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PHYSICAL AND MECHANICAL PROPERTIES AND RESISTANCE TO FUNGI OF SCOTS PINE AND BIRCH WOOD MODIFIED THERMALLY AND USING NATURAL OIL

Thermal modification and impregnation with natural oils may improve functional properties of wood. However, to a great extent changes in wood properties depend on the conditions of thermal modification process and on the impregnation method and type and amount of the oil used. The Wood Technology Institute in Poznan conducted research on thermal modification of wood which joined thermal modification and introduction of natural oils into wood. The aim of the research was to identify properties of Scots pine and birch wood subjected to such modification. This paper presents results of determinations of the effect of thermal and thermo-oil treatment of wood on its strength, equilibrium moisture content, and resistance to fungi. It was observed that some functional properties of wood improved and resistance to Basidiomycotina fungi increased, even after the wood was subjected to accelerated ageing by evaporation or leaching with water.

Keywords: wood, thermal modification, natural oil, strength, hygroscopicity, resistance to fungi

Introduction

The dynamic development, in terms of quantity and quality, of the production of materials which may substitute for wood causes the situation, where wood has been squeezed out from its traditional applications. One of the crucial factors discouraging designers and investors to treat wood as a whole building material consists in disadvantages of wood resulting from its affinity to water, and espe-

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cially, its unsatisfactory dimension and shape stability in humid conditions as well as its low resistance to biotic factors, especially to fungi. Stability of dimensions and shape in humid conditions has an essential influence on the performance of constructions made of wood and wood-based panels, when during their service life they are exposed to changing humidity. An increased moisture content of wood in many functional classes [PN-EN 335-1; PN-EN335-2; Ważny 2003, 2004] also exposes wood to fungi action. If wood is to be used in higher humidity conditions, then it is recommended to use wood species of higher natural stability and resistance. However, wood of such properties is less available and more expensive, and most of the European commercially important wood species are classified as low resistant to biotic factors [PN-EN 350-2]. Strength, hydrophobicity, dimension stability and resistance to destroying atmospheric and biological factors may be increased by modification of wood using, for instance, synthetic resins and chemical agents of the properties of biocides, mainly against fungi and insects [Kollmann 1936; Militz 2002; Fojutowski 2001, 2002; PN-EN 152-1; PN-EN 599-1; Ważny 2003]. However, resins and biocides are not neutral to the environment, despite the effort to make them environmentally friendly, low volatile, easily penetrating into wood and fixing in it. These substances may also constitute a difficulty in secondary use of wood, i.e. in wood recycling. A permanent trend in research concentrates on the search for better, safe to humans and to the environment, solutions for improvement of natural wood properties without limiting the possibilities of wood recycling after its service life is finished. The researchers look for solutions alternative to the use of biocides, for example for methods such as modification of wood by physical methods using natural, pro-ecological agents stabilising wood structure and impeding creation of such conditions in wood which would enable growth of fungi and insects. Thermally modified wood is an interesting proposal which was signalled already in 1930s but has been intensively developed only recently, including launching of industrial production. According to data found in the literature, such wood demonstrates advantageous functional properties like lower hygroscopicity, dimension stability higher than normal wood, and it is also characterised by better resistance to wood attacking fungi and better durability [Kollman 1936; Militz 2002; Mazela et al. 2004; Rep et al. 2004; Schwarze, Spycher 2005; Skyba et al. 2008; Welzbacher et al. 2006; Zaman et al. 2000]. Thermally modified wood is produced in Austria, Germany, Norway, Finland, Sweden etc., and in Poland as well [Noskowiak, Jabłoński 2007; Krawczyk 2007]. However, to a great extent, changes in wood depend on the conditions of thermal modification process. The Wood Science and Application Department of the Wood Technology Institute in Poznan has conducted its own research on wood thermal modification which joins heat treatment and introduction of natural oils into wood. In this way, the researchers in the Department aim to obtain wood of better physical and mechanical properties and of durability better than in the case of natural wood [Noskowiak, Jabłoński 2007]. Thermal modification together with impregnation of wood with oils may broaden possibilities of practical use of wood characterised by insufficient (without modification) quality and durability. Competitiveness of such wood in relation to wood species of better natural properties or in comparison with other non-wood building materials (ceramics, glass, aluminium, synthetic materials etc.) may increase. It may be expected that such modification of wood would make it possible to point new lines and ways of application of this valuable, ecological, and renewable raw material.

Aim and scope of the research

The aim of the research was to identify strength, equilibrium moisture content and resistance to decaying fungi of Scots pine sapwood and birch wood which was thermally modified and thermally modified plus impregnated with natural oil. The object of the research was Scots pine and birch wood (natural, thermally and thermo-oil modified) at the quadrant technical scale tested in the Wood Science and Application Department of the Wood Technology Institute in Poznan [Noskowiak, Jabłoński 2007]. Tests of physical and mechanical properties of wood encompassed determinations of wood density, bending strength and impact bending strength, compression strength, and wood equilibrium moisture content as well. Mycological tests included laboratorial identification of the effect of pure cultures of *Basidiomycotina* fungi species on tested wood. In natural wood *Basidiomycotina* fungi cause the most serious changes in the form of brown and white rot.

Materials and test methods

Materials

The tested material was in the form of planed little beams with sharp edges. The little beams were made of Scots pine sapwood (*Pinus sylvestris* L.) and birch (*Betula verrucosa* Ehrh.) and had the dimensions of 30 (thickness) $\times$ 80 $\times$ 950 mm. The impregnation of wood was carried out using industrially produced technical linseed oil of the density of 0.940 g/cm^3 containing 75% of the following acids: linoleic ($C_{18}H_{32}O_2$) and linolenic ($C_{18}H_{30}O_2$).

