

Article

Specific Gravity of Inner and Outer Larch Bark

Günther Kain ^{1,*}, Marco Morandini ², Marius-Catalin Barbu ^{1,3}, Alexander Petutschnigg ¹ and Jan Tippner ⁴

¹ Forest Products Technology and Timber Construction Department, Salzburg University of Applied Sciences, Markt 136a, 5431 Kuchl, Austria; marius.barbu@fh-salzburg.ac.at (M.-C.B.); alexander.petutschnigg@fh-salzburg.ac.at (A.P.)

² Barkinsulation GmbH, Schulstraße 27, 5412 Puch bei Hallein, Austria; morandini@barkinsulation.com

³ Faculty for Wood Engineering, Transilvania University of Brasov, B-dul. Eroilor nr. 29, 500036 Brasov, Romania

⁴ Department of Wood Science and Technology, Mendel University, Zemědělská 3, 61300 Brno, Czech Republic; tippner@centrum.cz

* Correspondence: gkain.lba@fh-salzburg.ac.at; Tel.: +43-699-819-764-42

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Abstract: Larch bark is an interesting resource for the production of insulation panels. As it consists of a sugar-rich inner bark and an outer bark containing more durable components, there is the requirement to separate these compartments. Additionally, bark is often mixed with wooden pieces after industrial debarking processes. In this study, the wet density, dry density, and specific gravity of wood, whole bark, and inner and outer bark are investigated using the pycnometer method, which has been proven to be adequate for the volume measurement of irregularly shaped, light objects such as bark flakes. Soaked with water, the density of the inner bark is highest, followed by wood, and the lightest is the outer bark. Because of different moisture contents, the wet density is not directly comparable. The outer bark sucked up less water than the inner bark. Focusing on the specific gravity, the wood is the heaviest, followed by the outer bark and the inner bark. The differences are significant for both methods, displaying a promising physical basis for separation methods based on density differences. These might be a means to pick out more durable and less hygroscopic outer bark particles from a bark mixture in order to produce optimized bark composites.

Keywords: tree bark; larch bark; specific gravity; natural resources; physical properties

1. Introduction

Tree bark is cellular tissue that is built as a peripheral layer outside of a tree's cambium as a shell of the xylem. Bark is made up of the outer bark or rhytidome and the inner bark or phloem. The cambium produces xylem cells toward the inner side and phloem cells toward the outer side. Within the primary bark, the cork cambium (phellogen) is built up over time. The cork cambium produces secondary cortex cells (phelloderm) towards the inner side and cork cells (phellem) towards the outer side [1]. Phelloderm, phellogen, and phellem make up the periderm, which is long-lasting with some trees (e.g., *Fagus sylvatica*) and is short-lived with most European trees (e.g., *Larix decidua*) [2]. In this case, it dies off after some time and is replaced by a new one on its inner side. The collection of periderms is called rhytidome, and it gives the bark its characteristic pattern [3]. The phloem consists primarily of conducting, sclerenchymatic, and parenchymatic cells and contains the conducting system for the assimilates of a tree. For this reason, it is predominantly made up of sieve elements [1]. The outer bark contains, to a high extent, dead tissue with various depositions in its cells to prevent the attack of microorganisms and the loss of water. Outlying the respective new periderm, suberin is stored in the cells, making them impervious to water [4].

With most tree species, phloem and periderm cannot be easily separated [5], apart from the cork oak (*Quercus suber*) [4]. On a larch tree, the bark has a thickness between 5 and 50 mm [4], and in industrial processes, a bark amount of 13%, based on a tree's volume, is assumed [6].

The equilibrium moisture content (EMC) of bark is slightly higher than the EMC of the corresponding wood under constant climatic conditions [7]. Sorption isotherms were investigated for the phloem and periderm of various species, and it was found that the periderm of poplar (*Populus sp.*) and birch (*Betula sp.*) is less hygroscopic than the phloem, probably due to a high suberin content. On the contrary, the periderm of spruce (*Picea abies*), pine (*Pinus sp.*), and horse chestnut (*Aesculus hippocastanum*) has a higher EMC than the corresponding phloem when the relative air humidity (RH) is below 90%. The EMC of the inner bark of spruce, pine, and poplar rises strongly above 90% RH and reaches an MC of 101% to 105%. These extreme values can be referred to as water-soluble sugars in the phloem [8]. Bark swells and shrinks more strongly than the corresponding wood. The volumetric expansion in softwood barks accounts for 10.9% to 16.6%, measured from oven-dry condition to fiber saturation [9].

