WOOD SPECIMENS UNDER STATIC BENDING LOAD: PROPERTIES AND BEHAVIOR

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Summary: Předložený příspěvek přináší nové informace o měření akustické emise během standardní ohybové zkoušky dřevěných vzorků. Výsledkem měření bylo nalezení typických vzorů akustické emise pro pět typů dřevěných vzorků. Na základě těchto poznatků bude v průběhu dalšího výzkumu proveden odhad chování jednotlivých vzorků a vznik porušení při ohybovém zatížení. Výrazně ortotropní vlastnosti dřeva ovlivňují významnou měrou možnost použití známých technik monitorování a vyhodnocení signálů AE. Při měření byly u vzorků zjišťovány další vlastnosti, zejména modul pružnosti, mez pevnosti, délka namáhání a hustota.

dřevo, zkouška statickým ohybem, akustická emise

Summary: The paper presents results of acoustic emission measurement project focused on commonly used static bending test of wood specimens. For five different wood types, typical AE patterns were identified in the acoustic emission records to further describe the under-the-stress behavior and fracture/failure development. Strong orthotropic properties of wood were found to be rather complicated to conform within known AE techniques. Evaluated properties of the wood material include MOE (modulus of elasticity), MOR (modulus of rapture), TSF (time to specimen failure), and density.

wood, static bending test, acoustic emission

Introduction

Strength properties are critical for safe utilization of wood as a construction material. Basic mechanical properties of wood are derived from static bending test. Results of the static bending test procedures according industrials standards include parameters of MOE (Modulus of Elasticity) and MOR (Modulus of Rupture). Further correlation relationships make it possible to estimate elastic constants and yield strength values. Currently, there is an ongoing research project in the Department of Wood Science laboratory of Mendel University in Brno that includes an innovative approach to static bending test applied to wood specimens. Acoustic emission method is being used in conjunction with the standard 3-point static bending procedure to gain additional information about the test progression for selected wood types (3 hardwoods, 2 softwoods).

Structure and Failure Mechanisms of Wood

Being a natural composite, wood may be described as an orthotropic material; that is, it has unique and independent mechanical properties in the directions of three mutually perpendicular axes: longitudinal, radial, and tangential (Winandy, 1994), (Green, 2001), and (Winandy, Rowelll, 2005). The longitudinal axis is parallel to the fiber (or grain); the radial axis is normal to the growth rings (perpendicular to the grain in the radial direction); and the tangential axis is perpendicular to the grain but tangent to the growth rings. Figure 1 shows three major axes in wood material.

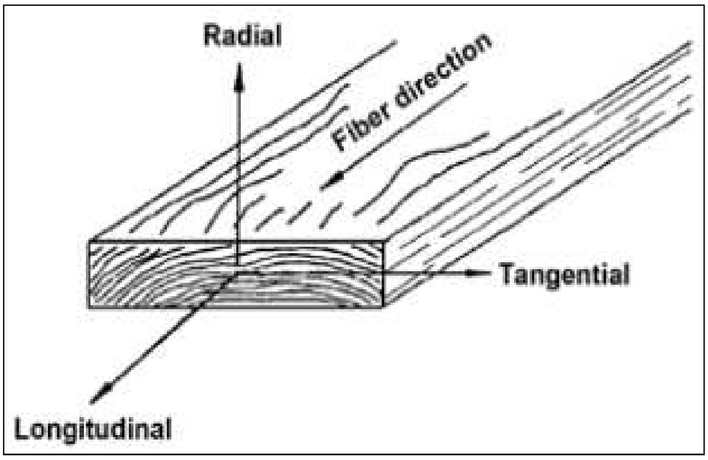

Figure 1: Three principal axes of wood (Augustin, 2008)

Microstructure of wood depends on whether the material is taken from coniferous trees (so called softwood) or broad-leaved trees (hardwood). In both types of wood, 90-95% of the cells are aligned along the longitudinal axis, while the remainder is in the radial directions. There are no cells in a tangential orientation. The distribution of cells is different in all three principal sections (in cross section, tangential section and radial section and wood is therefore very anisotropic.