Thermal modification and thermo-oil modification of wood

The modification of wood was conducted in the Wood Science and Application Department of the Wood Technology Institute at the test station with kiln drier and impregnation basin for impregnation of wood with linseed oil directly after

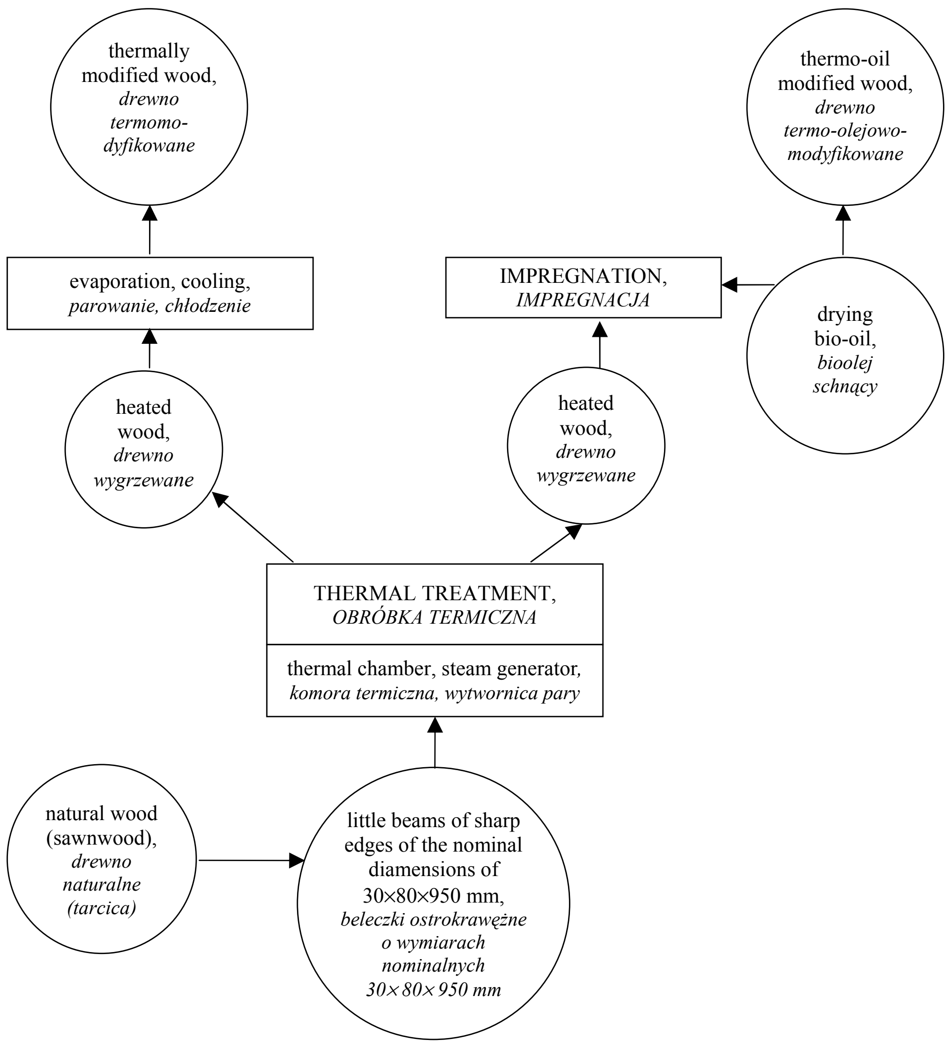

Fig. 1. Pictorial diagram of carried out termomodification and thermo-oil modification of wood

Rys. 1. Poglądowy schemat przeprowadzonej termomodyfikacji i termo-olejowej modyfikacji drewna

heating [Noskowiak, Jabłoński 2007]. The wood modification diagram is presented in fig. 1. Thermal modification, to which 63 little beams of each wood species were subjected, was conducted at the nominal temperature of 195°C which was reached inside the wood after four hours and maintained (with the maximum of 203°C) during the actual thermal modification process for the following three hours. Then the wood was subjected to evaporation and gently cooled within 2.5 hours to 140°C. After that, individual little beams were quickly weighted and measured and immediately immersed in linseed oil (20°C) for 14 hours. 18 little beams of Scots pine and 18 little beams of birch were impregnated. Thermal modification of the rest of the little beams was continued by introduction of steam and cooling down of the wood to the temperature of 12°C within 12 h. After that, thermally modified Scots pine and birch wood was taken out of the kiln drier. The oil was removed from the surface of the little beams of thermo-oil modified wood after they were taken out of the oil. The course of temperature changes inside the wood during thermal modification process is presented in fig. 2. Before the following tests all little beams were conditioned in normal conditions (20°C/65%) until the state of equilibrium moisture content was reached.

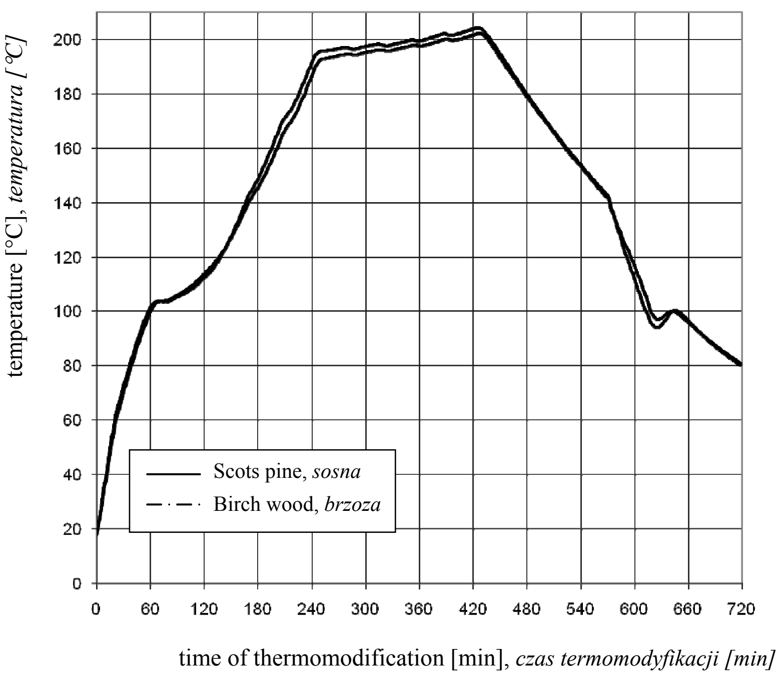

Fig. 2. Temperature of wood thermomodification (measurement inside thermo-modified little beams of wood)

Rys. 2. Temperatura termomodyfikacji drewna (pomiar wewnątrz termomodyfikowanych beleczek drewna)

Methods for testing physical and mechanical properties

In tests of physical and mechanical properties 9 little beams of each of the following six categories were used: made of thermally modified, thermally modified and oil impregnated, and not modified (natural, control) Scots pine wood, and made of thermally modified, thermally modified and oil impregnated, and not modified (natural, control) birch wood. The little beams were selected so as they represented the whole range of density of wood used in the tests. The selected little beams were planned on all longitudinal surfaces and cut into slats of the section of 20×20 mm which then were cut into samples 300 mm long. In this way 9 test samples were obtained from each little beam. After further cutting to the dimensions required by particular standards the samples were used for determination of respective physical and mechanical properties.