The porosity, density, and anatomy of bark differ significantly [10]. The bark density of the most important North American tree species was investigated, showing that bark can be 36% heavier (average of fir species) to 35% lighter (average of various larch species) than the respective wood (oven-dry mass referred to green volume basis) [11]. The specific gravity of the outer beech bark (0.75) is significantly higher than the specific gravity of the inner bark (0.57), as shown by the pycnometer method [12]. This author suggested the use of this density difference as a basis for the separation of beech bark compartments and proved the suitability of the pycnometer method for the volume determination of irregularly shaped, light objects.

Bark contains a high amount of sugar-containing components, especially in the phloem [1,13]. It is, therefore, more susceptible to insect and fungi attacks. The periderm, nonetheless, contains a high amount of extractives and polyphenolic acids, which add to the durable character of the material [14,15]. An extract from Turkish pine (*Pinus brutia*) was used to impregnate wood particles, which lead to an increase in the decay resistance of particleboard made from these materials [16].

Larch bark was used as a resource of thermal insulation materials [17], sound absorption materials [18], decorative panels [19,20], and various pressed composites [21] in laboratory production. Design objects made of pressed bark particles are marketed successfully [22]. The first successful attempts of applying bark insulation panels onto a real building have been made [23]. The mechanical [24] and physical building properties [25,26] of bark insulation panels are promising. It has been shown that green bark panels, using flavonoid extracts as a binder, can be produced [27]. An evaluation of volatile organic compounds emitting from larch bark showed that they are low, but aldehyde emissions have to be reduced when the bark is applied in the interior [28].

Further research will have to address the durability of bark insulation panels. One strategy is to reduce the ratio of sugar-rich phloem particles, which might be attractive for insects and fungi. The research question addressed in this study is whether there is a significant density difference between the inner and outer bark of larch (*Larix decidua* Mill.). If so, it could be used to separate carbohydrate-rich inner bark from the more resistant outer bark using density-based sorting processes, which might be relevant for the production of composites with improved decay and pest resistance.

2. Materials and Methods

The larch wood (reference material) and larch bark were collected from the sawmill Graggaber, Salzburg, Austria. Briefly, 21 defect-free larch heartwood samples, with a size of $20 \times 20 \times 20 \text{ mm}^3$, were prepared. Moreover, 30 larch bark pieces (Figure 1), with a size of approximately $10 \times 40 \times 4 \text{ cm}^3$, were collected from different batches of production and at different spots of the bark pile at a depth of approximately 20 cm [29]. The bark samples were collected in May 2020 right after debarking and stored in plastic bags until further processing. Due to the high cell division activity of larch trees in spring and the presence of an unlignified zone next to the cambium, bark and wood could be easily

separated, and, hence, the bark did not contain wood rests after mechanical debarking. From each bark sample, three pieces, with a size of $20 \times 60 \text{ mm}^2$, were cut using a band saw. The natural thickness of the bark pieces was not changed. Two bark pieces were separated into inner and outer bark using a scalpel (one piece for volume measurement, one piece for bark thickness measurement, respectively). Inner and outer bark were easily distinguishable due to the color contrast between the lighter inner bark and the darker outer bark (Figure 1). The coherence between inner and outer bark was low after soaking, enabling easy mechanical separation.



Figure 1. Larch (*Larix decidua* Mill.) bark piece containing inner and outer bark.

Before conducting further measurements, all samples were soaked in water at room temperature until no further water uptake could be detected, which was shown by repeated weight measurements.

The thickness of the inner and outer bark was determined at the thickest spot of each specimen using a digital sliding caliper with a precision of 0.01 mm.

A laboratory analytical balance, with a precision of 0.001 g, was used to determine the specimen mass after soaking (m_{wet}). The specimen volume of the cubic wood samples was determined by measuring their dimensions, the volume of irregular-shaped bark specimens was determined using the pycnometer method.

The moisture content of the samples was determined by drying them at $103 \pm 2 \text{ }^\circ\text{C}$ and measuring the weight of the water contained compared to the dry mass of the samples.

