UNIVERSITY of SOPRON

FACULTY OF WOOD ENGINEERING AND CREATIVE INDUSTRIES

10th HARDWOOD Conference Proceedings

12–14 October 2022 Sopron

Editors: Róbert Németh, Christian Hansmann, Peter Rademacher, Miklós Bak, Mátyás Báder

WOOD KPLUS

Mendel University in Brno

10TH HARDWOOD CONFERENCE PROCEEDINGS

Editors: Róbert Németh, Christian Hansmann, Peter Rademacher, Miklós Bak, Mátyás Báder

UNIVERSITY OF SOPRON PRESS

SOPRON, 2022

10TH HARDWOOD CONFERENCE PROCEEDINGS

Sopron, Hungary, 12-14 October 2022

ISBN 978-963-334-446-0 (pdf)
DOI https://doi.org/10.35511/978-963-334-446-0
ISSN 2631-004X (Hardwood Conference Proceedings)

Constant Serial Editors: Róbert Németh, Miklós Bak

Cover image based on the beech specimens of Radim Rousek and Mátyás Báder by Miklós Bak, 2021

The manuscripts have been peer-reviewed by the editors and have not been subjected to linguistic revision.

In the articles, corresponding authors are marked with an asterisk (*) sign.

University of Sopron Press, 2022
Responsible for publication: Prof. Dr. Attila Fábián, rector of the University of Sopron

Preliminary results of the investigations of lower quality oak lamellae with regard to their potential uses

Dénes Horváth[1*], Sándor Fehér[1]

[1] University of Sopron, Bajcsy-Zs. Str. 4, 9400 Sopron, Hungary

E-mail: hdenes68@t-online.hu; feher.sandor@uni-sopron.hu

Keywords: oak, lamella, bending strength, modulus of elasticity, classification

ABSTRACT

The primary aim of our study is to determine whether some of the waste from the processing of oak timber could be used for further processing. A higher proportion of wood recovery would create higher income through better yields and also better compliance with socio-environmental expectations. The research investigates the density, bending strength and bending modulus of elasticity of 50 lamellae (production waste). The total sample mass was taken out of industrial production due to some kind of wood failure. The results were compared with literature values and analysed according to EN 338 standard, classifying the sample as possible structural element. The sample could be qualified because it met the criteria of the standard both in the density measurement and bending test, despite smaller and larger wood failures of the specimens. It was found that the amount of smaller-sized oak lamella raw material currently used in industrial production could be expanded by the amount of lamellae free of coarse wood failures.

INTRODUCTION

Hardwood species typically have better mechanical properties than coniferous species and generally have better weathering resistance, fire resistance and aesthetics (Linsenmann 2016). Nowadays, the continuously rising price of raw materials for the sawmill industry, the occasional shortage of raw materials on the market and the ever increasing end-user demand for both quantity and quality are driving the secondary wood industry to improve yields. Accordingly, new applications for the small and low-grade assortment need to be found, one of these possibilities is gluing. The largest user of timber is the construction industry. According to Linsenmann (2016), hardwood will in future be predominantly used for construction products. It is likely that the largest volumes of smaller lamellae will be used in hybrid glued laminated timber (GLT) or hybrid cross-laminated timber (CLT) products. It is necessary to find the limits of wood failures that can be used to produce a structural product that meets current standards and application needs.

Bending strength, or modulus of rupture (*MoR*) has a prominent role in the design of load-bearing timber structures. The bending stress is composed of both tensile and compressive stresses, and the bending strength is determined by their magnitude and relationship to each other. The choice of the appropriate bending test method is very important, so standardised procedures should be followed. However, the timber classification standards (e.g. EN 338 2016 and EN 14081-1:2016 + A1 2019) for higher density hardwood species need considerable refinement based on several independent studies (Frühwald and Schickhofer 2004, Linsenmann 2016, etc.). In addition, studies on the analysis of small-sized industrial wood residues or negatively pre-classified lamellae, such as the work of Frühwald and Schickhofer (2004), are scarce. Large quantities of wood residues are generated, some of them could be further used to achieve significant yield improvements. The aim of this article is to investigate the properties of oak lamellae derived from wood processing plants, classified as 'wood waste', and to assess their potential for further use.

