THE IMPACT OF SOME ACTIVE COMPOUNDS IMPLIED IN THE PRESERVATION, UPON PHYSICAL-STRUCTURAL WOOD’S CHARACTERISTICS

Mikiko HAYASHI - Ion SANDU - Adeline CIOCAN - Viorica VASILACHE - Irina Crina Anca SANDU

Abstract: The work presents experimental data related to the changes of some physical-structural characteristics such as: coefficients of dimensional swelling (longitudinal, tangential and radial) and volume coefficients, density and porosity for four wood essences hydrous equilibrated (lime, poplar, fir and oak), which have been exposed to an active preservation treatment through immersion in propolis and red petroleum organic solutions. The changes produced during distilled water immersion, using the same treatment procedure were used for comparison.

Keywords: dimensional and volume swelling, wood’s density and porosity, active preservation, treatment by immersion

1. INTRODUCTION

It is known that there is a great variety of cultural heritage artifacts made of wood, natural or polychrome, which in time are affected by deterioration and degradation, due to environmental and antropic factors (Filipovici, J., 1964). Among other research directions our research group is dealing with the physical-structural modifications of the wood during its treatment with traditional compounds (red petroleum and organic solution of propolis) (Sandu, I., 2006; Luca, C., 1998; Sandu, I., 2008).

This work presents an impact survey of the active preservation of four wood essences (Limewood, poplar, fir-tree and oak-tree) and of their structural characteristics: dimensional variations by dilatation and shrinkage, density and porosity of the samples. The dimensional variations of the wooden specimens after treatment with organic solutions have been compared with the impact of water on these samples, using the same procedure through immersion in distilled water.

2. EXPERIMENTAL

New and old wood specimens of Limewood, poplar, fir-tree and oak-tree, which were cut at the following dimensions: 10x10x50mm and 10x20x40mm were considered for the experiments. Initially, the samples were weighed with digital analytical balances (PARTNER AT 220-C-2 and SARTORIUS LA5200D) and their humidity was measured through a resistive method with a hygrometer BES BOLLMANN. The three dimensions of the samples, corresponding to the three sections of the wood - longitudinal, radial and tangential - were measured with a MITUTOYO electronic instrument.

Dimensional variations (swelling and shrinkage) of the wood were measured on all three directions, expressing the following coefficients: longitudinal ($\beta_l$), radial ($\beta_r$), and tangential ($\beta_t$) swelling coefficient, but also volume swelling coefficient ($\beta_v$); and the same coefficients for shrinkage: $\alpha_l$, $\alpha_r$, $\alpha_t$ and $\alpha_v$. These dimensional coefficients have been calculated using the following equations (Suciu, P. N., 1971):

$$\beta_{l, r, t} = 100 \times \frac{(L_{\text{max}} - L_{\text{min}})}{L_{\text{min}}}$$  \hspace{1cm} (1)

respectively,

$$\alpha_{l, r, t} = 100 \times \frac{(L_{\text{max}} - L_{\text{min}})}{L_{\text{max}}}$$  \hspace{1cm} (2)
where: $L_{\text{max}}$ is the dimension for the highest humidity and $L_{\text{min}}$ is the dimension for the lowest humidity.

The volume coefficients have been calculated using the equations below:

$$\beta_v = 100 \times \frac{(V_{\text{max}} - V_{\text{min}})}{V_{\text{min}}}$$  \hspace{1cm} (3)

and respectively,

$$\alpha_v = 100 \times \frac{(V_{\text{max}} - V_{\text{min}})}{V_{\text{max}}}$$  \hspace{1cm} (4)

where: $V_{\text{max}}$ is maximum volume in cm$^3$, and $V_{\text{min}}$ is the minimum volume in cm$^3$.

For the determination of the density of wood samples described above, the following formula was applied after they were weighed and measured (longitudinally, tangentially, and radially) for calculating the volume:

$$\rho = \frac{M}{V}, \text{ (g/cm}^3\text{)},$$  \hspace{1cm} (5)

where $M$ is the sample’s weigh, and $V$ is the volume.

For the determination of the porosity the wood samples were first weighed and measured longitudinally, transversally, and radially. Afterwards the specimens were put into an oven at $105^\circ$C until they reached a constant weight and then into a desiccator under vacuum conditions, in water. The samples were kept there, until they were not floating anymore on the water, which means that the air from the wood’s pores has been replaced by water. After that the samples were weighed and measured on all the three directions (longitudinal, tangential and radial).

