Influence of Thermal Modification in Nitrogen Atmosphere on Physical and Technological Properties of European Wood Species with Different Structural Features

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Abstract: The wood of five European species: black poplar (Populus nigra L.), European beech (Fagus sylvatica L.), European ash (Fraxinus excelsior L.), European oak (Quercus robur L.), and Scots pine (Pinus sylvestris L.) was subjected to thermal modification in nitrogen atmosphere at 190 °C during 6 h. Native and modified wood was varnished and oiled in industrial conditions. Thermally modified (TM) wood was characterized by a greater absorption of varnish and oil when applying the first layer to the surface, which finally resulted in higher application values compared to native wood. In particular, after varnishing, there was a significant increase in gloss and radical change of colour. Regardless of the wood species, finishing process (varnishing, oiling), the ΔE values were close to or higher than 6, which proves high colour changes. Modified poplar, ash, and oak after varnishing had a different colour (ΔE higher than 12). The surface colour changes as a result of UV photoaging was individual, depending on the wood species and the method of finishing. In the case of the thickness of varnish coatings, the wood structure was important, i.e., on ring-porous hardwood and softwood they were thicker. In the case of wood species with a lower density, i.e., black poplar and pine, the thermal modification in nitrogen atmosphere process did not reduce the resistance of the varnish coat, and in the case of species with a higher density (oak, ash, beech) it decreased by one level. Thermal modification reduced the Brinell hardness of wood with wide rays (oak and beech) by 11%. The applied process of surface finishing by double varnishing or oiling did not significantly change the hardness of tested wood.

Keywords: black poplar; coating; colour; European ash; European beech; European oak; gloss; hardness; oiling; Scots pine; UV degradation; varnishing

1. Introduction

Thermal modification of wood is a process conducted in oxygen-free environmental in the temperature range from 160 °C to 260 °C [1]. The first works in this area were undertaken at the beginning of the 20th century in the USA, and later in Germany at the turn of the 1970s and 1980s [2,3]. These methods, however, did not find industrial application. It was not until the 1990s that commercial methods of wood modification developed, such as Retiwood and Le Bois Perdure in France, ThermoWood in Finland, Menz Holz and Oil-Heat-Treatment (OHT) in Germany, PLATO-wood in the Netherlands [3–5]. Recently, new modification methods have also been developed in Denmark—WTT and in Austria—Huber Holz [6]. The main differences between these methods based on the materials used (wood species, fresh or dried wood, wood moisture content, and dimensions) and the process conditions (one or two process stages, wet or dry process, heating medium, air or nitrogen as inert gas, heating and cooling rates, open or closed system) [7]. The global commercial production of modified wood is about 1 MM m³/year [8]. For this reason, investigation of wood after thermal modification is important.
An important factor determining the course of the modification process and consequently the properties of wood is the temperature [9,10]. Environmental is also important factor. Structural compounds of wood such as hemicelluloses, cellulose, and lignin very quickly decompose in oxygen atmosphere at high temperature. According to this, many heat treatment processes took place in inert atmosphere, such as ThermoWood, Le Bois Perdure, OHT, ThermoVuoto. Therefore, an inert atmosphere such as steam, nitrogen, or inert liquid should be used, or the gases should be continuously removed using a vacuum. Changes taking place in wood under the influence of temperature in the atmosphere of water vapor have been described very well in the literature [11–13]. Generating water vapor, however, requires the use of a large amount of energy and the collection of condensate formed during wood modification. A better atmosphere in this case is nitrogen, because less energy is used to heat it, and the condensate formed during the process has a much smaller volume. Nitrogen is a cheap and readily available gas. The conducted research shows that nitrogen modification is less destructive compared to modification in water vapor. The mass loss of black poplar modified in superheated steam for 2 h at the temperature of 160 °C, 190 °C, and 220 °C amounted to 3%, 4%, and 12%, correspondingly, while for black poplar modified in nitrogen modification these values amounted to 1%, 1%, and 7%, respectively [14,15]. Bal [16] also stated that the modification of black pine wood in nitrogen caused a smaller mass loss (0.8%, 1.3%, 2.9%) for temperatures of 180 °C, 200 °C and 220 °C compared to the thermal modification of wood in the air atmosphere (1.2%, 1.6%, 3.4%), during 150 min. Whereas the modulus of rupture was 2 MPa, 11 MPa, 20 MPa lower after modification in nitrogen and 4 MPa, 14 MPa, 24 MPa lower after modification in air, respectively compared to unmodified wood.

The influence of thermal modification on the wood properties is significant. After thermal treatment wood has higher dimensional stability, greater biological resistance to biotic factors [6,17–19]. The colour changes are a great advantage, which makes European species similar to exotic species [6,20,21]. The effect of thermal modification is reduced wood density, strength [22,23], which makes wood difficult to use as a construction material. Thermally modified wood is dedicated, in particular, to applications in outdoor conditions, especially for facades, decking, and garden furniture, which results mainly from increased resistance to water and biological factors. Thermally modified wood can be used in various applications such as interior wall panels, furniture and other value-added wood products. However, the wood surface is susceptible to degradation by weathering when exposed to outdoor conditions. Weathering is caused by exposure to ultraviolet radiation, moisture (rain, snow and dew) and wind [24]. Moreover, discolouration and formation of surface cracks often occur [7,25]. As a result of thermal modification, the wettability of wood is reduced [7,26,27]. Additionally, wood after modification is more brittle and its hardness decreases [28–30].

In order to improve the functional properties and durability of wood used especially outdoors, it should be finished [31,32]. When selecting coatings, several factors should be taken into account. The dynamic development of finishing agents allows for the optimal selection of the type of finish depending on the wood species, the expected conditions of use of the finished products. The coatings reduce the speed and amount of water absorbed, thus prevent changes in the moisture content of the finished products. It is also important to prevent wood discolouration as a result of UV radiation [33]. Additionally, the coatings can increase the wood hardness and increase its abrasion resistance [24]. Thermal modification has a positive effect on the application of paint and varnish coatings. After the process, wood is relatively dry and has no extractives in the form of resins, fats and waxes [34] and its pH is lowered [35,36].

For modified wood with significantly changed properties, the knowledge about the surface improvement processes and the results (effectiveness) of these measures is still incomplete. In particular, there are no reports on the technological properties of thermally modified wood in nitrogen atmosphere, especially finished with different coatings. The colour stability of thermally modified wood in overheated steam and covered with various
types of coatings was widely analysed [37,38]. The influence of wood heat treatment and coatings on hardness, scratch resistance [39], abrasion resistance [40] was investigated. It should be noted that this type of research was not carried out on thermally modified wood in a nitrogen atmosphere, especially in such a wide range of wood species with different morphological features. Therefore, the aim of the study was to determine the effect of heat treatment in nitrogen atmosphere, covered with oil and varnish, on selected physical and technological properties of European wood species with different structural features.

