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# ROT EVALUATION IN SPRUCE LOGS AND ROT REFLECTION INTO DIMENSIONS OF CHIPS FOR PARTICLEBOARDS

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## ABSTRACT

Chips for particleboards (PBs) can be obtained from different tree species or other lignin-saccharide sources. In this work, the following factors are analysed: (1) the degree and type of fungal rot in the Norway spruce (*Picea abies*) logs using the drill-resistance device "Resistograph" and the acoustic devices "Sylvatest-Duo", "Fakopp" and "Arbotom", and (2) following the reflection of wood-rot into dimensions of chips prepared for PBs. Using the devices, milder damage of logs caused by the white-rot Dark honey fungus (*Armillaria ostoyae*) was not detectable, but on the contrary, more serious damage of logs with the brown-rot Red banded polypore fungus (*Fomitopsis pinicola*) was clearly detectable. Wood chips prepared from the rotten logs had smaller dimensions compared to chips from the sound logs. By the sieve analysis, using the mesh diameters from 80 mm to 0.125 mm, the total percentage fractions marked as 7, 4, 2, 1, 0.5, 0.25, 0.125 and 0 were 31.1% for chips from the sound logs, 41.89% for chips from logs attacked by white rot, and 71.13% for chips from log attacked by brown rot.

**Key words**: spruce logs, rot, Resistograph, acoustic devices, chips, dimensions

## INTRODUCTION

Particleboards (PB) are produced from: (1) different wood sources – lower quality logs and trunks of conifers and broadleaves; – recycled furniture, trusses and other aged wood materials; – waste created at the production of new wood materials, e.g., carpentry products, PBs, plywood or glulam, (2) agricultural lignin-saccharide bio-polymers, derived from straw, stalk, bagasse, seed/fruit, leaf, grass, and palms; (3) textiles and papers produced from natural and synthetic fibers (ODOZI *et al.* 1986, ALWANI *et al.* 2014, IŽDINSKÝ *et al.* 2020, LEE *et al.* 2022).

The lower quality of logs is often given by their biological damage caused by wood-decaying fungi and wood-damaging insects. Chips prepared from bio-damaged wood sources may not have always acquire suitable yields, dimensions or other characteristics for the production technology of PBs and their properties required by valid standards, e.g., strength, elasticity, thickness swelling, fungal resistance, may not be achieved.

The rotten or otherwise bio-damaged wood logs most often come from accidental harvests (GÁPER 2003). For example, in 2020, the volume of accidental harvesting of tree wood material caused by the action of phytopathogenic organisms was 154 544 $m^3$. Of the reported volume, trees attacked by the white-rot Dark honey fungus (*Armillaria ostoyae*

/Romang./ Herink) accounted for 81 854 $m^3$ and by the brown-rot Red banded polypore fungus (*Fomitopsis pinicola* /Sw./ P. Karst.) for 754 $m^3$ (LEONTOVYČ *et al.* 2021).

*Armillaria ostoyae* is one of the significant parasites of spruce and other coniferous plants. It infects them at all stages of growth, i.e., from seedlings to adult trees. The infection is caused by the mycelium, which penetrates the wood mainly with the vascular rays. The external symptom of spruce damage is resin discharge or bottle shaping of the basal part of the stem. The fungus causes intense and rapid spreading of white wood rot. The genus *Armillaria* representatives of medium to large fruiting bodies, usually grown in clumps. The fruiting body is made up of a pileus and a stalk (GÁPER and PIŠÚT 2003). Due to the drought, an increase in fungal pathogens is also foreseen for the future. The current drought has been identified as the main factor in the death of spruce in the lowlands of the Czech Republic. The trees thus weakened were subsequently attacked by the Dark honey fungus. For example, Holuša *et al.* (2018) indicate that up to 50% of the trees studied have long-term drought with inducing activity of this fungus.

