Strength estimation of aged wood by means of ultrasonic devices

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Abstract

Because of ecological factors, recycling old (= aged) wood is getting more and more important, even in applications where mechanical strength plays a central role. The aim of this study was to examine certain mechanical parameters of old wood and to better understand the influence of aging on mechanical properties.

Therefore, measurements on boards and on small, clear wood specimens were carried out. Ultrasound velocities of longitudinal and, in some cases, of transversal waves were measured. Based on the results, elastic and shear moduli were determined. The measurements were performed on specimens of aged Norway spruce, European oak and Scots pine and compared with recent wood as a reference.

The measurements on boards revealed higher MOE values for old wood but the results for the small clear specimens do not confirm this observation. It is supposed that the difference is more likely a consequence of different densities and the structure of growth rings than a consequence of the wood age.

1 Introduction

Figure 1: Traditional swiss timber house built of oldwood (Photo: Matti AG.)

The necessity for recycling aged wood has remarkably increased over the last years. One plausible option is to use it as a source of energy. However, its application for furniture construction and interior design is getting more important as well. For these purposes, it is inevitable to know the mechanical properties and behaviour of aged wood.

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So far, only few references regarding this subject are available from literature and in some cases, the results therein are even contradictory. According to some authors (Borgin, Parameswaran et al. 1975; Nilsson and Daniel 1990; Erhardt, Mecklenburg et al. 1996), in wood only minor microscopic changes occur under normal circumstances and they do not cause any detectable decrease in mechanical strength. Holz (1981) reports a slight increase of the modulus of elasticity (MOE) for wood stored properly. This phenomenon was explained with relaxation of growth stresses. Weathered wood can be damaged by UV radiation, moisture and fluctuation of temperature as well as air humidity. These circumstances lead to chemical changes and degradation of wood. Therefore, it is advantageous to know the previous history of the examined material.

Since aged wood of high-quality is rather expensive and hardly available in appropriate dimensions, it was impossible to sample a reasonable number of specimens suitable for conventional mechanical tests. Thus we decided to apply an non-destructive ultrasonic testing approach.

2 Material and methods

2.1 Examinations on boards

The MOE of aged boards and, to serve as a reference, of specimens of recent structural timber was determined.

The aged boards were tested at the *Chaletbau Matti AG* (Gstaad, Switzerland). This company re-uses old wood to build traditional Swiss timber houses, so-called *chalets* (Figure 1.). The material was washed and conditioned at 65% relative humidity and 20°C and subsequently, the measurements were performed. *Chaletbau Matti* purchases its old wood from companies that deal with wood of deconstructed buildings. Thus, the origin and history of the material usually remain unknown. However, as all boards show signs of weathering (Figure 2), they obviously have been applied outdoors. Besides degradation of the surface, cracks and biotic infestation by insects and fungi was observed (Figure 3). Some boards also comprise bores or tree nails. Large knots indicate that the material has not been sorted before usage.

Figure 2: Weathered surface of an aged board

Figure 3: Damage due to insect attack

Norway spruce specimens were selected from different stacks avoiding samples with extreme damages and failures. The dimensions were highly variable with 25 to

85 mm × 95 to 497 mm × 1230 to 2645 mm (thickness × width × length). By means of dendrochronology, the wood age was assessed. 16 from a total of 112 boards were investigated each with more than 50 annual rings. Age determination was carried out at TU Munich (Germany). The regional origin of the boards supposedly was Switzerland resp. Southern Germany, as the chronologies showed the highest congruence in these areas. Based on this, the age of the specimens varies between 115 and 290 years.

As a reference, 150 Norway Spruce specimens were randomly taken from three different saw mills representing the main Swiss forest regions: Midlands, Jura and the Alps. The dimensions were 45 mm × 90 mm × 4000 mm (thickness × width × length). Planks with these dimensions are used as raw material to produce glued laminated timber beams, although a width of 90 mm is rather at the lower bound for this purpose. The investigated sample is part of a large national grading project which subjects destructive tests of about 1500 timber boards all together.

All specimens were tested with ultrasonic testing equipment (Sylvatest Duo, Concept Bois Technologie, frequency = 22 kHz), where a handheld device measures the ultrasound velocity within the boards. While specimens of recent wood were measured at only one position, 2-4 measurement points - depending on the width - were chosen for the old wood boards. In the latter case, the mean of the measured values was used for evaluation. Furthermore, density, annual ring numbers and distances were documented for every board. Figure 4 shows, how images of board slices were digitized by computer scanning systems. By means of these images, the number of annual rings (ARN) and the average annual ring distance (aARD) were assessed.