EXPERIMENTAL METHODS

Fifty specimens of 22 × 50 × 425 mm noble oak (*Quercus* spp.) with planed surface were tested. The specimens came from a sawmill of a Hungarian state forestry (Lenti, Hungary), processing oak logs from the surrounding area (*Quercus robur*, *Quercus petraea*). The specimens, which were the residues of the real industrial production, contained several wood failures. All the specimens were photographed (Fig. 1) and a detailed qualitative description was obtained by a thorough visual inspection.

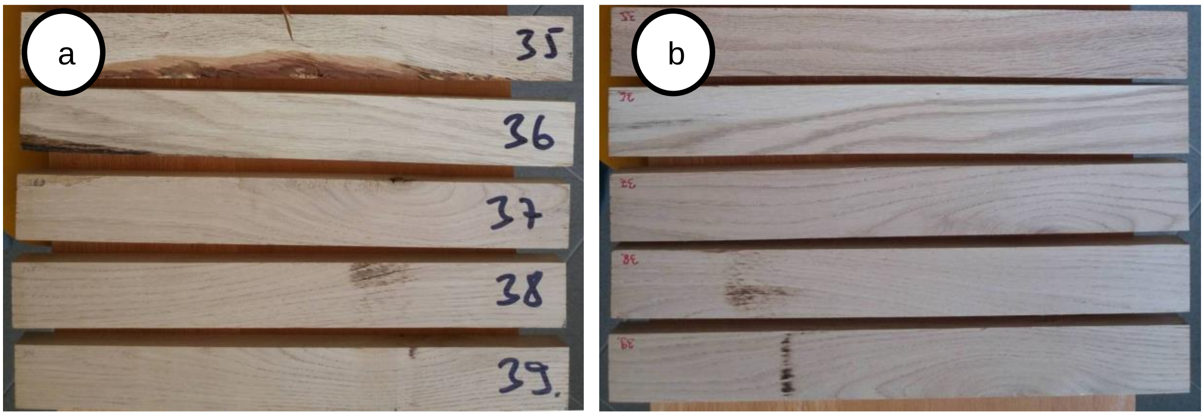

Figure 1: An example of the specimen photographs. Both the top (a) and back (b) of the specimens can be observed before the bending test

The specimens were conditioned at 20 °C temperature and 65% relative humidity. After equilibrium moisture content was reached, the moisture content of the specimens was checked with a capacitive moisture meter. The effect of prolonged conditioning was 12% moisture content with very small variation. The standard EN 384:2016 + A1 (2019) allows the density to be calculated as the ratio of the mass to the dimensions of the full-size specimens, which was preferable for us because the specimens had several wood failures. No modification factor was needed to determine the characteristic value of density required as a criterion for classification, which was thus given at the 5th percentile of the total sample mass.
For the 4-point static bending tests, we followed the requirements of the standard EN 408:2010 + A1 (2012) for structural timber, because our lamellae are intended to be installed in glued load-bearing elements. The bending tests were performed using an Instron 4208 (Instron Corporation, USA) material testing machine. The distance of the supports was 18 times the specimen thickness, while the distance between the loading rollers was 132 mm. The loading rate was 4.0 mm/min, which is in accordance with the standard. Before each measurement, an extensometer was fitted to the centre of the specimen, which gave the exact deflection value corresponding to the actual displacement of the loading rollers and the used force in the elastic phase of the bending test between 1000 N and 1800 N. The reason for sampling at low forces to calculate the bending modulus of elasticity (*MoE*) is that poor quality specimens may easily break, which can damage the extensometer (Fig. 2).

