Drewno. Pr. Nauk. Donies. Komunik. 2010, vol. 53, nr 184

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THE ASSESSMENT OF MECHANICAL PROPERTIES OF WOOD TREATED WITH IONIC LIQUIDS

The impregnation of wood with wood preservatives may have an influence on its physical and mechanical properties. The knowledge about the character of that influence is of great importance for characterisation of functional properties of wood and, as a consequence, determination of its use classes. The ionic liquids (ILs) of imidazolium tetrafluoroborates series, which for instance very well penetrate into Scots pine wood, are active against wood-destroying fungi and generally have a positive, although insignificant, influence on physical and mechanical properties of wood, especially on its resistance to colour change during exposure to light. However, various ILs may differ widely in that respect. Under POIG.01.03.01-30-074/08 project investigations were undertaken to clarify the influence of didecyldimethylammonium nitrite ([DDA][NO$_2$]) and IL with didecyldimethylammonium cation and anion of herbicide character ([DDA][herbicide]) on selected physical and mechanical properties of Scots pine wood (Pinus sylvestris L.). The miniature sapwood samples were subjected to sorption with the ILs by vacuum method. The properties of the treated wood were compared with those of control wood, i.e. untreated wood, using twin specimens. The average retention of ILs in wood was on the level of 3.6kg/m^3, 7.4kg/m^3, and 18.2kg/m^3. The tested ILs had only a very small influence, from -0.5% to +1.6%, on the compression strength of wood along the grain when oven-dry wood was tested. However, at equilibrium moisture content the compression strength along the grain, bending strength, and modulus of elasticity at bending of wood treated

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with ILs were distinctly lower, i.e. by 10%, 20% and 15% respectively. The equilibrium moisture content of wood treated with ILs was greater by 2-3% than that of control wood, which may be the reason for deterioration of wood mechanical properties. However, this speculation requires further investigations.

Keywords: ionic liquids, wood, Scots pine, compression strength, bending strength, equilibrium moisture

Introduction

Ionic liquids which belong to a special class of molten salts whose melting points are at the temperatures below 100°C, are considered as potential "green" and neoteric solvents [Li et al. 2004; Pernak et al. 2001; Pernak et al. 2004; Rogers, Seddon 2002; Wasserscheid, Welton 2002; Welton 1999]. The insignificant vapour pressure is a special advantage of ILs, because solvent emission to the atmosphere is very low. The synthesis, properties and application of ILs, for instance as potential wood preservatives, have been extensively studied recently [Cybulski et al. 2008; Kartal et al. 2005, 2006; Sheldon 2001; Rogers, Seddon 2002; Kubisa 2004; Pernak et al. 2004, 2005, 2006]. Some of ionic liquids, such as for example imidazolium tetrafluoroborate, lactate, pyridinium chlorides and acesulfamates, and many others, are active against wood-destroying fungi and penetrate deep into the pine wood structure [Pernak et al. 2004; Zabielska-Matejuk, Pernak 2009; Zabielska-Matejuk et al. 2010]. Ionic liquids (ILs) of imidazolium tetrafluoroborates series generally have positive, although insignificant, influence on physical and mechanical properties of wood, especially on its resistance to colour change during exposure to light [Fojutowski et al. 2007]. However, various different ILs may differ widely in that respect. For example 1-butyl-3-methylimdazolium chloride dissolves cellulose from pulp [Swatloski et al. 2002] and some imidazolium-based derivates are capable of wood liquefaction [Honglu, Tiejun 2006]. The impregnation of wood with wood preservatives may have an influence on physical and mechanical properties of wood. The knowledge about the character of that influence is of great importance for characterisation of functional properties of wood and, as a consequence, determination of its use classes presented in EN 335. Under POIG.01.03.01-30-074/08 project investigations were undertaken to clarify the influence of didecyldimethylammonium nitrite ([DDA][NO_2]) and IL with didecyldimethylammonium cation and anion of herbicide character ([DDA][herbicide]) on selected physical and mechanical properties of Scots pine wood (*Pinus sylvestris* L.). The above-mentioned ILs were used in the investigation as very interesting compounds for wood protection, because of their strong effectiveness against wood-attacking fungi [Zabielska-Matejuk et al. 2010].

Materials and experiment methods

Wood used in the tests

The Scots pine wood (*Pinus sylvestris* L.) came from fresh coniferous class III forest stands of the Wielkopolsko-Pomorski (III) natural forest region. Only sapwood of the wood was used. The defect-free wood, e.g. without sapstain, rot, worm holes, was gently artificially dried below 60°C before further treatment. The quality of the sapwood samples was in line with PN-EN 113 requirements. Identical (twin) samples of sapwood were cut from selected boards and used for the tests.

Ionic liquids (ILs)

The ILs used in the tests were prepared in the Poznan University of Technology laboratory, according to the described method [Zabielska-Matejuk et al. 2010]. The main substances used in the tests were didecyldimethylammonium nitrite ([DDA][NO_2]) and IL with didecyldimethylammonium cation and anion of herbicide character ([DDA][herbicide]). The concentration of each of the tested ILs was 91–97% and they were easy dissolved in propanol-2 and water-propan-2-ol mixture.