*Fomitopsis pinicola* is a common species of the genus *Fomitopsis*. It is mainly a saprophytic fungus infecting living and healthy trees. It causes red rot prism like decay with white mycelium in the cracks (ČERNÝ 1986). The fruiting body is hoof-shaped or triangular, and sometimes shelflike with orange-yellow margin. *F. pinicola* conks may grow for many years, each season adding a new layer of tubes. It is an important destroyer of conifer wood species, including the Norway spruce.

The type, degree and range of rot in the standing trees, harvested logs and wooden products can be determined visually as with the help of several instrumental methods (WANG *et al.* 2007, RINN 2009, REINPRECHT and HRIVNÁK 2012, REINPRECHT and PÁNEK 2012, ROHANOVÁ and NUNEZ 2012, HRIVNÁK *et al.* 2013, REINPRECHT 2016, GERGEĽ *et al.* 2022, HOVDE *et al.* 2022).

The chips and particles prepared from chips must have suitable dimensions – for example, exactly determined dimensions for the core layer and the surface layers at the production of the tree-layer PBs.

It is ideal if the chips for the PBs production have the following dimensions: length 20-50 mm; width 20-40 mm and thickness 3-5 mm. For the following prepared fine surface particles is recommended a thickness of around 0.2 mm, at which this dimension is determined directly by the condition and preparation process of particles. The width of particles for the surface layer of PBs should not exceed 2 mm and the length should not exceed 5 mm. The thickness of large particles for the core layer of PBs is generally recommended between 0.4 to 0.7 mm. The length and width of particles in the core layer are allowed to be relatively variable, but with the largest slenderness ratio, i.e., the ratio of the length to the thickness of the particle (DEPPE and ERNST 2000, IRLE and BARBU 2010).

The dimension of particle with the thickness under 0.125 mm or 0.08 mm, which was created either by processing (MARKOVÁ *et al*. 2016, OČKAJOVÁ *et al.* 2020, DEMBIŃSKI *et al*. 2022) or it was sorted, is regarded as dust not suitable to produce PB, due to a negative reduction in its properties, especially bending strength. In practice, there are these small particles – dust used for energy purposes, e.g., in the production of heat (KMINIAK *et al.* 2020).

The aim of this work was to analyse the influence of the white and brown rots in harvested Norway spruce logs on the dimensions of chips prepared for production of particleboards.

## MATERIALS AND METHODS

### Logs

From five Norway spruce (*Picea abies* Karst. L.) standing trees growing in the Central Slovakia, Forest region Budča, part No. 589 – two sound, two attacked by the white-rot fungus "Dark honey fungus" (*Armillaria ostoyae* /Romang./ Herink), and one attacked by the brown-rot fungus "Red banded polypore" (*Fomitopsis pinicola* /Sw./ P. Karst.) – were prepared 4 m long logs with diameters at the ends from 0.3 m to 0.45 m (Figures 1).

**(a) (b)**

**Fig. 1. The Norway spruce standing trees - attacked by the white-rot fungus *Armillaria ostoyae* with a typical pear-shaped trunk in the territorial part (a); - attacked by the brown-rot fungus *Fomitopsis pinicola* with presence of fruiting bodies and visually detectable rot (b).**

### Rot evaluation in logs

Presence and degree of rot in the Norway spruce logs was evaluated by four instrumental methods (Figure. 2):

- drill-resistance measurement – performed in the radial direction of log; the device Resistograph IML-RESI F400 (Instrumenta Mechanik Labor GmbH, Wiesloch, Germany), equipped with 400 mm-long and 3 mm-thick steel drill, was used; log quality is presented in a form of graphical report, where on the y-axis the none or minimal resistance-peak indicates a significant damage of wood, e.g., due to rot or crack, while the locally-lower resistance-peak in the defined annual circle belongs to the sap-wood and the locally-higher one belongs to the late-wood; a total of 25 boreholes were drilled into five logs (Figures 2a, 2b),
- 1-D ultrasonic measurement – performed in the longitudinal direction of log with a length of ($L_L$) in /m/, with an accuracy of 0.01 m; the device Sylvatest-Duo (CBS-CBT, Paris, France), equipped with 22 kHz conical transducers, which measures the transmission time of an ultrasonic wave ($T_{UW}$) (μs) through two conical transducers, one emitter and the other receiver located on the opposite sides of log, was used; a total of 20 $T_{UW}$ values were determined for five logs (Figures 2a, 2c); following the transmission velocity ($v_L$) in /m.s$^{-1}$/ was calculated, using the equation (1):

