assembly at a rate of 250 g/m^2. During pressing, the surplus adhesive was squeezed out, allowing each tree species the same amount of adhesive in the bondline. The beech, Scots pine, grey poplar heartwood (GpHW), grey poplar sapwood (GpSW), and grey poplar combination wood (GpCW) boards bonded with PVAc adhesive were pressed layered on top of each other, between two 28 mm thick solid wood boards (to dissipate the pressure), using F-clamps (Ellix – OBI, 700 mm), for 48 hours under a similar pressure of 0.38–0.5 N/mm^2. Eight F-clamps were applied along the length of the boards— one positioned at each side and the remaining six spaced at 80 mm intervals between them.

The same arrangement was also used for boards bonded with PUR adhesive.

Specimen preparation for tensile shear strength testing:

Beech, grey poplar, and Scots pine specimens were prepared by bonding together two layers of 32 oversized panels of 630 mm × 160 mm × 5 mm, in accordance with EN 205:2016. Each panel was free of visible defects, conditioned in an interior climate at 22 ± 2 °C and 65 % RH, and planed before bonding. After cutting with a circular saw, a total of 478 specimens were obtained, each measuring 150 mm × 20 mm and 2 × 5 mm thick, as shown in Fig. 3

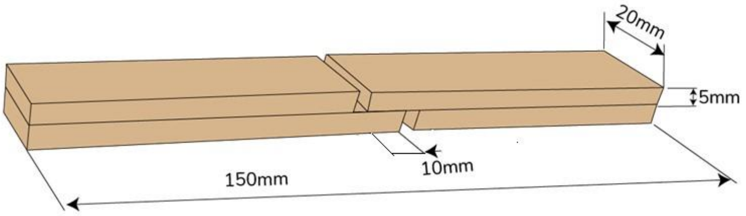

Fig. 3 Dimensions of the specimens prepared for shear tests.

Each specimen had a surface area of 200 mm² exposed to shear, following the principles outlined in EN 205:2016 and EN 302-1:2023. Both standards specify the use of beech wood specimens with growth ring angles relative to the surface between 30° and 90° and are intended for the classification of non-structural and structural adhesives, respectively. To evaluate the adhesion performance of grey poplar, specimens of different tree species were compared.

Tests on PVAc-bonded specimens followed EN 204 durability classes D1, D2, and D3.

- D1 involved testing under standard climate conditions (20 °C / 65% RH),
- D2 specimens were tested dry after stored in 20 °C water for 3 h, then reconditioned for 7 days at standard atmosphere,
- D3 involved two separate procedures:
- D3-1: tested wet after storage in 20 °C water for 4 days,
- D3-2: tested dry after reconditioning from storage in 20 °C water for 7 days.

These conditioning steps simulate increasing levels of moisture exposure and are used to assess the adhesive's resistance and performance in interior and semi-exterior conditions. Specimens bonded with PUR structural adhesive were tested based on the procedures of EN 302-1:2023:

- A1: specimens tested in a dry condition after being stabilized under standard atmospheric conditions,
- A2: specimens tested in a wet condition after immersion in cold water for 4 days,
- A3: specimens tested dry, after being conditioned again, following 4 days of immersion in cold water,
- A4: specimens tested in a wet condition after being immersed for 6 hours in boiling water, followed by 2 hours in cold water,
- A5: specimens reconditioned to a dry state and tested after undergoing the same treatment as in A4.

The number of specimens prepared for tensile shear strength tests with non-structural PVAc and structural PUR adhesive can be found in Table 1.

Tab. 1 Number of specimens prepared for tensile shear strength tests.

Tree species	Total nr.	PVAc	PUR	D1 GpHW/GpSW/GpC	D2	D3	A1	A2	A3	A4	A5
Grey poplar	240	170	70	110 49/22/39	20	15/25	14	14	14	14	14
Beech	72	31	41	12	6	6/7	10	6	11	6	8
Scots pine	109	55	54	14	14	13/14	11	11	10	11	11

Density measurements were performed right after testing the specimens for shear, from intact portions of the tested specimens. Density measurement of specimens: both the density at testing (ρ_n) and the absolute dry density (ρ_0) of the specimens for all 3 tree species were determined with the equation $\rho = m/V$ (g/cm^3), and the density belonging to 12% MC (ρ_{12}) was calculated according to ISO 13061-2: 2014. Density measurements of grey poplar were carried out on selected specimen batches, including 11 GpSW, 15 GpHW, and 15 GpC, for a total of 41 grey poplar specimens. Density determination was performed on 12 beech specimens, and for Scots pine, the same.