Investigated wood properties and method of their determination

The following wood properties were investigated:

– compression strength along the grain was measured in two variants according to PN-D-04102 and in accordance with ISO 3787 using a computerised “Instron” apparatus with the force load range up to 50 kN and 5 mm/min rate of head movement:
  a) using 6 twin pairs (a pair: control specimens – specimens treated with ILs solution of individual concentration) of specimens 20 × 20 × 30 mm artificially dried before the test at 103±2°C and tested oven-dry according to PN-72/C-04907, or
  b) using for each test series (control or treated with ILs solution of individual concentration) 30 specimens 20 × 20 × 30 mm conditioned in 65±5% relative humidity and 20±2°C to equilibrium moisture,
– bending strength was measured according to PN-D-04103 and modulus of elasticity (MOE) according to PN-D-04117 in accordance with ISO 3133 using 36 specimens of 20 × 20 × 300 mm for each test series; Before the test specimens were conditioned in 65±5% relative humidity and 20±2°C to equilibrium moisture. An computerised “Instron” apparatus with a force load

range up to 50 kN and 5mm/min rate of head movement was used for the tests. MOE was determined from the linear part of the force displacement curve using a standard procedure [Dias de Moraes et al. 2004],
- moisture content of wood according to PN-EN 13183-1.

Preparation of wood specimens

To minimise the effect of wood heterogeneity on the test results a special procedure for specimen collection was used. Seven specimens were cut along the grain one by one from one strip. 36 strips were used for tests of wood bending strength and modulus of elasticity at bending and 30 for tests of compression strength along the grain at equilibrium moisture content. To achieve good comparability of the test results the specimens were specially arranged: the first specimen from each strip was intended for the test with 0.5% [DDA][NO_2] concentration, the second – with 1.0% [DDA][NO_2], the third – with 2.5% [DDA][NO_2], the forth (central) was the control (not impregnated), the fifth – with 2.5% [DDA][herbicide], the sixth – with 1.0% [DDA][herbicide], and the seventh – with 0.5% [DDA][herbicide]. The specimens for compression strength determination on oven-dry wood were cut in pairs along the grain. In each pair one sapwood sample was then treated with IL solution, while the other was used as the control (not impregnated). 12 specimens were cut from one strip for each kind of ILs and each solution concentration.

Treatment of wood with IL and preparation to the tests

At the room temperature [DDA][NO_2] and [DDA][herbicide] are highly viscous, semi-solid substances, hence their solutions were prepared to treat the wood. ILs solutions of the following concentrations were used for wood impregnation: 0.5%; 1.0% and 2.5% in water-propan-2-ol mixture (10:1). The wood specimens were impregnated with ILs solutions by vacuum-pressure method according to the procedure described in PN-EN 113. The ILs retention in wood was determined by weighing the wood samples before and after the treatment and was expressed in kg/m^3. Before the treatment the wood specimens were dried to oven-dry mass at 103±2°C. After the treatment wood specimens were conditioned to constant mass in a conditioning chamber at 20^{o}C and 65% relative humidity, except the specimens intended for determination of compression strength along the grain in oven-dry wood which were dried to oven-dry mass at 103±2°C. Control wood was conditioned or dried in the same way as the wood specimens treated with ILs.

Expression of results

The absolute values of the properties were determined for individual samples. Those numbers were then used to calculate relative values (Δ_r) according to eq. 1:

$$\Delta_r=[(W_f - W_c)/W_c] \cdot 100\ [\%] \quad (1)$$

where: W_f represented the value for treated wood,
W_c represented the value for control sample.

The values recorded are average, minimum and maximum values with standard deviation and coefficient of variability. The assessment of significance of changes in wood properties is based on statistical test data according to ISO 2854, PN-N-01052/03 item 3.4: Comparison of means in two populations assuming the confidence level of 95% (significance level of $\alpha = 0.05$).

Results and discussion

Ionic liquids retention in wood specimens

The results of wood impregnation with the solutions of ionic liquids [DDA][NO_2] and [DDA][herbicide] presented in table 1 show very even retention of the ILs in wood. The retention of ILs in wood for both ILs used and both dimensions of the wood specimens is at three levels: about 3.6 kg/m^3, 7.5 kg/m^3

Table 1. Retention of ionic liquids in Scots pine sapwood (*Pinus sylvestris* L.)
Tabela 1. Retencja cieczy jonowych w bielu drewna sosny zwyczajnej (Pinus sylvestris L.)

