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The use of an acoustic technique to assess wood decay in laboratory soil-bed tests

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Abstract This study assesses the changes in elastic behaviour (i.e. modulus of elasticity – MOE) and mass loss of different hardwood and softwood species exposed to decay in laboratory soil-bed tests. Elasticity moduli were determined using conventional static methods as well as a dynamic method based on flexural vibration. The results obtained show a high correlation between dynamic and static bending measurements for all the timber species tested at different stages of fungal decay. Furthermore, the non-destructive MOE assessment proved to be a good tool for the early detection of wood decay.

Introduction

Methods generally applied to assess wood decay (e.g. mass loss detection, visual examination), although relatively simple to perform, are often destructive and not sufficiently sensitive to detect early stages of fungal decay. Strength testing has been reported to be a reliable test means to evaluate fungal attack of timber (Hardie 1980). Procedures for determining timber strength are relatively laborious and require stand-testing facilities; however, they provide quantitative and objective results. Assessment of the modulus of elasticity (MOE) is of particular interest for the evaluation of wood decay due to the non-destructive nature of this measurement.

Existing methods for determining MOE can be divided into two main groups, namely, static and dynamic test methods. Static techniques are conventionally used and described in most standards for MOE determination (e.g., EN 408 (1995) and DIN 52 186 (1978)). Dynamic methods, on the other hand, are based on resonant vibration excitation or ultrasonic pulse excitation of the test body (Görlacher 1984; Gray 1986). Although less frequently used, dynamic methods provide some advantages compared to static methods. Vibration techniques enable on-site measurements, they do not require laboratory stand equipment and they make possible a considerable reduction in testing time and labour costs.

Vibration methods were originally developed for the determination of the elastic constant (ie., the Young's module, shear modules and Poison's ratios) of

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isotropic materials. This methodology can also be used for purposes other than the global characterisation of the elastic behaviour of a material; e.g., for testing glue bonds in laminated lumber (Jayne 1955; Wang and Jwo 1985); determining moisture gradients in solid wood (Vermaas 1996); evaluating insect damages in construction wood (Lemaster et al. 1997); and assessing the quality of timber, lumber and wood-based panels (Dong et al. 1994; Schad et al. 1995; Walters and Westbrook 1970). Vibration techniques have also been applied for research purposes as a means to estimate the MOE of non-attacked wood (Görlacher 1984; Perstorper 1994). Little is known, however, about the applicability of this technique in the assessment of wood decay.

This study was set up to evaluate the potentials of non-destructive MOE methods for assessing wood decay in natural durability testing. For this purpose, both, the static and the dynamic MOE approach were employed. Bending measurements were compared with the mass loss data of attacked wood, the latter being the most conventional approach in wood decay assessment.

Materials and methods

Wood species

Untreated heartwood samples from four hardwood species differing in their susceptibility to fungal attack were chosen, namely: poplar (*Populus* spp.) (durability class - DC 5), elm (*Ulmus* spp.) (DC 4), keruing (*Dipterocarpus alatus*) (DC 3), teak (*Tectona grandis*) (DC1). Beech (*Fagus silvatica*) (DC 5) specimens were included as a reference. The tested softwood species included spruce (*Picea abies*) (DC 4), larch (*Larix decidua*) (DC 3–4). Specimens from Scots pine (*Pinus sylvestris*) sapwood (DC 5) were used as reference material. The natural durability classification is according to European Standards (EN 350 1993).

Laboratory soil-bed tests

Wood decay was assessed in non-sterile soil-bed tests based on the European prestandard ENV 807 (1993) under controlled environmental conditions promoting fungal attack (T = 26–28 °C; relative humidity = 70–80%). Plastic containers (360 × 550 × 190 (height) mm^3) were supplied with different soil layers (bottom to top): 20 mm of gravel, 20 mm of river sand and 150 mm of loam-based horticultural soil composition. Soil moisture and soil temperature were monitored on-line using probes connected to a computer system. Experimental details of the laboratory soil test used are described in earlier work (Machek et al. 1997a).