Softwood consists mostly from a single kind of wood cells – the tracheids. There are no vessels in coniferous wood. As a result, such wood material is much more uniform in structure than that of most hardwoods (Hoadley, 2000).

In microscopic scale, wood has predominantly a structure including parallel columnar cells (Winandy, Rowelll, 2005). The elongated cells can be considered as fibers, embedded in a matrix of the polymer lignin. The cell walls contain helical windings of cellulose micro fibrils.

It has been known that source of strength in solid wood is the wood fiber (Winandy, Rowelll, 2005). Wood is basically a series of tubular fibers or cells cemented together. Each fiber wall is composed of various quantities of three polymers: cellulose, hemicelluloses, and lignin. Cellulose is the strongest polymer in wood and, thus, is highly responsible for strength in the wood fiber because of its high degree of polymerization and linear orientation. The hemicelluloses act as a contact matrix for the cellulose and increase the packing density of the cell wall. Lignin not only holds wood fibers themselves together but also helps bind carbohydrate molecules together within the cell wall of the wood fiber.

As far as the wood damage mechanisms in compression are concerned, they include buckling, crushing, and kinking (Benabou, 2008). Buckling may be described as sudden failure of a structural member subjected to high compressive stress, where the actual compressive stress at the point of failure is less than the ultimate compressive stresses that the material is capable of withstanding. Crushing, on the other hand, represents breaking of material matrix into small fragments or powder. Kinking is a specific failure mode when initial misalignment of fiber causes damage of the fibers with subsequent shear deformation in the kink band region. However, outside this region, compression prevails. In tension, the behavior is much simpler: semi brittle rupture stands for major failure mode. Obviously, all these phenomena are oriented directionally.

Static Bending of Wood

As noted above wood has strongly orthotropic properties. This presumption is obviously reflected in the behavior of the specimen during the static bending test. When the specimen is subject to static bending test, it is loaded by compression stress on one surface and tensile stress on the other. This complicated distribution of stress results in a various shear displacements within the cross-section of the beam. Due to anisotropic structure, acoustic emission generated during clear wood damage process shows parameters dependent on loading type and its orientation with respect to grain direction.

Tensile load in the grain direction may produce acoustic emission is expected to come from several sources including separation of cellulose micro fibrils and lignin matrix, actual micro fibril breakage, and final fracture of the entire cell wall. In perpendicular direction, the cell walls are less reinforced with micro fibrils and overall cell wall strength is reduced. When a tensile loading is applied in this direction, it is likely that acoustic emission signals originate in degradation-related changes of cell wall lignin mass.

MATERIALS AND METHODS

Static Bending Test Basics

The ČSN 490115 standard defines procedures and settings for the static bending test as follows: the test is used to find ultimate static end load causing permanent damage of the tested specimen. Testing specimens must be in form of regular-shaped boxes with cross dimensions of 20 x 20 mm and length of 300 mm. The fiber direction has to correspond with specimen length dimension. The width b is measured in direction parallel to the annual rings, while the height h is measured in direction perpendicular to the rings. The specimen is placed on two supports at the ends while the third point provides downward pressure at the centre. The forces from above acts in radial direction, i.e. the annual rings are close to horizontal. The distance between the supports is defined as 12 x height. With the standard specimen size (see above), the support span is equal to 240 mm (ČSN 490115, 1979)

For the static bending test, the ZDM 5/51 machine was used in the Department of Wood Science laboratory, see Figure 2. Acoustic emission signal was measured and evaluated by state-of-art Dakel XEDO system (Dakel, 2005).

