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# Evaluation of Paraloid B-72 lime wood reinforcement efficiency.

PAWEŁ KOZAKIEWICZ[1], PIOTR MAŃKOWSKI[1], EWA WIŁKOJĆ[2]

[1] Katedra Nauki o Drewnie i Ochrony Drewna SGGW w Warszawie
[2] Pracownia Konserwacji, Zamek Królewski na Wawelu, Kraków

**Abstract:** Lime wood because of its workability and availability is commonly used by artists. Lime wood was commonly used for sculptures, reliefs, underpaintings and larger objects, such as altars. Main disadvantage of his wood is low natural resistance against insects and microorganisms. Majority of antique objects made of lime wood is in some way damaged. According to this fact, it is necessary to reliably evaluate efficiency of the treatments used for impregnation and reinforcement of monumental wood structure.

***keywords:*** lime wood, Paraloid B-72, preservation, wood density, modulus of elasticity, ultrasound

## INTRODUCTION

Two domestic species of lime are prezent in Poland. Nothern part of the country (almost whole lowland) small-leaved lime (*Tilia cordata* Mill.) is present, Southern part is dominated by large-leaved linden (*Tilia platyphyllos* Scop.). Second of the mentioned species grows faster, but is more demanding against habitat (Gałczyński 1928, Strojny 1981). Lime is the only broadleaved wood species with lifespan similar to oak. According to XVIII century writings of priest Krzysztof Kluk*) **„więcej tysiąca lat na pniu się nie psuje"**, reaching appreciable size: around 40m of height and 800 cm of stem perimeter (Strojny 1981).

Even in antiquity lime was named tree of thousand uses. Out of lime wood combat shields were made and in peaceful times spoons, bowls or altars. Out of lime bast shoes and mats were made (on eastern borderlands even to beginning of XX century). Lime for a long time was common in Poland, properties and usability of its wood was widely known.

Lime wood is straight-grained and soft, easily workable even with simple tooling. Because of that, it is eagerly and commonly used for sculptures, reliefs, underpaintings and altars. Nowadays, numerous objects made of lime wood are gathered in museal collections and churches (e.g. Altar in Mariacki church in Cracow). Objects are in various state of preservation, because this species of wood shows low natural resistance and is commonly attacked by insects and microorganisms (Kollmann, Cöte 1968, Krzysik 1978).

Verification of monumental lime wood reinforcement efficiency with variable chemicals seems to necessary for planning and performing of renovation or conservation works.

## TEST MATERIAL AND METHODIC

Base test material was wood doming from secondary underpaintings of „Guardian Angel" painted in 1725 roku (some suppose that painting presents Archangel Rafael guiding Tobias, and other that Guardian Angel and youth). Painting is exhibited in Basilica Minor in Łowicz Cathedral of Our Lady's Assumption. Wood from underpainting was strongly devastated by wood borer (*Anobium punctatum* De Geer). For reference purposes, contemporary defect-free lime wood, seasoned in normal conditions for 10 years, was also tested.

Out of antique and contemporary wood test samples were cut out, 30 cm long with cross-section of 20x20 mm, in accordance to PN-63/D-04117. Assuming that antique and contemporary lime wood shows similar hygroscopic properties (Burmester 1970, Kozakiewicz 2000), all samples were conditioned over saturated NaCl solution, with considerable benthic deposit, in aim to reach air-dry moisture content (equilibrium moisture content around 12-15%) (Schneider 1960).

After conditioning, density of the samples was tested with stereometric method in accordance to PN-77/D-04101, bending modulus of elasticity in accordance to PN-63/D-04117 and with ultrasonic method UMT-1 tester (frequency 100 kHz, amplification 35 dB, trigger level 8, repetition 12 Hz, Doppler gel – ultrasonographic gel), moisture content using drying and weighting method was also tested, in accordance to PN-77/D-04100.

Guided by previous conservation experience (Paciorek 1993, Młodożeniec 1996) one of the verified proofing substance was selected - Paraloid B-72 and used for impregnation. Paraloid B-72 is copolymer of methyl acrylate and ethyl methacrylate thermoplastic.

Samples were soaked in Paraloid B-72 toluene solution. According to conservation guidelines, three concentrations were used - 5, 10 and 20%. In every solution, samples were immersed three times for two hours. After evaporation of solvent, using drying and weighting method, amount of Paraloid B-72 deposited in wood was determined. After conditioning, density and bending modulus of elasticity was tested, using static bending and ultrasonographic tester.

## RESULTS AND ANALYSIS

Test results are shown in table 1 and on figures 1 and 2. Standard density range of air-dry lime wood ranges from 350 kg·m$^{-3}$ to 600 kg·m$^{-3}$ with average of 530 kg·m$^{-3}$. (Krzysik 1978). Density of contemporary lime wood, selected for tests, in dry state reached 441 kg·m$^{-3}$ and was similar to standard one. Wood attacked by wood borers showed significantly lower density of 375 kg·m$^{-3}$ (table 1). After Paraloid B-72 saturation average density increased by 15 kg·m$^{-3}$ in contemporary wood, in antique lime reached twice this value. This was caused by increased absorptivity of antique wood. Paraloid B-72 settled in larvar galleries filled by wood flour having different properties (absorbing power) in comparison to not impaired lignin-cellulose structure of lignified cell walls.