Ionic liquids / *Ciecze jonowe* — Specimens for / *Próbki do*	[DDA][NO_2]			[DDA][herbicide]		
	Concentration of solution [%] / *Stężenie roztworu [%]*					
	2.5	1.0	0.5	2.5	1.0	0.5
	Retention of ionic liquids in wood specimens [kg/m^3] / *Retencja cieczy jonowych w próbkach drewna [kg/m^3]*					
Bending Strength + MOE[1] / *Zginanie statyczne+MOE [1]*	*18.7*[2]	*7.7*	*3.8*	*19.6*	*7.7*	*3.7*
	17.3[3]	**7.1**	**3.6**	**17.5**	**7.1**	**3.5**
	15.7[4]	6.4	3.3	15.9	6.4	3.0
Compression strength / *Wytrzymałość na ściskanie*	*20.2*	*8.3*	*4.2*	*20.4*	*8.3*	*4.2*
	18.9	**7.6**	**3.8**	**18.9**	**7.8**	**3.8**
	18.2	7.3	3.7	18.4	6.9	3.6

[1] Modulus of elasticity at bending / *Moduł sprężystości przy zginaniu*
[2] Maximum / *Maksimum*
[3] Average / *Średnia*
[4] Minimum / *Minimum*

and 18 kg/m^3 according to the ILs solutions used: 0.5%; 1.0% and 2.5%, respectively. The wood was easily saturated with the ILs solutions by vacuum-pressure method without using high-pressure, but only by changing the pressure from vacuum to atmospheric.

Compression strength along the grain of oven-dry wood

The values of compression strength along the grain (table 2) for the control samples ranged from 90.4 to 103.1 N · mm^{-2} and for the samples impregnated with the ILs the strength ranged from 88.7 to 105.8 N · mm^{-2}. The variability coeffi-

Table 2. Compression strength along the grain of oven-dry Scots pine sapwood (*Pinus sylvestris* L.) control specimens and specimens impregnated with ionic liquids

Tabela 2. Wytrzymałość na ściskanie wzdłuż włókien w stanie zupełnie suchym próbek bielu drewna sosny zwyczajnej (Pinus sylvestris L.) nasyconych cieczami jonowymi i kontrolnych

Specimens description / *Opis próbek* — Values / *Wartości*	Twin pairs *Pary bliźniacze*		Twin pairs *Pary bliźniacze*		Twin pairs *Pary bliźniacze*		Twin pairs *Pary bliźniacze*		Twin pairs *Pary bliźniacze*		Twin pairs *Pary bliźniacze*	
	C[1]	N[2]2.5%	C	N1.0%	C	N0.5%	C	H[3]2.5%	C	H1.0%	C	H0.5%
	Compression strength along the grain *Wytrzymałość na ściskanie wzdłuż włókien*											
Average [N · mm^{-2}] *Średnia [N · mm^{-2}]*	95.3	94.8	99.8	101.4	98.1	97.8	97.5	98.6	98.4	97.5	96.1	97.1
Minimum [N · mm^{-2}] *Minimum [N · mm^{-2}]*	90.4	93.1	99.1	99.0	93.4	93.1	95.1	94.1	91.5	88.7	93.3	95.4
Maximum [N · mm^{-2}] *Maksimum [N · mm^{-2}]*	101.1	97.2	101.7	104.9	103.1	102.2	100.6	102.9	102.8	105.8	98.5	99.0
Standard deviation [N · mm^{-2}] *Odchylenie standardowe [N · mm^{-2}]*	3.5	1.4	1.1	2.2	3.6	3.7	1.9	3.6	4.2	6.3	2.0	1.6
Variation coefficient [%] *Współczynnik zmienności [%]*	3.7	1.5	1.1	2.2	3.7	3.8	2.0	3.7	4.2	6.5	2.0	1.6

[1] Control, Not impregnated / *Kontrola, Nienasycone*
[2] Impregnated with [DDA][NO_2] solutions / *Nasycone roztworami [DDA][NO_2]*
[3] Impregnated with [DDA][herbicide] solutions / *Nasycone roztworami [DDA][herbicyd]*

cients of the control and impregnated test pieces (for all tested IL retention levels) were between 1.1 and 4.2% and about 1.5–6.5%, respectively, pointing to a little scatter of results. The values of compression strength along the grain were very close for the treated and control samples. Therefore, for the pairs of twin samples at the confidence level of 95% the mean relative differences in compression strength along the grain of about minus 0.31% to +1.60% between the samples impregnated with the ILs (on every retention level) and the control samples (table 3) proved not to have been statistically significant. It demonstrates that compression strength along the grain of oven-dry wood containing to about 19 kg/m^3 of [DDA][NO_2] or [DDA][herbicide] may be at the same level as that of control, not impregnated wood.

