



LIGNIN FROM STEAM-EXPLODED WOOD AS BINDER IN WOOD COMPOSITES

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Abstract. A study demonstrating the approach of zero-waste technologies, a component of the Zero Emissions concept, and using lignin extracted from steam-exploded wood as adhesive in hot-pressed fibre boards and plywood to substitute phenol-formaldehyde resins is reported. Properties of sample boards containing different amount of lignin adhesive are compared between themselves and with the EU standards for fibre boards. A strong correlation of density and form stability under humid conditions with the lignin content is found. Results of testing mechanical properties of the boards suggest that effect of lignin on mechanical strength depends on the size of particles and hot-pressing temperature. Steam explosion and hot-pressing technologies tested in the study are shown to have potential of utilizing low-quality wood and waste from forest industry to make value-added products. Complementing a saw mill they represent a model of integrated technologies cluster in accordance with the concept of Zero Emissions facilitating environmental protection by reducing pollution and eliminating waste. Mixtures of commercial phenol-formaldehyde resins containing 10% lignin by weight, tested as plywood binders under conditions of factory production, show satisfactory cohesion.

Keywords: zero-waste technologies, wood composites, steam explosion (SE), SE lignin, adhesives.

1. Introduction

Natural wood is a complex and multifunctional composite material used by humans for a vast variety of their needs from the source of energy to the stuff for arts competing successfully with other substances and modern synthetics. During millennia humans have learned to improve and modify the natural properties of wood for special needs by special treatment and selection (Nagyvari *et al.* 2006). Plywood and a variety of pressed boards are well-known composite materials widely used in building constructions and furniture. Developed technologies allow to utilize low-quality wood and waste from forest and wood industries, particularly sawmills, to make value-added products complying with demands of zero-waste principles (Gravitis 2007). Indeed, by reducing pollution and utilizing waste the zero emissions and zero-waste technologies efficiently promote protection of the environment (Vaboliene and Matuzevicius 2005; Kvasauskas and Baltrenas 2008; Baltrenas and Zagorskis 2008). The general Zero Emissions concept emphasizes the shift from traditional linear industrial models in which wastes are considered the norm, to systems of integrated technologies where everything is used. It advocates an industrial transformation whereby businesses emulate sustainable cycles found in nature and where society minimizes the stress it imposes on the natural resource base and learns to do more with what the earth produces. In this way, industries are reorganized into clusters such that each industry's wastes/by-products satisfy the input requirements of another industry, and the integrated whole pro-

duces no waste of any kind (Gravitis 1999, 2006a, 2008; Gravitis and Della Senta 2001; Gravitis *et al.* 2001).

Some adhesive substance is the usual other component used to make composite boards the main ingredient of which is wood or other kind of biomass. Presently phenols are the main source of industrially used adhesives. About 95 percent of phenol produced in North America is derived from cumene oxidation. Cumene is made from petrochemicals – benzene and propylene for which reason the costs of these chemicals are driven by the price of oil. As the oil prices increase dramatically, the costs of wood composites (plywood, oriented strand board (OSB), medium density fibre (MDF) board, etc.) rise dramatically too – the prices of phenol-based adhesive resins show a direct correlation with the oil market prices. The other major adhesive component is formaldehyde produced from natural gas. However, in 2004 the International Agency for Research on Cancer has classified formaldehyde as human carcinogen. Along with economic considerations suggesting reducing the costs of wood adhesives by using aromatics from renewables at stable pricing of feedstock carbon, lately there is a growing interest in cheap self-binding (self-adhesive) wood composites.

The present study some results of which have been reported at meetings in Vilnius (Aboliņš *et al.* 2008) and Riga (Gravitis *et al.* 2008) and has been taken on as an attempt to use lignin extracted from wood processed by steam explosion auto-hydrolysis as the adhesive in hot-pressed fibre boards and plywood. The present report comprises a wider field of SE applications and new experimental results of other samples.

2. Experimental

2.1. Steam Explosion

Steam explosion (SE) is principally a rather simple process but complicated in technical details (Гравитис 1987). The biomass is treated with saturated steam, usually at pressures up to 4 MPa. The treatment time varies from some seconds to some minutes. After the treatment, within a split second, the biomass is decompressed (exploded) to the pressure of ambient atmosphere. The diagram of the SE process is shown in Fig. 1. The steam is generated by heating water in the boiler. Upon reaching the necessary steam parameters the sample is filled into the reactor and treated by steam at temperature of 235 °C and pressure of 3.2 MPa. After having been subject to treatment for a chosen duration the sample is forced out into receiver wherefrom it further proceeds to the separation column (Fig. 1). The steam-exploded material was used as a composite for self-binding fibre boards (see also Fig. 7).