$$v_L = L_L/T_{UW} \qquad (1)$$

- 1-D ultrasonic measurement – performed in the radial direction of log with a length in the defined diameter of ($L_D$) in /m/, with an accuracy of 0.01 m; the device FAKOPP Microsecond Timer (Fakopp Enterpriste Bt., Ágfalva, Hungary), equipped with two 45 kHz ultrasonic transducers US 2, which measures the transmission time of an ultrasonic wave ($T_{UW}$) in /μs/ between the transducers, was used; a total of 50 $T_{UW}$ values were determined for five logs (Figures 2a, 2d); following the transmission velocity ($v_R$) in /m.s$^{-1}$/ was calculated using the equation (2):

$$v_R = L_D/T_{UW} \tag{2}$$

- 2-D ultrasonic measurement – performed in the transversal area of log; the device Impulse Tomograph ARBOTOM Professional Pack 2D (Rinntech, Heidelberg, Germany), with a color graphical report of the sound zones and the less or more damaged zones in the log (RINN 2009), was used; a total of 15 measurements were performed for five logs (Figures 2a, 2e).

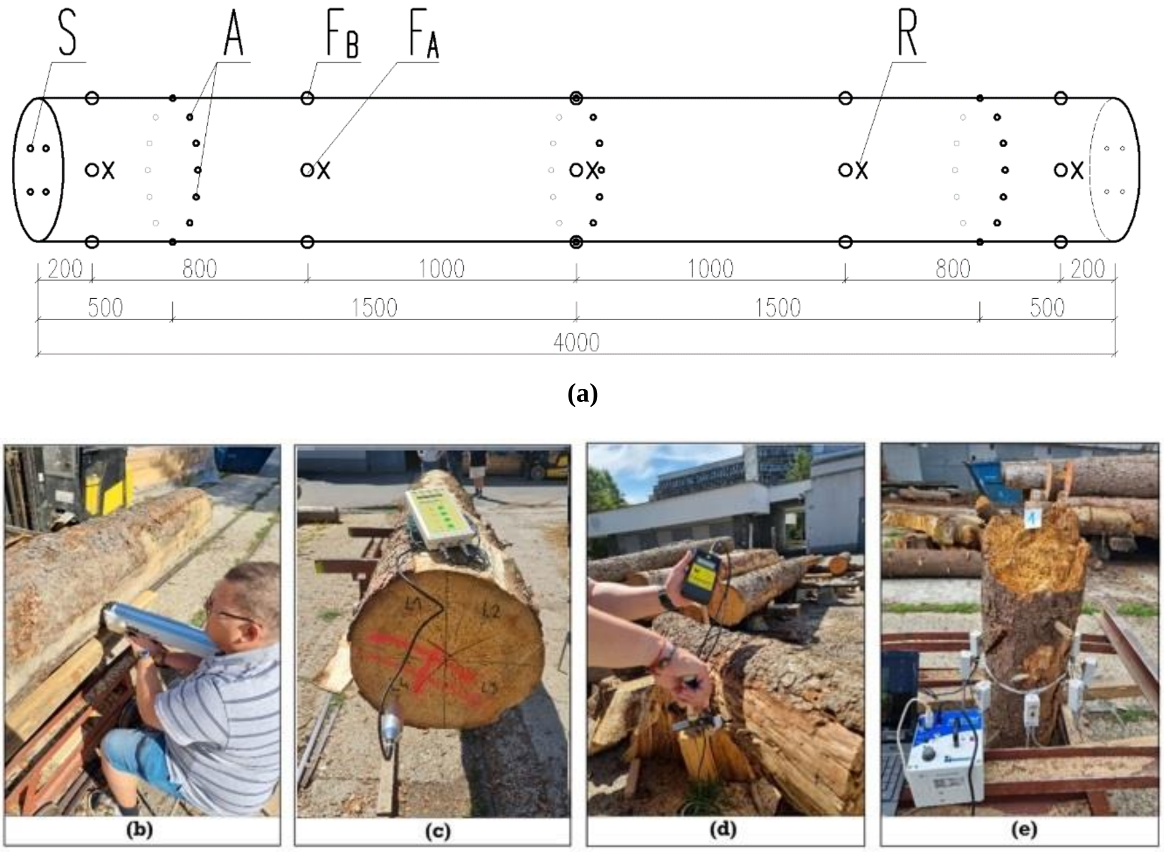


**Fig. 2. Evaluation of rot in the Norway spruce logs in the defined places (a) – by the Resistograph /R/ (b), and by three acoustic devices, i.e., Sylvatest-Duo /S/ (c), Fakopp /$F_B$ and $F_A$/ (d), and Arbotom /A/ (e).**

## Chips preparation and sieve analysis

The chips were prepared from the Norway spruce logs of three groups – sound, damaged by white rot, and damaged by brown rot. Firstly, from the logs were sawn boards with the thicknesses from 25 mm to 50 mm. The boards were then chipped on chips in the

230H drum mower (Klöckner KG, Hirtscheid—Erbach, Westerwald, Germany). For the wooden chips – which in a practice are further milled to particles used for PBs preparation – their basic macrostructural characteristics, i.e., dimensions, were determined by the sieve analysis.

A representative sample with a weight of 750-1200 g was selected from chips of a given log-group. The sample of chips was divided into 5-8 homogeneous chip sets with a weight of 150 g and undergo to the sieve analysis. During sieving, individual fractions of chips were captured on sieves arranged one above the other from the largest mesh diameter to the smallest mesh diameter. The set of sieves is finished with a solid bottom, into which the finest dust fraction of chips falls. Individual chip fractions captured on sieves with the mesh diameters from 80 mm to 0.125 mm – chip fractions marked as 80, 50, 40, 25, 20, 15, 12, 11, 7, 4, 2, 1, 0.5, 0.25, 0.125 and 0 (a solid bottom) – were weighed with an accuracy of 0.01 g, with following calculation of their percentage amounts.