2. Materials and Methods

2.1. Wood Sampling

Wood of European species with different structural features was used for the research (Table 1). Wood species represented various types of structure and differed in the size of wood rays.

Table 1. Investigated wood species.

| Latin Name             | Trade Name of Wood | Code According to EN-13556:2003 [41] | Wood Structure                       |
|------------------------|--------------------|--------------------------------------|-------------------------------------|
| *Populus nigra* L.     | black poplar       | PONG                                 | deciduous diffuse-porous with fine wood rays |
| *Fagus sylvatica* L.   | European beech     | FASY                                 | deciduous diffuse-porous with wide wood rays |
| *Fraxinus excelsior* L.| European ash       | FXEX                                 | deciduous ring-porous with fine wood rays |
| *Quercus robur* L.     | European oak       | QCXE                                 | deciduous ring-porous with wide wood rays |
| *Pinus sylvestris* L.  | Scots pine         | PNS                                  | coniferous                           |

The highest quality boards were obtained from the wood of the tested species, with no visible material defects (knots, slop of grain, resin pocked, bark pocked, reaction wood, wanes, blue stains, decays, insect holes, shakes, distortions, etc.). They were planed boards with dimensions of 25 mm (radial) × 140 mm (tangential) × 2500 mm (longitudinal), conditioned in a normal climate (temperature 20 °C ± 2 °C, relative humidity 65% ± 5%) to an air-dry condition. The boards were obtained from the butt part of the trunk, from the mature wood zone.

Each board was cut crosswise into four parts, approximately 620 mm long (Figure 1). In this way, “twin” parts of wood were obtained, half of which remained in their original state (native wood), and the other were thermally modified under nitrogen atmosphere.

Figure 1. Scheme of the division of boards into “twin” samples for thermal modification and subsequent surface finishing.

2.2. Thermal Modification in Nitrogen Atmosphere

The process of thermal modification of wood was carried out in nitrogen atmosphere. The modification was performed in an 0.25 m³ chamber (Explo Solutions sp. z o. o., Warsaw, Poland). The modification chamber is adjusted to working in pressures between −1 atm and 1 atm and is equipped with forced air circulation. The device is controlled by a computer, with the option to carry out a technological process composed of 8 steps and lasting up to 168 h.
The modification of wood was carried out at the temperature of 190 °C during 6 h. The thermal modification process was carried out according to the methodology described by Bytner et al. [15]. After the modification process, the wood was air-conditioned in a normal climate (temperature 20 °C ± 2 °C, relative humidity 65% ± 5%).

2.3. Moisture Content and Wood Density

Wood moisture content was determined by the non-destructive electrometric method according to EN 13183-3:2005 [42]. In all samples, the measuring probes of the capacitive moisture meter WIP-24 (Thanel, Gliwice, Poland) were placed on the bottom, unfinished wood surfaces. Wood density was determined using the stereometric method in accordance with ISO 13061-2:2014 [43].

2.4. Wood Surface Finishing

After the thermal modification process, the right surfaces of boards were planed. Re-planing was performed to remove contaminants after the modification process (fine surface stains). On the other hand, re-planing of the remaining samples, i.e., unmodified wood, was carried out to ensure the same mechanical treatment of the surface before the colour and gloss measurements, and above all, before the further finishing process.

The wood samples were finished by: varnishing or oiling in industrial conditions. The process of surface finishing of native and thermally modified wood was performed in industrial conditions at Parkiety Jabłoński (Tchórzynka Włościńska, Poland) parquet factory. Before applying the oil or varnish, the surfaces of the boards were sanded with a Costa Levigatrici S.P.A. model K7 wide-belt sander (Schio, Italy), with sanding belts of granulation P80, P120 and P150. The boards were coated on a Cefla model SmartParquet 300 (Imola, Italy). The agents were applied with rubber rollers and then cured with ultraviolet radiation (UV). Both sets (varnish and oil) were applied in two cycles: undercoat and coat. A three-component system was used for varnishing: Fondo UV118 (undercoat, one application), Fondo UV320 (undercoat, two applications) and Finitura UVR75-G30 (coat, two applications)—producer Chimiver (Via Bergamo, Italy). After the undercoat had cured, the surface was sanded with P280 and P320 belts. For oiling the wood, a two-component system was used: Osmo UV 5160 (undercoat, one application), 5134 (coat, one application)—producer Osmo (Warndorf, Germany). After the undercoat had cured, the surface was sanded with a K240 sanding roller. The parameters of the finishing process were in accordance with the instructions (technical sheets) of the used agents.

2.5. Wood Photoaging

The wood was photoaged in dedicated chambers. The exposure of the samples was carried out in parallel in four (identical in terms of operating parameters) UV-WL365-P36 chambers with settings and registration of the exposure time. The UV lamp consisted of 36 LEDs (powerLED 1W-UV 365 nm) with a power of 1W (efficiency approx. 95%) and a wavelength of 365 nm–370 nm, evenly distributed on the surface of 0.4 m × 0.4 m. The power of the lamp was therefore approx. 210 W × m⁻². The photoaging process was carried out for 100 h. The spectral characteristics of the diodes with the characteristics of the wave shift depending on the temperature were shown in Figure 2.

2.6. Determination of Wood Colour Parameters

The wood colour parameters were determined on the basis of the CIE L*a*b* model. Colour was described as the achromatic L* component and two chromatic components: a* and b*. The lightness L*, the chromatic coordinate on the red-green axis a*, and the chromatic coordinate on the yellow-blue axis b* were determined. Wood colour parameters were measured before and after surface finishing (varnishing or oiling), and after photoaging in six points in each sample. In total, results were gathered from 60 measurement points for unmodified (native) wood, for modified wood before and after surface finishing, and after photoaging process. Simultaneously with the measurement of the colour parameters,
the gloss was determined. The device used to measure colour parameters and gloss was Spektromaster 565-D (Erichsen GmbH & Co. KG, Hemer, Germany). Measurements were made with a D65 illuminant and a 10° standard observer. The total colour difference ΔE was determined in accordance with ISO 7724-3:1984 [44].

Figure 2. Characteristics of powerLED 1W-UV 365 nm diodes in the UV-WL365-P36 chamber radiator: (a) wavelength—relative spectral power, (b) case temperature—peak wavelength shift.