Table 3. Relative changes of compression strength along grain of Scots pine sapwood (*Pinus sylvestris* L.) control specimens and specimens treated with ionic liquids, dried to 0% moisture content
Tabela 3. Względne zmiany wytrzymałości na ściskanie wzdłuż włókien próbek bielu drewna sosny zwyczajnej (Pinus sylvestris L.) kontrolnych i nasyconych cieczami jonowymi, wysuszonych do wilgotności 0%

Ionic liquids *Ciecze jonowe*					
[DDA][NO_2]			[DDA][herbicide]		
Ionic liquid concentration [%] *Stężenie cieczy jonowej [%]*					
2.5	1.0	0.5	2.5	1.0	0.5
Relative changes of compression strength along grain [%] *Względne zmiany wytrzymałości na ściskanie [%]*					
-0.52	1.60	-0.31	1.12	-0.91	1.04

Compression strength along the grain of wood in equilibrium moisture condition

The values of compression strength along the grain (table 4 and fig. 1) for the control samples ranged from 44.7 to 66.7 $N \cdot mm^{-2}$ and for the samples impregnated with the ILs from 30.3 to 61.7 $N \cdot mm^{-2}$. The variability coefficients of the control and impregnated test pieces (for all tested IL retention levels) were about 9.3% and between 9.2 and 14.2%, respectively, pointing to a relatively little scatter of results. The values of compression strength along the grain were lower by about 10% (in the range from 7.7% to 13.6%) for the wood samples impregnated with [DDA][NO_2] or [DDA][herbicide] than for the control samples. The level of the mean relative difference in compression strength along the grain between the impregnated and control samples at the confidence level of 95% proved to have been statistically significant. The compression strength along the grain of the impregnated and control wood in equilibrium moisture condition was distinctly smaller than that of the oven-dry wood, which had been expected. However, the equilibrium moisture of the wood impregnated with the ILs was by 2–3% greater than the equilibrium moisture content of the control wood, which might have been the reason for less compression strength along the grain of the impregnated wood than of the control wood.

Table 4. Compression strength along the grain of Scots pine sapwood (*Pinus sylvestris* L.) control specimens and specimens impregnated with ionic liquids, tested at equilibrium moisture

Tabela 4. Wytrzymałość na ściskanie wzdłuż włókien w stanie wilgotności równowagowej próbek bielu drewna sosny zwyczajnej (Pinus sylvestris L.) nasyconych cieczami jonowymi i kontrolnych

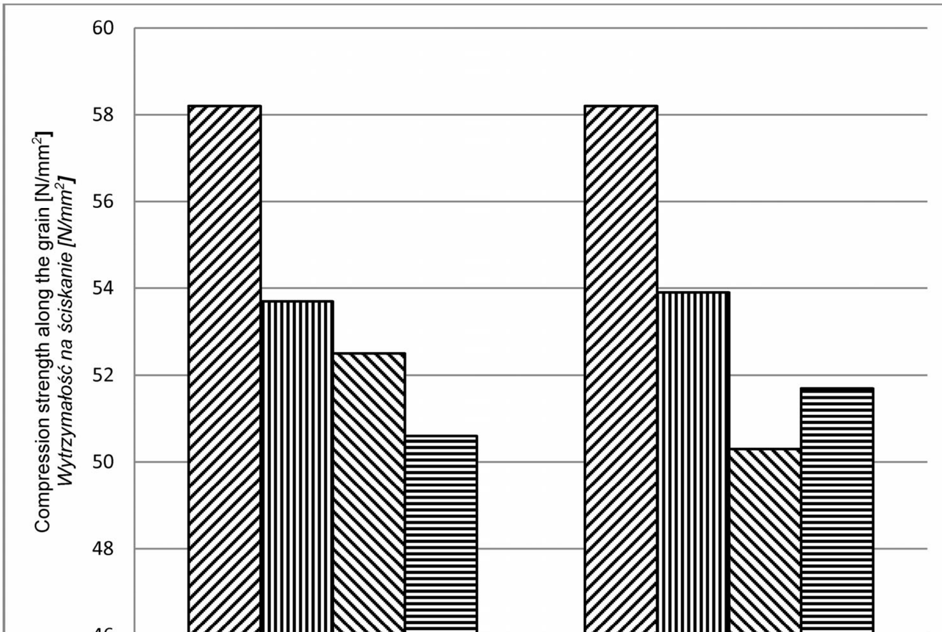
Specimens description / *Opis próbek* — Values / *Wartości*	Not impregnated[1] *Nienasycone[1]*	Impregnated with $[DDA][NO_2]$ solutions[2] [%] *Nasycone roztworami $[DDA][NO_2]$[2] [%]*			Impregnated with [DDA][herbicide] solutions[2] [%] *Nasycone roztworami [DDA][herbicyd][2] [%]*		
	Control *Kontrola*	2.5	1.0	0.5	2.5	1.0	0.5
	Compression strength along the grain *Wytrzymałość na ściskanie wzdłuż włókien*						
Average $[N \cdot mm^{-2}]$ *Średnia $[N \cdot mm^{-2}]$*	58.2	53.7	52.5	50.6	53.9	50.3	51.7
Minimum $[N \cdot mm^{-2}]$ *Minimum $[N \cdot mm^{-2}]$*	44.7	39.3	38.8	30,3	40.3	39.5	39.5
Maximum $[N \cdot mm^{-2}]$ *Maksimum $[N \cdot mm^{-2}]$*	66.7	61.7	60.9	60.3	61.0	56.8	59.6
Standard deviation $[N \cdot mm^{-2}]$ *Odchylenie standardowe $[N \cdot mm^{-2}]$*	5.4	5.3	5.4	7.2	5.0	4.9	4.7
Variation coefficient [%] *Współczynnik zmienności [%]*	9.3	9.9	10.4	14.2	9.3	9.8	9.2

