# DEFECTS IN WOOD FROM ASPECT OF PHYSICAL ACOUSTICS

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**ABSTRACT**
Reaction wood is an important defect of wood structure. In conifers the abnormal wood on the underside of leaning trunks is generally called compression wood.
The most characteristic properties of fully developed compression wood are of physical nature: high density, low elasticity, tensile stress and rigidity, dark colour. Experiments were done on the typical compression spruce wood, common spruce and on the resonant spruce wood.
From the evaluation of experimental results follows that despite the high density of annual rings, the compression spruce wood is unsuitable material for making the resonant body of string musical instruments.

**INTRODUCTION**
The resonant wood has a particular position in framework of technological materials. The task of resonant wood is to amplify and give appropriate timbre to a signal generated by a string of musical instrument. Thus the resonant spruce wood is a material used for making of the top plate of string instruments, top plate of acoustical guitars, resonant board of pianos etc. From macroscopic point of view the resonant spruce wood is characterised by relatively high density of annual rings (optimum 7 rings/cm in radial direction). The uniformity or evenness of annual rings, parallelism of annual rings in radial cut, low quotient of summer wood and overall impression of "light wood", almost "white wood" belong to the next macroscopic mark of the resonant spruce wood. The areas of the resonant wood are in the latitude of the middle Europe in the height above sea level of around 1000 m; in south the direction (e.g. in Italy) such wood grows in higher latitudes. It grows at the northern slopes with a relatively short vegetal period. For this reason, the resonant wood is typical by high density of annual rings.
The slopes where the resonant wood can be found are often submitted to steep wind. The trees, especially some individuals in exposed positions must resist the wind. In case that the tree is during a longer time exhibited to such impact, the layer of late wood in framework of annual ring is heavy and so it rises the zone of compression wood. At the same time the density of annual rings does not change significantly. The compressed wood is as a resonant material unsuitable. The producers of musical instruments do not accept it for the given purpose. The question, if the compressed wood is typical by distinctive characteristics of physical acoustics is topical. In our study was experimentally examined the characteristics of physical acoustics of the compressed wood, the wood from zone near the compressed wood and the resonant wood.

The aim of our experiments was to study if there is any difference in the characteristics of physical acoustics of the resonant and the compressed wood.

## 2. EXPERIMENTS

The following characteristics of physical acoustics: density ρ, modulus of elasticity E, acoustical constant A were examined experimentally. The results are introduced at the moisture content of wood 12 %. This moisture content is considered as referential.

### 2.1. Material

The test specimens were obtained from spruce trees, slashed in the middle Slovakia during the winter season of 1999/2000. The hight over sea of the coppice is 900 – 1000 m. The trees were sawed by two perpendicular cuts parallel with longitudinal axis short after slash. The radial boards were prepared from these quarters. These experimental radial boards were the same as the elements for the resonant board of piano. The boards containing the compressed zone were used for measurements. The characteristics of physical acoustics of these boards were calculated and compared with characteristics of resonant wood (obtained in earlier experiments).

### 2.2. Method

The test specimens obtained from radial cuts had a shape of boards, of thickness of 0.015 m, of various width, length of 0.6 m (axial direction) in the first experiment. The specimens were exposed to driven bending oscillations on the VIBROVIZER apparatus. The source of signal are the oscillations of loudspeaker membrane. The examined test board, appropriately supported under their influence gets some from basic vibration modes (2,0), or (0,2) – see fig. 1 and fig. 2. The resonant frequencies of modes were used for calculation of E-modulus and respectively for calculation of acoustical constant A.

