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POSSIBILITIES FOR IMPROVEMENT OF MOISTURE AND STRENGTH PROPERTIES OF DECAYED SPRUCE WOOD WITH NATURAL RESINS

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ABSTRACT

The paper presents effects of the selected natural conservation substances – resins (colophony, dammar, mastic, sandarac and shellac) on some moisture and mechanical properties of intentionally decayed Norway spruce (*Picea abies* L. Karst.) wood, i.e. the kinetics of water sorption (S), the kinetics of volume swelling (β), the compression strength (σ), and the modulus of rupture in bending (MOR). Spruce samples 25x15x50 mm, 20x20x30 mm and 8.5x8.5x120 mm (RxTxL) were firstly attacked by the brown-rot fungus *Coniophora puteana* during 0, 2, 4, 6, 8, 10, or 12 weeks into various degrees of rot (Δm – average weight losses varied between 0.48 % and 28.11 %, and density decreases ranged between 0.73 % and 21.48 %), and then impregnated with 20 % solutions of natural resins with their retentions (R) from 66 to 118 $kg.m^{-3}$.

The mastic proved to be the most effective for the stability of decayed spruce against water. For example, in the 168 hour of the water sorption test, the drop of S_{168} was about 27.5 % (shellac) up to 36.9 % (mastic) or 37.6 % (dammar), and the drop of β_{168} was about 14.0 % (sandarac) up to 32.1 % (mastic).

The natural resins also partly improved the strength (σ and MOR) properties of the decayed and sound spruce. At the sound spruce, the compression strength was increased approx. by about 6.3 % (shellac) to 15.4 % (sandarac), and the MOR by about 3.8 % (sandarac) to 10.4 % (colophony). A similar strengthening effect of the natural resins was determined for the decayed spruce. However, the natural conservation substances were not able to change the exponential decrease of the strength characteristics of decayed spruce with growth of the weight losses (σ, or MOR = a + b.exp/-c.Δm/).

KEYWORDS: Norway spruce, decay, natural resins, conservation, sorption, swelling, strength.

INTRODUCTION

Various physical and mechanical properties of wood are changed, obviously impaired, due to its damaging by biological and environmental factors. Old damaged historical wooden structures or sculptures can be renovated and reinforced by more methods, including their conservation with natural and synthetic substances (Zelinger et al. 1982, Rowell 1990, Barthez et al. 1999, Morgós 1999).

The stiffness, strength, dimensional stability, or other important properties of old deteriorated woods can be improved with convenient conservation substances (acrylates, epoxy resins, natural resins, etc.), including also substances for a waterlogged wood stabilization (PEGs - polyethylene-glycols, sugars, etc.). Conservation substances of different chemical structure are applied by specific techniques (painting, spraying, soaking, vacuum-pressure impregnation) with the aim to achieve their optimal localization in wood (surface coating, cell wall bulking, lumen-filling or filling-up reintegrating). Selection of the optimal conservation substance depends on more factors which are related preferentially to characteristics of the historical wood, e.g. to its dimensions, surface treatments, combination of one or more wood species, environmental indoor or outdoor expositions, location, extent and degree of damages, moisture contents, etc. (Unger et al. 2001, Reinprecht 2008a).

The cell wall bulking method, convenient mainly for waterlogged archaeological wood, is usually carried out with ethylene-glycols, low molecular amino- or phenol-formaldehyde resins or reactive monomers. This method is primarily suitable for dimensional stabilization of deteriorated wood to reduce shrinkage or re-swelling of cell walls. However, its contribution for improving of the mechanical properties of wood is not always clear. Some chemicals improve the stiffness and strength of wood cell walls, e.g. hydrophilic water-soluble reactive thermosetting resins (lower molecular urea-, melamine-, phenol-formaldehyde resins) and hydrophilic reactive monomers (2-hydroxyethylmethacrylate). Cellulose and other building components of the cell walls of wood can be strengthened and dimensionally stabilized by recombination through the cross-linking reactants, e.g. with epoxy-compounds, isocyanates, anhydrides (Hill 2006, Rowell 1990), or 1,3-dimethylol-4,5-dihydroxy-ethylene-urea (Zee et al. 1998). On the other hand, some other chemicals weaken the mechanical properties of conserved wood, e.g. non-reactive lower molecular polyethylene-glycols (PEG 300 – PEG 1000), sugars or inorganic salts (Reinprecht and Varínska 1999, Unger et al. 2001).