Moisture content (MC) of the specimens was measured according to ISO 13061-1:2014 for 12 beech, 12 Scots pine, and 41 grey poplar specimens.

Tensile shear strength tests of PVAc bonded lap joints: following the required pretreatment, the specimens were tested at a rate of traverse of 50 mm/min using an Instron 5566 universal testing machine (Instron Corporation, USA), applying tensile force parallel to the bond line until failure. PUR-bonded lap joints were tested similarly, using the same device, but with a load increase rate of 2 kN/min in accordance with EN 302-1.

Statistical analysis was performed to evaluate the significance of the differences by using independent two-sample t-tests (also called Student's test). One-way ANOVA tests were also performed to assess the significance of the differences between groups of specimens, followed by Tukey's HSD (Honestly Significant Difference) test wherever it was reasonable. Pearson's correlation analysis was also performed to examine the relationships between variables.

RESULTS AND DISCUSSION

Moisture content:

The average MC (%) of three tree species at the time of testing is shown in Table 2, with the standard deviation and the variance (the mean of the squared deviations from the mean).

Tab. 2 Moisture content of the specimens.

	Beech	Scots pine	GpHW	GpSW	GpC
MC (%)	9.0	9.3	10.2	10.8	9.6
st. dev.	2.5	1.8	1.7	0.70	1.2
Var (%)	17.6	3.4	16.2	6.6	1.2

The MC of the tested wood specimens ranged around 10%, with no significant difference between the tree species, according to Student's test. Beech specimens showed the greatest variation in MC, with some specimens having MC values around 6%, whilst others reached up to 12.6%. Grey poplar sapwood was the most uniform in moisture content, with all specimens following the same preconditioning at the standard atmosphere.

Density:

The average density of specimens at testing (ρn), the absolute dry density (ρ0), and the calculated density belonging to 12% MC (ρ12) were calculated for all tree species, and they are shown in Table 3. Beech specimens had the highest density of all, with 36% higher than Scots pine, 61.9% higher than GpHW, 68.6% higher than GpSW, and 58.4% higher than GpC. The absolute dry density of the GpSW was different and lower than the density of the

GpHW as shown in Table 3. The density of the GpC was 6.3% higher than the density of the GpSW. The density of GpHW was 4.0% higher than the density of GpSW. The absolute dry density of the GpSW was the lowest among all tested specimens.

Tab. 3 The density of the specimens.

	Beech	Scots pine	GpHW	GpSW	GpC
ρ_n (kg/m^3)	694.3	505.0	438.4	414.8	427.5
st dev	42.7	57.5	58.1	50.8	49.3
ρ_0 (kg/m^3)	652.8	479.8	403.0	387.3	411.8
st. dev.	35.3	53.8	48.4	48.0	44.9
ρ_{12} (kg/m^3)	668.9	504.0	438.5	41.1	427.6
st. dev.	42.9	52.3	58.1	50.8	51.0

A one-way ANOVA was performed to assess the differences in density among the different grey poplar specimens. At a 0.05 significance level, no significant difference was found between the density values of the 3 different grey poplar specimen types ($F(2, 42) = 1.01, p > 0.05$). However, this was not the case when the same test was performed, including Scots pine density. A one-way ANOVA indicated a significant difference among the four groups ($F(3, 56) = 10.33, p < 0.05$). Post-hoc analysis using Tukey's HSD revealed that the density of Scots pine specimens and beech specimens differs significantly from all other groups, whilst the density of the beech specimens was the highest.