2.7. Film Thickness and Cross-Cut Test

The thickness of the coatings was determined by the ultrasonic method with the use of a portable instrument, ultrasonic coating thickness gage PosiTector 200 (DeFelsko Corporation, Ogdensburg, NY, USA). It is a portable non-destructive ultrasonic gauge for simultaneous measurement of the thickness of one, two or three single coating layers on a non-metallic substrate, such as wood, concrete, glass, plastic or rubber. The measurement was carried out in accordance with the requirements of ISO 2808:2007 [45] and at the same points as the colour and gloss measurement.

The resistance of coatings to separation from wood was determined by the cross-cut method according to ISO 2409:2020 [46] using the Peters rotary cutter N 034 (JB Labtech, Gdynia, Poland) consisting of a cutting head in the form of a circular knife (6 blades at 1 mm spacing) and a handle. The incisions were made obliquely (angle approx. 45°) in relation to the wood grain, with one stroke at a speed ranging from 2 m × s$^{-1}$ to 5 m × s$^{-1}$. The pressure force was selected so that the cuts reached to the substrate (wood), but with the smallest possible incision in the substrate. In each of the selected fields, two incisions perpendicular to each other were made, which formed the required grid of incisions (cross-cut areas). The resistance classification was made on a scale from 0 to 5, based on comparing the appearance of the cross-cut area with the drawings and description provided in ISO 2409:2020 [46].

2.8. Brinell Hardness Test

The Brinell hardness was determined according to the recommendations of ISO 6506-1:2014 [47]. Hardness was determined for native and modified wood on a raw (unfinished) surface, after finishing, i.e., after varnishing and after oiling. The hardness was tested using the Vexus SBRV-100D digital hardness tester (Powertech S.C., Andrychów, Poland) with the use of a steel ball with a diameter of 10 mm as an indenter, with a loading force of 980.7 N and a working time of 15 s, using carbon paper, so that the bowl and the outline of the recess (imprint) are better visible. Due to the anisotropic structure of the wood, the resulting impressions were not perfectly circular, therefore in each of them two diameters were measured (parallel and perpendicular to the grain) and on this basis the average value was calculated and then the Brinell hardness.
2.9. Statistical Analysis

The statistical analysis of results was carried out with the use of the STATISTICA Version-12 software of StatSoft, Inc. (TIBCO Software Inc., Palo Alto, CA, USA). The analysis was based on the t-test or the ANOVA (Fischer’s F-test), with a significance level ($p$) of 0.05. The percentual impact of the analysed factors (temperature and time of modification), the so-called Factor Influence on the selected properties of tested wood species was analysed. The control group was unmodified wood.

3. Results

3.1. Wood Density, the Application Rate of Agents and Film Thickness

Black poplar wood had wide annual growth rings, covering mainly the heartwood zone with an average density of 369 kg × m$^{-3}$. European beech, European oak and European ash had medium annual growth rings. In the case of beech, it was sapwood, without false heartwood (average density 681 kg × m$^{-3}$), oak-heartwood (average density 671 kg × m$^{-3}$), and ash was mainly heartwood (average density 726 kg × m$^{-3}$). Pine wood had narrow annual growth rings mainly from the sapwood zone (average density 595 kg × m$^{-3}$). Density (taking into account the width of annual growth rings) was a typical for individual wood species [48,49]. Within individual species, samples of practically constant, repeatable density were obtained, which is confirmed by very low values of standard deviations (Table 2) and thus the coefficients of variation in all cases below 3%. This proves the repeatability of the material used in all research variants.

Table 2. Native wood density (standard deviation in parentheses), the application rate of agents.

| Wood Species | Wood Density (kg × m$^{-3}$) | Application Rate (g × m$^{-2}$) |
|--------------|-----------------------------|---------------------------------|
|              |                             | Varnish | Oil |
|              |                             | N       | TM  | N       | TM  |
| poplar       | 369 (5)                     | 111     | 128 | 16      | 17  |
| beech        | 681 (20)                    | 102     | 112 | 16      | 19  |
| ash          | 726 (14)                    | 122     | 146 | 16      | 18  |
| oak          | 671 (3)                     | 105     | 132 | 18      | 20  |
| pine         | 595 (7)                     | 118     | 129 | 18      | 20  |

During the application of agents, both varnish and oil, no clear technological differences depending on the wood species used were found. A noticeable difference between native (N) and thermally modified (TM) wood in all the tested wood species was the slightly higher varnish and oil absorption when the first layer was applied to thermally heated wood. As a consequence, this resulted in slightly higher values of deposition for thermally heated wood (Table 2).

During heat treatment process hemicelluloses as first change their structure. Deacetylation process was conducted to create an acetic acid, which indicates depolymerisation process [50,51]. Most of the extractives disappear or degrade but new ones appear as degradation products from decomposition of other structural components of wood [52]. Due to chemical changes occurring during modification at high temperature, thermally treated wood, regardless of the species or type of structure, shows a lower equilibrium moisture content (EMC) compared to native wood [14,15,53–55]. The lower moisture content of TM wood contributes to the observed higher absorption of agents. Regardless of this, no differences were observed in the curing (drying) process of oil and varnish coatings on native and TM wood. The second important factor affecting the greater absorption of agents, which translates into a higher application rate, is the lower density of TM wood as a result of mass loss, which is a consequence of chemical changes occurring during modification at high temperature. Wood with a lower density is characterized by a greater surface porosity and roughness, which are increased after heat treatment [56], and has less surface free energy [57–59].
Different varnish coating thicknesses were obtained, depending on the species of wood (Figure 3a). In the case of wood with clearly inhomogeneous grain structure: ring-porous oak and ash, and softwood–pine wood, thermal modification significantly increased the thickness of the coating. Most likely, the penetration depth of the varnish was greater in these wood species. The greatest changes in the thickness of the coating were recorded for ash wood (the coating was 2.5 times thicker for TM wood than for native). Much smaller changes were observed in the homogeneous diffuse-porous wood of poplar and beech. The coating thickness in the TM poplar and beech wood was 6% and 17% higher, respectively, than for native wood, and these differences were statistically significant (t-test, $p \leq 0.05$).