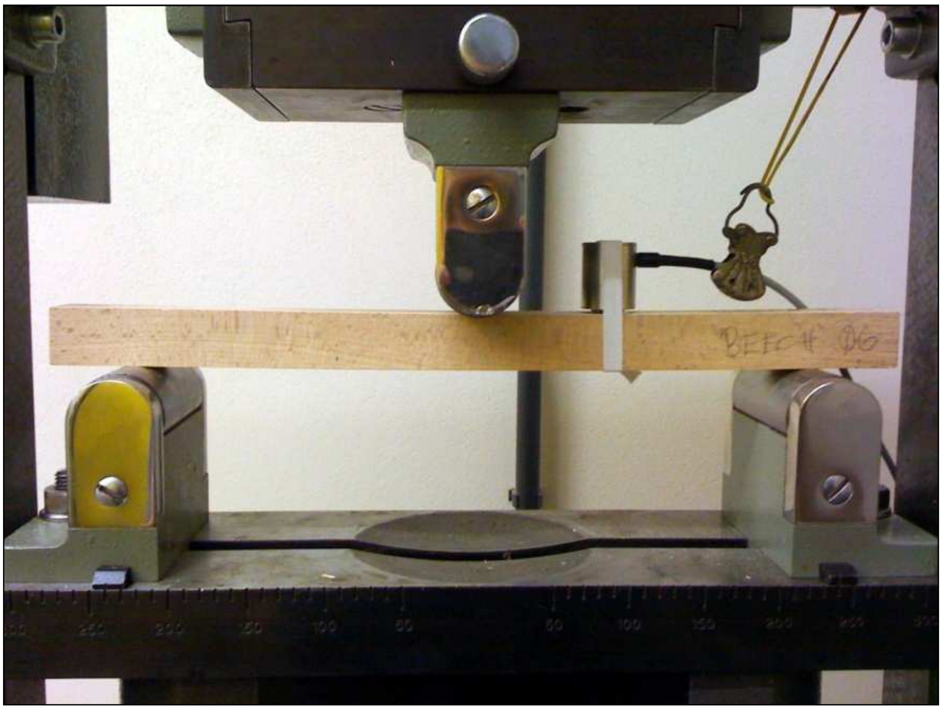

Figure 2: Static bending test specimen with acoustic emission sensor attached

Acoustic Emission Method

Acoustic emission ranks among NDT (non-destructive testing) methods. Acoustic emissions are stress waves produced by the sudden internal stress redistribution of the materials caused by the changes in the internal structure. Possible causes of the internal-structure changes are crack initiation and growth, crack opening and closure, dislocation movement, twinning, phase transformation in monolithic materials and fiber breakage in composites (Varner, 2007). Most of the acoustic emission sources are damage-related; thus, the detection and monitoring of such emissions are commonly used to predict material failure. In technical diagnostics, acoustic emission method has been used to monitor rotational part status (friction/cavitations of bearings and gears), detection of micro-cracks, pressure vessel defects, tubing system defects, aircraft structure testing, and bridge status diagnostics. Acoustic emission technique has proven useful in fatigue testing and destruction experiments (Kreidl, 2006). Many interesting applications for acoustic emission testing have been developed in recent years in wood science. The objective of the technique is to measure parameters for specific properties of the material under test. As far as wood science applications are concerned, the method was used to monitor sap flow in grown-up trees (Černý, Mazal, Čermák, 2011). In order to determine acoustic emission parameters, influence of wood species, moisture content and type of sensor should be taken into account (Bucur, 1995).

Acoustic emission may come from several sources in context of the static bending test: bending machine noise, contact-surface friction noise, gradual collapsing of wood cell walls, and final fracture of the specimen body.

As expected, final stage fracture always generates peak acoustic emission bursts (even in audible spectra range). This moment corresponds to MOR (modulus of rupture) ultimate loading conditions.

Instrumentation of the Experiment

Dakel XEDO AE analyzer, a single Dakel sensor and Dakel Daemon software were used to monitor and record acoustic emission signals. A 35 dB pre-amplifier was connected to a special low frequency slot in the Dakel XEDO analyzer. The slot was adjusted to cover the frequency range of 10 - 200 kHz. A cylinder-shaped Dakel AE 469 sensor was used for all the bending test runs (Dakel, 2005).