[1] Equilibrium moisture: 10.1%

[1] Wilgotność równowagowa: 10.1%

[2] Equilibrium moisture in normal conditions (65% R.H., 20°C) of wood impregnated with the solution of:
- $[DDA][NO_2]$: 2.5%–12.6%; 1.0%–13.2%; 0.5%–13.0%, or
- [DDA][herbicide]: 2.5%–12.6%; 1.0%–12.9%; 0.5%–13.0%

[2] Wilgotność równowagowa dla klimatu normalnego (65% wilgotności względnej, 20°C) drewna nasyconego roztworem:
- *$[DDA][NO_2]$: 2.5%–12.6%; 1.0%–13.2%; 0.5%–13.0%, lub*
- *[DDA][herbicyd]: 2.5%–12.6%; 1.0%–12.9%; 0.5%–13.0%*



	[DDA][NO2]	[DDA][herbicide] / *[DDA][herbicyd]*
0	58,2	58,2
2,5%	53,7	53,9
1%	52,5	50,3
0,5%	50,6	51,7

Fig. 1. Compression strength along the grain of Scots pine sapwood (*Pinus sylvestris* L.) specimens impregnated with ionic liquids and control specimens tested at equilibrium moisture[1] as a function of type and concentration of ionic liquids
Rys. 1. Wytrzymałość na ściskanie wzdłuż włókien w stanie wilgotności równowagowej[1] próbek bielu drewna sosny zwyczajnej (Pinus sylvestris L.) nasyconych cieczami jonowymi i kontrolnych w zależności od rodzaju i stężenia cieczy jonowych

[1] Equilibrium moisture see legend to table 4
[1] Wilgotność równowagowa w legendzie do tabeli 4

Bending strength and modulus of elasticity of wood in equilibrium moisture condition

The mean bending strength of treated wood containing to about 17.5 kg/m^3 of the IL was smaller than that of the control sample. The respective mean value was 107.5 N · mm^{-2} for the control wood and for the test pieces impregnated with the ILs the respective values were in the range from 81.1 to 87.8 N · mm^{-2} (table 5 and fig. 2). The mean relative difference for each of the tested ILs was of about minus 20% (between 18.3 and 24.6%). Similar results were obtained for modulus of elasticity for the control and impregnated samples. The mean value was 11604 and ranged from 9618 to 10239 $N \cdot mm^{-2}$, respectively, (table 6 and fig. 3). The mean values of relative differences between modulus of elasticity for the impregnated and control samples were minus 14.3% for wood with

Table 5. Bending strength of Scots pine sapwood (*Pinus sylvestris* L.) specimens at equilibrium moisture

Tabela 5. Wytrzymałość próbek bielu drewna sosny zwyczajnej (Pinus sylvestris L.) na zginanie statyczne przy wilgotności równowagowej

Specimens description / *Opis próbek* — Values / *Wartości*	Not impregnated[1] *Nienasycone*[1]	Impregnated with [DDA][NO_2] solutions[2] [%] *Nasycone roztworami [DDA][NO_2]*[2] *[%]*			Impregnated with [DDA][herbicide] solutions[2] [%] *Nasycone roztworami [DDA][herbicyd]*[2] *[%]*		
	Control *Kontrola*	2.5	1.0	0.5	2.5	1.0	0.5
	Bending strength *Wytrzymałość na zginanie statyczne*						
Average [$N \cdot mm^{-2}$] *Średnia [$N \cdot mm^{-2}$]*	107.5	86.4	86.2	81.1	87.8	86.6	82.6
Minimum [$N \cdot mm^{-2}$] *Minimum [$N \cdot mm^{-2}$]*	83.8	64.7	68.1	55.2	64.8	60.5	57.2
Maximum [$N \cdot mm^{-2}$] *Maksimum [$N \cdot mm^{-2}$]*	134.4	102.5	105.6	103.4	114.7	105.8	102.3
Standard deviation [$N \cdot mm^{-2}$] *Odchylenie standardowe [$N \cdot mm^{-2}$]*	11.5	9.6	9.4	12.6	11.6	11.2	13.2
Variation coefficient [%] *Współczynnik zmienności [%]*	10.7	11.1	10.9	15.5	13.2	12.9	16.0