A 250 mL pycnometer (NS 14/23, Carl Roth) filled with reverse osmosis water at a temperature of $20 \text{ }^\circ\text{C}$ and a density (ρ_{water}) of 0.998 g/cm^3 was used. Specimens were put into the pycnometer; some of them had to be cut into smaller pieces due to the narrow bottleneck of the pycnometer. A ground-in stopper was inserted to ensure that the pycnometer is completely filled with water and specimens. The specimen volume in soaked condition (V_{wet}) was determined according to Equation (1), considering the mass of the pycnometer filled with water (m_1), the mass of the sample soaked with water (m_{wet}), and the mass of the pycnometer containing the sample (m_2).

$$V_{wet} = \frac{m_1 + m_{wet} - m_2}{\rho_{water}} \quad (1)$$

The samples' wet density was calculated according to Equation (2), based on the wet mass of the specimen (m_{wet}) and the wet volume (V_{wet}).

$$\rho = \frac{m_{wet}}{V_{wet}} \quad (2)$$

The specific gravity (G) was determined using Equation (3), considering the absolutely dry mass (m_{dry}) and the wet volume (V_{wet}) of the specimen.

$$G = \frac{\frac{m_{dry}}{V_{wet}}}{\rho_{water}} \quad (3)$$

The maximum moisture content (MC_{max}) was estimated according to Equation (4) [7]:

$$MC_{max} = \frac{1.54 - G}{1.54 * G} * 100 \quad (4)$$

Statistical analyses were performed using SPSS 18 (IBM). Differences in mean values were tested for their statistical significance using a pair-wisely conducted ANOVA.

3. Results and Discussion

The objective of this study is the determination of the inner and outer bark density of larch bark. Larch wood was used as reference material. The volume of irregular-shaped wooden specimens is most often determined using the immersion method [30]. Specimens are fully submerged in water; the mass of the displaced water is determined and converted into specimen volume. Using the pycnometer method, the specimen is put in a completely water-filled pycnometer, and its volume is determined based on weight measurements according to Equation (1). The pycnometer method, rather than the water immersion method, was used for volume determination in this study due, partly, to very thin and light inner bark pieces, which could not be easily immersed. It was shown that the pycnometer method is well suited for the wet volume determination of bark pieces, which is in accordance with Winter [12], using the same method for inner and outer beech bark.

Measurements of total bark thickness, determined at the thickest spot of the individual pieces, accounted for 23.2 mm on average (standard deviation (SD) = 2.7 mm, sample size (N) = 10) and an average inner bark thickness of 3.1 mm (SD = 0.8 mm, N = 10). Hence, the average inner bark content of the investigated larch bark accounts for 13% (SD = 3%). A bark thickness of 5 to 50 mm for the larch species is reported in the literature [4].

3.1. Moisture Content

The wet-based moisture content (MC) was higher than the fiber saturation point (approximately 30%) for all specimens (Table 1). Hence, all specimens were swollen to the maximum volume. The MC of larch wood was lowest on average (55%) and the MC of the inner bark was highest (365%). The moisture content of the whole bark accounted for 85%. This value is supported by literature reporting an average moisture content of Tamarack bark (*Larix laricina*) of 98% and Western larch bark (*Larix occidentalis*) of 65% of fresh bark in industrial applications [11]. The high MC of the inner bark is indirectly supported by an investigation of the ECM of the inner bark, finding that it can reach extreme values when containing free water due to an abundance of conduction cells and water-soluble sugars in the phloem [8].

Comparing the MC of bark with the theoretical maximum moisture content according to Equation (4), the water saturation of the outer bark was lowest at 28%. One of the woods accounted for 43%, and the water saturation of the inner bark was highest with 92%. These results are in accordance with the bark's anatomy (Figure 2). The phloem is the conduction layer for photosynthesis products in a tree. Its cells are predominantly made up of sieve elements [31]. This might be an explanation for the very high water uptake of the inner bark. The low water saturation of the larch wood is in accordance with the findings of Malkov et al. [32], whereby penetration of aqueous solutions into larch heartwood has low efficiency, which is caused by the structure of wood capillaries and wood density. The outer bark is enriched with suberin, making the bark hydrophobic, and this is most likely the reason for its low water saturation.

Table 1. Specimen moisture content and density of larch (*Larix decidua* Mill.).