Chosen physical and mechanical properties of wood before and after thermal modification were determined by measuring, acc. to standardised methods, the following features:

a) equilibrium moisture content of samples, conditioned to a constant mass, in normal conditions (20ºC/65%), by oven-dry method [PN-EN 13183-1:2004],
b) density, by stereometric method [PN-77/D-04101],
c) bending strength and modulus of elasticity at three-point bending [PN-77/D-04103 and PN-63/D-04117],
d) parallel to grain compression strength [PN-79/D-04102],
e) impact bending strength [PN-79/D-04104].

Method for testing wood resistance to *Basidiomycotina* fungi

For mycological tests of Scots pine sapwood the following material was taken: a medium density little beam of natural and thermally modified wood, and three little beams of various retention of linseed oil: 32 kg/m^3 (minimum), 128 kg/m^3 (medium), 223 kg/m^3 (maximum) from thermally modified and linseed oil impregnated Scots pine wood. In the case of birch wood the situation was similar and the following material was taken: one little beam of natural and thermally modified wood, and three beams of the following retentions: 76 kg/m^3, 189 kg/m^3, and 328 kg/m^3. The wood was planed on all sides to the thickness of 25 mm, cut into slats of the width of 15 mm. These slats were cut transversely to grain into samples of the length of 50 mm. In this way, samples of the dimensions of $15 \times 25 \times 50$ mm for testing of wood resistance to *Basidiomycotina* fungi were obtained. For comparative purposes and as a control material samples of the same as the above-mentioned dimensions were prepared from natural and not subjected to any property modifying treatment Scots pine sapwood and birch wood.

Tests were conducted in the temperature of 22±1°C and relative humidity of 70 ± 5%, i.e. in optimum conditions for the processes of decay of lignocellulosic substance by *Basidiomycotina* fungi.

The tests based on a method which is an adaptation of agar-block method for determination of toxic values (fungicidal values) [PN-EN 113]. For 16 weeks samples were exposed to pure culture of *Coniophora puteana* (Schum. ex Fr.) Karst. (BAM Ebw.15) fungus which causes brown rot of wood – in the case of Scots pine wood testing, or *Trametes versicolor* (Linnaeus ex Fries) Pilat (CTB 863 A) fungus causing white rot of wood – in the case of birch wood testing. *Coniophora puteana* fungus is a fungus characteristic of softwood decay, and *Trametes versicolor* fungus attacks hardwood. The properties of control wood were in accordance with the requirements of [PN-EN 113] standard. Samples of this wood were used as control ones and as samples for verification of decay activity of used strains of fungi (6 samples for each purpose). The strains of fungi came from the collection of the Wood Technology Institute in Poznan. In each variant 6 check wood samples (kept on a sterile culture medium in the same conditions as samples exposed to fungi) were used to calculate corrective coefficients (changes in mass caused by other factors than fungi). According to PN-EN 113, ten samples of each variant were exposed to fungi. One sample of tested wood and one sample of control wood were placed in one Kolle flask for testing thermally modified wood (also modified with oils). For testing of check and control of activity, two check samples or two samples for activity control were placed in one Kolle flask.

Before exposure to fungi samples were sterilised with steam in an autoclave (20 min, 121°C). Check samples were sterilised in autoclave in the same way as tested samples, i.e. samples exposed to fungi.

Tests of resistance to *Basidiomycotina* fungi were conducted on wood samples which had not been subjected to additional ageing procedures and which were subjected to ageing by evaporation before they were exposed to fungi [PN-EN 73], i.e. a 12-week action of air of the temperature of 40 ± 2°C and flow velocity of 1 ± 0.1m/s in an aerodynamic tunnel – the process was conducted by the Building Research Institute, or ageing by leaching with water [PN-EN 84], i.e. full impregnation of samples with distilled water and keeping of the samples under distilled water of the temperature of 20 ± 2°C at the proportion of around 5 volumes of water to one volume of wood, during 14 days, within which period the water was exchanged nine times. The wood mass loss caused by *Basidiomycotina* fungi was the criterion for resistance to decay. The assessment of wood resistance to *Basidiomycotina* fungi was made according to the recommendations of a standard concerning classification of natural durability of wood [PN-EN 350-1], by calculating the ratio ($x = U_t/U_k$) of average corrected mass loss of modified or thermo-oil modified wood samples (U_t) to average mass loss of control samples (U_k), assuming the following assessments: durability class

(KT) 1, $x < 0.15$ – very durable; KT 2, $0.15 < x \leq 0.30$ – durable; KT 3, $0.30 < x \leq 0.60$ – moderately durable; KT 4, $0.60 < x \leq 0.90$ – slightly durable; KT 5, $x > 0.90$ – not durable.

Test results and their presentation

Physical and mechanical properties

The results of determinations are presented in fig. 3 and 4 and in table 1. The obtained data indicates that thermal modification of wood resulted in a decrease in wood density by around 8%, whereas thermo-oil modification of wood brought about an increase in wood density by around 18%. Thermal and thermo-oil modification of wood resulted in a decrease in bending strength of Scots pine sapwood to the level of approx. 90 % of the value characterising natural wood, and in the case of birch wood, to the level of 73% (thermal modification) and 84% (thermo-oil modification) of the value characterising natural wood. The impact bending strength of wood decreased as well. For the Scots pine wood the strength of modified wood was around 92% of the value characterising natural wood, and for birch wood 72–75% of the strength characterising natural wood. The modulus of elasticity at bending and compression strength of modified Scots pine sapwood and birch wood increased in comparison to natural wood. A greater increase was observed for birch wood than for Scots pine wood. The modulus of elasticity at bending for birch wood rose to 144% – thermal modification, 159% – thermo-oil modification, and for Scots pine wood to 117% and 123%, respectively. The parallel to grain compression strength of birch wood increased to 132% – thermal modification, 145% – thermo-oil modification, and of Scots pine wood to 117% and 118%, respectively.