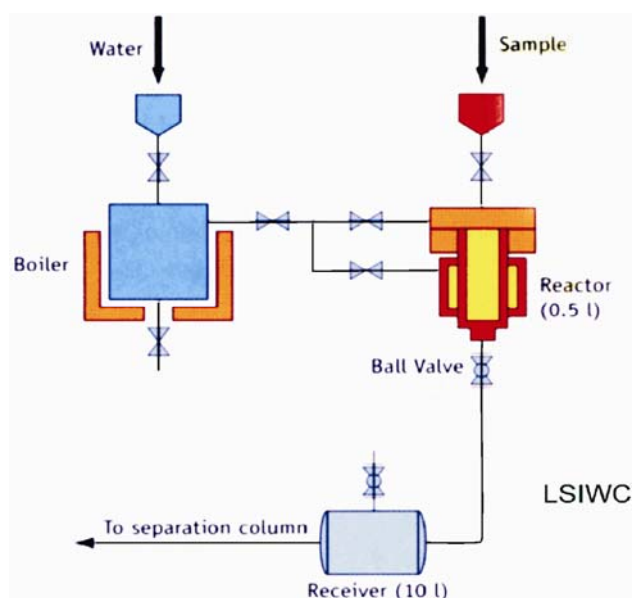


Fig. 1. Diagram of the experimental SE unit

Empirically, conditions of the steam explosion can be characterised by a single treatment severity index comprising temperature and time (Overend and Chornet 1987). During SE the decomposed wood components, particularly lignin, act as self-supplying adhesives. SE wood fibres are a modified hierarchical assembly of thermodynamically incompatible components. Modified tailored fibres, particularly nano-particles, have been generated under certain SE conditions (Kallavus and Gravitis 1995; Gravitis 2006b).

The biomass after steam explosion auto-hydrolysis represents a mixture of its main ingredients – cellulose, soluble sugars, and lignin. The soluble parts are removed by adding water. Lignin is extracted from the residual by solving it in 0.4% solution of NaOH wherefrom it is precipitated by adding hydrochloric acid to neutralise the solution. Precipitated mass is rinsed in water to remove the remnant of sodium chloride before filtration. After

drying in air the filtrate turns into powder presented as steam-exploded lignin used as the binder in the hot-pressed sample boards or plywood adhesive supplement in the tested plywood samples. The block diagram of fractionation of SE wood is shown in Fig. 2.

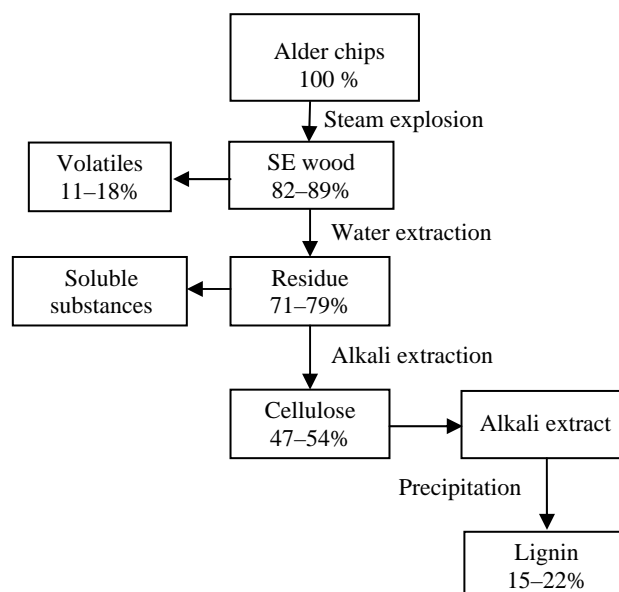


Fig. 2. Separation of the main components of steam-exploded wood biomass

2.2. Instrumental methods

The raw material for hot-pressed board samples was studied by an L&W Fibre Tester analyser to determine such fibre parameters as *length*, *width*, *shape factor* (the ratio of projected to actual length), *coarseness* (mass per unit length), and ratio of *finer* (fibers less than 0,2 mm), of the steam-exploded wood biomass and extracted cellulose.