The sifting procedure was following: (1) the weighed chips were poured onto the top sieve; (2) the set of sieves was closed with a lid; (3) the actual sieving process in the sieving device lasted 10 minutes. The set of sieves was divided into two parts, i.e., first, the chips with a weight of 150 g were sieved through a set of sieves with the mesh diameters of 80, 50, 40, 25, 20.15, 12, 11 mm and bottom, and subsequently, the fraction of chips caught at the bottom was sieved in the second step through a system of sieves 7, 4, 2, 1, 0.5, 0.25, 0.125 mm and bottom.

## RESULTS AND DISCUSSION

### Rot presence in logs

*Drill-resistance analysis*

The drill-resistance semi-destructive analysis of the Norway spruce logs with the IML RESI 400 Resistograph evidently documented the visually ascertained damage of wood caused by the brown-rot fungus *F. pinicola* (Figure 1b), when the rotten log No 1 gave in all five measurements 1/0 - 1/4 almost no resistance to the drill needle penetration – which indirectly showed the presence of extensive and intense rot (Figure 3).

On the contrary, the visually traceable attacks of logs by the white-rot fungus *A. ostoyae* (Figure 1a) were not more clearly detectable by the Resistograph, because drill-resistances of these logs to the drill needle penetration were comparable with drill-resistances of the sound logs (Figure 3 – see results for logs No 1). Larger densities at the individual curves and the end of the measurement are result of the increased growth of the wood around the circumference of the trunk. The analysis of logs attacked by white rot caused by the parasitic wood-decaying fungus *A. ostoyae* detects the presence of the developing so-called mixed - combined rot (ORŁOŚ 1955). More pronounced physical changes in the output curves are noticeable at measurements 1/0 and 1/1 (Figure 3), which represent the lower (basal) parts of the trunk - log. This can also be explained by the fact that spruce root rot is mainly caused by a root parasitic fungus and the infection in the tree gradually progresses from the roots upwards to the trunk. Even the external symptoms of the disease, i.e., the significant bottle-like thickening of the basal part of the trunk – log points to the reported process of rotting.