Evaluation of tensile shear strength of specimens bonded with non-structural PVAc adhesive

Tensile shear tests were performed to evaluate grey poplar in comparison with Scots pine and determine whether it can serve as a possible substitute for Scots pine regarding bonding properties. The test standards specify beech wood for specimen preparation; as a result, beech specimens were also prepared. Beech has a dense wood with a firm predisposition to shrinkage and warping, with an average porosity of 55%. Scots pine warps less than spruce, but compression wood might be problematic; its porosity is reported to be 67% in average. Porosity is not reported for grey poplar, but is reported at 78% for its close relative, aspen (*Populus tremula*) (Kärki, 2001). Grey poplar's indicative mechanical properties are reported based on literature (Molnár and Bariska, 2002): bending strength of 67.5 MPa, tensile strength of 82.3 MPa, shear strength of 7.8 MPa, and compressive strength of 38.3 MPa. The same source specifies for Scots pine bending strength of 40-205 MPa, tensile strength of 35-196 MPa, shear strength of 6.1 – 14.6 MPa, and compressive strength of 35 - 94 MPa. These values for Beech are reported: bending strength of 74 - 210 MPa, tensile strength of 57 - 180 MPa, shear strength of 6.5 - 19 MPa, and compressive strength of 41 - 99 MPa.

Table 4 shows the average tensile shear strength values of the tested beech, Scots pine, and grey poplar specimens—for the D1 condition of a non-structural water-based PVAc adhesive, along with the standard deviation.

Tab. 4 Average tensile shear strength of specimens bonded with a non-structural PVAc adhesive (tested for D1, D2 and D3 conditions).

τ PVAc (N/mm^2)	Beech	Scots pine	GpHW	GpSW	GpC
D1	11.4	5.7	6.2	7.9	7.6
st dev.	3.9	1.2	1.1	1.0	1.0
D2	10.3	7.1	-	-	5.4
st.dev.	2.8	0.9	-	-	1.7
D3 - 1	1.1	2.0	-	-	1.2
st.dev.	0.5	0.3	-	-	0.4
D3 - 2	12.1	6.6	-	-	5.0
st.dev.	1.6	1.6	-	-	1.2

EN 204 specifies that test specimens should be prepared from beech wood, as the standard is intended for the classification of thermoplastic wood adhesives used in non-structural applications.

D1 condition requires a minimum tensile shear strength of 10 N/mm^2 of beech specimens under dry conditions. While the tested beech specimens met this requirement, neither the grey poplar nor the Scots pine specimens achieved this threshold. The fact that beech specimens achieved the required shear strength with this adhesive indicates that both the bonding conditions and the adhesive were suitable for the experiment. To check whether the average shear strength value of Scots pine falls within the typical range, a literature search was conducted. Doruk (2021) measured an average of 6.25 MPa for the D1 dry tensile shear strength of PVAc-bonded Scots pine specimens. A study by Li *et al.* (2015) reported shear strength values of 4.12– 10.28 N/mm^2 for Scots pine bonded with PVAc non-structural adhesive, depending on adhesive spread, press time, and applied pressure. Although the adhesives came from different manufacturers, the values we measured for Scots pine are consistent with previously published data. In the absence of shear strength data for grey poplar, its tensile shear strength is evaluated against the same measured values for Scots pine. Despite the higher Scots pine density, the dry D1 tensile shear strength of the tested grey poplar specimens was higher than that of the Scots pine specimens, with the highest values recorded for GpSW; however, the difference was not significant at the 5% significance level according to the t-test. However, these values should not be considered the absolute shear strength of Scots pine or grey poplar; rather, they provide a useful basis for comparing whether grey poplar can perform similarly or better than Scots pine when prepared and tested under comparable conditions.

A one-way ANOVA performed on the tensile shear strength averages of the grey poplar specimens resulted in a statistically significant difference among the three groups ($F(2, 107) = 26.28$, $p < 0.01$), whilst Tukey's HSD revealed that GpHW has significantly lower D1 tensile shear strength than the other two. The density values of the grey poplar specimens were not aligned with the achieved D1 tensile shear strength: the specimen groups GpSW and GpC exhibited significantly higher tensile shear strength than the GpHW, whilst there was no significant difference in their density. This indicates that density alone is not the main influencing factor of the adhesion. This observation is further supported by the results for Scots pine, which exhibited a significantly higher density than grey poplar specimens, while showing the lowest D1 tensile shear strength.