According to Krzysik (1978) static bending modulus of elasticity of air-dry lime wood ranges from 5,8 GPa up to 17,2 GPa. Average value is 7,4 GPa (the same value is given by Wagenführ 2007). Modulus of elasticity of tested contemporary lime wood held in mentioned range (average of 6400 MPa), antique wood showed lower values (average of 4200 MPa), having lowered strength properties.

**Table 1.**
Selected mechanical and physical properties of lime wood before and after Paraloid B-72 saturation

| Phsical /mechanical feature of lime wood | Notation and unit | Type of lime wood | | | |
|---|---|---|---|---|---|
| | | Natural before consolidation | Natural after consolidation | Old before consolidation | Old after consolidation |
| Sample | N | 11 | 11 | 11 | 11 |
| Content of Paraloid B-72 in % dry wood (P): | | | | | |
| - average | $\bar{x}$ [%] | 0 | 3,3 | 0 | 8,1 |
| - standard deviation | Σ [%] | - | 0,9 | - | 2,3 |
| - variation coefficient | Y [%] | - | 27,2 | - | 28,6 |
| Density ($g_{12}$): | | | | | |
| - average | $\bar{x}$ [kg/m$^3$] | 441 | 456 | 375 | 405 |
| - standard deviation | Σ [kg/m$^3$] | 38 | 36 | 11 | 14 |
| - variation coefficient | Y [%] | 8,6 | 7,9 | 3,1 | 3,5 |
| Ultrasound velocity MC=12% (v): | | | | | |
| - average | $\bar{x}$ [MPa] | 5357 | 5219 | 4545 | 4194 |

| | | | | | |
|---|---|---|---|---|---|
| - standard deviation<br>- variation coefficient | σ [MPa]<br>υ [%] | 171<br>3,2 | 222<br>4,2 | 212<br>4,7 | 203<br>4,8 |
| MOE (12) PN-63/D-04117 ($E_{st}$): | | | | | |
| - average<br>- standard deviation<br>- variation coefficient | $\bar{x}$ [MPa]<br>σ [MPa]<br>υ [%] | 6437<br>635<br>9,9 | 6310<br>704<br>11,2 | 4177<br>505<br>12,1 | 4038<br>490<br>12,1 |
| MOE(12) ultrasound method determinate ($E_d$): | | | | | |
| - average<br>- standard deviation<br>- variation coefficient | $\bar{x}$ [MPa]<br>σ [MPa]<br>υ [%] | 9447<br>1280<br>13,5 | 9258<br>1313<br>14,2 | 5769<br>582<br>10,1 | 5305<br>509<br>9,6 |