Generally, the drill-resistance of wood substance in logs with a milder white rot damage was comparable with the sound wood substance, while the wood substance having a higher damage by brown rot was evidently more accessible for the penetration of the drill. Similar results achieved REINPRECHT and HRIVNÁK (2012) for logs of five tree species.

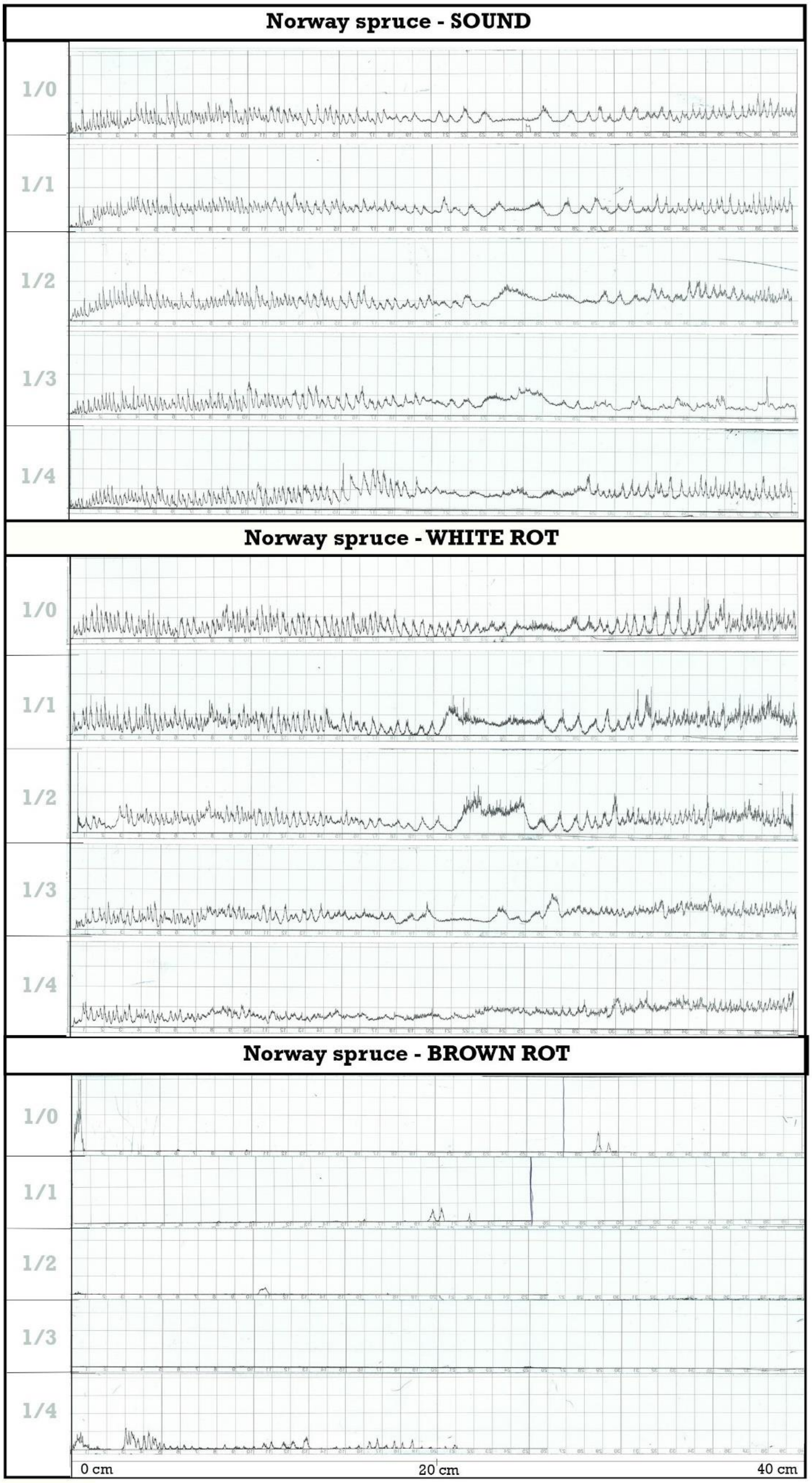


**Fig. 3. Wood quality "rot presence" of the Norway spruce logs evaluated by the Resistograph.**

*Acoustic analyses*

The speed of ultrasonic waves in the longitudinal direction ($v_L$) and in the radial direction ($v_R$) were very similar in the sections of sound logs and logs attacked by white rot. It was confirmed by several different acoustic measurements – using Sylvatest-Duo, Fakopp, and Arbotom. In the longitudinal direction measurements performed with the Sylvatest-Duo, the average velocity of ultrasonic waves ($v_L$) in the sound logs was 6271 $m.s^{-1}$ and in the logs attacked by white rot even higher 6383 $m.s^{-1}$. In a log attacked by brown rot the average value of ultrasonic waves ($v_L$) was smaller only 5588 $m.s^{-1}$. Similar values of $v_L$ for the Norway spruce logs having different stages of rot, in average namely 5076 $m.s^{-1}$, determined REINPRECHT and HRIVNÁK (2012) using the acoustic device Pundit Plus.

While the measured data in the longitudinal direction of individual logs did not show larger differences, the speeds of ultrasonic waves measured in the radial direction ($v_R$) differed more from each other. The individual values of ultrasonic waves ($v_R$) determined by Fakopp Microsecond Timber showed in some cases the II. medium degree of damage characterized by values approaching to 920 $m.s^{-1}$. However, the average values for two sound logs (1187 $m.s^{-1}$) and two logs attacked by white rot (1249 $m.s^{-1}$) were very similar, without a significance difference. The greatest IV. degree of spruce wood damage, which is characterized by $v_R \leq$ 750 $m.s^{-1}$, was determined in a log attacked by brown rot, with an average value of 622 $m.s^{-1}$.

**Tab. 1. Wood quality of the Norway spruce logs evaluated by the acoustic devices Sylvatest and Fakopp.**

| NORWAY SPRUCE LOG | SYLVATEST Longitudinal direction $v_L$ ($m.s^{-1}$) | | | | FAKOPP Radial direction – A and B $v_R$ ($m.s^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Place in log** | **S1** | **S2** | **S3** | **S4** | | **F1 0.2 m** | **F2 1 m** | **F3 2 m** | **F4 3 m** | **F5 3.8 m** |
| Sound log No 1 | 6284 | 6145 | 6545 | 6601 | A | 1192 | 1263 | 1308 | 1228 | 1250 |
| | | | | | B | 1072 | 1230 | 1147 | 1021 | 1024 |
| Sound log No 2 | 6128 | 5982 | 6261 | 6224 | A | 1125 | 1235 | 1183 | 1145 | 1111 |
| | | | | | B | 1250 | 1272 | 1242 | 1213 | 1226 |
| White rot log No 1 | 6742 | 6567 | 6540 | 6540 | A | 1085 | 1269 | 1137 | 1264 | 1366 |
| | | | | | B | 1123 | 1133 | 1220 | 1263 | 1263 |
| White rot log No 2 | 6164 | 6224 | 6224 | 6063 | A | 1299 | 1339 | 1341 | 1279 | 1409 |
| | | | | | B | 1240 | 1330 | 1328 | 1100 | 1235 |
| Brown rot log No 1 | 5532 | 5423 | 5641 | 5754 | A | 641 | 927 | 611 | 510 | 1032 |
| | | | | | B | 375 | 633 | 483 | 413 | 590 |

Notes: 1) Places of the ultrasound measurements in the logs are schematically shown in Figure 1. 2) The average moisture contents (w) of spruce logs during ultrasound measurements were as follows: 18% for sound logs; 21.8% for logs with white rot; 29.3% for log with brown rot.