As a result of modification the equilibrium moisture content of Scots pine and birch wood decreased very distinctly, which evidences high hydrophobation of wood (table 1).

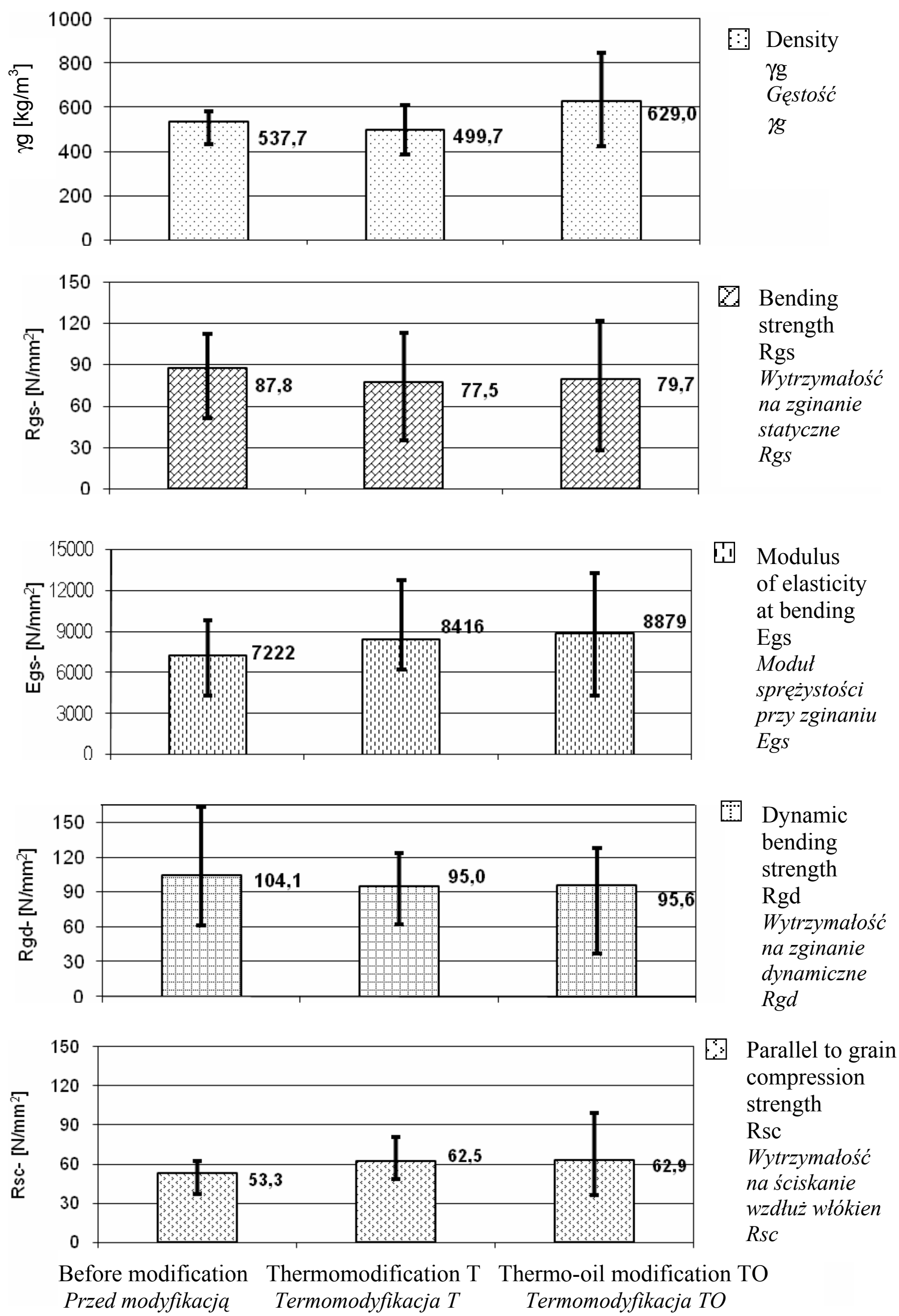

Fig. 3. Physical and mechanical properties of modified Scots pine sapwood
Rys. 3. Właściwości fizyczno-mechaniczne modyfikowanego drewna sosny-biel