Sixty specimens (10 × 5 × 100 mm^3) per wood species were used. Specimens were placed vertically in the soil with 20 mm of their length protruding above the soil surface. Replicates were selected to be free of visual defects and to have approximately the same mass. The stakes were left to be moisture equilibrated at ambient conditions before exposition to soil.

Monitoring

Wood decay was assessed by determining the mass losses as well as the losses of both static and dynamic modulus of elasticity (MOE) at different stages of wood decay, most commonly after 6, 12, 18, 26 and 34 weeks of exposure. After each exposure period, a replicate set of 10 stakes was withdrawn from the soil-bed randomly. Stakes were cleaned from any adherent mycelium and soil. Prior to strength measurement, the stakes were saturated with water. For this purpose, stakes were placed in a vacuum vessel for approx. 60 h.

The mass loss of the attacked stakes was determined gravimetrically, oven-drying at 103 °C overnight. Mass loss of each test specimen was expressed as percentage of the initial dry mass.

The static MOE was determined by 3-point bending according to the German standard (DIN 52 186 (1978)) in a universal testing equipment type Roell & Korthaus. The applied force load was adjusted to cause a deflection of 0.75 mm. The load was applied at a uniform rate of motion of 2 mm/min. The MOE dynamic tests were carried out using the Grindo*Sonic* MK5 'industrial'. (J.W. Lemmens N.V., Leuven, Belgium). Due to the geometry and the mass of the samples, transverse vibration measurements were recorded. Each specimen was supported horizontally on two sponge rubber pieces located at a distance from each end of $0.224 \times L$ (L = length of the sample). The vibration energy was initiated into the specimens through a light elastic tap on the middle of length on top surface (tangential direction) – stake anti-node. The resulting vibration was detected by a transducer that was brought in contact with the front face (tangential plane) of specimens, close to support position – the nodal zone, in order to gain strongest reading. The MOE dynamic was calculated based on the equation derived by Hearmon (1966) [Eq. 1]. This mathematical expression uses the natural frequency of wood together with the data describing the mass and shape of the specimen.

A schematic representation of the test set-up used is shown in Fig. 1.

$$MOE_{dyn} = \frac{4 \cdot \pi^2 \cdot l^4 \cdot f^2 \cdot p \cdot A}{m_1^4 \cdot I} \cdot \left(1 + \frac{I}{l^2 \cdot A} \cdot K_1\right) \qquad (1)$$

Where:

I	moment of inertia [mm^4]
A	area of the cross section [mm^2]
f	frequency [kHz]
p	mass density [kg/m^3]
l	length [mm]
$K_1 =$	49.48
$m_1 =$	4.72

Results and discussion

Mass losses and changes in elastic behaviour were assessed in laboratory soil-bed tests using eight wood species differing in their susceptibility to fungal decay.

Figure 2 illustrates the correlation between MOE measurements performed by the dynamic and static approach on non-attacked specimens of beech and spruce. The strong correlation between static and dynamic MOE data is clearly indicated by the high regression coefficients (R^2) of 0.96 and 0.97 calculated for beech and spruce, respectively. High correlation coefficients ranging from 0.94 to 0.97 were also found for all other tested hardwood and softwood species. These results are

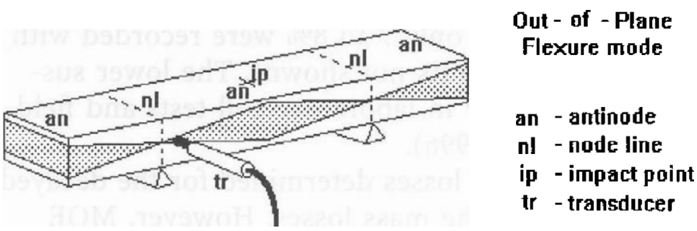

Fig. 1. Apparatus for measuring vibration parameters of rectangular wood specimens by free vibration