For oil, practically no influence of the wood species was observed, i.e., the average thickness of the obtained coating after applying the oil was similar in all samples of native wood and amounted to 40–50 µm (Figure 3b). Regardless of the species of wood, the thermal modification significantly influenced the thickness of the oil layer by reducing its thickness (unlike in the case of varnishing) and these differences were statistically significant. The thickness of the oil layer was about 15% lower for TM wood than for native wood. The exception was oak wood, for which there were no differences in the thickness of the oil coating in native and TM wood. For example, in studies carried out by Vidholdová et al. [40] on Turkey oak (Quercus cerris L.) native and thermally modified wood (at temperatures of 175 °C and 195 °C for 4 h) finished natural linseed oil, hard wax oil, and hard wax, the same thickness of the surface finishes was formed.

3.2. Wood Colour and Gloss
3.2.1. Parameters Determined after Finishing

The appearance of the wood surface after varnishing and oiling was presented in Figure 4.

The organoleptic observations showed that the thermal modification definitely changed the colour of the wood to dark brown, with the oak wood being the darkest and the pine wood the lightest. Varnishing resulted in a noticeably stronger effect of enhancing (darkening) the colour compared to oiling. Moreover, varnishing, as compared to oiling, regardless of the species of wood, also resulted in a significantly greater gloss, which makes the difference in colour between oiled and varnished samples hardly noticeable in Figure 4.

The changes in the value colour components ($L^*$, $a^*$, $b^*$) after finishing the wood surface (varnishing, oiling) were presented in Table 3. It should be stated unequivocally...
that as a result of the surface finishing of native (N) and thermally modified (TM) wood, there was a change in colour and gloss.

| Wood Species | Before Finishing | After Varnishing | After Oiling |
|--------------|------------------|-----------------|-------------|
|              | Native Wood      | Thermally Modified Wood | Native Wood | Thermally Modified Wood | Native Wood | Thermally Modified Wood |
| poplar       |                  |                  |             |                         |             |                         |
| beech        |                  |                  |             |                         |             |                         |
| ash          |                  |                  |             |                         |             |                         |
| oak          |                  |                  |             |                         |             |                         |
| pine         |                  |                  |             |                         |             |                         |

Figure 4. Native and thermally modified wood before and after varnishing and oiling.
After varnishing, the native wood darkened ($\Delta L^*$ from $-1.53$ to $-8.11$), the colour of the wood changed mainly towards yellow ($\Delta b^*$ from $4.68$ to $7.49$), to a lesser extent towards red ($\Delta a^*$ from $0.60$ to $3.16$). After varnishing, the TM wood showed a different direction of colour changes than the native wood and due to greater $L^*$ changes, a greater total colour change $\Delta E$ was noted. After varnishing, the TM wood darkened significantly ($\Delta L^*$ from $-5.02$ to $-13.29$), the colour of the wood changed mainly towards blue ($\Delta b^*$ from $-2.36$ to $-10.17$), to a lesser extent in towards the red colour ($\Delta a^*$ from $0.24$ to $4.59$). The exception was TM pine wood, which after varnishing turned yellow ($\Delta b^*$ at $3.46$) and not blue.

After oiling, the native wood darkened ($\Delta L^*$ from $-2.41$ to $-9.13$), the colour of the wood changed mainly towards yellow ($\Delta b^*$ from $4.75$ to $8.68$), and to a lesser extent towards red ($\Delta a^*$ from $0.70$ to $3.09$). Thermally modified wood after oiling showed a different direction of colour changes than the native wood after oiling. After oiling, the TM wood darkened significantly ($\Delta L^*$ from $-5.15$ to $-10.26$), depending on the species, the colour of the wood changed mainly towards red ($\Delta a^*$ from $0.87$ to $4.95$) or towards blue colour ($\Delta b^*$ from $-0.34$ to $-5.89$).

Thermal modification affects the colour of the wood [40,60,61]. During thermal modification, mainly hemicelluloses are degraded. Organic acids such as acetic acid and formic acid are produced parallel. It was stated that these acids influence the darkening of wood [62]. Additional use of acidic varnish coatings may cause darkening of the wood [63]. Coatings can also react with wood components, which can affect the final colour of the wood. The greatest changes were observed for the $L^*$ parameter [60,64]. In the case of $a^*$ and $b^*$ parameters, different directions of changes were observed, which depend on many factors, i.e., wood species, the modification process parameters. The $a^*$ parameter increased, $b^*$ decreased in black locust after heat treatment in nitrogen atmosphere [20] or the values of $a^*$ and $b^*$ decreased for pine wood after modification in water steam [65]. Similar results were obtained for oak wood by Gurleyen et al. [66], which investigated the effect of thermal modification and application of a matt varnish coating on the colour of the wood. The obtained results indicated a decrease in the $L^*$ parameter of thermally modified oak wood ($212 \, ^\circ C$ for 2 h) and varnished to 17.9 from 56.8 recorded for native oak wood after varnishing. After varnishing of modified wood at 190 $^\circ C$, an increase in $a^*$ parameter and a decrease in $a^*$ were found for the temperature of 212 $^\circ C$. A decrease in the $b^*$ parameter was noted across the entire modification temperature range with respect to native wood covered with matt varnish. Pelit [63] noted a decrease in lightness after thermal modification in steam by 62% in Scots pine and up to 64% in beech samples, while the parameter $b^*$ has decreased up to 40% in Scots pine samples and up to 70% in beech samples depending on heat treatment parameters. It was observed increase of $a^*$ value in Scots pine and decrease $a^*$ value in beech for non-coated wood samples. Other relationships were obtained for this wood additionally coated with varnish. The use of varnish coating on a native pine and subjected to thermal modification caused its darkening, increasing the

| Wood Species | After Varnishing | After Oiling |
|--------------|-----------------|-------------|
|              | $\Delta L^*$    | $\Delta a^*$| $\Delta b^*$| $\Delta L^*$| $\Delta a^*$| $\Delta b^*$|
|              | N   | TM | N   | TM | N   | TM | N   | TM | N   | TM | N   | TM |
| poplar       | -3.85 | -13.29 | 1.71 | 3.14 | 7.49 | -5.51 | -2.41 | -10.26 | 0.70 | 4.39 | 8.68 | -2.81 |
| (0.75)       | (1.31) | (0.54) | (0.35) | (1.51) | (1.53) | (0.44) | (2.02) | (0.13) | (0.80) | (0.83) | (0.69) |
| beech        | -1.53 | -5.70 | 0.60 | 3.66 | 5.73 | -2.36 | -3.22 | -5.15 | 1.12 | 4.35 | 7.49 | -0.34 |
| (0.54)       | (0.73) | (0.21) | (0.48) | (1.55) | (1.03) | (0.57) | (0.57) | (0.29) | (0.40) | (1.40) | (0.09) |
| ash          | -2.19 | -9.93 | 1.05 | 0.24 | 5.22 | -10.17 | -5.50 | -8.21 | 0.71 | 2.48 | 6.31 | -3.85 |
| (0.24)       | (1.52) | (0.17) | (0.08) | (1.48) | (1.69) | (1.08) | (1.64) | (0.18) | (0.56) | (1.45) | (0.09) |
| oak          | -8.11 | -10.32 | 3.16 | 0.67 | 4.68 | -7.56 | -9.13 | -10.26 | 3.09 | 0.87 | 4.75 | -5.89 |
| (2.09)       | (1.03) | (0.49) | (0.16) | (0.68) | (1.40) | (2.58) | (1.10) | (0.29) | (0.21) | (0.26) | (0.70) |
| pine         | -3.67 | -5.02 | 2.06 | 4.59 | 4.77 | 3.46 | -9.06 | -6.84 | 2.53 | 4.95 | 6.46 | 3.45 |
| (0.97)       | (1.52) | (0.55) | (0.49) | (1.14) | (1.11) | (2.18) | (0.73) | (0.69) | (0.46) | (0.29) | (0.65) |