Sample (-)	Moisture Content (%)				Wet Density ² (g/cm ³)		Dry Density ³ (g/cm ³)		Specific Gravity (-)	
	Mean	SD	Maximum ¹	SD	Mean	SD	Mean	SD	Mean	SD
Wood	54.65	8.01	127.33	23.97	0.81	0.07	0.60	0.07	0.53	0.07
Whole bark	84.79	20.20	229.68	37.53	0.61	0.15	0.40	0.05	0.34	0.04
Inner bark	364.39	95.54	395.73	84.72	0.99	0.23	0.26	0.05	0.22	0.04
Outer bark	58.31	15.37	208.60	27.54	0.56	0.14	0.43	0.04	0.37	0.04

¹ Calculation based on Equation (4). ² Calculation based on Equation (2). ³ Dry volume of bark calculated based on wet volume and average volumetric shrinkage, according to Martin and Christ [9].

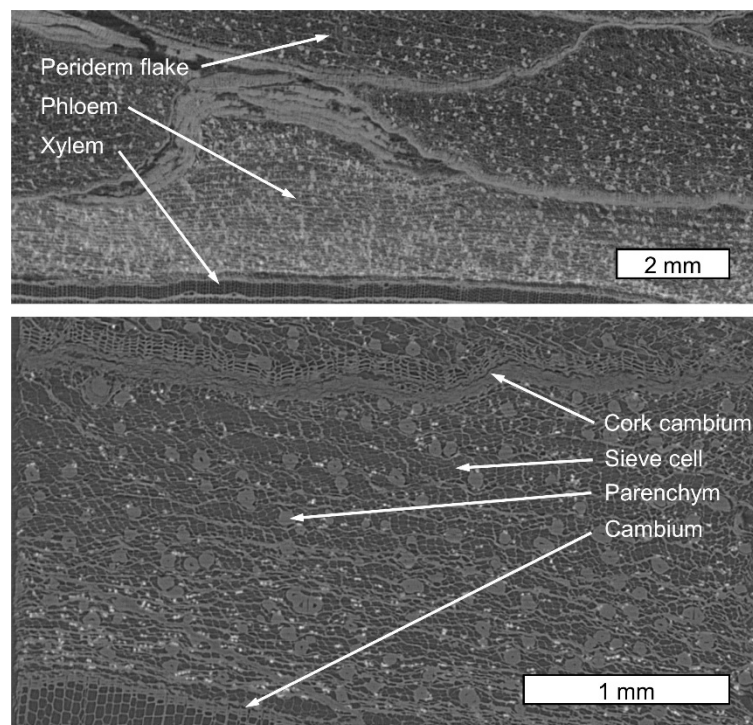


Figure 2. CT-tomogram of a larch wood and bark piece (resolution upper picture 10 μ m, lower picture 2.5 μ m).

3.2. Density

The wet density determined based on the pycnometer method has a low variation within the material phase but a high variability between the investigated phases (Table 1). The moisture content influences the density, and hence, as the MC varies to a great extent, the densities cannot be compared. The wet density of the larch wood (0.81 g/cm³) corresponds to the lower limit that is reported for green larch wood [33]. The dry density of the larch wood is 9% higher than what is reported as a literature value [33]. The reason is that wood with narrow annual rings was predominantly used. The average green weight of Tamarack and Western larch bark is 0.59 and 0.55 g/cm³, respectively [11]. The wet density of the whole bark in the current study accounts for 0.61 g/cm³, approximately 3% higher than Tamarack, probably caused by the fact that the bark in the cited study was not soaked in water in the industrial environment.

3.3. Specific Gravity

Contrary to density, the specific gravity can be used to compare the four samples because the different MCs (Table 1) have no effect due to the use of the dry mass in Equation (3). The differences

in MC do not have an effect on the specimen volume as the MC is above fiber saturation and the specimens are in a maximum swollen state.

The pycnometer method yields a specific gravity for wood, whole bark, inner bark, and outer bark of 0.53 (SD = 0.07), 0.34 (SD = 0.04), 0.22 (SD = 0.04), and 0.37 (SD = 0.04), respectively (Figure 3). Literature reports a specific gravity for European larch wood between 0.16 and 0.57, with an average of 0.48 [34]. The value determined in this study is in the upper range of the reference due to narrow annual rings. The larch wood specimens investigated had an average ring width of 0.95 mm (SD = 0.10 mm).