The porosity has been determined using the following equation:

$$P = (1-\rho_o/1530) \times 100 \text{ (})%\text{)}$$  \hspace{1cm} (6)

where: $\rho_o$ is the density of the wood dried in the oven, calculated using the following relationship: $\rho_o = \frac{M_0}{V_0}, \text{ (g/cm}^3\text{)}$.

3. RESULTS AND DISCUSSION

3.1. The influence of different treatments on the modifications of the dimensions of wood

Since the hygroscopic water in the wood varies according the humidity present in the environment, the shrinkage and swelling of the wood are permanent phenomena which lead to dimensional variations. Therefore the behavior of the wood in relationship to the atmosphere’s conditions is considered one of its disadvantages. Thus, these types of studies are very important, with respect to limits of these variations, considering that beyond these the wood could get into pre-collapsed state. In this respect, the study of the swelling and shrinkage phenomena is useful for knowing the dimensional changes of wooden specimens (this representing a factor which contributes to the prevention of negative consequences in any field where the wood is used), for the explanation and prevention of the deformations and defects.

In the Fig. 1-4 the variations during the swelling of the Limewood, poplar, fir-tree and oak-tree specimens, after immersion in: distilled water (used as reference), red petroleum and alcoholic solution of propolis are presented.
Fig. 1. Dimensional variations of the Limewood specimens after the treatment with the studied systems:
   a. Longitudinal variations; b. Radial variations; c. Tangential variations

Fig. 2. Dimensional variations of the poplar wood specimens after the treatment with the studied systems:
   a. Longitudinal variations; b. Radial variations; c. Tangential variations
Fig. 3. Dimensional variations of the fir-tree wood specimens after the treatment with the studied systems:
   a. Longitudinal variations; b. Radial variations; c. Tangential variations

Fig. 4. Dimensional variations of the oak-tree wood specimens after the treatment with the studied systems:
   a. Longitudinal variations; b. Radial variations; c. Tangential variations
In Table 1 the ratios of swelling on all the three directions for limewood, poplar, fir-tree and oak-tree specimens after immersion in distilled water, alcoholic solution of propolis and red petroleum are presented, using as reference the longitudinal swelling.

<table>
<thead>
<tr>
<th>Wooden species</th>
<th>Immersion system</th>
<th>Swelling (%)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Longitudinal</td>
<td>Radial</td>
<td>Tangential</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value</td>
<td>Ratio</td>
<td>Value</td>
<td>Ratio</td>
</tr>
<tr>
<td>Limewood</td>
<td>Water</td>
<td>0,42</td>
<td>1,00</td>
<td>6,95</td>
<td>16,55</td>
</tr>
<tr>
<td></td>
<td>Alcoholic solution of</td>
<td>0,38</td>
<td>1,00</td>
<td>5,27</td>
<td>13,87</td>
</tr>
<tr>
<td></td>
<td>propolis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red petroleum</td>
<td>0,11</td>
<td>1,00</td>
<td>0,50</td>
<td>4,55</td>
</tr>
<tr>
<td>Poplar</td>
<td>Water</td>
<td>0,35</td>
<td>1,00</td>
<td>4,19</td>
<td>11,97</td>
</tr>
<tr>
<td></td>
<td>Alcoholic solution of</td>
<td>0,26</td>
<td>1,00</td>
<td>2,58</td>
<td>9,92</td>
</tr>
<tr>
<td></td>
<td>propolis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red petroleum</td>
<td>0,09</td>
<td>1,00</td>
<td>0,46</td>
<td>5,11</td>
</tr>
<tr>
<td>Fir-tree</td>
<td>Water</td>
<td>0,48</td>
<td>1,00</td>
<td>2,07</td>
<td>4,31</td>
</tr>
<tr>
<td></td>
<td>Alcoholic solution of</td>
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<td>1,00</td>
<td>1,40</td>
<td>5,00</td>
</tr>
<tr>
<td></td>
<td>propolis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red petroleum</td>
<td>0,10</td>
<td>1,00</td>
<td>0,44</td>
<td>4,40</td>
</tr>
<tr>
<td>Oak-tree</td>
<td>Water</td>
<td>0,33</td>
<td>1,00</td>
<td>1,09</td>
<td>3,30</td>
</tr>
<tr>
<td></td>
<td>Alcoholic solution of</td>
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<td>1,00</td>
<td>0,60</td>
<td>2,73</td>
</tr>
<tr>
<td></td>
<td>propolis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red petroleum</td>
<td>0,07</td>
<td>1,00</td>
<td>0,33</td>
<td>4,71</td>
</tr>
</tbody>
</table>