During the analysis of the shear strength results of the grey poplar specimens, the question arose as to whether the grey poplar specimens could reach a D1 tensile shear strength of 10 N/mm^2 at all. By checking the measured data for all grey poplar D1 specimens, it was found that among 110 specimens tested, only one heartwood–sapwood combination exceeded this threshold, while seven additional specimens achieved values above 9.48 N/mm². This leads to the conclusion that there may be bonding parameters that, in the present study, were only partially met but, if identified and consistently applied, could result in stable, high adhesion. This assumption is also supported by the findings of Li *et al.* (2015), who indicated that adhesive spread and applied pressure were the primary factors influencing shear strength, which increased with a given increase in these two. These results suggest that, by optimizing pressing time, adhesive spread, temperature, surface quality, and, furthermore, by using pressure tailored specifically to grey poplar, it may be possible to achieve higher, more consistent tensile shear strength.

The average D2 tensile shear strength of the beech specimens exceeded the expected minimum value of 8 N/mm², whereas the Scots pine and grey poplar specimens did not. Moreover, the D2 tensile shear strength of grey poplar was lower than the average for Scots pine. Grey poplar exhibited elevated sensitivity to D2-type short-term soaking, performing the weakest compared to beech and Scots pine.

When tested under the D3 first condition (after 4 days of soaking), only the Scots pine specimens reached the required minimum tensile shear strength of 2 N/mm², but the performance of grey poplar was similar to that of beech specimens. Under the D3 second condition—regaining a strength above 8 N/mm² after 7 days of reconditioning—this criterion was met exclusively by the beech specimens. However, the reconditioned grey poplar specimens recovered tensile shear strength above 5 N/mm², which corresponds to the average dry strength previously observed in Scots pine specimens.

Tensile shear strength of specimens bonded with a structural PUR adhesive:
Under the A1 condition, only the beech specimens met the expected minimum dry tensile shear strength of 10 N/mm². For the A3 condition, beech specimens also recovered to the required 8 N/mm². In all other cases, however, the specimens remained below the minimum values specified in EN 301, as shown in Table 5.

Tab. 5 Average tensile shear strength of specimens bonded with a structural PUR adhesive (tested for A1, A2, A3, A4 and A5 conditions).

τ PUR (N/mm^2)	Beech	Scots pine	GpC
A1	10.1	7.8	5.4
st.dev.	3.8	0.9	0.8
A2	2.7	4.7	4.2
st.dev.	1.3	0.6	1.1
A3	8.4	8.4	5.1
st.dev.	1.5	1.3	1.5
A4	1.9	4.1	3.9
st.dev.	0.6	0.7	0.5
A5	4.6	7.0	5.4
st.dev.	2.3	1.6	1.2

Grey poplar consistently showed the lowest average tensile shear strength across both dry and wet tests under conditions A1 through A5 compared to Scots pine. However, their performance was not significantly lower (t-test, 5% significance level) than that of the Scots pine specimens.

Grey poplar specimens outperformed the average tensile shear strength of beech specimens under the A2, A4, and A5 conditions. The grey poplar showed a better bonding potential with a PUR structural adhesive than with a non-structural PVAc.

For the PUR structural adhesive, the A1 dry shear strength results aligned with the density values of the tree species. Higher density was associated with higher dry strength. The relationship between the density of the specimens and their A1 dry tensile shear strength was analyzed using Pearson's correlation coefficient and simple linear regression. Pearson's correlation indicated an almost perfect positive correlation (r = 0.999), showing that higher-density specimens consistently exhibited higher tensile shear strength. Linear regression analysis further quantified this trend, resulting in the model:

$$\tau = -0.23 + 0.016 \times \rho_0 \tag{1}$$

This model suggests that an increase of 100 kg/m³ in density corresponds to an approximate increase of 1.6 MPa in tensile shear strength. These results support the conclusion that, for a reactive adhesive, higher density is associated with higher bond strength, as denser materials provide more reactive sites per unit volume.