Figure 2: Static bending test according to EN 408:2010 + A1 (2012)

The local *MoE* is derived from pure bending and is the value used in the design of a load-bearing structure. However, we have performed a global *MoE* test and calculation based on the standard EN 408:2010 + A1 (2012) for ease of implementation, which always gives a lower result than the local *MoE* (Ravenshorst et al. 2004). The values of local *MoE* and global *MoE* are close to each other. Unfortunately, the standard EN 384:2016 + A1 (2019) only specifies a conversion formula for conifers, for hardwoods it requires the determination of an individual formula, for which we did not have sufficient sample number. We could not find a specific conversion method for oak wood in the literature, so for safety we will use the always lower global *MoE* results for further calculations. Based on the standard EN 384:2016 + A1 (2019), we calculated the adjusted *MoE* value (MoE_{adj}) of the specimens. From this, the characteristic value for the classification can be calculated, which is the average of the MoE_{adj} values of the specimens. According to the requirements of EN 384:2016 + A1 (2019), the *MoR* results were converted to take into account the dimensional effect, so that the adjusted *MoE* value (MoR_{adj}) of each specimen was obtained. The third weakest of the 49 evaluated specimens in ascending order gives the 5th percentile of the *MoR*, which is the basis for the further calculation. It corresponds to the characteristic *MoR* value.

RESULTS AND DISCUSSION

Physical-mechanical properties and density are closely related, although this is limited for higher density hardwood species (Frühwald and Schickhofer 2004, Ravenshorst 2004, etc). In our investigations, we determined an average density of 714.4±80.1 kg/m^3, which is slightly higher than the literature values (Molnár 2004: 690 kg/m^3) and can be considered as a high value considering the poorer material quality. The higher density of knots and the possible presence of tensile wood may also play a role. The significant, but acceptable scatter is mainly due to the presence of sapwood and bark, fissures and other lack of material. From the density values of the total sample mass, a near ideal bell curve can be obtained, which confirms the good quality of the tests. The relative standard deviations of the investigated properties are acceptable even with the poorer wood quality, so our results can be considered relevant.

A 4-point static bending test was carried out; one measurement error occurred, the test data of a specimen has been lost, therefore Fig. 3 shows the test results for 49 specimens. As an example, the results in Fig. 3b can be used, for subsequent non-destructive tests to predict strength values.

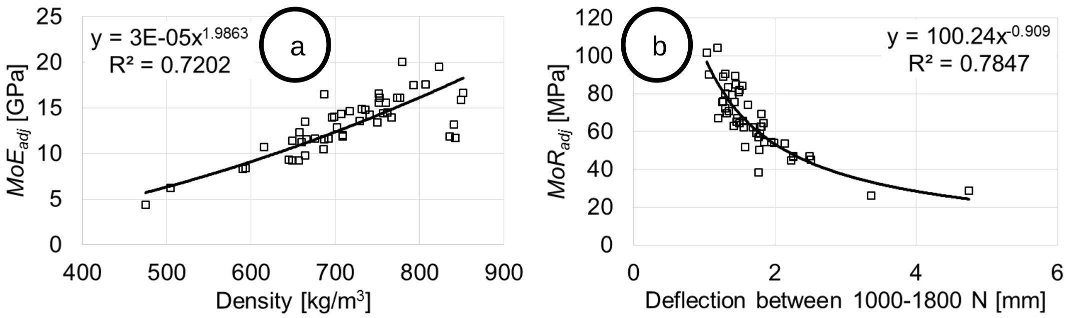

Figure 3: Adjusted bending modulus of elasticity (MoE_{adj}) of the tested oak specimens as a function of density (a) and adjusted modulus of rupture (MoR_{adj}) of the specimens as a function of deflection in the elastic range (b)