The data showed a clear increase in gloss, much greater after varnishing than after oiling (Figure 6). These dependencies concerned both native and thermally modified wood. After varnishing, the highest increase in the gloss of native wood was recorded for beech (ΔG at the level of 17.77 GU), slightly lower for poplar wood (ΔG at the level of 17.28 GU), and the lowest for pine wood (12.28 GU). After varnishing, a high increase in the gloss of TM wood was recorded—the highest for beech wood (ΔG at the level of 18.77 GU), and the lowest for poplar wood (6.95 GU). After oiling, an increase in the gloss of native wood was noted—the highest for pine wood (ΔG at 6.97 GU), and the lowest for poplar wood (ΔG at 1.00 GU). After oiling, an increase in the gloss of TM wood was noted—the highest for beech wood (ΔG at 6.10 GU), and the lowest for poplar wood (1.70 GU). For native wood of all species, the differences between ΔG after oiling and varnishing were statistically significant (Table 4). Similar relationships were noted for TM wood.
Table 4. Statistical analysis of the ΔE and ΔG results (s—significant differences, ns—no significant differences, based on the t-test, p ≤ 0.05).

| Wood Species/ Variants | Poplar | Beech | Ash | Oak | Pine |
|------------------------|--------|-------|-----|-----|------|
|                        | N_V    | TM_V  | N_O | TM_O| N_V  | TM_V  | N_O | TM_O| N_V  | TM_V  | N_O | TM_O|
| Poplar                 |        |       |     |     |      |       |     |     |      |       |     |     |
| N_V                    | s      | s     | s   | ns  | s    | s     | ns  | s   | ns   | s     | s   | ns  |
| TM_V                   | s      | s     | s   | s   | s    | ns   | s   | s   | s    | ns   | s   | s   |
| N_O                    | ns     | s     | s   | s   | s    | s    | s   | s   | s    | s    | s   | s   |
| TM_O                   | s      | s     | s   | s   | ns   | s    | s   | s   | s    | ns   | s   | s   |
| Beech                  |        |       |     |     |      |       |     |     |      |       |     |     |
| N_V                    | s      | s     | s   | s   | s    | s    | s   | s   | s    | s    | s   | s   |
| TM_V                   | ns     | s     | s   | ns  | s    | s    | s   | s   | s    | s    | s   | s   |
| N_O                    | ns     | s     | s   | s   | s    | s    | s   | s   | s    | s    | s   | s   |
| TM_O                   | s      | s     | s   | s   | ns   | s    | s   | s   | s    | ns   | s   | s   |
| Ash                    |        |       |     |     |      |       |     |     |      |       |     |     |
| N_V                    | ns     | s     | s   | s   | s    | s    | s   | s   | s    | s    | s   | s   |
| TM_V                   | s      | ns    | s   | ns  | s    | s    | s   | s   | s    | s    | s   | s   |
| N_O                    | ns     | s     | s   | s   | s    | s    | s   | s   | s    | s    | s   | s   |
| TM_O                   | ns     | s     | s   | s   | s    | s    | s   | s   | s    | s    | s   | s   |
| Oak                    |        |       |     |     |      |       |     |     |      |       |     |     |
| N_V                    | ns     | s     | s   | s   | ns   | s    | s   | s   | s    | ns   | s   | s   |
| TM_V                   | ns     | s     | s   | s   | ns   | s    | s   | s   | s    | ns   | s   | s   |
| N_O                    | ns     | s     | s   | s   | s    | s    | s   | s   | s    | s    | s   | s   |
| TM_O                   | ns     | s     | s   | s   | ns   | s    | s   | s   | s    | ns   | s   | s   |
| Pine                   |        |       |     |     |      |       |     |     |      |       |     |     |
| N_V                    | s      | s     | s   | s   | ns   | s    | s   | s   | s    | s    | s   | s   |
| TM_V                   | ns     | s     | s   | s   | ns   | s    | s   | s   | s    | s    | s   | s   |
| N_O                    | s      | s     | s   | ns  | s    | s    | s   | s   | s    | s    | s   | s   |
| TM_O                   | ns     | s     | s   | s   | ns   | s    | s   | s   | s    | s    | s   | s   |

**Figure 6.** The gloss changes ΔG of varnished, oiled native and thermally modified wood.

Thermal modification reduces the gloss value of wood [69,70]. The use of coatings may change this trend. Can [71] investigated the effect of modification and finishing of pine and poplar wood on the gloss value. It has been shown that the modification process has a negative effect on the gloss value, and the use of a water-based (AQUA), polyurethane-based (PUR), and an oil/wax-based (OIL + WAX) coating results in a slight reduction of
the gloss value. The exception was water-based varnish, for which an increase in gloss was noted. Demirci et al. [72] showed that the applied varnish coatings have an ambiguous effect on the gloss of wood. Three species of wood were tested—pine, beech and oak covered with three types of coatings—alkyd, two-part polyurethane, and water-borne. Native wood had a gloss of 51 to 54 gloss. The use of the alkyd coating increased the gloss value to 90 gloss and the other two coatings reduced the gloss to around 30 gloss. Similar research was carried out by Çakıcıer et al. [39] with ash wood, which was modified, among others, by at 180 °C for 3 h and 6 h. Four different varnish coatings to finish the wood surface were used. The use of three of them (cellulose lacquer, synthetic varnish, water-based varnish) increased the gloss of the wood, one coating (polyurethane varnish) caused a decrease in gloss. The native ash wood had a gloss level of 22 GU, after modification at 180 °C and 3 h, it increased to 46 glosses, and extending the modification time by another three hours increased the gloss by 2 units. The highest gloss values (79 gloss) were observed after using synthetic varnish.