The positive relationship observed between wood density and the tensile shear strength of PUR adhesive-bonded specimens is consistent with results reported in the literature. Follrich *et al.* demonstrated that the tensile strength of bonded end-grain joints increases with wood density, suggesting that greater cell wall material improves adhesion performance (Follrich *et al.*, 2008). Similarly, Wagenführ found that tensile shear strength generally increases with species density across European softwood and hardwood species (Wagenführ *et al.*, 2016). More recently, Meethaworn, Srivaro, and Khongtong reported that the shear strength of adhesive joints for densified wood increased progressively with density within the range of 1.05 to 1.30 g/ cm³, indicating that higher density substrates consistently exhibited higher shear performance (Meethaworn *et al.*, 2022).

Grey poplar exhibited significantly lower tensile shear strength than beech; however, unlike beech, it remained mostly intact after soaking in water, similar to Scots pine, and regained its dry strength after soaking. Only after boiling in water and testing wet did its shear strength decrease; even then, it was roughly twice that of beech and comparable to Scots pine. The highest dry tensile shear strength measured for GpC was 6.7 N/mm². These results suggest that, by optimizing bonding parameters, higher tensile shear strength can be achieved while remaining as stable to water soaking as Scots pine.

During the tensile shear tests, the phenomenon was observed that dry grey poplar specimens mostly failed in the wood. This observation subsequently led to two additional tests.

On the one hand, the specimens were examined microscopically to identify possible cracks, as grey poplar has been described by Molnár and Bariska (2002) as a tree species prone to cracking during kiln drying.

On the other hand, a hypothesis was proposed that the wood material may possess an intrinsic characteristic of low tensile resistance, which could explain why higher shear strength values cannot be achieved during adhesive bonding. Therefore, the specimens were tested under uniaxial tension parallel to the grain, which provides a suitable method for evaluating the tensile properties of solid wood specimens.

CONCLUSION

The adhesive strength of the specimens was assessed under dry and wet conditions, in comparison with beech wood and Scots pine specimens, using concepts derived from EN standards. While beech specimens met the minimum dry strength required by the standards for both adhesive types, neither grey poplar nor Scots pine achieved this threshold. However, grey poplar specimens bonded with the non-structural PVAc adhesive exhibited significantly higher average dry tensile shear strength than Scots pine, particularly in sapwood specimens. Conversely, when bonded with the structural PUR adhesive, Scots pine generally outperformed grey poplar, although in certain moisture-exposed conditions (A2, A4, A5), grey poplar matched or even exceeded the performance of beech. Notably, grey poplar heartwood, despite its higher density, showed lower dry adhesive strength than the less dense sapwood, indicating that factors beyond density—such as anatomical structure play a crucial role.

The density values of the grey poplar specimens were also not aligned with the achieved D1 tensile shear strength: two specimen groups, GpSW and GpC, exhibited significantly higher tensile shear strength than GpHW, whilst there was no significant difference in density between the groups.

However, when the specimens were bonded with a structural PUR reactive adhesive, a very strong, statistically significant correlation was found between density and the A1 tensile shear strength of the bonded specimens. The A1 dry shear strength results were aligned with the density values of the tree species. Higher density was associated with higher dry strength, with an almost perfect positive correlation ($r = 0.999$). These results support the conclusion that, for a reactive adhesive, higher density is associated with higher bond strength, as denser materials provide more reactive sites per unit volume.

A limitation of the work is that only two adhesive systems and short-term strength properties were evaluated, with long-term durability not considered. Even so, the results underline the broader implication that grey poplar could reduce reliance on declining pine resources and contribute to a more sustainable diversification of raw materials in the wood industry. Although grey poplar did not reach the adhesive strength levels of beech, its overall performance was comparable to Scots pine across several test conditions, despite its significantly lower density. This suggests that, with proper adhesive selection and process optimization, grey poplar—especially its sapwood—could be a viable alternative to coniferous species like Scots pine in both non-load-bearing and selected load-bearing applications.

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AUTHORS' ADDRESSES

Csilla Mária CSIHA PhD.
University of Sopron
Faculty of Wood Engineering and Creative Industries
Institute of Applied Sciences Bajcsy
Zsilinszky 4., H-9400, Sopron
csiha.csilla@uni-sopron.hu