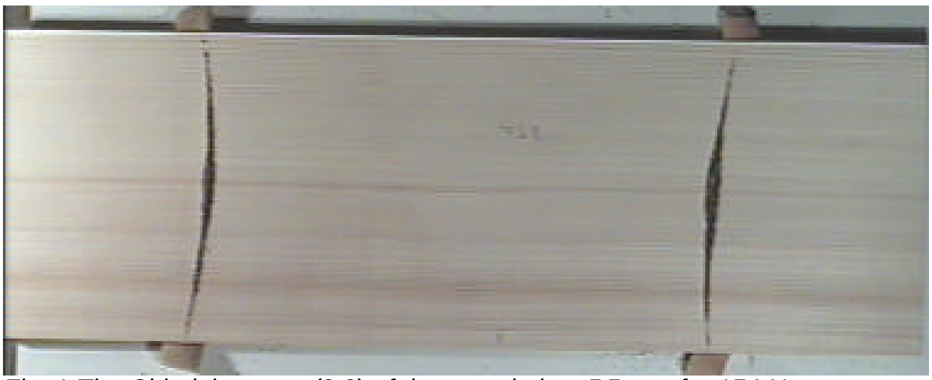

*Fig. 1 The Chladni pattern (2,0) of the tested plate R5a on f = 154 Hz*

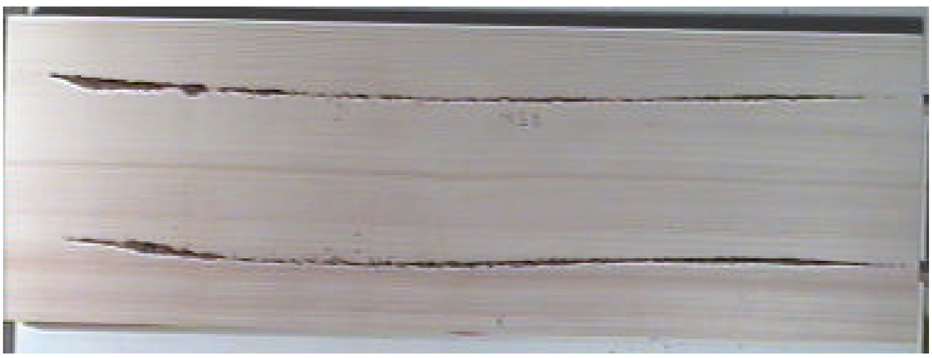

*Fig. 2 The Chladni pattern (0,2) of the tested plate R5a on f = 348 Hz*

The boards were cut into strips with cross dimensions 0.015 x 0,015 m after finishing the measurements on the VIBROVIZER. The characteristics of physical acoustics of these test specimens were measured on the system AKUSTOMAT. The test specimen is fastened in the middle in the AKUSTOMAT.
Consider the case of standing waves in a test bar of the density ñ, fastened in the middle. Coming out from wave equation

$$\frac{\partial^2 s}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 s}{\partial t^2} \qquad (1)$$

Hooke's law and Newton's Second law of motion, the cross section displacement s is determined by equation

$$\frac{\partial^2 s}{\partial x^2} = \frac{\rho}{E}\frac{\partial^2 s}{\partial t^2} \qquad (2)$$

where ñ is the density of the material and E its Young's modulus, for an elastic bar with length $\ell$ for the modulus E, at the basic resonant frequency $f_r$ of standing waves it follows

$$E = 4l^2 f_r^2 \rho \qquad (3)$$

Thus the wood density ñ, the acoustic constant A given by [Andrejev, 1938]

$$A = \frac{c}{\rho} = \sqrt{\frac{E}{\rho^3}} \qquad (4)$$

and the modulus E (relation 3) are considered as the relevant characteristics of physical acoustics when evaluating wood as a material for musical instruments. This fact follows from experiments (e.g. [Rajèan, 1998]).

The gist of the AKUSTOMAT is a PC with an MRF board (measurement of relevant frequencies) and with other subsystems. The MRF board generates a succession of signals at acoustic frequencies. The amplified signal goes to an exciter (e.g. loudspeaker) and creates oscillations in test specimen. On the other side of the test specimen, a piece of iron foil of negligible mass is glued. If from one side of such a test specimen is acted the sinusoidal signal in interval of appropriate frequencies, it rises in it, at certain – resonant frequencies, the longitudinal standing wave which manifests by maximum potential at the detector. The first, or basic resonant frequency was used for the calculation of E-modulus and the A-constant [Rajèan, 1998].
The selected results from our measurements are introduced in table form, as well as in 2D and 3D graphs.

2.3. Results

The main values of density, of E-modulus in longitudinal direction and inherent acoustical constant for the boards using VIBROVIZER and AKUSTOMAT are introduced in table 1. The values in the columns "VIBROVIZER" were obtained on the base of one measurement and following calculations. The values in the columns "AKUSTOMAT" were calculated as mean values from 5 – 15 measurements on strips. (The number of strips depended on the width of inherent board).
The tendency in the examined characteristics of physical acoustics as a function of position in the board is possible to appreciate on the base of the table 2, or fig. 3 respectively. The test specimen, the nearest to outer edge of the board is in the fig. 3 denoted by number 1. The numbers gradually increase in the central direction (of the board), in given case in direction of the compressed wood zone. It is obvious that the approaching to the compressed wood zone brings up the increase of density and decrease of elasticity represented by E-modulus and A-constant.