Results obtained by the Impulse Tomograph ARBOTOM Professional Pack 2D device, evaluatimg damages in the 2-D area of logs (Figure 2e), were in good agreement with results obtained in the radial direction of logs achieved by the Resistograph (Figures 2b and 3) and the Fakopp (Figure 2d, Table 1, Figure 4). For example, from 15 measurements with the Tomograph, there in this work are visually presented the sound (green) and rotten (orange) zones in a one section of log attacked by white rot and in a one section of log attacked by brown rot (Figure 5). In the case of log-section damaged with white rot, the rot gradually developed in its central part, as it was confirmed by yellow-orange stains (Figure 5a). In the case of the samples attacked with the brown-rot fungus *F. pinicola*, an extensive rot on the entire cross-section of a log was confirmed (Figure 5b).

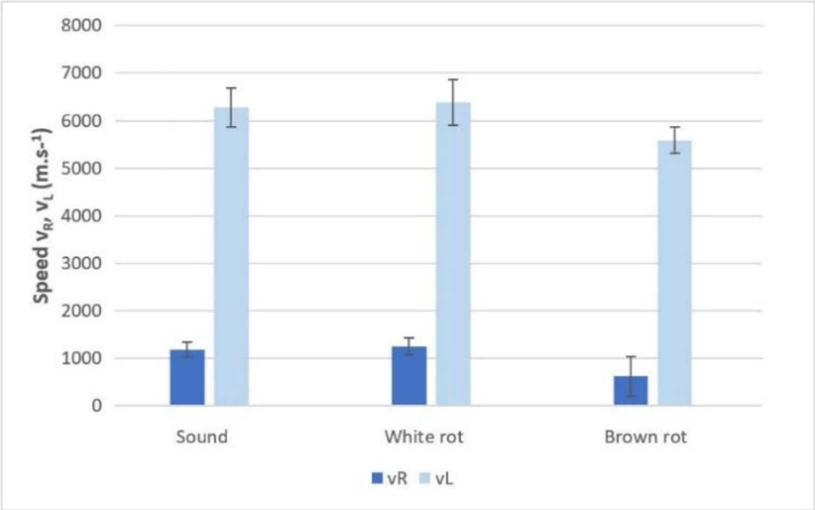


**Fig. 4. Average speeds of ultrasonic waves in the longitudinal direction ($v_L$) and the radial direction ($v_R$) through the Norway spruce logs (see tab. 1).**

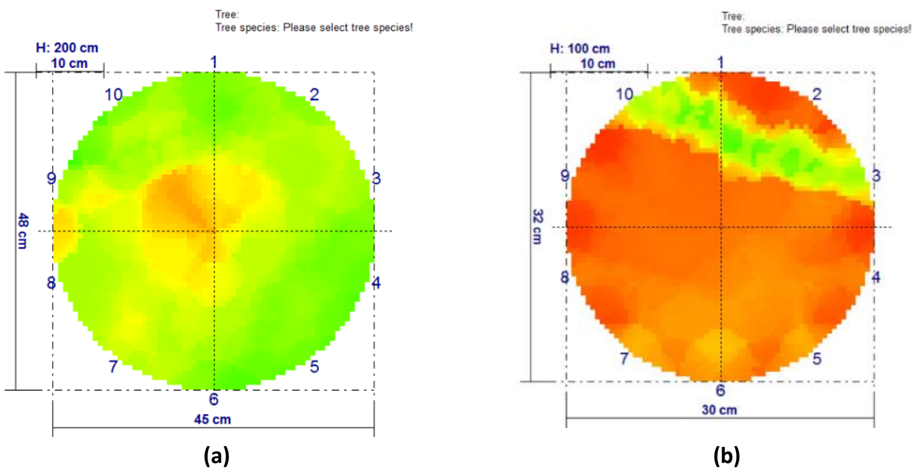


**Fig. 5. The Norway spruce logs evaluated by the Arbotom – log-section with white rot (a), log-section with brown rot (b).**