ZDM 5/51 machine was used to perform the test. This machine uses electric power unit and spiral gear drive to lift the bridge with lower support assembly. The device has been installed in the Department of Wood Science laboratory. The ZDM 5/51 bending test machine was equipped with a PC terminal with the M-Test 1.77 software for test control purposes.

RESULTS

The experiment showed quite a different behavior of individual wood type specimens subject to static bending test. In this very first phase of the research, acoustic emission RMS vs. loading force plots were created for each of the 50 regular specimens and 5 Teflon-tape specimens. The aim was to overview the plots and find typical patterns for future observations.

Property parameters of the static bending test itself included MC (moisture content), density, TSF (time to specimen failure), F_{max} (maximum loading force at ultimate strength level), MOE (modulus of elasticity) in bending and MOR (modulus of rupture) in bending. As far as the low friction modification of the static bending test is concerned, no significant influence was indicated from the plots. Table 1 lists average bending property values.

Wood type	MC (%)	Density (kg/m^3)	TSF (sec)	F_{max} (N)	MOE (MPa)	MOR (MPa)
Oak	7,6	662,5	59,4	2178,5	11076,5	106,8
Beech	6,2	670,9	73,1	2998,3	11866,7	129,4
Poplar	7,6	383,8	74,7	1394,7	6880,0	66,7
Pine	6,8	499,0	100,4	2085,3	10662,1	94,3
Spruce	8,7	525,0	73,3	1875,7	9233,0	84,7

Table 1: Average property values for 5 wood type groups

The essential aim of this research was to find specific AE response patterns for individual wood types. In this paper, acoustic response of two wood types will be presented: Oak (hardwood) and Spruce (softwood).

Oak specimens can be divided into 2 behavior-specific groups. 3 specimens showed no AE activity during the entire bending run; they remained silent until the major fracture. The rest of the testing group showed strong pulses in 80% of ultimate load. Oak wood breakage resembled to simple-tension type failure with short horizontal portions parallel to grain and vertical bridging perpendicular to grain. On some specimens, kink bands were visible under upper loading support. Typical Oak specimen plot can be seen in figure 3 below.