*Table 1 Mean values of physical and acoustical characteristics for individual plates obtained by use of the VIBROVIZER and AKUSTOMAT respectively*

| test specimen | VIBROVIZER | | | AKUSTOMAT | | |
|---|---|---|---|---|---|---|
| | ñ [kg.m$^{-3}$] | $E_x$ [GPa] | A [m$^4$.kg$^{-1}$.s$^{-1}$] | ñ [kg.m$^{-3}$] | $E_x$ [GPa] | A [m$^4$.kg$^{-1}$.s$^{-1}$] |
| R1 | 469,916 | 10,902 | 10,250 | 472,140 | 11,9019 | 10,6330 |
| R2 | 468,664 | 14,658 | 11,933 | 485,907 | 16,3325 | 11,9416 |
| R3 | 467,035 | 12,651 | 11,144 | 483,440 | 14,3340 | 11,3241 |
| R4a | 497,090 | 15,220 | 11,131 | 500,198 | 16,1851 | 11,3594 |
| R4b | 494,821 | 14,437 | 10,916 | 496,069 | 15,4778 | 11,1915 |
| R4c | 452,587 | 14,186 | 12,370 | 462,767 | 14,5215 | 12,0357 |
| R5a | 477,987 | 12,297 | 10,612 | 485,774 | 13,2994 | 10,7576 |
| R5b | 468,740 | 11,021 | 10,345 | 479,507 | 12,8126 | 10,7865 |
| R8a | 468,434 | 15,860 | 12,422 | 476,533 | 16,4690 | 12,3595 |
| R8b | 471,850 | 15,623 | 12,195 | 482,220 | 16,8710 | 12,2729 |
| R9 | 495,283 | 15,164 | 11,172 | 501,124 | 16,2002 | 11,3148 |
| R11a | 498,242 | 14,521 | 10,835 | 504,149 | 16,2590 | 11,2803 |
| R11b | 493,350 | 15,430 | 11,336 | 502,706 | 16,8829 | 11,5119 |
| R12a | 463,682 | 9,497 | 9,760 | 478,381 | 10,4864 | 10,0312 |
| R12b | 445,019 | 10,049 | 10,678 | 461,047 | 11,2594 | 10,8496 |
| R13a | 452,484 | 10,639 | 10,716 | 470,038 | 12,0735 | 10,9181 |
| R13b | 457,500 | 10,052 | 10,246 | 469,484 | 11,2925 | 10,5640 |

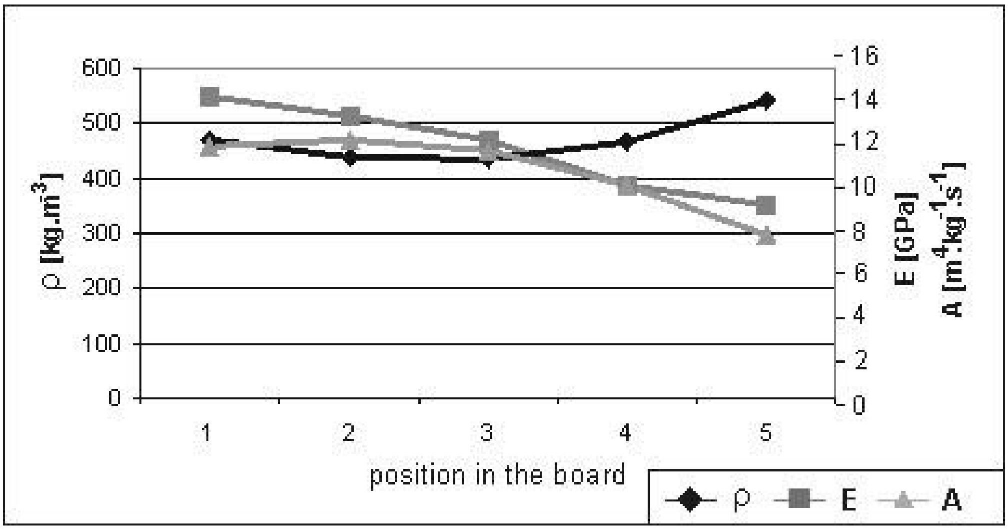


*Fig. 3 Density, E–modulus and acoustical constant along the plate R13a*

*Table 2 ñ, E, A as a function of position in the plate R13a*

| test specimen | number of test specimen | ñ [kg.m$^{-3}$] | $E_x$ [GPa] | A [m$^4$.kg$^{-1}$.s$^{-1}$] |
|---|---|---|---|---|
| R13a | 1 | 464,762 | 14,7650 | 12,1275 |
| | 2 | 442,797 | 13,7753 | 12,5963 |
| | 3 | 439,063 | 12,4359 | 12,1213 |
| | 4 | 463,660 | 10,0514 | 10,0418 |
| | 5 | 539,907 | 9,3398 | 7,7035 |

The convenient, quick and comfortable comparison of characteristics of the physical acoustics of the resonant and the compressed wood enables the plotting in 3D, as shown the fig. 4. This concept of plotting is a part of both our measuring systems.