The lumen-filling method is primarily suitable for strengthening of wood cells. Filling of lumens in cell-elements of wood can be carried out with synthetic polymers (with acrylics in toluene, polyesters and epoxy-resins in acetone, higher molecular melamine-formaldehyde or other water-soluble thermosetting resins), further with hydrophobic reactive monomers which in the conserved wood create polymeric structures by heat or γ-irradiation (styrene, methyl-methacrylate), and also with hydrophobic non-reactive natural substances (oils, waxes, resins).

It is commonly well-known, that the improvement of individual properties of wood at conservation processes depends on more factors:

- wood species,
- type, location, extent and degree of bio-damages and other defects in wood,
- chemical-physical-mechanical properties of the conservation substance,
- macro- and micro-distribution of the conservation substance in wood.

In our previous works (Horský and Reinprecht 1986, Reinprecht 1993, Reinprecht and Varínska 1999, Reinprecht et al. 1999), the influences of selected synthetic polymers (acrylics, amino-formaldehyde resins, phenol-formaldehyde resins, epoxy resins and polyethylene-glycols) on the mechanical, moisture and acoustical properties of bio-damaged hardwoods and softwoods have been studied.

In this work, the effect of selected natural conservation substances – resins (colophony, dammar, mastic, sandarac and shellac) is studied from the point of view of their influence on some moisture and mechanical properties of the Norway spruce samples which were firstly damaged into different degrees of rot with the brown-rot fungus *Coniophora puteana*. The spruce wood is often a material part of cultural heritage – historical structures, sculptures and other artefacts which are un-rarely damaged by fungi and insects with a negative impaction on their physical and mechanical properties. Conservation of decayed spruce elements in cultural heritage artefacts is therefore an important task for wood researches and restoring workers. Basic part of this study was presented as poster, at the 4th International Conference - COST Action IE0601, October 20-22, 2010, Izmir – Turkey (Reinprecht 2010).

MATERIAL AND METHODS

Spruce wood

Thereee types of the Norway spruce (*Picea abies* L. Karst.) sapwood samples with the following dimensions were used in the experiment (radial x tangential x longitudinal):

- 25x15x50 mm, for the kinetics of water sorption and volume swelling (n = 144),
- 20x20x30 mm, for the compression strength (n = 180),
- 8.5x8.5x120 mm, for the modulus of rupture in bending (n = 180).

All samples were prepared from one sound 75-year old log cut in the territory of "Forest Company in Zvolen - Slovakia". The samples were selected in accordance with the following criteria: a) free of knots, cracks, insect galleries, rot, or other growth abnormalities, heterogeneities and defects; b) uniform orientation of fibrils. Subsequently, 504 selected samples were assorted into 21 homogeneous groups (3 different dimensions of samples x 7 different degrees of their planned decay attacks) with respect to their initial densities in the oven dry state (ρ_o from 343 to 467 $kg.m^{-3}$), i.e. in each group were samples with lower, medium and higher densities.

Decay of spruce wood

The Norway spruce samples with known initial weights in the oven dry state (m_o) were intentionally attacked by the brown-rot fungus *Coniophora puteana* (Schumacher ex Fries) Karsten, (Stamm BAM Ebw. 15). Fungal attack of samples was carried out in Kolle's flasks at a temperature of 22 ± 1 °C and a relative humidity of air 70-80 %, with the aim to achieve seven different degrees of rot. Thus, the decay lasted 0, 2, 4, 6, 8, 10, or 12 weeks. After the decay attacks, the samples were taken out from Kolle's flasks, their surfaces were purified from fungal mycelia, and finally they were submitted to the two-stage drying process to achieve the oven dry state (m_{od}). The first stage of natural drying was performed in a laboratory room (t = 20–25 °C, φ = 60–70 %, τ = 100 h), and the second stage of drying in a laboratory drying chamber in three phases (I. t_1 = 60 °C, τ_1 = 1 h; II. t_2 = 80 °C, τ_2 = 1 h; III. t_3 = 103 ± 2 °C, τ_3 = 4 h). The aim of the used drying process was to sterilize and avoid formation of checks and deformations in samples.