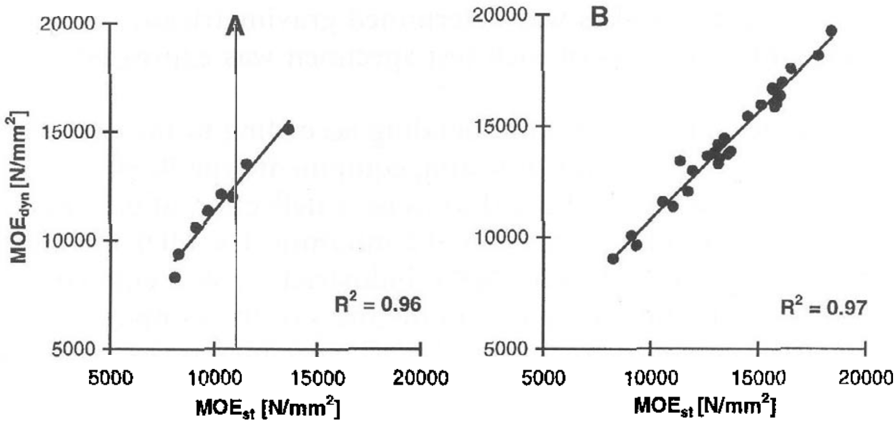

Fig. 2. Correlation between the modulus of elasticity (MOE) determined by the dynamic (vibration) approach and conventional bending method for sound beech (A) and spruce (B) specimens

in agreement with previous reports (Perstorper 1994; Machek et al. 1997b) and confirm the existence of a strong correlation between both static and dynamic approaches regardless of specimen dimensions or wood species.

MOE values calculated using static bending are known to be somewhat lower than those measured by flexural vibration (Görlacher 1984). In our study, we also observed that the static MOE measured in the tangential plane was approximately 5% lower than the MOE determined using the vibration technique. Cracks and other imperfections in the specimens structure have been suggested to account for the lower values in the static modulus (Price 1928). Similar conclusions were drawn by Ide (1935) in experiments investigating the strength of rocks.

Table 1 illustrates the relationship between static MOE and dynamic MOE for all tested hardwood species at different stages of wood decay. These results show the high correlation between static and dynamic elasticity data for non-attacked wood, but also for decayed and heavily decayed wood. In all cases except for teak, high correlation coefficients exceeding 0.95 indicate that the regression accounts for more than 90% of the variation.

Figure 3 illustrates the time course of wood decay for various hardwood species as indicated by the total losses of woody mass as well as by the losses of both static and dynamic MOE. For all the timber species considered, the recorded dynamic MOE data were very similar to those found by the static measurements. The extent of wood decay increased generally with decreasing natural wood durability. Non-durable and slightly durable species were rapidly attacked in the soil-bed tests. The MOE losses observed for beech, poplar and elm after only 12 weeks of exposure ranged from 77 to 86%, whereas for Scots pine and spruce the MOE losses were considerably lower and ranged from 22 to 27%. In the same time period, elasticity losses for the moderately durable timber keruing reached approximately 25% and for larch 15%. The very durable teak showed MOE losses of around 10%. The total losses of woody mass for hardwood species presenting low resistance to fungal decay (durability class 5 and 4) after 12 weeks of exposure ranged from 35 to 40%. Lower mass losses of only 7 to 8% were recorded with softwood species in the same time period (results not shown). The lower susceptibility of softwood species to fungal decay in laboratory soil tests and field trials has been reported earlier (Militz et al. 1996).

The results obtained indicate that the MOE losses determined for the decayed wood specimens followed the same trend as the mass losses. However, MOE

Table 1. Correlation between the dynamic MOE (vibration method) and static MOE as determined for different wood species exposed to fungal decay in soil-bed tests. Hardwood species were exposed to decay for 0, 6, 12, 18, 26 and 34 weeks. In the regression equation, 'Y' is the dynamic MOE and 'X' represents the static MOE