As we can observe from the Table 1, the longitudinal modifications along the fibers are the smallest, almost insignificant. Therefore, to analyze the ratio of variations on all the three directions the longitudinal swelling has been considered as reference. For limewood, the tangential swelling is about 21 times greater than the longitudinal swelling at the immersion in water, and the radial one 17 times greater. The alcoholic solution of propolis induces swelling variations very close to water, while the red petroleum induces radial and tangential variations from 4.5 to 11 times greater. It is interesting to compare from this point of view all four essences: limewood behaves differently than poplar which is close to fir-tree but very different from oak-tree.

In order to make a comparative study of the impact of all the three solutions used in the treatment of wood at immersion, the decreases of swelling degree taking the water as reference for the other two systems: alcoholic solution of propolis and red petroleum (see Table 2) has been taking into account.

From Table 2 it can be assessed that the red petroleum gives the smallest degree of swelling, but the dynamic and variation of the ratio on all the three directions is much
different than the other three essences. If for limewood the variation of the ratio increases from longitudinal to radial and then to tangential, for poplar wood is different, radial direction having the biggest value. The fir-tree and oak-tree wood specimens present these ratios quite close, or in a short interval of values (4.3-6.2).

The decrease of swelling degree on all the three directions of wood at immersion in the studied solutions, taking as reference the water immersion

<table>
<thead>
<tr>
<th>Wooden species</th>
<th>Direction</th>
<th>Immersion system</th>
<th>Value</th>
<th>Ratio</th>
<th>Value</th>
<th>Ratio</th>
<th>Value</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limewood</td>
<td>Longitudinal</td>
<td>Water</td>
<td>0.42</td>
<td>1.00</td>
<td>0.38</td>
<td>1.11</td>
<td>0.11</td>
<td>3.82</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td></td>
<td>6.95</td>
<td>1.00</td>
<td>5.27</td>
<td>1.32</td>
<td>0.50</td>
<td>13.90</td>
</tr>
<tr>
<td></td>
<td>Tangential</td>
<td></td>
<td>8.69</td>
<td>1.00</td>
<td>7.90</td>
<td>1.10</td>
<td>0.49</td>
<td>17.73</td>
</tr>
<tr>
<td>Poplar</td>
<td>Longitudinal</td>
<td>Water</td>
<td>0.35</td>
<td>1.00</td>
<td>0.26</td>
<td>1.35</td>
<td>0.09</td>
<td>4.80</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td></td>
<td>4.19</td>
<td>1.00</td>
<td>2.58</td>
<td>1.62</td>
<td>0.46</td>
<td>9.11</td>
</tr>
<tr>
<td></td>
<td>Tangential</td>
<td></td>
<td>6.62</td>
<td>1.00</td>
<td>4.91</td>
<td>1.35</td>
<td>1.09</td>
<td>6.07</td>
</tr>
<tr>
<td>Fir-tree</td>
<td>Longitudinal</td>
<td>Water</td>
<td>0.48</td>
<td>1.00</td>
<td>0.28</td>
<td>1.71</td>
<td>0.10</td>
<td>4.80</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td></td>
<td>2.07</td>
<td>1.00</td>
<td>1.40</td>
<td>1.48</td>
<td>0.44</td>
<td>4.70</td>
</tr>
<tr>
<td></td>
<td>Tangential</td>
<td></td>
<td>4.91</td>
<td>1.00</td>
<td>3.97</td>
<td>1.24</td>
<td>1.12</td>
<td>4.38</td>
</tr>
<tr>
<td>Oak-tree</td>
<td>Longitudinal</td>
<td>Water</td>
<td>0.33</td>
<td>1.00</td>
<td>0.22</td>
<td>1.50</td>
<td>0.07</td>
<td>4.71</td>
</tr>
<tr>
<td></td>
<td>Radial</td>
<td></td>
<td>1.09</td>
<td>1.00</td>
<td>0.60</td>
<td>1.82</td>
<td>0.33</td>
<td>3.30</td>
</tr>
<tr>
<td></td>
<td>Tangential</td>
<td></td>
<td>3.98</td>
<td>1.00</td>
<td>1.75</td>
<td>2.27</td>
<td>0.64</td>
<td>6.22</td>
</tr>
</tbody>
</table>