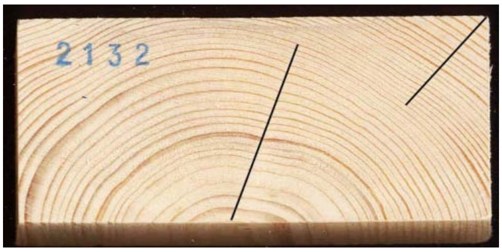

Figure 4: Determination of the mean annual ring distance

2.2 Examinations on clear specimens

The MOE and shear moduli were determined on small, clear specimens made of both, old and recent wood.

The material for aged specimens partially came from collections (*Museum of Art and History, Genf*; *Warsaw University of Life Sciences*), and also from deconstructed buildings (via *Chaletbau Matti AG*.). The wood age was again determined using dendrochronology. The reference material either came from Switzerland or from Poland (provided by the *Warsaw University of Life Sciences).* Table 1 gives an overview of age and origin of the investigated materials.

Table 1: Age and origin of the raw material for clear specimens

ID	Wood species	Provided by	Origin	Age
SA1	Norway spruce	Museum of Art and History	Switzerland	ca. 250 years
SA2		Chaletbau Matti AG	Unknown	ca. 90 years
SR		ETH Zurich	Switzerland	recent
OA1	European oak	Museum of Art and History	Switzerland	ca. 230 years
OA2		Warsaw University of Life Sciences	Poland	ca. 200 years
OR1		Warsaw University of Life Sciences	Poland	recent
OR2		ETH Zurich	Switzerland	recent
PA	Scots pine	Warsaw University of Life Sciences	Poland	ca. 100 years
PR		Warsaw University of Life Sciences	Poland	recent

The specimens were tested with two devices. With the BPV (Steinkamp, frequency 50 kHz), the longitudinal sound velocity was measured on specimens with dimensions of 20 mm × 20 mm × 200/400 mm (thickness × width × length) allowing to estimate their MOE. Furthermore, small cubic specimens with an edge length of 10 mm were tested with the Epoch XT (Olympus). With this device, measuring the velocity of both, longitudinal and transversal waves (1.00 and 2.23 MHz, resp.), was possible, so besides the MOE, also the shear modulus can be estimated.

3 Results

3.1 MOE of the boards

Figure 5 shows the dynamic MOE values for specimens of old and recent timber. The correlation coefficients and the slopes of the trend lines are quite similar for both groups of specimens and agree with well-known data for this types of measurement. The MOE of old wood is shifted to higher values than that of recent wood. However, predictability of the structural performance of the tested specimens based on ultrasonic measurements would be of same quality.