Thermal modification reduces the equilibrium moisture content of wood. The lower amount of moisture increases the smoothness of the surface, which seems to be important in the case of thin paint coatings. In addition, the use of several layers of the coating increases the surface smoothness, which may translate into increased light reflection and increased gloss value, as demonstrated on beech wood in research conducted by Slabejová et al. [73].

The statistical analyses showed that the species and thermal modification shaped all the parameters of the wood colour and thus the total colour difference ∆Ε (Table 5). The wood species determined the ∆Ε values to the greatest extent (factor influence at the level of 30%), while the thermal modification to the greatest extent (factor influence at the level of 67%) affected the differentiation of the chromatic coordinate on the yellow-blue axis b*. The type of coating “individually” showed a statistically significant effect on the differentiation of ∆a* and ∆b*, but it was small (at the level of 2%). However, in interaction with thermal modification, the influence of this factor in 12% was responsible for the variability of ∆Ε. It should be noted that the changes in gloss resulted to the greatest extent from the type of coating used (factor influence at the level of 76%).

When analysing the influence of the species and thermal modification within a given coating (Figure 7) on the colour parameters, it should be stated that the wood species shaped changes in L*, a*, b* and ∆Ε in a comparable manner. On the other hand, the impact of thermal modification was only comparable in the case of changes in b* (impact at the level of approx. 70%). The interaction between the species and the modification showed a similar effect on changes in a* (influence at the level of about 50%). For a given coating, the gloss variation was mainly influenced by the wood species and the interaction between the species and wood modification.
Table 5. The percentual influence of selected factors on the changes of colour parameters ($\Delta L^*$, $\Delta a^*$, $\Delta b^*$), $\Delta E$, $\Delta G$ of wood.

| Factor               | $\Delta L^*$ | Fisher's F-Test | Significance Level | Influence of Factors (%) | $\Delta a^*$ | Fisher's F-Test | Significance Level | Influence of Factors (%) |
|----------------------|--------------|-----------------|-------------------|--------------------------|--------------|-----------------|-------------------|--------------------------|
|                      | $F$          | $p$             | $X$               |                          | $F$          | $p$             | $X$               |                          |
| Species (1)          | 80.776       | 0.000000        | 25                |                          | 77.993       | 0.000000        | 25                |                          |
| Modification (2)     | 382.073      | 0.000000        | 29                |                          | 200.965      | 0.000000        | 16                |                          |
| Coatings (3)         | 3.586        | 0.061155        | 0                 |                          | 23.538       | 0.000005        | 2                 |                          |
| (1) $\times$ (2)     | 76.936       | 0.000000        | 24                |                          | 129.119      | 0.000000        | 42                |                          |
| (1) $\times$ (3)     | 33.897       | 0.000000        | 10                |                          | 3.353        | 0.012782        | 1                 |                          |
| (2) $\times$ (3)     | 1.066        | 0.304275        | 0                 |                          | 33.768       | 0.000000        | 3                 |                          |
| (1) $\times$ (2) $\times$ (3) | 11.912   | 0.000000        | 4                 |                          | 10.346       | 0.000000        | 3                 |                          |
| Error                | -            | -               | 8                 |                          | -            | -               | 8                 |                          |

| Factor               | $\Delta b^*$ | Fisher's F-Test | Significance Level | Influence of Factors (%) | $\Delta E$ | Fisher's F-Test | Significance Level | Influence of Factors (%) |
|----------------------|--------------|-----------------|-------------------|--------------------------|-----------|-----------------|-------------------|--------------------------|
|                      | $F$          | $p$             | $X$               |                          | $F$       | $p$             | $X$               |                          |
| Species (1)          | 87.156       | 0.000000        | 13                |                          | 38.566    | 0.000000        | 30                |                          |
| Modification (2)     | 1816.623     | 0.000000        | 67                |                          | 65.444    | 0.000000        | 13                |                          |
| Coatings (3)         | 62.018       | 0.000000        | 2                 |                          | 1.166     | 0.282874        | 0                 |                          |
| (1) $\times$ (2)     | 83.387       | 0.000000        | 12                |                          | 18.724    | 0.000000        | 15                |                          |
| (1) $\times$ (3)     | 5.692        | 0.000361        | 1                 |                          | 10.824    | 0.000000        | 8                 |                          |
| (2) $\times$ (3)     | 6.933        | 0.009804        | 0                 |                          | 60.356    | 0.000000        | 12                |                          |
| (1) $\times$ (2) $\times$ (3) | 6.716   | 0.000079        | 1                 |                          | 3.731     | 0.007143        | 3                 |                          |
| Error                | -            | -               | 4                 |                          | -         | -               | 19                |                          |

| Factor               | $\Delta G$  | Fisher's F-Test | Significance Level | Influence of Factors (%) |
|----------------------|--------------|-----------------|-------------------|--------------------------|
|                      | $F$          | $p$             | $X$               |                          |
| Species (1)          | 22.148       | 0.000000        | 5                 |                          |
| Modification (2)     | 0.618        | 0.433661        | 0                 |                          |
| Coatings (3)         | 1259.817     | 0.000000        | 76                |                          |
| (1) $\times$ (2)     | 15.301       | 0.000000        | 4                 |                          |
| (1) $\times$ (3)     | 10.395       | 0.000000        | 3                 |                          |
| (2) $\times$ (3)     | 12.121       | 0.000741        | 1                 |                          |
| (1) $\times$ (2) $\times$ (3) | 20.759   | 0.000000        | 5                 |                          |
| Error                | -            | -               | 6                 |                          |
In general, it can be stated that after photoaging, native and thermally treated wood, regardless of the surface finish (varnishing, oiling), darkened (Table 6). The exception was TM poplar and oak wood after varnishing, native and TM oak and pine wood after oiling, which lightened as a result of photoaging. However, it should be noted that the ΔL* values regardless of the direction of changes (darkening, lightening) were small and in most cases did not exceed three units.

For the varnished and oiled samples, the regularity of changes in a* and b* components was also noticeable. The colour of native wood samples changed towards red (increase in a* value) and yellow (increase in b* value). In the case of coated TM wood samples, no clear direction of changes in a* and b* parameters was found after photoaging. These changes depended on the species of wood and the surface finish (varnish, oil).