[1] Equilibrium moisture: 10.6%

[1] Wilgotność równowagowa: 10.6%

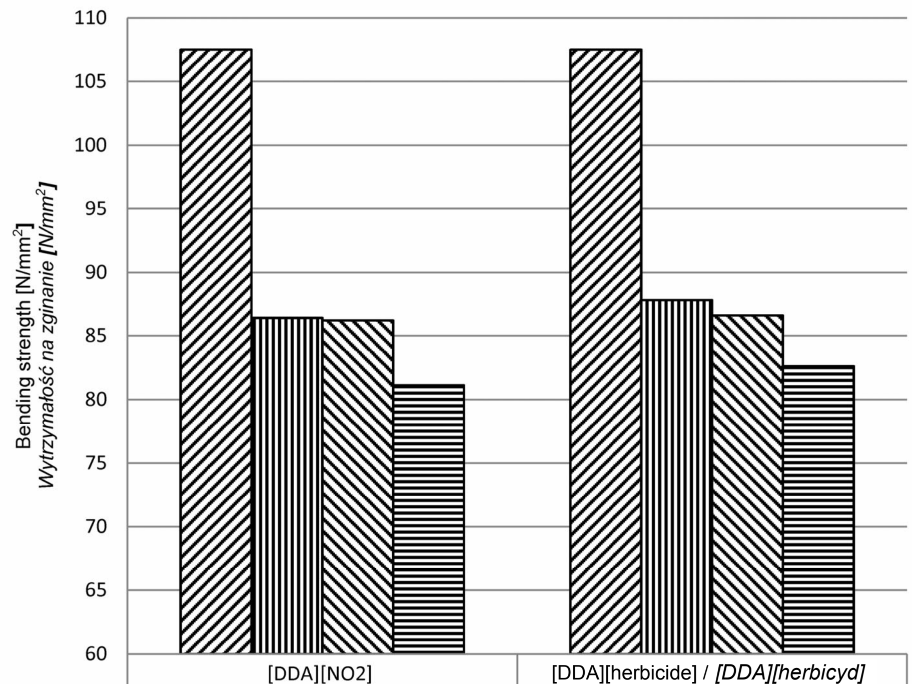
[2] Equilibrium moisture in normal conditions (65% R.H., 20°C) of wood impregnated with the solution of:

- [DDA][NO_2]: 2.5%–12.7%; 1.0%–12.5%; 0.5%–12.5%, or
- [DDA][herbicide]: 2.5%–12.5%; 1.0%–12.7%; 0.5%–12.6%

[2] Wilgotność równowagowa dla klimatu normalnego (65% wilgotności względnej, 20°C) drewna nasyconego roztworem:

- *[DDA][NO_2]: 2.5%–12.7%; 1.0%–12.5%; 0.5%–12.5%, lub*
- *[DDA][herbicyd]: 2.5%–12.5%; 1.0%–12.7%; 0.5%–12.6%*

[DDA][NO_2] and minus 14.0% for wood with [DDA][herbicide]. The differences were statistically significant at the confidence level of 95%. The equilibrium moisture level of the wood containing the ILs was about 2% greater than the equilibrium moisture of the control wood, similar to the equilibrium moisture of the wood tested for compression strength along the grain.



	[DDA][NO2]	[DDA][herbicide] / *[DDA][herbicyd]*
0	107,5	107,5
2,5%	86,4	87,8
1%	86,2	86,6
0,5%	81,1	82,6

Fig 2. Bending strength of Scots pine sapwood (*Pinus sylvestris* L.) specimens at equilibrium moisture[1] as a function of type and concentration of ionic liquids
Rys.2. Wytrzymałość próbek bielu drewna sosny zwyczajnej (Pinus sylvestris L.) na zginanie statyczne przy wilgotności równowagowej[1] w zależności od rodzaju i stężenia cieczy jonowych

[1] Equilibrium moisture see legend to table 5
[1] Wilgotność równowagowa w legendzie do tabeli 5

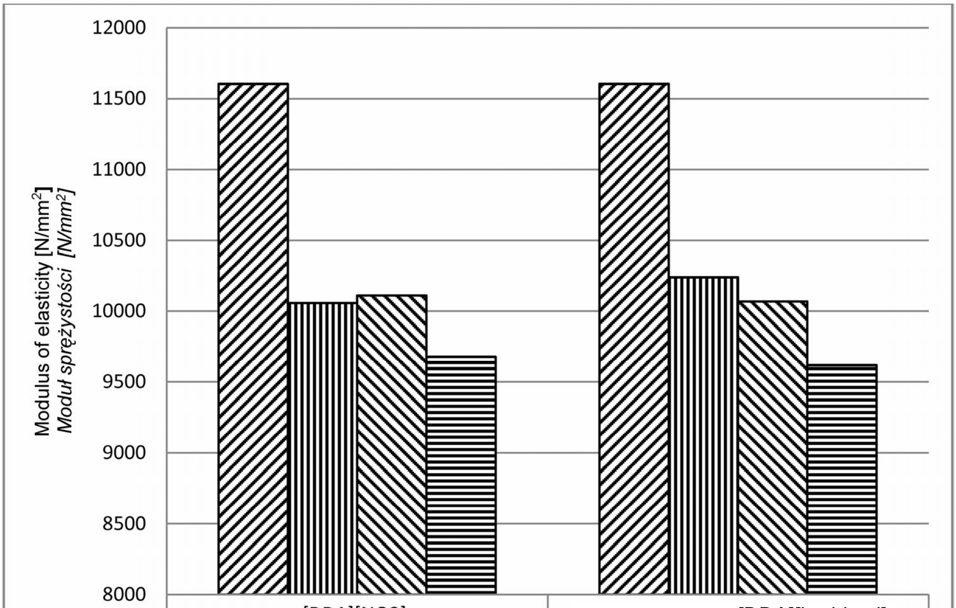
Table 6. Modulus of elasticity at bending of Scots pine sapwood (*Pinus sylvestris* L.) specimens at equilibrium moisture[1]