The study of variation of the volume coefficients at the immersion allows gives a clear indication of the swelling process for the three solutions (Fig.5-8).
Thus, the variations of the swelling volume coefficients for red petroleum became after the sorption at the surface, almost linear, the process taking place with an uniform speed. On the contrary, in water and propolis the process obeys different sorption processes depending on the degree of impregnation, three stages being identified: the sorption process at the external surface, the sorption at the internal surface and the sorption at the membranes and intracellular places.

From this point of view, the four studied essences present totally different behaviors. For limewood there is the greatest difference, almost 16 times, between the volume swelling for red petroleum and that of protolytic solutions (water an alcohol). The poplar and oak are on the second place with a difference of 6 times and then comes fir-tree with almost 5 times. It is worthy to notice that the values for volume swelling coefficients in case of red petroleum treatment are very close for lime and oak-tree wood specimens (approximately 1.1%), for poplar and fir-tree wood specimens (approximately 1.7%) respectively; for the last ones the values are almost 1.5 greater than for the first two.

The degree of swelling decreases in this order: lime (18%)>poplar (11%)>fir-tree(8%)>oak-tree(7%).

The alcoholic solution of propolis has an interesting behavior, giving a variation of the swelling degree as in the case of water, but a little bit smaller: limewood (16%) > poplar(8%) > fir-tree (6%) > oak-tree (3%). These differences can be due to the different chemical composition of the four essences, which have different behavior in the three solutions.

3.2. The influence of treatments on wood specimens’ density

Since the treatments have been done by immersion, based on diffused and osmosis processes, an increase of the density until mass per unit volume became constant, according to a logarithmic curve, was expected. In the Figs. 9-12, the variations curves for the density of limewood, poplar, fir-tree and oak-tree wood samples, after immersion in water, propolis solution and red petroleum are presented for comparison.

In the first 30 minutes, the density of the samples increases significantly (see Table.3). The fir-tree wood, in the first 30 minutes, incorporates the largest quantity of red petroleum 77%, lime and oak about 60% and at the end poplar with only 40%. In return, in case of water immersion, the oak-tree wood incorporates in the first 30 minutes more water than the limewood, and after that poplar and fir-tree wood samples. Due to immersion in alcoholic propolis solution, in the first 30 minutes, the fir-tree incorporates the most, than oak-tree and
poplar and limewood comes at the end. Knowing these variations, can be an important criterion for the selection of the best compound implied in active preservation.

![Graphs showing density variations for lime, poplar, fir, and oak woods.](image)

**Fig. 9.** Variation of the density in time for limewood specimens at immersion  
**Fig. 10.** Variation of the density in time for poplar wood specimens at immersion  
**Fig. 11.** Variation of the density in time for fir-tree wood specimens at immersion  
**Fig. 12.** Variation of the density in time for oak-tree wood specimens at immersion

| Sample       | Treatment                              | The rate of density’s increase  
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>30 minutes* (%)</td>
</tr>
<tr>
<td>Limewood</td>
<td>Water immersion</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Alcoholic solution of propolis immersion</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Red petroleum immersion</td>
<td>59</td>
</tr>
<tr>
<td>Poplar</td>
<td>Water immersion</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Alcoholic solution of propolis immersion</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Red petroleum immersion</td>
<td>40</td>
</tr>
<tr>
<td>Fir-tree</td>
<td>Water immersion</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Alcoholic solution of propolis immersion</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Red petroleum immersion</td>
<td>77</td>
</tr>
<tr>
<td>Oak-tree</td>
<td>Water immersion</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Alcoholic solution of propolis immersion</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Red petroleum immersion</td>
<td>60</td>
</tr>
</tbody>
</table>

* ) Percentage of the final density after immersion (additionally), in the first 30 minutes  
**) The increase of the final density compared to normal density of the wood at the equilibrium moisture content
If we refer to the increase of the density, the biggest percentage is obtained for the immersion in water, than for propolis and the smallest is for red petroleum for all wooden essences. This fact is easy to explained since this is the order of decrease of the densities for all the three solutions.