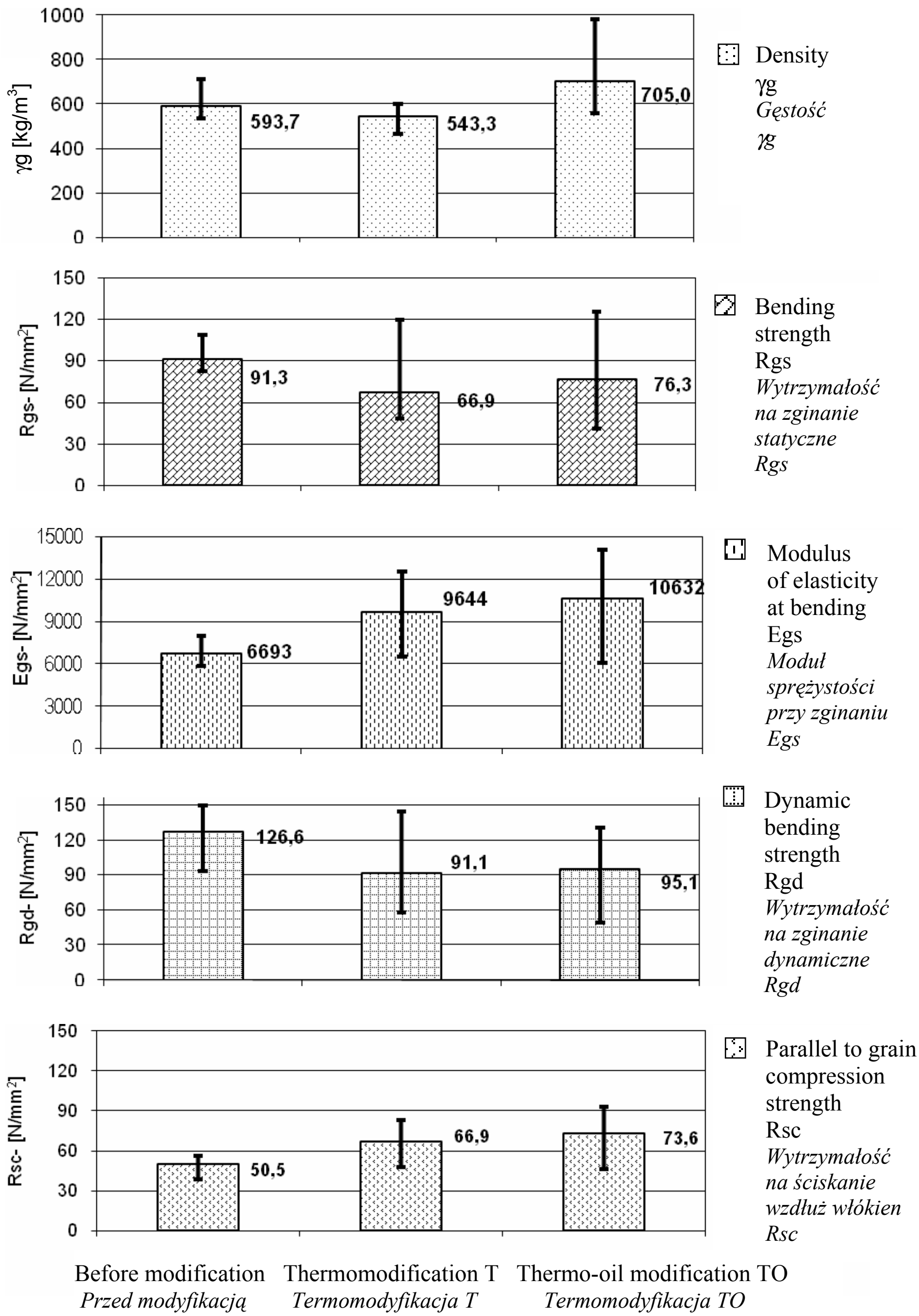

Fig. 4. Physical and mechanical properties of modified birch wood
Rys. 4. Właściwości fizyczno-mechaniczne modyfikowanego drewna brzozy

Table 1. Equilibrium moisture content of Scots pine sapwood and birch wood at standard conditions: 20°C, 65% RH

Tabela 1. Wilgotność równowagowa drewna bielu sosny i brzozy w warunkach klimatu normalnego: 20°C, 65% wilgotności względnej

Tested property *Badana właściwość*	Statistical measures *Miary statystyczne*	Before modification *Przed modyfikacją*	*Modification* Modyfikacja	
			T	TO
Moisture content of Scots pine samples [%] *Wilgotność próbek sosnowych [%]*	$x_{śr}$	11,70	5,37	4,31
	x_{min}	10,93	3,73	2,65
	x_{max}	12,96	6,39	7,36
	s	0,66	0,66	1,32
Moisture content of birch wood samples [%] *Wilgotność próbek brzozowych [%]*	$x_{śr}$	12,30	4,18	3,07
	x_{min}	11,89	3,61	1,90
	x_{max}	12,68	4,46	6,38
	s	0,28	0,26	1,04

Notes: T – Thermomodification, TO – Thermo-oil modification; values: $x_{śr}$ – mean, x_{min} – minimum, x_{max} –maximum, s – standard deviation.

Objaśnienia: T – Termomodyfikacja, TO – Termo-olejowa modyfikacja; wartości: $x_{śr}$ –średnia, x_{min} – minimalna, x_{max} –maksymalna, s – odchylenie standardowe.

Wood resistance to *Basidiomycotina* fungi

The results of determination are presented in tables 2–5. The decay activity of *Coniophora puteana* fungus was high, which is evidenced by mass losses in the order of 30%, whilst 20% is required. On the other hand, the decay activity of *Trametes versicolor* fungus was relatively low and equalled around 12% in comparison with 15% required from the fungus by EN 113 for Scots pine and 20% required for beech. The obtained data indicates that *Basidiomycotina* fungi caused less mass losses in the case of thermally modified Scots pine sapwood and birch wood and thermally modified and linseed oil impregnated Scots pine sapwood and birch wood, than in the case of control wood. Thermal modification alone resulted in the least increase in the resistance of Scots pine sapwood. Samples of this wood were decayed in 12 to 16%, whilst in thermo-oil modified Scots pine sapwood mass losses ranged from 2.0 to 6.3%, without an explicit relation to the degree of their saturation with linseed oil. Mass losses of thermally modified and thermo-oil modified birch wood ranged from 1.4 to 5.3% and there was an evident trend to a decrease in mass losses as retention of linseed oil in wood rose. Additionally, the tests demonstrated that, as regards mycology, thermally modified and thermo-oil modified Scots pine sapwood and birch wood is resistant to leaching by water and changes caused by evaporation, because caused by *Basidiomycotina* fungi mass losses of wood subjected to these ageing procedures did not increase significantly in comparison with not aged wood. It is a very positive feature in the aspect of use of wood products in conditions where they are directly exposed to atmospheric factors. It is also worth noticing, that after fungi tests moisture content of thermally modified wood, and, to even a greater extent, of thermo-oil modified wood, was much lower than in the case of control wood (table 5). It additionally points to increased hydrophobicity of wood as a result of thermal modification and thermo-oil modification. These results, which were obtained for the control wood moisture content level in the order of 50% for Scots pine sapwood and 30% for birch wood, confirm the effect of a much increase in hydrophobicity of wood as a result of thermal and thermo-oil modification. The said effect was observed also during tests of equilibrium moisture content of wood at the moisture content level of 12% (table 1).