Weight losses (Δm) and density decreases ($\Delta\rho$) of samples attacked by the fungus *C. puteana* were determined by the Eqs. 1 and 2:

$$\Delta m = [(m_o - m_{od}) / m_o] . 100 \quad (\%) \tag{1}$$

$$\Delta\rho = [(\rho_o - \rho_{od}) / \rho_o] . 100 \quad (\%) \tag{2}$$

where: m_o or ρ_o – mass or density of the sound sample before decay in the oven dry state, m_{od} or ρ_{od} – mass or density of the decayed sample in the oven dry state.

Conservation of spruce wood with natural resins

Samples having a different degree of rot and conditioned (4 weeks at a temperature of 20 ± 1 °C and at a relative humidity of air 45 ± 2 %) to the equilibrium moisture content "EMC" ≈ 6 % were then subjected to pressure impregnation with 20 % solutions of the following natural conservation substances – natural resins:

- dammar → in toluene,
- colophony, mastic, sandarac, or shellac → in ethanol.

Chemical structures and physical properties of these natural substances are well-known and were described by Zelinger et al. (1982), Unger et al. (2001), Reinprecht (2008b), or other researches. The conservation process was carried out in the Dreyer-Holand-Merten KG device using modified Lowry pressure impregnation technique at 0.8 MPa (3 hours) 20 °C.

Retentions (R) of the natural resins into the sound and decayed spruce samples were evaluated by the gravimetric method and calculated by the Eq. 3:

$$R = 0.01 \cdot C \cdot (m_{c\text{-}w} - m_w) / V_w \qquad (\mathrm{kg.m^{-3}}) \qquad (3)$$

where: C = 20 % concentration of the natural resin; $m_{c\text{-}w}$ = weight of the sample determined immediately after conservation; m_w = weight of the sample before conservation at a moisture approx. w ≅ 6 %; V_w = volume of the sample before conservation.

Properties of sound and decayed spruce wood after conservation with natural resins

Effect of the used natural resins on some moisture and mechanical properties of the Norway spruce wood was assessed on the basis of the following analyses.

The water sorption tests (S, β), at a temperature of 20 °C and at a relative humidity of air 76 %, were performed in glass desiccators above distilled water saturated with NaCl. Values of the kinetics of water sorption (S) and the kinetics of volume swelling (β) have been determined in the following time intervals: τ = 1, 2, 4, 16, 32, 48, 168, and 1008 hours, for each tested sample by the Eqs. 4 and 5:

$$S = 100 \cdot (m_\tau - m_o) / m_o \qquad (\%) \qquad (4)$$
$$\beta = 100 \cdot (V_\tau - V_o) / V_o \qquad (\%) \qquad (5)$$

where: m_o or V_o = mass or volume of the sample in the oven dry state; m_τ or V_τ = mass or volume of the sample in a definite time of the sorption test.

The compression strength parallel to grain (σ) of the samples conditioned to moisture content level of approx. 12 % was calculated by the Eq. 6:

$$\sigma = F_{max} / (a \cdot b) \qquad (\mathrm{MPa}) \qquad (6)$$

where: F_{max} = the maximum loading force in N; a, b = transversal dimensions of the sample in mm.

The modulus of rupture (MOR) of the samples conditioned to moisture content level of approx. 12 % was determined by the 3-point bending test in their tangential direction, and calculated by the Eq. 7:

$$MOR = (3 \cdot F_{max} \cdot l_o) / (2 \cdot b \cdot h^2) \qquad (\mathrm{MPa}) \qquad (7)$$

where: b = width of the sample in mm, h = height of the sample in mm, l_o = 100 mm.

RESULTS AND DISCUSSION

Weight losses and density decreases of the decayed spruce

It is well-known that the natural resistance of the spruce sapwood against rotting fungi is poor, and it is inserted only to the 5th class of natural durability by EN 350-2. In this experiment, in accordance with this knowledge, the spruce samples exposed to the brown-rot fungus *Coniophora puteana* from 2 to 12 weeks lost their initial weights (Δm) in an average by about 0.48 % to 28.11 %, and their densities decreased ($\Delta\rho$) in an average by about 0.73 % to 21.48 % (Tab. 1).

Tab. 1: The weight losses (Δm) and the density decreases ($\Delta\rho$) of the Norway spruce samples of 3 types after their degradation with the brown-rot fungus Coniophora puteana from 2 to 12 weeks.