3.3. The influence of the treatment on the wood’s porosity

Since the porosity has an inverse proportional variation with wood’s density, it is expected that its variation decreases proportionally with the increase of the density. In the Fig.13-16 it can be observed that the porosity of the four essences vary in time at immersion, according to the same rule as for density.

In Table 4 the rate of the porosity’s decrease for all four wood essences after immersion in water, propolis alcoholic solution and red petroleum is presented. Fir-tree wood, in the first 30 minutes, incorporates the greatest quantity of red petroleum, while the porosity decreases with 77%, then limewood and oak-tree with about 60% and finally poplar with only 40%.

In return, for water immersion, the oak-tree wood’s porosity decreases more than limewood, than poplar and fir-tree. After immersion in propolis alcoholic solution, in the first 30 minutes, the fir-tree’s porosity decreases most, than oak-tree, poplar and at the last limewood specimens. Knowing these variations is very important in the selection of the right dispersive compound used for active preservation.
Table 4

The rate of the decrease of wood’s porosity after immersion in solutions

<table>
<thead>
<tr>
<th>Sample</th>
<th>Treatment</th>
<th>30 minutes* (%)</th>
<th>6,5 hours** (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limewood</td>
<td>Water immersion</td>
<td>60</td>
<td>19.41</td>
</tr>
<tr>
<td></td>
<td>Propolis alcoholic solution immersion</td>
<td>42</td>
<td>18.45</td>
</tr>
<tr>
<td></td>
<td>Red petroleum immersion</td>
<td>59</td>
<td>16.50</td>
</tr>
<tr>
<td>Poplar</td>
<td>Water immersion</td>
<td>55</td>
<td>18.87</td>
</tr>
<tr>
<td></td>
<td>Propolis alcoholic solution immersion</td>
<td>44</td>
<td>16.97</td>
</tr>
<tr>
<td></td>
<td>Red petroleum immersion</td>
<td>40</td>
<td>14.15</td>
</tr>
<tr>
<td>Fir-tree</td>
<td>Water immersion</td>
<td>50</td>
<td>18.35</td>
</tr>
<tr>
<td></td>
<td>Propolis alcoholic solution immersion</td>
<td>69</td>
<td>11.92</td>
</tr>
<tr>
<td></td>
<td>Red petroleum immersion</td>
<td>77</td>
<td>11.92</td>
</tr>
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<td>Oak-tree</td>
<td>Water immersion</td>
<td>64</td>
<td>11.14</td>
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<tr>
<td></td>
<td>Propolis alcoholic solution immersion</td>
<td>60</td>
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</tr>
<tr>
<td></td>
<td>Red petroleum immersion</td>
<td>60</td>
<td>5.11</td>
</tr>
</tbody>
</table>

*) Percentage from the final porosity after immersion (additionally) in the first 30 minutes
**) The decrease of the final porosity compared with normal porosity of the wood at equilibrium moisture content

4. SUMMARY

- Dimensional changes of different wooden species under the influence of treatment with red petroleum and propolis, allow the evaluation of swelling and volume coefficients on all the three directions (longitudinal, radial and tangential), which represent the basis for density and porosity calculations of the wood samples;
- It has been pointed out that red petroleum gives the smallest degree of swelling for all four essences, and the dynamic and ratio variation on all the three directions are very different from one essence to the other;
- The variation of swelling coefficients in red petroleum, after the surface sorption, is almost linear, the process taking place with an uniform speed, while in water and propolis, the process obeys different sorption laws depending on the degree of impregnation; in this case three stages were identified: sorption at the external surface, sorption at the internal surface and membrane and intracellular sorption;
- With regard to density’s increase, the highest percentage is obtained during the water immersion, then for propolis and the smallest is for red petroleum for all four essences, which is easy to be explained, since in this order decrease the density of all the three solutions;
- Concerning the decrease of porosity, the smallest percentage was calculated for water immersion, then for propolis and the greatest was for red petroleum, for all the four wooden essences.

LITERATURE


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