## Effect of rot on the production of wood chips

The dimensional characteristics of wood chips prepared by the same standard technology depend on the wood species, moisture content of wood, and rot or other damages in the wood structure. The type and degree of rot largely affects the size of wood chips. It is a consequence of the easer breakdown of the wood morphological elements, e.g., fibres, in which are depolymerized polysaccharides and overall is disturbed the lignin-saccharide matrix.

The sieve analysis showed that from logs attacked by white rot and mainly by brown rot were prepared chips with smaller dimensions (Table 2). Any chips affected by rot were caught on sieves with sizes 80 and 50. For chips from the sound-healthy logs, on the sieve of 80-size was 0.32% chips of their total amount, and on the sieve of 50-size was 0.57% chips. Chips from sound logs were in the largest amount chaptered on the sieves with sizes from 20 to 4, at which their largest percentage was on the 12-size which represented 21.93% of their total amount.

The largest amount of chips from logs attacked by white rot was caught on sieves with sizes from 20 to 4 (84.10%), i.e., similarly to chips from sound logs (87.91%). The largest percentage amount of chips from white rot logs and sound logs was caught on the 12-size (19.93% vs. 21.93%). On the other hand, the largest percentage of chips attacked by brown rot was caught on the 4-size, which represented 23.92% of their total amount.

The dust content of wood chips from sound logs was 0.03%, 0.06% from white rot logs, and even to 0.99% from brown rot log.

**Tab. 2. Fractions of chips prepared from the Norway spruce logs.**

| MESH SIZE [mm] | CHIPS FRACTIONS [%] | | |
|---|---|---|---|
| | Sound log | White rot in log | Brown rot in log |
| **80** | 0.32 | 0 | 0 |
| **50** | 0.57 | 0 | 0 |
| **40** | 0.58 | 0.38 | 0 |
| **25** | 4.30 | 4.10 | 1.20 |
| **20** | 9.92 | 9.45 | 3.90 |
| **15** | 21.71 | 17.12 | 7.26 |
| **12** | **21.93** | **19.52** | 9.02 |
| **11** | 8.59 | 7.37 | 7.33 |
| **7** | 15.53 | 17.18 | 13.24 |
| **4** | 9.93 | 13.46 | **23.92** |
| **2** | 3.92 | 7 | 14.01 |
| **1** | 1.19 | 2.62 | 9.28 |
| **0.5** | 0.40 | 0.90 | 5.08 |
| **0.25** | 0.14 | 0.35 | 2.98 |
| **0.125** | 0.15 | 0.32 | 1.63 |
| **0 [Bottom]** | 0.03 | 0.06 | 0.99 |

(a) (b) (c)

**Figure 6. Fractions of the Norway spruce chips obtained at the sieve analysis – sound (a), white rot (b), brown rot (c).**

## CONCLUSION

- In the Norway spruce logs the drill-resistance and acoustic methods clearly identified the brown rot caused by the fungus *Fomitopsis pinicola*, however, the white rot caused by the fungus *Armillaria ostoyae* was only barely identifiable by them. These results came out from different type and degree of rotting in searched logs.

- The dimensions of wood chips, which have been prepared by the same technology from the individual spruce logs, depended on the type and degree of rot in logs – i.e., the fractions of chips having relatively smaller dimensions, intercepted between a mesh diameter of 7 mm and a bottom of 0 mm, were obtained in the lowest amount of 31.1% from sound logs, in a higher amount of 41.89% from logs attacked by white rot, and in the highest amount of 71.13% from log attacked by brown rot.
- The experiments showed that the process of wood chipping in the technology of PBs preparation should be appropriately adjusted – optimized with regard to the quality of the input wood material, specifically in our case with regard to the type and degree of wood rot in the logs in order to achieve high-quality PBs.

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