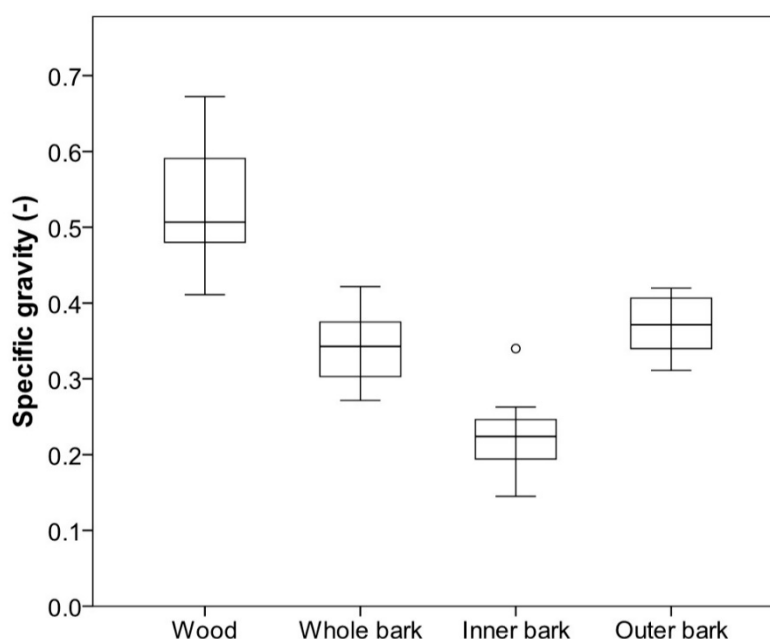


Figure 3. Comparison of specific gravity of larch wood and bark.

The specific gravity of European larch bark is not reported in the literature, to the authors' best knowledge. Miles and Smith [11] reported a specific gravity of Western larch of 0.33 and Tamarack of 0.30, in accordance with Vaucher [4] reporting 0.28. The specific gravity of European larch bark is 0.34 (SD = 0.04), comparable to the values of the cited larch species.

The specific gravity of the whole bark is significantly ($p < 0.001$, 36%) lower than the specific gravity of the wood. Hence, larch bark belongs to the lightest barks compared with a study of North American tree barks [11]. The inner bark is, on average, 58% lighter than the wood. The difference is highly significant ($p < 0.001$). The outer bark is, on average, 30% lighter than the wood, a difference which is highly significant ($p < 0.001$) as well. The inner bark is highly significantly ($p < 0.001$) lighter than the outer bark (on average, 41%).

Based on the specific gravity, the density difference between the inner and outer bark of *Larix decidua* is high and could be used for density-based separation processes (e.g., centrifuges). In a water-soaked condition, i.e., the wet density, there is also a clear density difference between inner and outer bark (the latter is 43% lower). The estimated dry density (Table 1) indicates that the density relation between the inner and outer bark is reversed when the bark is dried. In this case, the outer bark is 65% heavier than the inner bark. Due to the extremely different moisture levels, density-based separation of larch phloem and periderm is likely to be problematic, with moderate moisture levels when the density differences are less pronounced because the density of the inner bark is higher than the density of the outer bark when it is wet and lower when it is dry.

Further experimental work will have to clarify whether inner and outer bark can be efficiently separated in the debarking process. A potential solution would be a 2-step debarking process using milling machines to remove the outer bark in a first step and the inner bark in a second step. Due to the density differences between the inner and outer bark, particles could be separated after fractionation

using centrifuges. Another strategy is to single out particles with a high outer bark ratio in order to decrease the average phloem content of a bark composite.

4. Conclusions

It was shown that the pycnometer method is appropriate for the volume determination of larch bark with its flake periderm. The water uptake of air-dried larch wood and bark is highly unequal, the inner bark taking up nearly the full amount of its theoretical pore volume, whilst the wood and the outer bark are only saturated by 43% and 28%, respectively, after water immersion.

The specific gravity was shown to be a good indicator of the density of different bark compartments due to their varying moisture content. The specific gravity is declining from larch wood and the outer bark towards the inner bark.

The density of the outer bark is 43% (wet volume basis) lower than the inner bark when it is soaked and approximately 65% higher when it is dry. In both cases, density-based fractionation processes can be applied. Problems caused by a similar density might occur with medium moisture content.

Density-based separation could be a means to separate the carbohydrate-rich inner bark from the durable outer bark in substantial bark-use, preconditioned that the bark compartments can be mechanically separated.

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