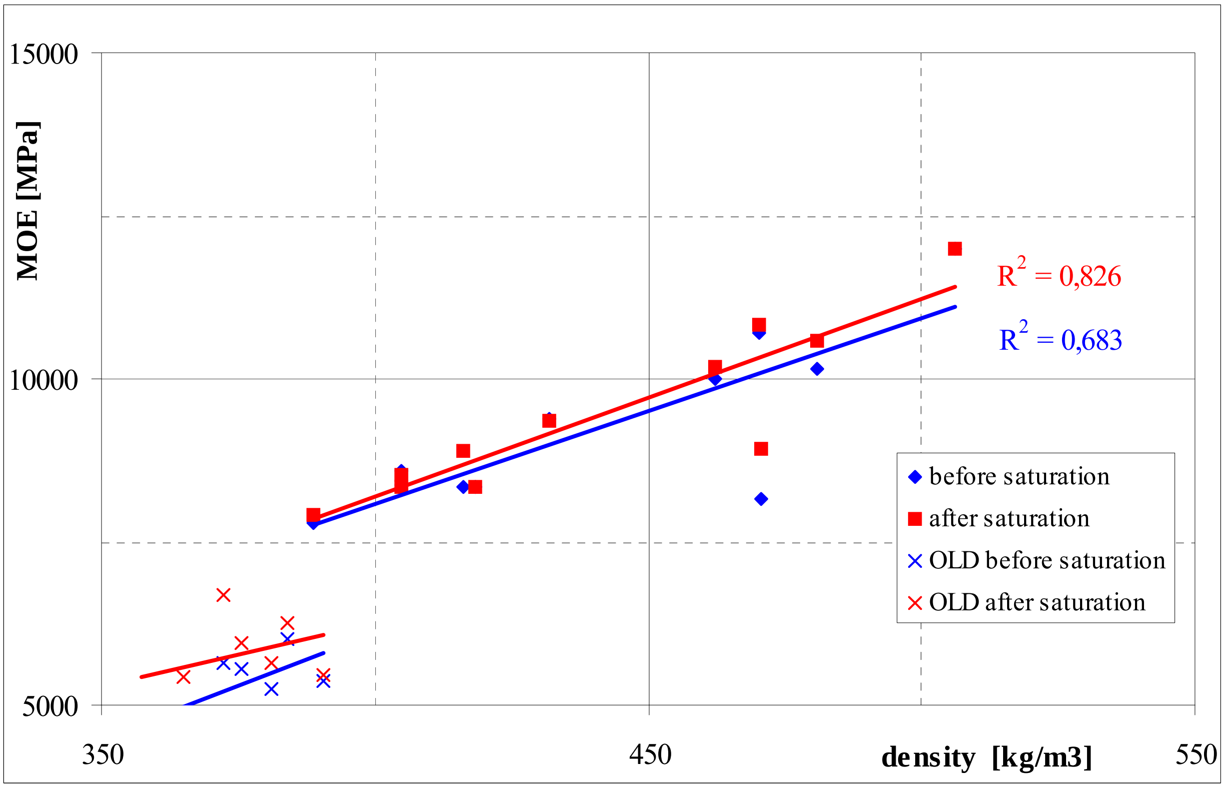


Fig.1. Dependence of lime wood of 12% moisture content and modulus of elasticity tested with ultrasonic method. (squares – points obtained for contemporary wood, crosses – points obtained for antique wood)

Wood devastated by wood borers show lowered modulus of elasticity values against noticed density. For example, in sound lime wood of 350 $kg \cdot m^{-3}$ density modulus should reached around 8000 MPa, but in tested antique wood values showed 6000 MPa only.

Introduction of Paraloid B-72 into the wood caused insignificant density gain and slight modulus of elasticity changes. Most probably preservative penetrating cell walls caused permanent swell, meaning displacement of cellulose chains, which caused changes of modulus of elasticity along the grain, in both sound and insect devastated wood. Changes were noticed independently of modulus measurement method type. (table 1.).

Observation of 100 kHz ultrasonic waves moving along the grain enables quick wood quality evaluation. Sound lime wood shows low wave damping, in damaged one damping is considerably higher. Saturation of wood with Paraloid B-72 practically does not change damping value.

CONCLUSION

1. Velocity of 100 kHz ultrasonic waves in sound lime wood along the grain averages 5350 $m\cdot s^{-1}$ and is higher than in partially damaged by wood borer lime, reaching 4550 $m\cdot s^{-1}$. Introduction of Paraloid B-72 into wood structure does not change these values.
2. Independently on Paraloid B-72 saturation damping of ultrasonic waves in damaged antique lime wood is considerably higher than in contemporary, sound wood. Preservation does not change this dependencies.
3. Reinforcement of lime wood with Paraloid B-72 causes insignificant density gain of the wood and slight modulus of elasticity along the grain changes. In antique wood damaged by insects changes are more visible than in contemporary, sound wood.

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**Streszczenie:** *Ocena skuteczności wzmocnienia struktury drewna lipowego Paraloidem B-72.* Drewno lipy ze względu na łatwość obróbki i wykończenia, było przez wieki chętnie wykorzystywane jako tworzywo artystyczne. Obecnie w zbiorach muzealnych i kościołach znajduje się dużo cennych obiektów zabytkowych wykonanych z drewna lipowego.

Drewno to jest w różnym stopniu zniszczone ( drewno lipowe ma niską naturalną trwałość) Jednym ze stosowanych sposobów konsolidacji zabytkowego drewna jest jego nasycanie związkami chemicznym np. Paraloidem B-72. Dobierając do badań zabytkowe drewno lipowe uszkodzone przez kołatki oraz zdrowe drewno współczesne określono wpływ nasycenia drewna Paraloidem B-72 na wybrane właściwości fizyczne, które zostały oznaczone metodami nieniszczącymi.

Prędkość przejścia fal ultradźwiękowych o częstotliwości 100 kHz wzdłuż włókien w zdrowym drewnie lipowym jest większa od prędkości w drewnie zniszczonym przez owady. Wielkość tłumienia fal ultradźwiękowych w zdrowym drewnie lipowym jest istotnie niższa w porównaniu do drewna zabytkowego.

Wprowadzanie do struktury drewna Paraloidu B-72 powoduje nieznaczny wzrost gęstości drewna i niewielkie zmiany modułu sprężystości wzdłuż włókien. Zmiany te w uszkodzonym przez owady drewnie zabytkowym są wyraźniejsze w porównaniu do drewna współczesnego.

Corresponding authors:

dr inż. Paweł Kozakiewicz
Katedra Nauki o Drewnie i Ochrony Drewna
Wydział Technologii Drewna, Szkoła Główna Gospodarstwa Wiejskiego
ul. Nowoursynowska 159 (budynek nr 15)
02-787 Warszawa
e-mail: pawel_kozakiewicz@sggw.pl

dr inż. Piotr Mańkowski,
Katedra Nauki o Drewnie i Ochrony Drewna
Wydział Technologii Drewna, Szkoła Główna Gospodarstwa Wiejskiego
ul. Nowoursynowska 159 (budynek nr 15)
02-787 Warszawa
e-mail: piotr_mankowski@sggw.pl

dr Ewa Wiłkojć, Główny Konserwator
Zamek Królewski na Wawelu
31-001 Kraków, Wawel 5
tel. 422 4155 wew. 338
fax. 422 19 50
e-mail: zamek@wawel.krakow.pl