A Mettler Toledo TGA/SDTA851 thermal gravimeter and a Mettler Toledo DSC822 differential scanning calorimeter were used to detect thermal effects and anomalies (loss of mass and glass transition temperature T_g) in samples of the extracted lignin.

The concentration of lignin in hot-pressed board samples was evaluated from infrared spectra recorded by a Perkin Elmer "Spectrum One" Fourier transform spectrometer. The 32 repeated infrared absorption spectrum scans at the rate of 0.2 cm^{-1}/s at resolution of 4 cm^{-1} of each of the three samples prepared for the purpose covered the range from 450 to 2000 cm^{-1} . The Spectrum 5.0.1 (Perkin Elmer Instruments LLC) software was used for correction of the base line and normalisation of the spectra.

Mechanical properties (modulus of elasticity and bending strength (EN 310:1993)) of hot-pressed board samples were tested by a universal machine for testing material resistance ZWICK/Z100 at the LSIWC. The same kind of testing machine was used to examine the properties of plywood samples at the Joint Stock Company "Latvijas Finieris".

The testing results of the board and plywood samples were compared with European standards (EN 312: 2003, EN 622-2:2004, EN 314-2:1993).

2.3. Sampling

Lignin used in the experiments was extracted from long-term sample growths of grey alder (*Alnus incana* L.) Moench) wood after being processed for 2 min by saturated steam at 235 °C under pressure of 3.2 MPa. The same kind of raw material was used to make the experimental hot-pressed fibre board samples.

Five kinds of board samples of the size 10×10 cm hot-pressed in a single stage at 8 MPa during 10 min were prepared for tests:

B1 – binderless boards of shredded alder chips sifted through a 2 mm mesh sieve;

B2 – self-binding boards of shredded alder chips mixed with lignin extracted from the steam-exploded mass at the proportion 4:1 by weight of absolutely dry mass;

B3 – self-binding boards of ground SE cellulose – residue of the steam-exploded pulp after extraction by water and 0.4% solution of NaOH;

B4 – self-binding boards of ground SE cellulose mixed with SE lignin at the proportion 4:1;

B5 – self-binding boards of non-fractioned air-dried steam-exploded pulp.

The hot-pressed boards were left in the press for two hours to cool down while the pressure decreased. Conditions under which the board samples have been pressed are specified in Table 1.

Table 1. Processing regimes of hot-pressed board sample. In all cases the pressing pressure was 8 MPa and the duration 10 min

Sample	Temperature, °C	Components
B1	225	Alder chips (2 mm mesh)
	221	
	227	
B2	196	Alder chips : Lignin = 4 : 1
	192	
B3	225	SE cellulose residue
B4	186	SE cellulose : Lignin = 4 : 1
	196	
B5	170	Air-dried SE mass
	190	

The weight of all samples was calculated to contain 100 g of absolutely dry mass. The dry mass of a B2 sample contains 80 g of shredded chips and 20 g of lignin powder. The moisture content and mass of samples are given in Table 2. The wood component for a board sample first is mixed with the lignin binder on a sheet of paper, then discharged into a flask and shaken until reaching a uniform colour. Ingredients for B1 and B2 samples were prepared to make three sample boards, the masses for B4 and B5 – for two, and mass for B3 – for one sample board.

Mechanical properties of the boards were tested on 30×95 mm specimens cut from the hot-pressed samples. After mechanical tests the same test pieces were used to evaluate the effect of moisture on form stability (swelling) for which purpose the fractured side of one of the

Table 2. Moisture and outweigh mass of components of the board samples

Sample		B1	B2	B3	B4	B5
Moisture, %	Main component	7.91	7.91	5.94	5.94	4.8
	Lignin (L2)	–	5.90	–	5.90	–
Mass, g	Main component	109	87	106	85.1	105
	Lignin (L2)	–	21.2	–	21.2	–
	Sample	109	108	106	106	105

broken halves was cut off to 30×30 mm specimens to obtain a smooth surface.

The plywood samples were prepared in the laboratory of Joint Stock Company “Latvijas Finieris” from three birch veneer sheets of the size 600×900×1.5 mm bonded by 5 different kinds of adhesives (Table 3) spread uniformly over the surface of a veneer sheet prior to covering it with the next sheet to be glued to at right angle between the direction of fibres of adjacent sheets. Commercial phenol formaldehyde resin adhesive (PF_{com}) was taken for two samples (P1). Adhesive for other two samples (P2) was made of mixture of the commercial phenol formaldehyde resin with steam-exploded lignin (L) in the proportion of 9:1 of absolutely dry masses of the components. Adhesive of the group of 4 plywood samples (P3) was the commercial phenol formaldehyde resin mixed with glue used by the factory to bond plywood sheets.