Compared to natural Scots pine sapwood, which acc. to PN-EN 350-2 is classified as class 5 – not durable as regards its resistance to *Basidiomycotina* fungi, thermally modified Scots pine wood may be classified as class 3 – moderately durable, and thermo-oil modified Scots pine sapwood may be classified as class 1 – very durable, even with the lowest of the tested content of linseed oil. Thermal modification of birch wood, which acc. to PN-EN 350-2 is classified as class 5 – not durable, caused an increase in durability of this wood which allowed its formal classification as class 2 – durable as regards resistance to *Basidiomycotina* fungi, whilst the durability index (value) “x” is equal to the border value of this class and class 3 – moderately durable. Thermo-oil modified birch wood moderately saturated with linseed oil may be classified as class 3 – moderately durable at the value of durability index “x” which only insignificantly exceeds the border of class 2 – durable. Thermally modified birch wood minimally and maximally impregnated with linseed oil may be classified as class 2 – durable, whilst at the minimum retention the value of durability index “x” is equal to the border value of this class and class 3 – moderately durable. The situation is similar as in the case of birch wood subjected to thermal modification only. The value of durability index “x” for thermally modified birch wood containing the maximum amount of linseed oil is the lowest among the values determined for tested thermally modified and thermo-oil modified birch wood, but the said value also approximates to the border of class 2 – durable and class 3 – moderately durable. Therefore thermally modified and thermo-oil modified birch wood is characterised by durability at the border of class 2 – durable and class 3 – moderately durable.

The observed changes in wood properties resulting from thermal modification and thermo-oil modification may be connected with such phenomena as: partial dehydration and decarboxylation of cellulose chains, reduction of the number of hydrophilic hydroxyl groups, polymerisation of lower polysaccharides into branched, network polysaccharides, and demethylation (weak) of lignin. Many properties of wood are improved as a result of modification; however, some strength properties of wood are worsened by thermal and thermo-oil modification. It was stated by other authors as well, that this effect may limit possibilities of the use of such modified wood in structures connected with mechanical loads, and it also points to the need of further research, if adverse phenomena are to be eliminated [Bengtsson et al. 2002; Junghans, Niemz 2006; Welzbacher et al. 2006, 2008].

Table 2. Results of determination of the resistance of thermally modified and thermally modified and linseed oil impregnated Scots pine sapwood to *Coniophora puteana* fungus

Tabela 2. Wyniki oznaczania odporności termomodyfikowanego oraz termomodyfikowanego i nasyconego olejem lnianym drewna sosny (biel) na działanie grzyba Coniophora puteana

Retention of linseed oil in wood [kg/m^3] *Nasycenie drewna olejem lnianym [kg/m^3]*	Scots pine – *Coniophora puteana* fungus *Sosna – grzyb Coniophora puteana*						
	Without ageing *Bez starzenia*			Leached – EN84 *Wymywana – EN84*		Evaporated – EN73 *Odparowana – EN73*	
	Mean mass loss of tested series U_t [%] *Średni ubytek masy serii badanej U_t [%]*	Mean mass loss of control samples U_k [%] *Średni ubytek masy próbek kontrolnych U_k [%]*	x/durability class* *x/klasa trwałości**	Mean mass loss of tested series [%] *Średni ubytek masy serii badanej [%]*	Mean mass loss of control samples [%] *Średni ubytek masy próbek kontrolnych [%]*	Mean mass loss of tested series [%] *Średni ubytek masy serii badanej [%]*	Mean mass loss of control samples [%] *Średni ubytek masy próbek kontrolnych [%]*
0 Thermally modified wood not impregnated *Drewno modyfikowane termicznie nienasycane*	16,7	38,4	0,43/3	12,2	31,3	13,1	36,7
32 (Minimum)	2,3	42,5	0,05/1	3,3	37,2	2,0	42,2
128 (Mean) *(Średnie)*	5,3	36,7	0,14/1	6,3	33,7	5,6	42,4
223 (Maximum)	5,0	38,8	0,13/1	5,2	36,1	3,9	38,0
0 (Activity control) *0 (Kontrola aktywności)*	–	36,1	–	–	36,1	–	32,7

Notes: *x = U_t/U_k; durability classes: 1 – very durable, 2 – durable, 3 – moderately durable, 4 – slightly durable, 5 – not durable.

*Objaśnienia: *x = U_t/U_k; klasy trwałości: 1 – bardzo trwałe, 2 – trwałe, 3 – średnio trwałe, 4 – mało trwałe, 5 – nietrwałe.*

Table 3. Results of determination of the resistance of thermally modified and thermally modified and linseed oil impregnated birch wood to *Trametes versicolor* fungus
Tabela 3. Wyniki oznaczania odporności termomodyfikowanego oraz termomodyfikowanego i nasyconego olejem lnianym drewna brzozy na działanie grzyba Trametes versicolor

Retention of linseed oil in wood [kg/m³] *Nasycenie drewna olejem lnianym [kg/m³]*	Birch – *Trametes versicolor* fungus *Brzoza – grzyb Trametes versicolor*						
	Without ageing *Bez starzenia*			Leached – EN84 *Wymywana – EN84*		Evaporated – EN73 *Odparowana – EN73*	
	Mean mass loss of tested series U_t [%] *Średni ubytek masy serii badanej U_t [%]*	Mean mass loss of control samples U_k [%] *Średni ubytek masy próbek kontrolnych U_k [%]*	x/durability class* *x/klasa trwałości**	Mean mass loss of tested series [%] *Średni ubytek masy serii badanej [%]*	Mean mass loss of control samples [%] *Średni ubytek masy próbek kontrolnych [%]*	Mean mass loss of tested series [%] *Średni ubytek masy serii badanej [%]*	Mean mass loss of control samples [%] *Średni ubytek masy próbek kontrolnych [%]*
0 Thermally modified wood not impregnated *Drewno modyfikowane termicznie nienasycane*	4,2	14,1	0,30/2	1,4	10,7	3,9	13,5
76 (Minimum)	4,4	14,7	0,30/2	3,7	9,7	5,3	12,8
189 (Mean) *(Średnie)*	4,8	14,4	0,33/3	2,9	8,8	4,6	12,9
328 (Maximum)	3,1	12,8	0,24/2	2,9	9,0	2,4	11,0
0 (Activity control) *0 (Kontrola aktywności)*	–	11,9	–	–	11,9	–	11,8