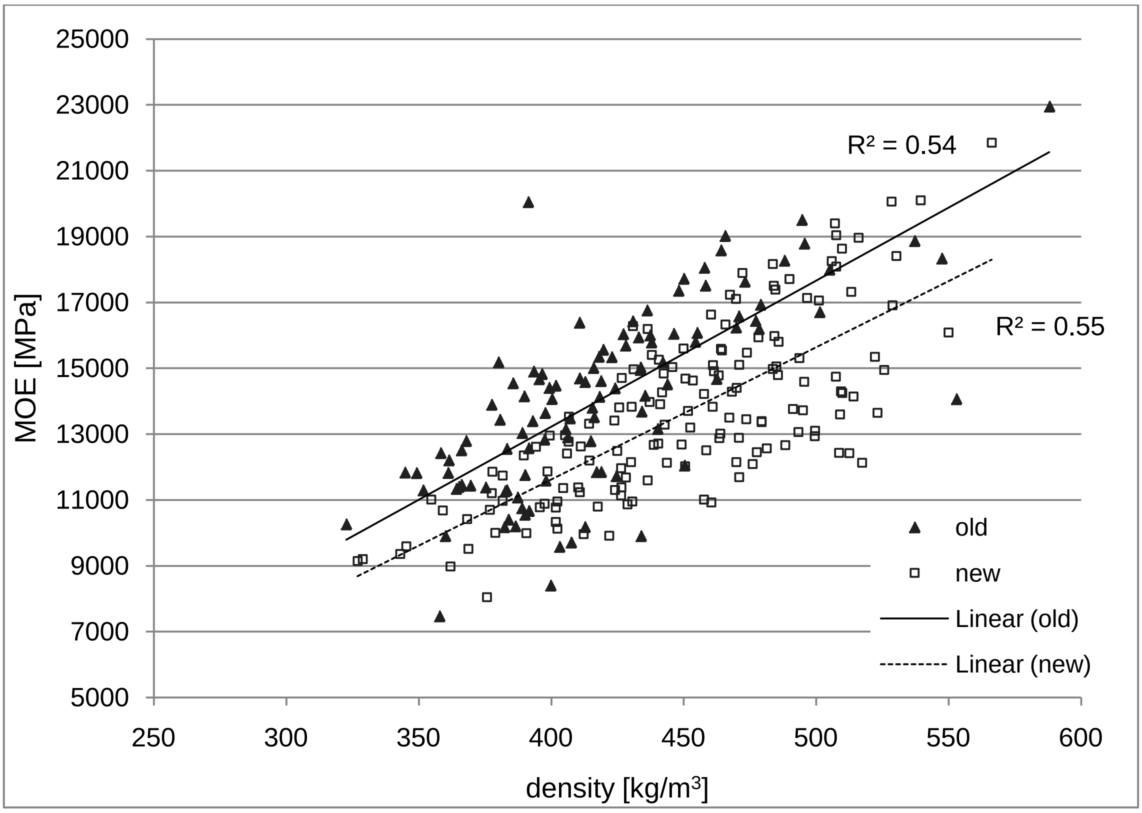

Figure 5: MOE depending on the raw density

To assess the suitability of the data for further evaluation, the distributions of MOE, density and average annual ring width were investigated too. In all cases, the distributions were assumed to be normal (Figures 6 to 8).

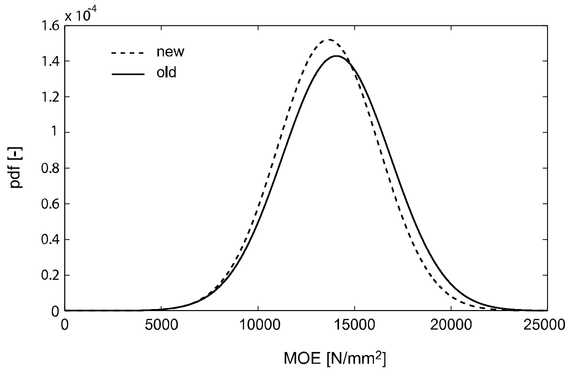

Figure 6: Deviation of the MOE
(pdf = probability density function)

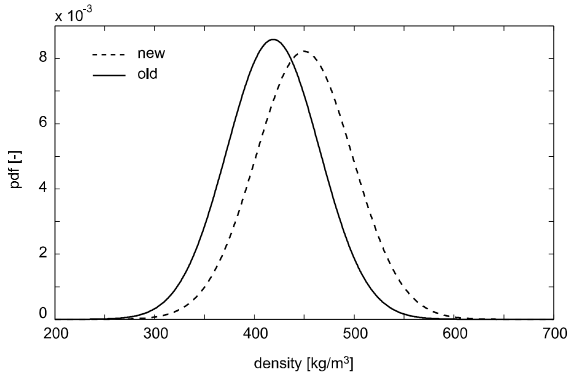

Figure 7: Deviation of the density

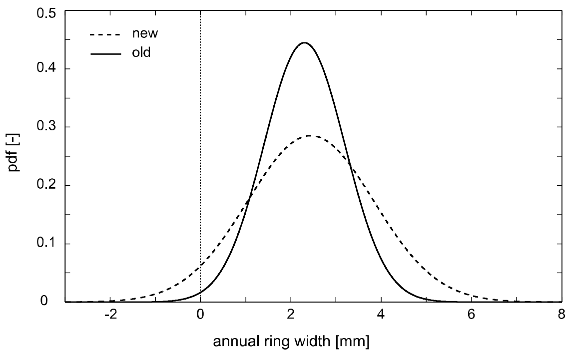

Figure 8: Deviation of the average annual ring width

As can be seen in Figure 6, the mean values and standard deviations of the MOE were almost identical for old and new wood specimens and the probability density functions are rather congruent. In contrast, the probability density functions (pdf) of the timber densities differ clearly between specimens of new and old wood (mean values of densities: 450 vs. 420 kg/m^3; Figure 7). The mean values of the annual ring widths are again close to each other, but the standard deviation is much higher for new wood specimens. It has to be noted that the graphs in Figure 8 extend remarkably to the negative range. This indicates, that the real distribution cannot be exactly described with a normal distribution.