Time of decay (weeks)	Weight loss (%)						Density decrease (%)					
	25x15x50		20x20x30		8.5x8.5x120		25x15x50		20x20x30		8.5x8.5x120	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
2	0.77	(0.258)	0.48	(0.169)	0.61	(0.089)	1.47	(1.130)	0.73	(1.059)	2.80	(1.439)
4	1.29	(0.111)	1.28	(0.174)	1.86	(0.427)	1.54	(0.871)	1.36	(1.015)	3.67	(1.247)
6	2.72	(0.340)	2.63	(0.478)	4.78	(1.017)	3.47	(1.202)	2.81	(1.017)	5.37	(3.213)
8	7.22	(1.036)	6.31	(1.432)	12.57	(1.694)	5.49	(2.453)	4.14	(1.472)	10.22	(3.304)
10	17.10	(1.468)	14.02	(2.209)	16.72	(2.052)	10.56	(3.744)	10.82	(2.874)	12.53	(1.738)
12	21.15	(1.026)	28.11	(2.656)	25.44	(2.738)	15.43	(4.127)	21.48	(3.842)	17.80	(3.663)

$\bar{x}$ - Arithmetic mean value
SD – Standard deviation in parentheses
n – Number of replicates (samples) in each series: 12 samples 25x15x50 mm, 18 samples 20x20x30 mm, 18 samples 8.5x8.5x120 mm
Totally 288 samples of the Norway spruce wood were attacked by the fungus *C. puteana*, 72 samples 25x15x50 mm (n = 12 x 6 times of decay = 72) 108 samples 20x20x30 mm (n = 18 x 6 times of decay = 108), 108 samples 8.5x8.5x120 mm (n = 18 x 6 times of decay = 108).

Retention of natural resins into the sound and decayed spruce

The retentions (R) of the natural resins into the Norway spruce samples were evidently higher with prolongation their previous fungal attack with *Coniophora puteana* (Fig. 1). This result can be explained either by a higher permeability of the decayed spruce wood with perforated pits in the cell walls of tracheids (Schwarze et al. 2006), and also by a higher porosity and a lower density of more decayed spruce samples (Tab. 1).

The cumulative resin's retentions evaluated at different degrees of rot (i.e. evaluating the retentions together for all 5 natural resins and for all 3 types of spruce samples) increased closely with the prolongation of decay processes in spruce from 0 to 12 weeks: R_0 = 66.0 kg.m^{-3}, R_2 = 81.8 kg.m^{-3}, R_4 = 86.5 kg.m^{-3}, R_{289} = 98.6 kg.m^{-3}, R_8 = 107.3 kg.m^{-3}, R_{10} = 112.9 kg.m^{-3}, R_{12} = 118.1 kg.m^{-3} (Fig. 1).

The cumulative resin's retentions evaluated for individual natural substances (i.e. evaluating the retentions for all 3 types of spruce samples in different degrees of rot) were mutually comparable (Fig. 1). However, the highest retention was determined for the colophony and the lowest one for the sandarac: $R_{Colophony}$ = 100.3 kg.m^{-3}, R_{Dammar} = 87.9 kg.m^{-3}, R_{Mastic} = 89.3 kg.m^{-3}, $R_{Sandarac}$ = 73.3 kg.m^{-3}, $R_{Shellac}$ = 78.7 kg.m^{-3}.

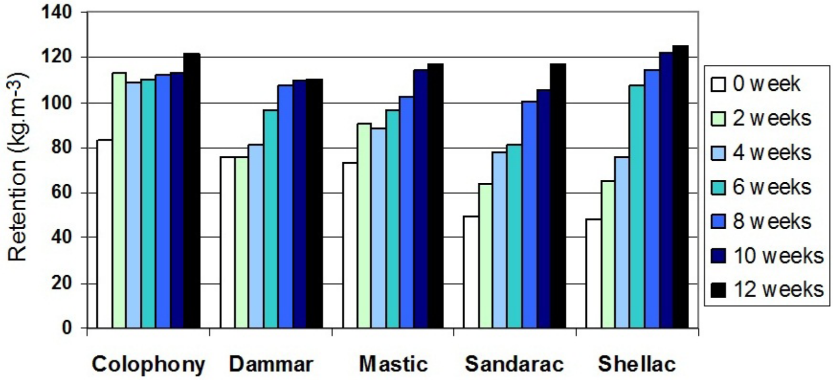


Fig. 1: The average retentions (R) of the natural resins into the Norway spruce sapwood (together for samples of all 3 types: 25x15x50 mm; 20x20x30 mm; 8.5x8.5x120 mm) having different degrees of brown rot (time of decay by C. puteana from 0 to 12 weeks).