Tabela 6. Moduł sprężystości przy zginaniu statycznym próbek bielu drewna sosny zwyczajnej (Pinus sylvestris L.) przy wilgotności równowagowej[1]

Specimens description / *Opis próbek* — Values / *Wartości*	Not impregnated[1] *Nienasycone[1]*	Impregnated with $[DDA][NO_2]$ solutions [%] *Nasycone roztworami $[DDA][NO_2]$ [%]*			Impregnated with [DDA][herbicide] solutions [%] *Nasycone roztworami [DDA][herbicyd] [%]*		
	Control *Kontrola*	2.5	1.0	0.5	2.5	1.0	0.5
	Modulus of elasticity at bending *Moduł sprężystości przy zginaniu statycznym*						
Average $[N \cdot mm^{-2}]$ *Średnia $[N \cdot mm^{-2}]$*	11604	10056	10109	9679	10239	10066	9618
Minimum $[N \cdot mm^{-2}]$ *Minimum $[N \cdot mm^{-2}]$*	9212	7736	7700	6243	8188	8309	6994
Maximum $[N \cdot mm^{-2}]$ *Maksimum $[N \cdot mm^{-2}]$*	13167	11252	12520	12184	13578	12736	11750
Standard deviation $[N \cdot mm^{-2}]$ *Odchylenie standardowe $[N \cdot mm^{-2}]$*	997	1042	1098	1407	1201	1135	1445
Variation coefficient [%] *Współczynnik zmienności [%]*	8.6	10.4	10.9	14.5	11.7	11.3	15.0

[1] Equilibrium moisture see legend to table 5

[1] Wilgotność równowagowa w legendzie do tabeli 5



	[DDA][NO2]	[DDA][herbicide] / *[DDA][herbicyd]*
0	11604	11604
2,5%	10056	10239
1%	10109	10066
0,5%	9679	9618

Fig. 3. Modulus of elasticity at bending of Scots pine sapwood (*Pinus sylvestris* L.) specimens at equilibrium moisture[1] as a function of type and concentration of ionic liquids

Rys. 3. Moduł sprężystości przy zginaniu statycznym próbek bielu drewna sosny zwyczajnej (Pinus sylvestris L.) przy wilgotności równowagowej[1] w zależności od rodzaju i stężenia cieczy jonowych

[1] Equilibrium moisture see legend to table 5

[1] Wilgotność równowagowa w legendzie do tabeli 5

Conclusions

1. As a result of the tests carried out on identical wood specimens it was observed that impregnation of Scots pine sapwood with ionic liquids [DDA][NO_2] and [DDA][herbicide] in the amount ranging from 3.5 to 19.0 kg/m^3:
   – had no effect on the compression strength parallel to grain tested according to PN-C-04907:1972 standard on oven-dry wood (change in the

compression strength of wood above minus 5%, from -0,5% to +1,6%, not statistically significant at the confidence level of 95%),
- resulted in a 2–3% increase in the equilibrium moisture content of wood under standard conditions (RH 65%/20°C),
- decreased bending strength, compression strength parallel to grain, and modulus of elasticity in the state of equilibrium moisture content under standard conditions (RH 65%/20°C) by around 20%, 10% and 15%, respectively.

2. The differences between average values of the bending strength, compression strength and modulus of elasticity at bending of the control samples and the samples impregnated with the ionic liquids were statistically significant (at the confidence level of 95%).
3. The differences between average values of the bending strength, compression strength and modulus of elasticity at bending of the samples impregnated with the ionic liquids of various concentrations (different retention degrees) were statistically insignificant (at the confidence level of 95%).
4. Further studies should be conducted to check whether the decrease in the strength and modulus of elasticity observed at the wood moisture content equivalent to the equilibrium moisture content under standard conditions is a result of higher equilibrium moisture content of the wood impregnated with the tested liquids or an effect those liquids have on the wood tissue.

Acknowledgements

This investigation received financial support from project POIG.01.03.01--30-074/08 “Ionic liquids in innovative technologies connected with processing of lignocellulosic raw materials” co-financed by the European Regional Development Found within the Innovative Economy Operational Program 2007–2013.