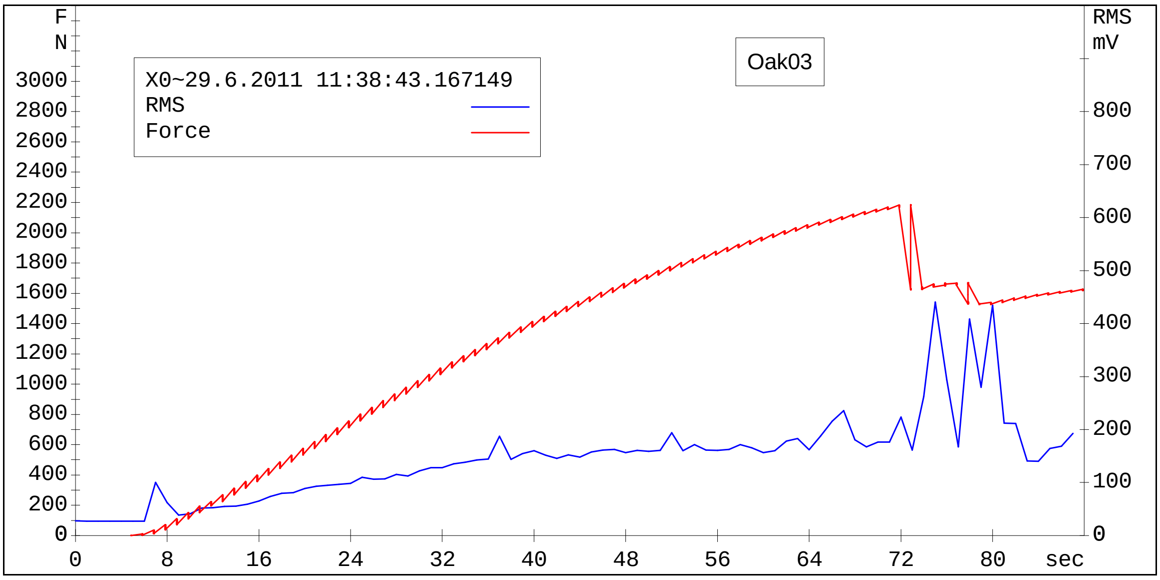

Figure 3: Typical plot of loading force vs. AE RMS for Oak specimens

Spruce specimens represented the most diversified set of under-the-load behavior. 3 specimens showed interesting trend of multiple minor failures and hardening prior to final master failure. The minor failures marked the ultimate strength of the specimen. However, there was a strong residual rigidity in comparison with other wood type groups (see Figure 4 below). As far as the fracture type of Spruce group is concerned, it was rather difficult to find a pattern there as well. Most of the specimens failed in a combination of plain tension and massive cross-grain destruction.

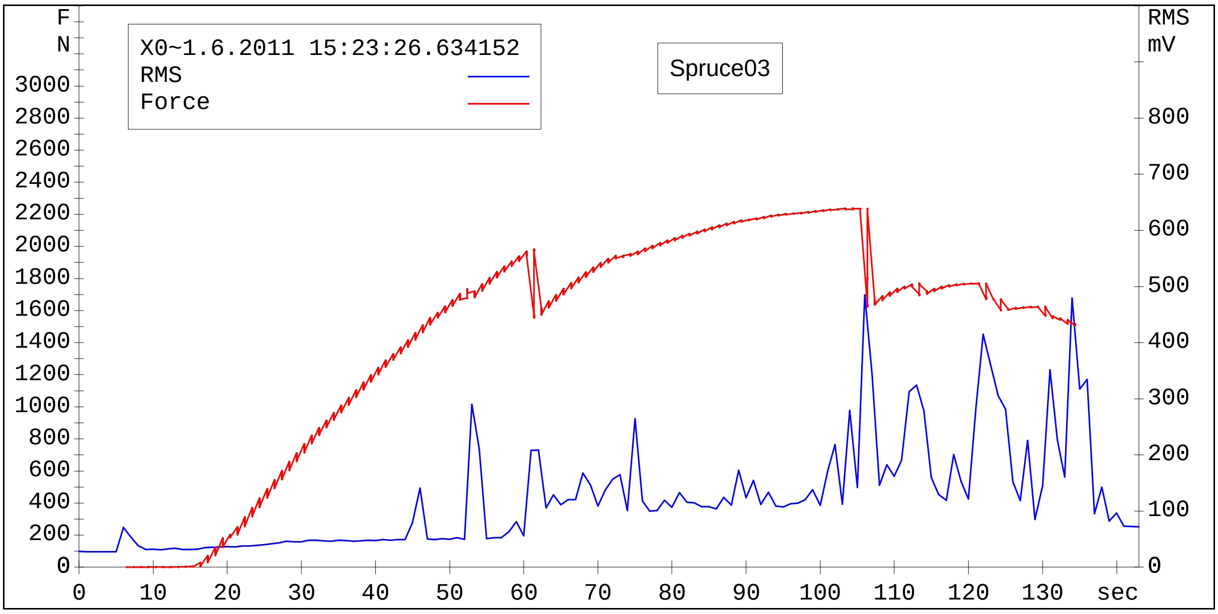

Figure 4: Typical plot of loading force vs. AE RMS for Spruce specimen group.

CONCLUSIONS

In this project, acoustic emission method has been used to describe under-stress behavior of 5 wood type specimens during a static bending test. Essential methodology guidelines were elaborated with respect to complicated material properties and structure of wood. However, not all issues were successfully resolved.

Unfortunately, there is no way of performing a perfectly "standard" or "repeatable" bending test; some compromises are needed to establish general rules for the procedure. On the other hand, this experiment simulates "real-life" conditions and materials that can be found in the wood processing industry.

ACKNOWLEDGMENTS

Authors would like to thank the Dakel ZD Rpety for acoustic emission equipment support.

This study was supported by the Internal Grant Agency of Faculty of Agronomy, Mendel Univerzity in Brno, IP No. 10/2010.

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