Totally 420 spruce samples were impregnated with the natural resins: - 180 sound samples → 0 week of decay (n = [12+12+12 = 36] x 5 substances = 180); - 240 decayed samples → 2-12 weeks of decay (n = [2+3+3 = 8] x 6 times of decay x 5 substances = 240).

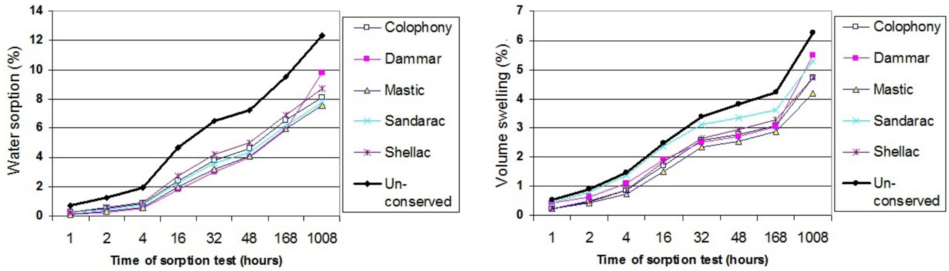
A certain difference in these retentions could be explained either by the unequal densities and dynamic viscosities of the 20 % solutions ($\eta_{Colophony}$ = 4.41 mPa.s, η_{Dammar} = 1.76 mPa.s, η_{Mastic} = 3.26 mPa.s, $\eta_{Sandarac}$ = 4.58 mPa.s, $\eta_{Shellac}$ = 7.93 mPa.s), and also by some structural differences (morphological, anatomical, and permeability) of the selected sound and rotten samples arranged into testing groups before the conservation processes.

Moisture properties of the conserved spruce

Both tested moisture properties, i.e. the water sorption (S) (Fig. 2a) and the volume swelling (β) (Fig. 2b), of the decayed spruce samples decreased evidently after their treatment with the natural resins. The anti-moist effects of all five natural substances were comparable. Only the mastic had a partly better anti-sorption and anti-swelling effect in comparison with the others (Fig. 2, Tab. 2). Generally, the anti-moist effects of the natural conservation substances were more marked at the beginning of the sorption tests, i.e. from 1 to 48 hours (Fig. 2, Tab. 2).

For example, at the sorption tests lasting 16 hours, the water sorption of the conserved spruce samples was in comparison with the un-conserved ones lower by about 41.0 % (shellac), 57.4 % (mastic) up to 61.4 % (dammar), while their volume swelling was lower by about 3.1 % (sandarac) up to 39.0 % (mastic). After 168 hours of the sorption test, the water sorption of the conserved spruce samples was in comparison with the un-conserved ones lower by about 27.5 % (shellac) up to 36.9 % (mastic) or even 37.6 % (dammar), while their volume swelling was lower by about 14.0 % (sandarac) up to 32.1 % (mastic), see Tab. 2.

The dammar had very good anti-sorption and anti-swelling effects up to 168 hours of the sorption test. However, then its anti-moist efficiency decreased and after 1008 hours "42 days" it was the poorest (Fig. 2).



a) b)

Fig. 2: The kinetics of water sorption (S) and the kinetics of volume swelling (β) at φ = 76 % and t = 20 °C of the decayed Norway spruce sapwood replicates which either were or were not conserved with natural resins.

Each point in the Fig. 2 represents arithmetic mean value of 12 replicates (2 samples x 6 times of fungal attack by *C. puteana* during 2, 4, 6, 8, 10, or 12 weeks).

Conditions of the sorption test: t = 20 °C; φ = 76 %; τ = 1008 hours.

The anti-moist effects of the natural resins were similar for the sound spruce samples, as well. These results are not presented in this work.