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ISO 3787:1976 Wood – Test methods – Determination of ultimate stress in compression parallel to grain

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PN-77/D-04103 Drewno - Oznaczanie wytrzymałości na zginanie statyczne

PN-63/D-04117 Fizyczne i mechaniczne własności drewna – Oznaczanie współczynnika sprężystości przy zginaniu statycznym

PN-72/C-04907 Środki ochrony drewna – Oznaczanie wpływu na wytrzymałość drewna

PN-EN 113:2000/A1:2004 Środki ochrony drewna – Metoda badania do oznaczania skuteczności zabezpieczania przeciwko podstawczakom rozkładającym drewno – Oznaczanie wartości grzybobójczych

PN-EN 335-1:2007 Trwałość drewna i materiałów drewnopochodnych – Definicja klas użytkowania – Część 1: Postanowienia ogólne

PN-EN 335-2:2007 Trwałość drewna i materiałów drewnopochodnych – Definicja klas użytkowania – Część 2: Zastosowanie do drewna litego

PN-EN 13183-1:2004 Wilgotność sztuki tarcicy – Część 1: Oznaczanie wilgotności metodą suszarkowo-wagową

PN-N-1052–03:1984 p.3.4 Statystyka matematyczna – Badania statystyczne – Porównywanie wartości średnich w dwóch populacjach

OCENA WŁAŚCIWOŚCI MECHANICZNYCH DREWNA ZABEZPIECZONEGO CIECZAMI JONOWYMI

Streszczenie

Impregnacja drewna środkami ochrony drewna może wpływać na jego fizyczne, mechaniczne i biologiczne właściwości. Wiedza o charakterze tego wpływu ma istotne znaczenie dla ustalenia klas użytkowania drewna. W badaniach drewna sosny (*Pinus sylvestris* L.) zabezpieczonego cieczą jonową: tetrafluoroboranem 3-heptyoloksymetylo-1-metyloimidazoliowym, stwierdzono pozytywny jej wpływ na właściwości fizyczno-mechaniczne drewna, m.in. na zwiększenie trwałości barwy. Różne ciecze jonowe mogą mieć różny wpływ na właściwości drewna, chociaż nie można wykluczyć podobieństw wpływu związków o zbliżonej budowie. W ramach projektu badawczego POIG.01.03.01-30-074/08 podjęto badania oddziaływania dwóch cieczy jonowych: azotynu didecylodimetyloamoniowego [DDA][NO_2] i cieczy z kationem didecylodimetyloamoniowym i anionem o charakterze herbicydu [DDA][herbicyd], wprowadzonych w roztworach wodno-alkoholowych do drewna metodą próżniowo-ciśnieniową, na jego wytrzymałość. Retencje cieczy jonowych w drewnie zróżnicowano przez zastosowanie trzech różnych ich stężeń w roztworach. Badania wykonano na bielu drewna sosny (*Pinus sylvestris* L.), jako drewnie modelowym. Podstawowej oceny wpływu cieczy jonowych na wytrzymałość drewna dokonano przez zbadanie wytrzymałości na ściskanie wzdłuż włókien (zgodnie z PN-C-04907:1972) po wysuszeniu nasycanych cieczami jonowymi próbek do stanu zupełnie suchego. Następnie dokonano oznaczeń wytrzymałości na ściskanie wzdłuż włókien metodą według PN-D-04102:1979 oraz wytrzymałości i modułu sprężystości przy zginaniu drewna metodami: według PN-D-04103:1977 i PN-D-04117:1963. Oznaczenia te wykonano stosując drewno o równowagowym stanie wilgotności w klimacie normalnym (wilgotność powietrza 65%/20°C).

W rezultacie badań wykonanych na bliźniaczych próbkach drewna stwierdzono, że nasycanie bielu drewna sosny zwyczajnej cieczami jonowymi [DDA][NO_2] i [DDA] [herbicyd] w ilości 3,5 do 19,0 kg/m^3:

– nie wpływa na wytrzymałość na ściskanie wzdłuż włókien badaną zgodnie z normą PN-C-04907:1972 w stanie zupełnie suchego drewna (zmiany w zakresie od –0,5% do +1,6% kwalifikowane są według normy jako brak zmian),
– powoduje zwiększenie wilgotności równowagowej drewna w klimacie normalnym (65%/20°C) o 2–3%,
– zmniejsza wytrzymałość na zginanie statyczne, wytrzymałość na ściskanie wzdłuż włókien oraz moduł sprężystości drewna w stanie wilgotności równowagowej, dla klimatu normalnego (65%, 20°C), odpowiednio o około: 20%, 10% i 15%.

Różnice pomiędzy wartościami średnimi wytrzymałości na zginanie, wytrzymałości na ściskanie i modułu sprężystości przy zginaniu próbek kontrolnych i próbek nasycanych cieczami jonowymi są statystycznie istotne (przy poziomie ufności 95%).

Różnice pomiędzy wartościami średnimi wytrzymałości na zginanie, wytrzymałości na ściskanie i modułu sprężystości przy zginaniu próbek nasycanych cieczami jonowymi o różnych stężeniach (różne stopnie retencji) są statystycznie nieistotne (przy poziomie ufności 95%).

Dalszych badań wymaga sprawdzenie czy obniżenie wytrzymałości i modułu sprężystości przy wilgotności drewna odpowiadającej wilgotności równowagowej dla klimatu normalnego jest wynikiem wyższej wilgotności równowagowej drewna nasycanego testowanymi cieczami, czy oddziaływania tych cieczy na tkankę drzewną.

Słowa kluczowe: ciecze jonowe, drewno, sosna, wytrzymałość na ściskanie, zginanie, wilgotność równowagowa