Notes: *x = U_t/U_k; durability classes: 1 – very durable, 2 – durable, 3 – moderately durable, 4 – little durable, 5 – not durable.
*Objaśnienia: *x = U_t/U_k; klasy trwałości: 1 – bardzo trwałe, 2 – trwałe, 3 – średnio trwałe, 4 – mało trwałe, 5 – nietrwałe.*

Table 4. Moisture content of thermally modified and thermally modified and linseed oil impregnated Scots pine after exposure to *Coniophora puteana* fungus

Tabela 4. Wilgotność termomodyfikowanego oraz termomodyfikowanego i nasyconego olejem lnianym drewna sosny po działaniu grzyba Coniophora puteana

Retention of linseed oil in wood [kg/m^3] *Nasycenie drewna olejem lnianym [kg/m^3]*	Moisture content of wood after exposure to fungus [%] *Wilgotność drewna po działaniu grzyba [%]*					
	Scots pine sapwood, not subjected to ageing *Sosna (biel) niestarzone*		Scots pine sapwood, subjected to ageing by leaching acc. to EN 84 *Sosna (biel) starzone przez wymywanie wg EN 84*		Scots pine sapwood, subjected to ageing by evaporation acc. to EN 73 *Sosna (biel) – starzone przez odparowanie wg EN 73*	
	Tested *Badane*	Control *Kontrolne*	Tested *Badane*	Control *Kontrolne*	Tested *Badane*	Control *Kontrolne*
0 – thermally modified wood, not impregnated *0 – drewno modyfikowane termicznie, nienasycane*	36,0 $^{31,4}_{44,7}$	53,2 $^{43,5}_{59,8}$	31,5 $^{20,2}_{39,5}$	49,3 $^{29,6}_{64,0}$	33,3 $^{28,0}_{39,0}$	57,9 $^{49,8}_{66,0}$
Minimum – 32	22,0 $^{18,8}_{28,2}$	53,2 $^{45,5}_{61,5}$	19,6 $^{16,7}_{22,2}$	47,7 $^{39,5}_{56,2}$	26,5 $^{20,1}_{47,9}$	62,9 $^{51,3}_{68,8}$
Mean *Średnie* – 128	19,9 $^{16,5}_{30,1}$	48,6 $^{39,3}_{56,5}$	20,5 $^{17,8}_{26,3}$	50,1 $^{44,3}_{63,1}$	20,3 $^{16,8}_{28,1}$	57,7 $^{41,3}_{67,3}$
Maximum – 223	19,1 $^{15,6}_{24,0}$	47,6 $^{33,4}_{64,7}$	19,2 $^{15,5}_{20,9}$	50,6 $^{40,3}_{57,2}$	19,8 $^{15,8}_{22,3}$	55,8 $^{44,6}_{65,6}$

Table 5. Moisture content of thermally modified and thermally modified and linseed oil impregnated birch after exposure to *Trametes versicolor* fungus
Tabela 5. Wilgotność termomodyfikowanego oraz termomodyfikowanego i nasyconego olejem lnianym drewna brzozy po działaniu grzyba Trametes versicolor

Retention of linseed oil in wood [kg/m³] *Nasycenie drewna olejem lnianym [kg/m³]*	Moisture content of wood after exposure to fungus [%] *Wilgotność drewna po działaniu grzyba [%]*					
	Birch wood, not subjected to ageing *Brzoza niestarzone*		Birch wood, subjected to ageing by leaching acc. to EN 84 *Brzoza starzone przez wymywanie wg EN 84*		Birch wood, subjected to ageing by evaporation acc. to EN 73 *Brzoza starzone przez odparowanie wg EN 73*	
	Tested *Badane*	Control *Kontrolne*	Tested *Badane*	Control *Kontrolne*	Badane *Tested*	Control *Kontrolne*
0 – thermally modified wood, not impregnated *0 – drewno modyfikowane termicznie, nienasycane*	26,7 $^{19,1}_{47,5}$	32,9 $^{30,8}_{35,8}$	21,8 $^{19,1}_{24,4}$	32,1 $^{30,1}_{35,0}$	27,3 $^{21,2}_{38,7}$	34,0 $^{30,7}_{35,7}$
Minimum – 76	19,1 $^{13,9}_{27,6}$	33,2 $^{29,8}_{36,1}$	18,0 $^{14,2}_{21,5}$	32,9 $^{30,6}_{34,9}$	24,0 $^{14,4}_{33,5}$	36,7 $^{30,5}_{47,5}$
Mean *Średnie* – 189	21,4 $^{16,9}_{27,1}$	34,0 $^{29,9}_{37,9}$	16,7 $^{13,5}_{19,3}$	31,8 $^{29,2}_{33,5}$	21,4 $^{15,8}_{26,5}$	32,3 $^{29,5}_{34,5}$
Maximum – 328	18,2 $^{15,3}_{24,1}$	32,4 $^{29,1}_{34,8}$	18,7 $^{15,5}_{24,7}$	33,0 $^{30,08}_{38,0}$	19,8 $^{17,7}_{22,2}$	32,1 $^{29,5}_{34,9}$

Conclusions

1. In comparison to natural wood, thermally modified and thermo-oil modified Scots pine sapwood and birch wood demonstrates an increase in compression strength and modulus of elasticity at bending. At the same time, their bending strength and impact bending strength decrease.
2. Thermal and thermo-oil modification of wood distinctly increases its hydrophobicity, which is evidenced by a lower, than in the case of natural wood, equilibrium moisture content of modified wood and much lower, than in the

case of control wood, values of moisture content of this wood after end of mycological tests carried out in the conditions of high humidity.