This result can be explained by a non-polar character of toluene solvent in which the dammar was applied, i.e. without its possibility to penetrate into cell walls of wood. Following can be proposed this hypothesis: – the water molecules from air had a better possibility to diffuse deeper into the cell walls of wood through the dammar barrier presented on the outside surfaces of the secondary S3 layer of cells only at a longer period of the sorption test.

Tab. 2: The water sorption and the volume swelling of the conserved and the un-conserved decayed Norway spruce replicates after 16 and 168 hours of the sorption test at φ = 76 % and t = 20 °C.

Moisture property			Conservation natural substance					Un-conserved
			Colophony	Dammar	Mastic	Sandarac	Shellac	
Sorption	16 h	$\bar{x}$	2.40	1.80	1.99	2.26	2.75	4.66
		Drop (%)	48.6	61.4	57.4	51.4	41.0	-
	168 h	$\bar{x}$	6.55	5.92	5.99	6.17	6.88	9.49
		Drop (%)	31.0	37.6	36.9	35.0	27.5	-
Swelling	16 h	$\bar{x}$	1.71	1.91	1.51	2.39	1.83	2.47
		Drop (%)	30.7	22.8	39.0	3.1	26.1	-
	168 h	$\bar{x}$	3.10	3.05	2.87	3.63	3.28	4.22
		Drop (%)	26.7	27.9	32.1	14.0	22.4	-

$\bar{x}$ – arithmetic mean value from 12 decayed replicates (%).

Drop – percentage decrease of the moist-property of the conserved decayed spruce in comparison with the un-conserved decayed spruce.

Mechanical properties of the conserved spruce

All natural resins had a partly positive effect on the strength properties (σ, MOR) of the sound and the decayed spruce samples (Fig. 3, Fig. 4a, Fig. 5a, Tab. 3). The strength characteristics were evaluated separately for the conserved and the un-conserved samples attacked before into similar degrees of rot (i.e. both the conserved and the un-conserved groups of samples had almost identical initial weight losses "Δm" caused by the fungal attacks lasting from 0 to 12 weeks), see Fig. 4b ($p = 0.5483$) and Fig. 5b ($p = 0.8124$).

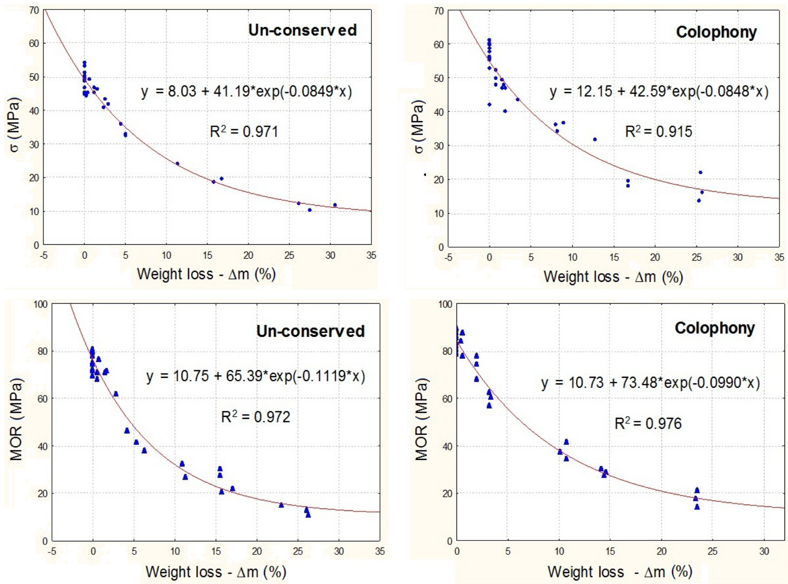
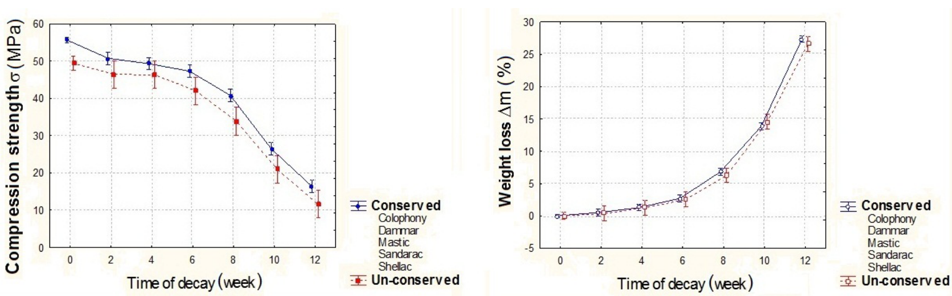