3.2 MOE of clear specimens

In Table 2, the results of the measurements on prismatic specimens are summarized and compared to bibliographical references determined in mechanical tests.

Table 2: Results and reference values for the MOE (mean values and standard deviations)

ID	Wood species	ρ [kg/m^3]	MOE [MPa]	n
SA1	Norway spruce	538	20176±2313	8
SA2		455	15287±990	20
SR		410	14994±981	24
reference*		300-640	7300-21400	
OA1	European oak	641	12578±989	9
OR1		679	18682±1835	9
reference*		430-960	9200-13500	
PA	Scots pine	472	14955±1577	9
PR		548	19516±712	9
reference*		300-860	6900-20100	

ρ = density at 20°C/65% RH; MOE = modulus of elasticity;
n = number of specimens
* (Molnár 2004)

In contrast to the average density, the MOE values are in the upper part of the range given by the references. This could be due to different testing methods.

Although non-destructive approaches already cause 10-40% higher values compared to mechanical tests (Dívós and Tanaka 2005; Keunecke, Sonderegger et al. 2007), the results for oak are even clearly higher, especially that of the new specimens. The MOE of spruce is practically the same for old and new wood. For oak and pine specimens, the MOE of recent wood is higher. However, due to different densities, this effect certainly cannot be ascribed to aging.

In Table 3, the results for small, cubic specimens are summarized and compared to bibliographical references determined with a similar method.

Table 3: Measured and reference values of elastic and shear moduli in the principal anatomic directions for oak, spruce and pine wood (means and standard deviations)

ID	Wood species	MOE_L [MPa]	MOE_R [MPa]	MOE_T [MPa]	G_{LR} [MPa]	G_{LT} [MPa]	G_{RT} [MPa]	ρ [kg/m³]	n
OA2	European oak	12001 ±2723	2958 ±336	2201 ±138	984 ±84	1125 ±68	432 ±32	607	10
OR2		17075 ±2685	4023 ±95	2528 ±42	1536 ±216	1211 ±95	536 ±73	721	10
ref.*		19185 ±966	3868 ±55	2129 ±61	1597 ±121	943 ±84	485 ±16	669	10
SA1	Norway spruce	19008 ±2680	2129 ±36	924 ±169	894 ±95	754 ±107	148 ±28	498	11
SA2		17852 ±434	2294 ±83	973 ±34	1014 ±97	773 ±30	118 ±22	470	10
SR		12983 ±452	2398 ±45	958 ±51	953 ±154	954 ±136	137 ±26	467	11
ref.*		19207 ±463	2103 ±201	637 ±61	868 ±114	710 ±60	114 ±9	454	10
ref.**		13800 ±2760	1800 ±191	1170 ±247	617 ±75	587 ±60	53 ±6	399	120

MOE = modulus of elasticity; L, R, T = longitudinal, radial, tangential;
G = shear modulus; ρ = density at 20°C/65% RH; n = number of specimens
* (Merz 2009); ** (Keunecke, Sonderegger et al. 2007)

The values for aged oak specimens are obviously lower than those of recent wood specimens. However, a distinct conclusion cannot be drawn because of the low number of specimens, the relatively high scattering and differing densities.

The spruce results are in the same range and in agreement with reference values, except for the MOE_L and G_{LT} values, which are either clearly lower or higher.

4 Discussion

For the boards, higher values of MOE were measured for the old wood than for the recent timber specimens within the same density range. On the other hand, the results for clear specimens did not show any obvious differences. An explanation for this discrepancy can be the low number of specimens and the differing densities of the latter, which make a clear statement impossible. In case of the boards, a possible influence of the annual ring structure on the elastic behaviour can be taken into account. As a consequence, an aging effect on the mechanical properties could not be ascertained.

The relation between MOE and wood density was nearly the same for old and recent wood specimens, as similar trend lines and correlation coefficients show for the measurements on boards. As a result, grading methods developed for recent wood may also work for old wood. However, due to the frequent occurrence of fungal decay and infestation of insects, a previous control is inevitable.

Acknowledgements

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