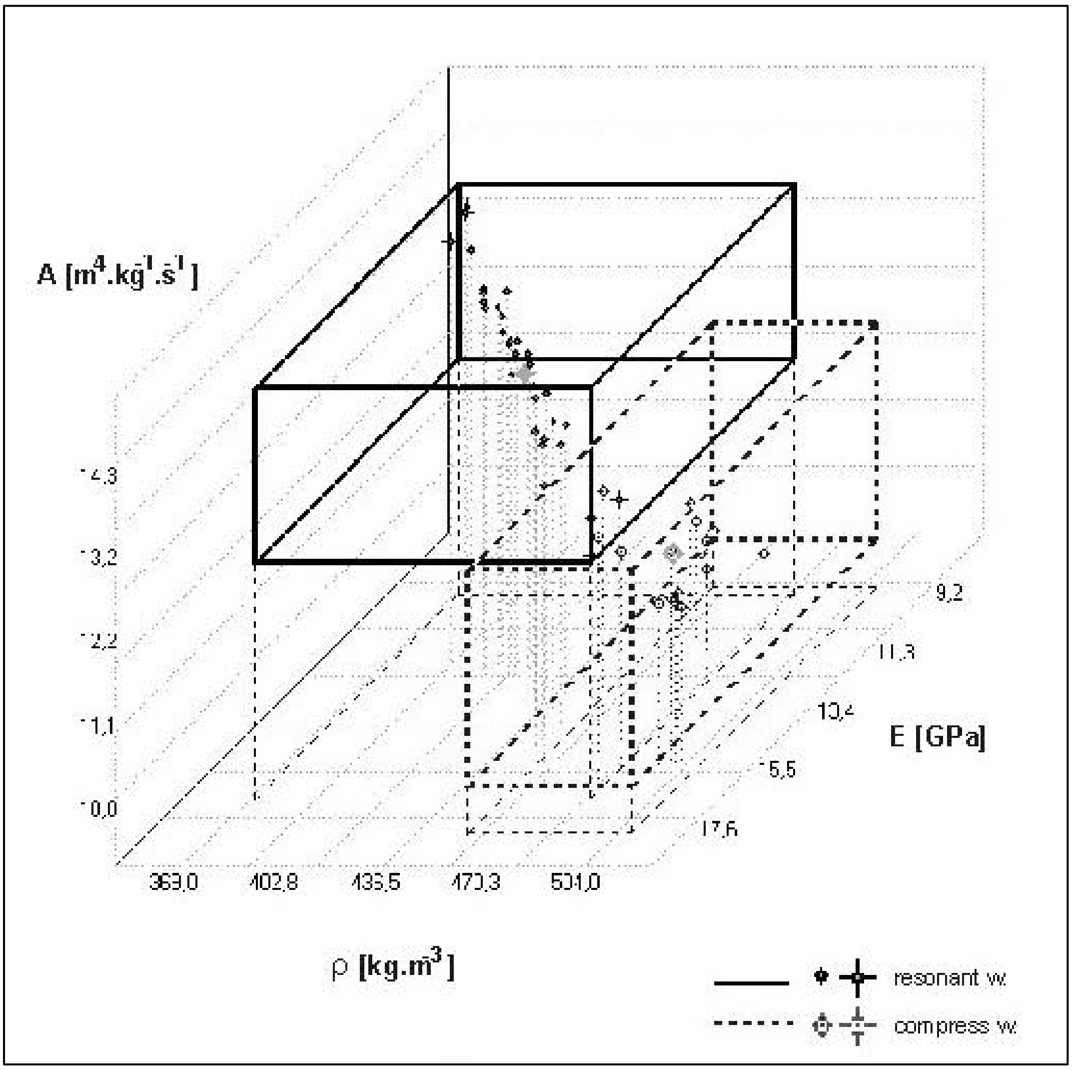


*Fig. 4.Density ñ, E–modulus and A–constant of high–quality resonant spruce wood (mjstr) and set of compression spruce wood (reak12) at the reference moisture contend 12 %*

The set of resonant spruce wood depicted in fig. 4 was obtained from high quality material determined by experts (Lupaè, Holiš, 1994) on the base of empirical knowledge for making a master violin.

**3. DISCUSSION - CONCLUSION**

We consider the use of 3D graphs going from measurements and calculations as the optimal means of evaluation of wood as a material for music instrument making. It has been shown that this means permits the evaluation of wood as a material for subsystems of various instruments [e.g. Urgela, 1998, Èulík, 2001], for indication of the influence of impregnation and other substances used for surface treatment or the gluing of wood [Danihelová, 1998]. It is also accepted by some violin making masters [e.g. Pilaø, 2001].

It is evident from the experimental results that the resonant spruce wood is – under given conditions mentioned in the introduction, especially the high density of annual rings – typical by low density and by high acoustical constant. [Rajèan, 1998]. For the compressed wood is evident the opposite tendency, although the main condition – high density of annual rings – is satisfied. The compressed wood has also statistically significant difference of characteristics of physical acoustics and there exists also the physical justification for its rejection as a resonant material for string musical instruments.

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