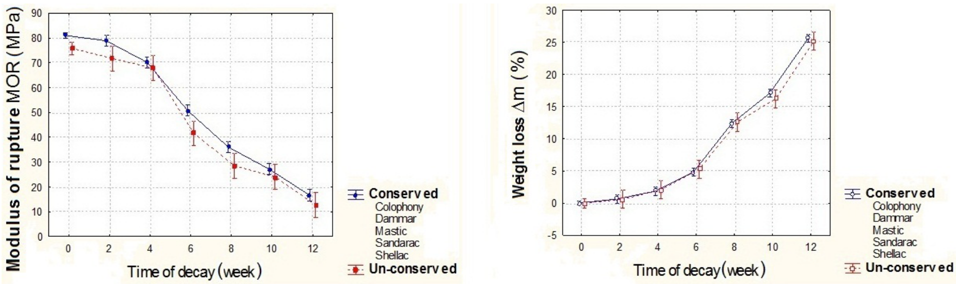
Fig. 3: The exponential drop of tested mechanical properties (y = σ or MOR) of the Norway spruce with rot increasing (x = Δm), i.e. here for the un-conserved samples and the samples conserved with colophony (see also Tab. 3).



a) b)

Fig. 4: The compression strength (σ) of the conserved and un-conserved Norway spruce samples (a), the samples of which were attacked before by C. puteana into different degrees of rot - Δm (b).

95 % confidence intervals for a different number of replicates (samples): - Un-conserved spruce → 12 sound or 3 decayed replicates (Σ = 12 + 3x6 = 30 samples); - Conserved spruce → 60 sound or 15 decayed replicates (Σ = 60 + 15x6 = 150 samples)



a) b)

Fig. 5: The modulus of rupture (MOR) of the conserved and un-conserved Norway spruce samples (a), the samples of which were attacked before by C. puteana into different degrees of rot - Δm (b).
95 % confidence intervals for a different number of replicates (samples): - Un-conserved spruce → 12 sound or 3 decayed replicates (Σ = 12 + 3x6 = 30 samples); - Conserved spruce → 60 sound or 15 decayed replicates (Σ = 60 + 15x6 = 150 samples).

The compression strength (σ) of the sound spruce increased significantly after its conservation from 49.4 MPa (un-conserved) to 52.5 MPa (conserved by shellac) or maximally to 57.0 MPa (conserved by sandarac). By using the Duncan's test it was statistically documented for all natural substances (Tab. 3). The exponential decrease of this strength, in consequence of higher degrees of rot, was well defined by the relation σ = a + b.exp/-c.Δm/, both for the group of the un-conserved spruce samples and also for all the groups of the conserved spruce samples (Fig. 3, Tab. 3). Comparing the total strengthening effect of all five natural substances (colophony, dammar, mastic, sandarac and shellac), it is evident that they improved the compression strength both at the sound spruce by about 12.6 % (from 6.3 % by shellac to 15.4 % by sandarac), and also at the decayed spruce (Tab. 3). In spite of the fact that the total strengthening effect of five natural substances was not statistically significant in all cases, i.e. in the Duncan's test it was not significant for samples attacked by C. *puteana* during 4 weeks (p = 0.157), their final positive effect on the σ was statistically significant with p = 0.0000 (Fig. 4a).

The modulus of rupture in bending (MOR) of the sound spruce increased significantly after its conservation from 75.8 MPa (un-conserved) to 78.7 MPa (conserved by sandarac) or maximally to 83.7 MPa (conserved by colophony). By the Duncan's test it was statistically documented, except the sandarac, for all other natural resins (Tab. 3). The exponential decrease of the modulus of rupture, connected with higher degrees of rot, was well defined by the equation MOR = a + b.exp/-c.Δm/, both for the group of the un-conserved spruce samples and also for all the groups of the conserved spruce samples (Fig. 3, Tab. 3). Comparing the total strengthening effect of all five tested natural conservation substances, it is evident that they improved the MOR both at the sound spruce by about 6.9 % (from 3.8 % by sandarac to 10.4 % by colophony), and also at the decayed spruce (Tab. 3). Similarly as at the compression strength, the total strengthening effect of five natural substances on the bending was not statistically significant in all cases, in the Duncan's test it was not significant for samples attacked by C. *puteana* during 4 weeks (p = 0.377),10 weeks (p = 0.223) and 12 weeks (p = 0.127), however their final positive effect on the MOR was statistically significant with p = 0.0000 (Fig. 5a).