The trend lines in Fig. 3 are plotted using the results from all (49) specimens. The relationship between density and MoE_{adj} was found to be good with an exponential approximation (Fig. 3a), with a coefficient of determination of 72%. This means that even for lower quality oak specimens, mechanical properties can be inferred from the density value. The coefficient of variation of the density was found to be 11.2%, while all the properties investigated had much higher values (23.9%-25.7%) (Fig. 4). Outstandingly low densities occur due to high sapwood ratio, loose knots, fissures and other material imperfections, consistent with weakening of the material structure. Specimens unsuitable for further use can thus be easily selected. With increasing density, higher *MoR* and *MoE* can be expected, as well as reduced deflection in the elastic range. Furthermore, poor strength results at normal density are observed for some specimens. In these cases, knots

and/or slope of grain weakened the material structure, while the density was not deteriorated. Consequently, the density test helps, but is not in itself sufficient to qualify the specimens. The best relationship between the deflection measured in the elastic range and the MoR_{adj} can also be obtained by an exponential approximation (Fig. 3b). The coefficient of determination is high again (78%). Deflection and *MoR* are not only closely related for sound wood, but also for lower quality hardwood lamellae. This provides a good basis for the non-destructive rating.
Another observation is that high MoR_{adj} means above average MoE_{adj}. However, extremely low MoR_{adj} also occurred with near average MoE_{adj}. These problems can be avoided by using several methods combined (Frühwald and Schickhofer 2004). Thus, further relationships should be explored, for example for dynamic modulus of elasticity.

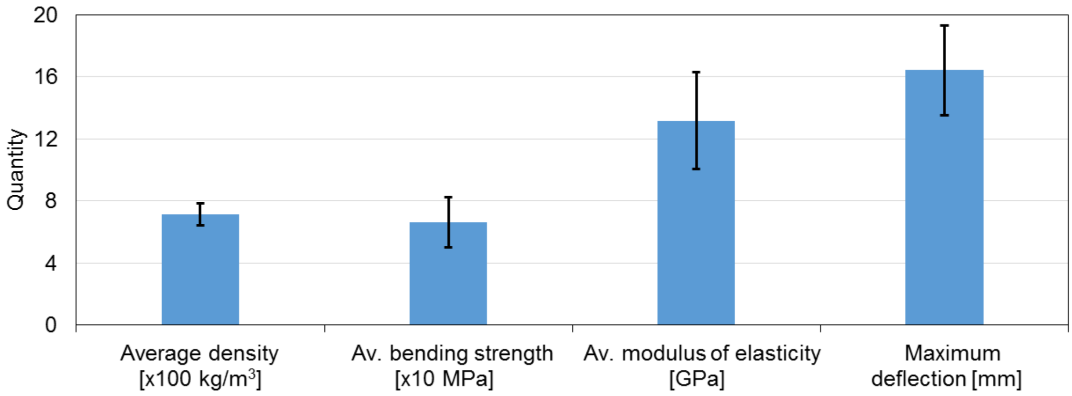

Figure 4: Average tests results

In accordance with the standard EN 338 (2016), the classification of the sample group was carried out as described previously: density and bending strength were determined based on the characteristic 5^{th} percentile, while modulus of elasticity was determined based on the characteristic average value. The characteristic density thus gave a classification of D45, the characteristic *MoR* D35 and the characteristic *MoE* D45 for the 49 specimens, giving an overall classification of D35 for the total sample mass. Furthermore, applying the standard EN 338 (2016) on a specimen-by-specimen basis, the majority of the specimens could be classified in the D30-D50 group, which is a particularly good result considering the wood materials currently used for structural purposes. It is important to note that using the specimens from our tested and graded (wood waste) material for the production of structural wooden elements would have a positive impact on profitability.
No visual classification of the specimens has been done. However, it was clearly visible that, as an example the specimen number 35 shown in Fig. 1 had coarse wood failures (i.e. rejectable), which has been confirmed by the mechanical results (MoR_{adj}: 28.9 MPa, MoE_{adj}: 4.41 GPa). It can be concluded that lamellae including coarse wood failures (large knots, significant material imperfections, strong slope of grain) are not suitable for further processing. Of course, visual grading cannot always give an accurate prediction, as it is difficult to determine the degree of slope of grain (Fig. 2). Based on the results introduced so far, the industrial application of the majority of our test specimens is appropriate. Density is the main determinant, however, the knots strongly influence the results.