In general, it can be stated that after photoaging for varnished and oiled beech wood (native, thermally modified), varnished and oiled ash wood (native), and oiled pine wood

![Figure 7. The percentual influence of species and thermal modification on the changes of colour parameters (ΔL*, Δa*, Δb*), ΔE, AG of wood after (a) varnishing and (b) oiling (numbers 0–100 in Figure—Influence of Factors (%)).](image)

### Table 6. Changes of the wood colour parameters (standard deviation in parentheses) after the surface photoaging.

| Wood Species | Varnish |        |        |        | Oil |        |        |
|--------------|---------|--------|--------|--------|-----|--------|--------|
|              | ΔL*     | Δa*    | Δb*    | ΔL*    | Δa* | Δb*    |
|              | N       | TM     | N       | TM     | N   | TM     | N       | TM     |
| poplar       | –1.42   | 3.99   | 0.98    | –0.35  | 0.38| 1.71   | –1.89   | –0.70  |
|              | (0.36)  | (0.02) | (0.18)  | (0.10) | (0.11)| (0.05) | (0.25)  | (0.05) |
| beech        | –4.61   | –3.28  | 2.38    | –2.27  | 1.82| –5.19  | –5.24   | –3.39  |
|              | (0.69)  | (0.70) | (0.53)  | (0.08) | (0.38)| (0.24) | (1.51)  | (1.02) |
| ash          | –5.52   | –1.31  | 2.56    | 1.19   | 2.24| 1.73   | –7.37   | –1.62  |
|              | (0.76)  | (0.26) | (0.52)  | (0.15) | (0.64)| (0.19) | (1.16)  | (0.02) |
| oak          | –2.97   | 0.43   | 1.27    | 0.38   | 1.77| –0.75  | 1.76    | 1.89   |
|              | (0.70)  | (0.12) | (0.18)  | (0.10) | (0.38)| (0.07) | (0.49)  | (0.21) |
| pine         | –2.50   | –2.07  | 2.53    | 0.31   | 3.28| –2.99  | 8.72    | 0.35   |
|              | (0.08)  | (0.46) | (0.02)  | (0.07) | (0.93)| (0.60) | (0.67)  | (0.02) |

In general, it can be stated that after photoaging for varnished and oiled beech wood (native, thermally modified), varnished and oiled ash wood (native), and oiled pine wood...
(native), ΔE was from approx. 6 to approx. 9 (Figure 8). According to the evaluation criteria of overall colour change ΔE [67,68] it means high colour changes. In most of the other variants, the ΔE values ranged between 2 and 3, which means the colour difference visible with high quality screen [67,68]. Moreover, it should be noted that after photoaging, the smallest colour changes ΔE were recorded for TM wood after oiling (except for beech wood). After photoaging, the gloss of varnished and oiled wood was lower, on average by two units (Figure 9).

**Figure 8.** The total colour difference ΔE of varnished, oiled native and thermally modified wood after photoaging (s—significant differences, ns—no significant differences between native wood after oiling and varnishing, or between thermally modified wood after oiling and varnishing, based on the t-test, $p \leq 0.05$).

**Figure 9.** The gloss changes ΔG of varnished, oiled native and thermally modified wood after photoaging (s—significant differences, ns—no significant differences between native wood after oiling and varnishing, or between thermally modified wood after oiling and varnishing, based on the t-test, $p \leq 0.05$).

UV radiation changes the wood colour parameters [74,75]. It also affects paint and varnish coatings, which is also confirmed by literature data [76]. Research in this direction was conducted by Ayata and Cakicier [37]. The authors examined the oak, pine and beech after thermal modification (ThermoWood) and the application of water-based varnish coatings. There was a change in the a* parameter, which initially decreased and then increased, and there was an increase in $b^*$ and $L^*$ proportional to the exposure time. Silva and Pastore [77] exposed to UV radiation five species of exotic wood—native and varnished. The obtained results indicate a significant influence of the varnish coatings on the reduction of the colour change caused by the UV radiation. The exception was the pine wood, for
which the level of change \( \Delta E \) was similar for both native and varnished wood. The most sensitive component of wood to UV radiation is lignin. Its degradation leads to a change in the colour of the wood towards yellow and affects the colour change the most. For this reason, varnish coatings should protect against UV radiation [78].

3.3. Cross—Cut Test

The example images of the cross—cut areas were presented in Figure 10 and the results of the test of resistance of coatings to separation from wood by the cross—cut method were summarized in Table 7. The process of thermal modification in nitrogen increases the brittleness of wood, which, unfortunately, generally has a negative effect on the resistance of the coatings. Similar observations were made on Turkey oak wood (Quercus cerris L.) where the resistance was higher on native wood than on the thermally modified wood [40].

![Typical images of cross—cut areas in poplar and oak wood after varnishing and oiling.](image)

**Figure 10.** Typical images of cross—cut areas in poplar and oak wood after varnishing and oiling.

| Wood Species | After Varnishing | After Oiling |
|--------------|-----------------|--------------|
|              | Native Wood     | Thermally Modified Wood | Native Wood | Thermally Modified Wood |
| poplar       | ![Image of poplar wood after varnishing](image) | ![Image of poplar wood after oiling](image) | ![Image of native poplar wood](image) | ![Image of native poplar wood](image) |
| beech        | ![Image of beech wood after varnishing](image) | ![Image of beech wood after oiling](image) | ![Image of native beech wood](image) | ![Image of native beech wood](image) |
| ash          | ![Image of ash wood after varnishing](image) | ![Image of ash wood after oiling](image) | ![Image of native ash wood](image) | ![Image of native ash wood](image) |
| oak          | ![Image of oak wood after varnishing](image) | ![Image of oak wood after oiling](image) | ![Image of native oak wood](image) | ![Image of native oak wood](image) |
| pine         | ![Image of pine wood after varnishing](image) | ![Image of pine wood after oiling](image) | ![Image of native pine wood](image) | ![Image of native pine wood](image) |

**Table 7.** The test method results for assessing the resistance of coatings to separation from wood according to ISO 2409:2020 [46].

| Wood Species | Cross—Cut Test | After Varnishing | After Oiling |
|--------------|----------------|-----------------|--------------|
|              | Native (N)     | Thermally Modified (TM) | Native (N) | Thermally Modified (TM) |
| poplar       | 2              | 2               | 2            | 3            |
| beech        | 1              | 2               | 1            | 2            |
| ash          | 1              | 2               | 1            | 2            |
| oak          | 1              | 2               | 1            | 2            |
| pine         | 2              | 2               | 2            | 2            |

The impact of thermal modification was individual and depended on the species of wood. In the case of species with a lower density, i.e., black poplar (Figure 10) and pine, thermal modification did not reduce the resistance of the varnish coat, and in the case of species with a higher density (beech, ash, oak) there was a reduction by one level from 1 to 2 (Table 7). Similar relationships were also noted in the case of resistance of the oil coating. The exception was poplar wood, for which, after thermal modification, the resistance of the oil coating deteriorated, i.e., it was reduced by one level from 2 to 3.
3.4. Brinell Hardness of Wood after Finishing

The hardness of native wood of all tested species (Table 8) was higher than the average hardness values given by Wagenführ [48]. Most likely, it resulted from the selection of the research material in the form of the highest quality sawn timber obtained from the perimeter part of the stems, i.e., mature wood.