Wood species	Durability class EN 350	Correlation coefficient R^2	Regression equation
Beech	5	0.961	$y = 0.94x + 1683$
Poplar	5	0.985	$y = 1.03x + 1035$
Elm	4	0.990	$y = 1.03x + 2135$
Keruing	3	0.950	$y = 1.14x + 4455$
Teak	1	0.865	$y = 1.15x + 1229$

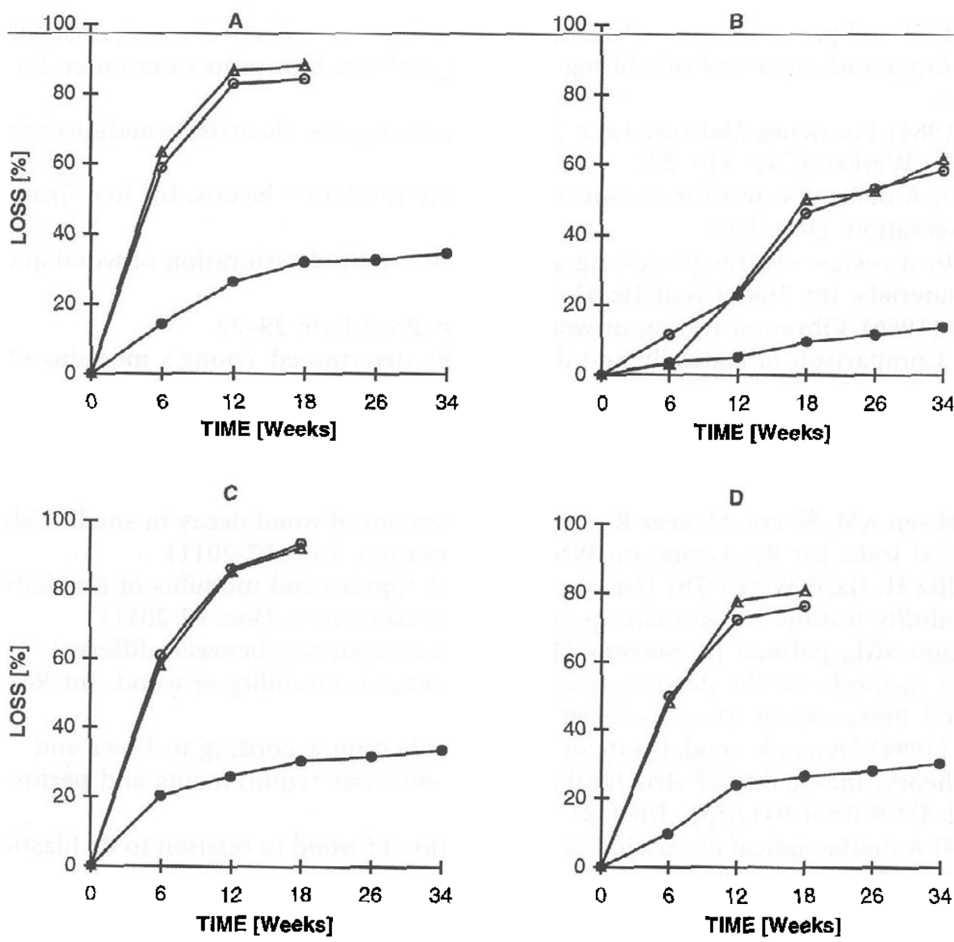

Fig. 3. The time course of wood decay in laboratory unsterile soil tests analysed by mass loss (-●-), MOE static (-▲-) and MOE dynamic (-O-). The wood species tested included: beech (A), keruing (B), poplar (C) and elm (D)

determination provided a much higher sensitivity compared to mass losses. These results are not surprising since significant losses in strength can develop during the first stages of wood decay, when mass losses are still very low (Tsuomis 1993).

Conclusions

The results of this research indicate that MOE testing is a suitable and sensitive method for assessing wood decay. A very good correlation was found between the MOE data determined by the conventional static approach and the used dynamic method both for sound wood as well as for wood decayed to different extents. The vibration technique investigated here provided a simple, reliable and non-destructive tool to assess wood decay, suggesting its potentials in natural durability testing.

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