Our results were also compared with the test results of absolutely sound wood. Taschner (2013) tested sessile oaks; he used only selected fault-free (knotless, straight-grained, dense year ring structure, etc.) wood material from Hungary. Furthermore, results also available in the literature, for example in the book of Molnár (2004). For the best comparability, Table 1 presents our results without the application of the modification factors prescribed by the standard EN 384:2016 + A1 (2019).

Table 1: Comparison of mechanical properties of our sample with literature values. Abbreviations: MoR_{mean} - mean bending strength obtained in bending tests; MoE_{mean} - mean bending modulus of elasticity obtained in bending tests; n.a. - not applicable

	All specimens (49 pcs.)		Taschner (2013)		Molnár (2004)	
	MoR_{mean} [MPa]	MoE_{mean} [GPa]	*MoR* [MPa]	*MoE* [GPa]	*MoR* [MPa]	*MoE* [GPa]
Average	97.3	12.5	112.7	12.5	110.0	13.0
Deviation	25.0	3.0	15.9	1.9	n.a.	n.a.
Variance	25.7%	23.9%	14.1%	14.9%	n.a.	n.a.

The average density of our specimens (714.4±80.1 kg/m^3) is in line with the literature average as previously presented, as well as the results of Taschner (2013) (692±44 kg/m^3). Table 1 shows that the average bending strength of the oaks we tested is somewhat lower than the average values of the sound wood. Our average bending modulus of elasticity can be considered to be in line with the results of both Taschner (2013) and Molnár (2004), even if the deviation is taken into account. It can thus be concluded again that there is a large amount of additional wood material suitable for further industrial use in our sample, i.e. in the residual wood material currently removed from industrial production.

CONCLUSIONS

Over the past decades, there has been a continuous shortage of raw materials for the sawmill industry. One possible solution is to explore and strengthen the potential for further utilisation of low-quality sawmill assortments. The average results of density, 4-point bending strength and bending modulus of elasticity of our 49 pieces of specimens are within the literature values for noble oak species, i.e. they can meet the general industry requirements despite their wood failures. The tested total sample mass became a strength classification of D35 according to the relevant standard EN 338 (2016), so it is suitable for further processing. The study shows that low density clearly indicates strength problems. The lamellae can be used, inter alia, for the production of structural glued laminated timber, which would allow part of the currently 'waste' wood to be marketed as a very high added value product. The wooden raw material base can therefore be expanded by the lamellae currently classified as waste, free of coarse wood failures.

ACKNOWLEDGEMENT

This publication was made in frame of the project TKP2021-NKTA-43 which has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme.

REFERENCES

Frühwald, K. and Schickhofer, G. (2004) Strength grading of hardwoods. In: *Proceedings of the 8th World Conference on Timber Engineering - WCTE 2004*. WCTE 2004 Secretariat, Helsinki, Vol. 3: 675-679.

Linsenmann, P. (2016) *European hardwoods for the building sector (EU Hardwoods)*. Holzforschung Austria, Wien, 57 p.

Molnár, S. (2004) *Faanyagismeret (Knowledge of wood)*. Szaktudás Kiadó Ház, Budapest, Hungary.

EN 14081-1:2016 + A1 (2019) *Timber structures. Strength graded structural timber with rectangular cross section. Part 1: General requirements*. Standard, European Committee for Standardization (CEN).

EN 338 (2016) *Structural timber. Strength classes*. Standard, European Committee for Standardization.

EN 384:2016 + A1 (2019) *Structural timber. Determination of characteristic values of mechanical properties and density*. Standard, European Committee for Standardization.

EN 408:2010 + A1 (2012) *Timber structures. Structural timber and glued laminated timber. Determination of some physical and mechanical properties*. Standard, European Committee for Standardization.

Ravenshorst, G., van der Linden, M., Vrouwenvelder, T., van de Kuilen, J.W. (2004) An economic method to determine the strength class of wood species. *HERON* **49**(4): 297-326.

Taschner, R. (2013) *A tölgyek nagy értékű hasznosítását befolyásoló tényezők vizsgálata és összehasonlító elemzése*. PhD dissertation, University of West Hungary, Sopron, 124 p.