3. In comparison to natural wood, thermally modified and thermo-oil modified Scots pine sapwood and birch wood demonstrates an increased resistance to Basidiomycetes *Coniophora puteana* and *Trametes versicolor* causing brown and white rot of wood, respectively.
4. An increased resistance of thermally modified and thermo-oil modified Scots pine sapwood and birch wood to *Basidiomycotina* fungi is not decreased as a result of leaching with water and ageing by evaporation, which is an advantageous functional property in the aspect of direct exposure of wood to atmospheric factors.
5. The resistance of thermally modified Scots pine sapwood to *Basidiomycotina* fungi increases as a result of wood impregnation with linseed oil, whereas the resistance of thermally modified birch wood to *Basidiomycotina* fungi is similar to the resistance of thermally modified birch wood impregnated with linseed oil.
6. Thermal modification increases durability of Scots pine sapwood towards *Basidiomycotina* fungi from class 5 – not durable to class 3 – moderately durable, and of thermo-oil modified Scots pine sapwood even to class 1 – very durable.
7. Thermal and thermo-oil modification of birch wood increases durability of this wood towards *Basidiomycotina* fungi from class 5 – not durable to the boarder of classes 2 – durable and 3 – moderately durable.

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WŁAŚCIWOŚCI FIZYCZNO-MECHANICZNE ORAZ ODPORNOŚĆ NA DZIAŁANIE GRZYBÓW DREWNA SOSNY I BRZOZY ZMODYFIKOWANEGO TERMICZNIE I Z ZASTOSOWANIEM OLEJU NATURALNEGO

Streszczenie

W porównaniu z drewnem naturalnym drewno modyfikowane termicznie wykazuje pewne korzystne właściwości użytkowe takie jak zmniejszona higroskopijność, wyższa stabilność wymiarowa. Może się również cechować lepszą odpornością na rozkład powodowany przez grzyby oraz zwiększoną trwałością. Należy jednak zachować pewną ostrożność używając drewna modyfikowanego ze względu na ryzyko zmniejszenia właściwości wytrzymałościowych, co może ograniczać wykorzystanie tego drewna w konstrukcjach obciążonych mechanicznie. Zmiany właściwości drewna wynikające z modyfikacji termicznej w dużym stopniu zależą od warunków termicznych i wilgotnościowych w trakcie procesu modyfikacji. Próbowano otrzymać drewno ulepszone metodą modyfikacji termo-olejowej. Celem niniejszych badań było określenie wytrzymałości, hydrofobowości i odporności drewna termomodyfikowanego i drewna poddanego modyfikacji termo-olejowej na działanie grzybów powodujących rozkład (*Basidiomycotina)*. Obiektem badań były próbki bielu drewna sosny zwyczajnej (*Pinus sylvestris* L.) oraz drewna brzozy (*Betula verrucosa* Ehrh.) o wymiarach 30 (grubość) × 80 × 950 mm. Drewno było modyfikowane termicznie w temperaturze około 195°C, którą osiągnięto wewnątrz próbek po 4 h i utrzymywano przez kolejne 3 h. Drewno po ostudzeniu do 140°C impregnowano olejem lnianym poprzez zanurzenie w oleju (20°C) przez 14 h (rys. 1 i 2). Po klimatyzowaniu w warunkach 20°C/65%RH próbki drewna ostrugano mechanicznie na wszystkich powierzchniach podłużnych i przycięto, aby otrzymać próbki o wymiarach odpowiednich do wymagań stosowanych norm. W wyniku termomodyfikacji gęstość drewna zmniejszyła się o 8%, ale wzrosła o 18% w wyniku modyfikacji termo-olejowej (rys. 3 i 4). W porównaniu z wartościami wytrzymałości dla drewna naturalnego, drewno sosny zwyczajnej i brzozy poddane termomodyfikacji i modyfikacji termo-olejowej wykazało zwiększoną wytrzymałość na ściskanie wzdłuż włókien (do 118% dla drewna sosny i do 130–145% dla drewna brzozy, rys. 3 i 4) oraz moduł elastyczności przy zginaniu (do 117–123% dla drewna sosny i do 144–158% dla drewna brzozy), ale zmniejszaną wytrzymałość na zginanie (do około 90% dla drewna sosny i do 73–83% dla drewna brzozy) oraz wytrzymałość na zginanie dynamiczne (do około 92% dla drewna sosny i do około 70% dla drewna brzozy). W porównaniu z drewnem naturalnym wilgotność równowagowa drewna poddanego termomodyfikacji i modyfikacji termo-olejowej była wyraźnie obniżona w przypadku obu badanych gatunków drewna (tabela 1). Modyfikowane drewno sosny zwyczajnej i brzozy badane metodą opartą na normie EN 113 cechowało się zwiększoną odpornością na działanie grzybów *Coniophora puteana* lub *Trametes versicolor* odpowiednio po wymywaniu (EN 84) lub odparowaniu (EN 73) (tabele 2 – 5). Wyższa odporność drewna na działanie grzybów *Basidiomycotina*, nawet po sztucznym starzeniu, ma duże znaczenie z punktu widzenia zastosowań drewna. W wyniku termomodyfikacji lub modyfikacji termo-olejowej klasyfikacja drewna pod względem trwałości (EN 350-1) polepszyła się z klasy 5 – nietrwałe do klasy 3 – umiarkowanie trwałe w przypadku termomodyfikowanego drewna sosny zwyczajnej i nawet do klasy 1 – bardzo trwałe w przypadku drewna sosny zwyczajnej zmodyfikowanego metodą termo-olejową. W przypadku drewna brzozy klasyfikacja zmieniła się z klasy 5 do przełomu klas 2 i 3. Po testach grzybowych wilgotność drewna termomodyfikowanego i poddanego modyfikacji termo-olejowej była wyraźnie niższa niż drewna naturalnego: dla drewna sosny zwyczajnej: 50% – drewno naturalne, 30% – drewno termomodyfikowane, około 20% – drewno poddane modyfikacji termo-olejowej; dla drewna brzozy: 33% – drewno naturalne, 22–27% – drewno termomodyfikowane, około 20% – drewno poddane modyfikacji termo-olejowej (tabele 4 i 5). Potwierdza to także silną hydrofobizację drewna spowodowaną obróbką termiczną i termo-olejową. Istnieje potrzeba dalszych badań w celu poprawy wyników modyfikacji termicznej i termo-olejowej drewna w zakresie jego wytrzymałości.

Słowa kluczowe: drewno, termo-olej, modyfikacja, wytrzymałość, wilgotność równowagowa, grzyby, rozkład, starzenie, odporność