Table 8. Brinell hardness (H) of wood before and after varnishing, oiling; standard deviation in parentheses, *—statistically significant differences between H of wood before finishing and after finishing—varnishing or oiling, ns—non-statistically significant differences between H of wood before finishing and after finishing—varnishing or oiling, based on the t-test, p ≤ 0.05).

| Wood Species | Brinell Hardness (N × mm⁻²) |
|--------------|-----------------------------|
|              | Before Finishing | After Varnishing | After Oiling |
|              | N    | TM   | N    | TM   | N    | TM   |
| poplar       | 30.2 | 30.3 | 33.3 | 36.4 | 31.3 | 31.0 |
| beech        | 44.8 | 39.9 | 45.3 | 37.3 | 38.8 | 38.8 |
| ash          | 42.6 | 43.0 | 49.6 | 42.3 | 52.9 | 42.6 |
| oak          | 44.5 | 39.2 | 40.4 | 39.0 | 43.3 | 46.0 |
| pine         | 40.7 | 37.0 | 39.2 | 37.1 | 35.6 | 36.7 |

After thermal modification, there was a decrease in wood hardness, and it was significant for beech and oak (species with wide wood rays) and amounted to 11%. Significant changes in hardness were not noted for poplar, ash and pine wood (Table 8), containing fine rays. Percin et al. [13] reported that the modification of beech wood at a low temperature of 150 °C and for 1 h increases its hardness in all anatomical directions from 35 MPa to 36 MPa, from 36 MPa to 38 MPa and from 67 MPa to 69 MPa in the radial, tangential and longitudinal direction. After modification at a higher temperature, i.e., 200 °C, there was a slight decrease in the hardness of the wood to the level of 32 MPa, 32 MPa and 62 MPa for the given anatomical directions. Salca and Hiziroglu [30] investigated the hardness of common alder (Alnus glutinosa L.), red oak (Quercus falcata Michx.), Southern pine (Pinus taeda L.) and yellow poplar (Liriodendron tulipifera L.) using Janka’s methods perpendicular to the grain. The tests were carried out on thermally modified wood at 120 °C and 190 °C for 3 h and 6 h. It has been shown that for red oak and common alder wood a decrease in hardness was noted for all variants of modification, while in the case of Southern pine and yellow poplar there was a slight increase hardness except for the conditions of heat treatment 190 °C and 6 h. Rautkari et al. [79] studied changes in the Brinell hardness of pine wood (sapwood and heartwood). Wood after treatment in saturated steam changed hardness. For sapwood there was an increase in hardness from 11.6 MPa to 12.0 MPa, and for heartwood, a decrease in hardness from 11.4 MPa to 10.7 MPa after wood modification at 150 °C for 3 h. Increase in modification temperature to 180 °C caused a decrease wood hardness to the level of about 9 MPa for both tested zones of pine wood. Sedlar et al. [80] investigated Brinell hardness of thermally modified beech wood and recorded a decrease for 3%, 15%, and 25% on cross, radial, and tangential section, respectively for a modification temperature of 200 °C and a modification time of 48 h.

Covering wood with varnish or oil did not significantly increase the hardness of the wood, as evidenced by the lack of significant differences between the analysed mean values (Table 8). The exception was native poplar wood after varnishing, native ash wood after varnishing and oiling, TM poplar wood after varnishing and TM oak wood after oiling. Kurt and Özçifçi [81] reported that varnish types increased the Brinell hardness, except for synthetic varnish. While cellulosic varnish increased Brinell hardness values by 93% on average, polyurethane varnish increased it by 92% on average, and synthetics decreased it by 22% on average. On the other hand, Çakıcıer et al. [39] showed that coating modified wood with varnishes reduces its hardness.
4. Conclusions

The process of thermal modification (in nitrogen atmosphere at 190 °C during 6 h) was carried out on five species of European wood representing different types of structure and differing in the size of wood rays. Based on the conducted research and analyses, the following conclusions were formulated:

- The process of surface finishing by varnishing and oiling poplar, oak, ash, beech and pine (native and thermally modified) was correct in the developed technology—it was effective. The effect of finishing was, among other things, a significant increase in gloss (especially after varnishing), as well as a radical change of colour (its strengthening) of all species of wood.

- The nature of surface colour changes as a result of UV photoaging (for 100 h) was individual. In general, wood with varnish coatings was much more resistant to colour change compared to oiled wood.

- The process of thermal modification in nitrogen significantly influenced the thickness of the varnish and oil coatings. The thermally treated wood had slightly thicker varnish coats and slightly thinner oil coats compared to the analogous ones in native wood. In the case of the thickness of the varnish coatings, the type of wood structure was also important.

- In the case of wood with a lower density, i.e., black poplar and Scots pine, the thermal modification process in nitrogen did not reduce the resistance of the varnish coat, and in the case of a higher density of hardwood species (oak, ash, beech) there has been a decrease by one level from 1 to 2.

- The process of thermal modification of wood with wide wood rays (oak and beech) caused the reduction of Brinell hardness in longitudinal sections. In other cases (ash, poplar, pine), the hardness did not change significantly. The applied surface finishing process by means of double varnishing or oiling did not change this property significantly.

Author Contributions: Conceptualization, P.K. and J.Z.; methodology, P.K.; formal analysis, P.K., A.L. and M.D.; investigation, P.K.; data curation, P.K. and A.L.; writing—original draft preparation, P.K., A.L. and M.D.; writing—review and editing, A.L.; visualization P.K. and A.L.; supervision J.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was financed by the National (Polish) Centre for Research and Development (NCBiR), program “Environment, agriculture and forestry”—BIOSTRATEG II, project “Intelligent systems for breeding and cultivation of wheat, maize and poplar for optimized biomass production, biofuels and modified wood” (acronym CropTech), No BIOSTRATEG2/298241/10/NCBR/2016.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

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