Tab. 3: The compression strength parallel to grain (σ) and the modulus of rupture in bending (MOR) of the conserved and unconserved Norway spruce samples: – a) sound; – b) sound and decayed.

Strength property of spruce	**Conservation natural substance**					**Un-conserved**
	Colophony	Dammar	Mastic	Sandarac	Shellac	
	A	B	C	D	E	F
Compression strength						
a) Sound						
$\bar{x}$	55.9	55.8	56.9	57.0	52.5	49.4
SD	4.99	1.26	2.00	3.56	0.97	2.80
n	12	12	12	12	12	12
Duncan test	EF	EF	EF	EF	ABCDF	ABCDE
b) Sound and Decayed						
$\sigma = a+b.\exp(-c.\Delta m)$						
a	12,2	7.4	7.3	10.8	2.7	8.0
b	42.6	47.7	48.3	44.2	50.6	41.2
a+b	54.8	55.1	55.6	55.0	53.3	49.2
c	0.085	0.063	0.052	0.067	0.054	0.085
Δm	0.7-25.6	0.3-29.0	0.4-27.6	0.5-26.6	0.6-30.3	0.1-30.6
n	30	30	30	30	30	30
R^2	0.915	0.959	0.968	0.908	0.967	0.971
Modulus of rupture						
a) Sound						
$\bar{x}$	83.7	80.8	80.3	78.7	81.5	75.8
SD	4.09	2.80	3.49	4.02	3.74	3.76
n	12	12	12	12	12	12
Duncan test	CDF	F	AF	A	F	ABCE
b) Sound and Decayed						
$MOR= a+b.\exp/-c.\ \Delta m/$						
a	10.7	14.8	16.3	14.4	3.9	10.8
b	73.5	66.3	63.9	63.2	78.3	65.4
a+b	84.2	81.1	80.2	77.6	82.2	76.2
c	0.099	0.107	0.123	0.108	0.064	0.112
Δm	0.5-23.5	0.6-22.6	0.6-27.5	0.5-31.7	0.7-25.5	0.5-26.4
n	30	30	30	30	30	30
R^2	0.976	0.976	0.968	0.965	0.979	0.972

$\bar{x}$ – arithmetic mean value (MPa)
SD – standard deviation (MPa)
n – number of replicates
Duncan test – Letter(s) "A till F "indicate(s) statistically significant difference between the tested groups of conserved "A till E" and un-conserved "F" spruce samples on the 95 % level ($p \leq 0.05$)
a, b – coefficients (MPa)
c – coefficient ($\%^{-1}$)
Δm – minimal and maximal weight losses of spruce samples at their decay with *C. puteana* lasting 2-12 weeks (%)
R^2 – coefficient of determination.

In the previous work Reinprecht and Varínska (1999) found that the shellac had not more apparent influence on the MOR of the sound spruce or beech samples. In their work the MOR was apparently increased by the epoxy resin (by about 47.7 % at spruce, and by about 43.3 % at beech), while on the other hand, the MOR was evidently decreased by the PEG 1000 (by about 16.5 % at spruce, and by about 18 % at beech).

CONCLUSIONS

The achieved results give the opportunity to come to the following conclusions:

- Moisture characteristics "the kinetics of water sorption" and "the kinetics of volume swelling" of the decayed Norway spruce samples were expressively slowed down – improved after treatment with all tested natural conservation substances (colophony, dammar, mastic, sandarac, or shellac). The anti-moist effects of the mastic could be characterized as partly better in comparison with the other used natural substances.
- Strength characteristics "the compression strength parallel to grain" and "the modulus of rupture in bending" of the sound spruce samples and also of the decayed spruce ones were moderately but usually significantly improved (by about 4 till 15 %) after conservation with the natural resins. To sum up, the colophony had the best strengthening effect.

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