The same adhesive mixed with the steam-exploded lignin in the proportion of 9:1 of absolutely dry mass was used to make one plywood sample (P4). Adhesive for one more sample (P5) was made mixing commercial phenol formaldehyde resin with steam-exploded lignin solution in 0.4% NaOH (25% lignin and 75% NaOH) in the dry substance weight proportion of 9:1.

Amount of adhesive consumed was within the range of 165–195 g/m². The packets of veneer sheets were put under pressure of about 0.1 MPa for 15–30 min to flatten the layers before binding under higher pressure (1.8 MPa) at 127 °C temperature.

The binder adhesion was evaluated on test pieces of the size 25×150 mm cut from the plywood sheet samples. From both sides of each sample about 2.5 mm wide cuts were made through the surface layer at the distance of 25 mm (EN 314-1:2004).

Table 3. Adhesives and bonding regime of plywood samples

Sample	Adhesive	Temp. °C	Press. MPa	Time min
P1	PF _{com}	127	1.8	4
P2	PF _{com} :L = 9:1			
P3	PF _{com} + hardener			
P4	(PF _{com} +hardener.):L 9:1			
P5	PF _{com} : (0.25 L + 0.75 NaOH) = 9:1			

2.4. Testing of board and plywood samples

Density determined as mass per unit volume (in g cm^{-3}) of the hot-pressed board samples calculated as the ratio of sample mass m divided by the product of length a , width b , and thickness t of the sample:

$$\rho = \frac{m}{a \cdot b \cdot t}. \quad (1)$$

Density was calculated for each of the three specimens of the size 95×30 mm cut from each of the hot-pressed sample boards.

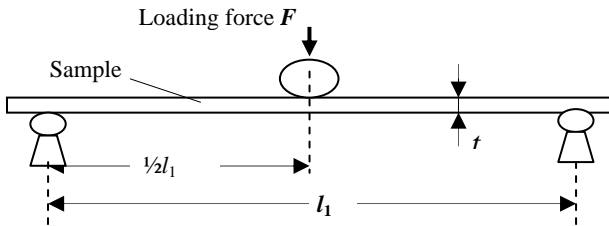


Fig. 3. Schematic representation of bending experiment

The modulus of elasticity is calculated from data of bending test (Fig. 3) in the course of which the ends of a specimen are rested on two supports while the central part is bent by loading at the rate of 1 mm per minute until the specimen breaks (EN 310:1993):

$$E_m = \frac{l_1^3 \cdot (F_2 - F_1)}{4 \cdot b \cdot t^3 \cdot (a_2 - a_1)}, \quad (2)$$

where l_1 is the distance between supports, in mm; b – width of the specimen, in mm; t – thickness of the specimen, in mm; $(F_1 - F_2)$ – increase of the load over the linear part of the bending curve, $(a_2 - a_1)$ – increase of deformation with respect to $(F_1 - F_2)$ in the middle of the test piece.

The bending strength f_m is calculated from the maximum force of load F_{max} in N mm^{-2} (EN 310:1993):

$$f_m = \frac{3 \cdot F_{max} \cdot l_1}{2 \cdot b \cdot t^3}. \quad (3)$$

All the board samples were tested for swelling after soaking for 24 hours in deionised water, the thickness being measured before and after the treatment. The swelling G_t is calculated as the ratio (EN 317:1993):

$$G_t = \frac{t_2 - t_1}{t_1} \cdot 100, \quad (4)$$

where t_1 is thickness before soaking, in mm; t_2 – thickness after soaking in water for 24 hours, in mm.

After that the board samples were dried in air for about two weeks until reaching constant weight to calculate residual swell:

$$G'_t = \frac{t'_2 - t_1}{t_1} \cdot 100, \quad (5)$$

where t_1 is thickness of the sample before the swelling test, in mm; t'_2 – thickness of the sample dried for 2 weeks after the swelling test, in mm.

Shear strength characterising the plywood binder quality is calculated (in N mm^{-2}) from the failing force of the test piece from equation 6 (EN 314-1:2004). The load applied at a constant rate of motion so that rupture occurred within 30 ± 10 s.

$$f_v = \frac{F}{h \cdot b}, \quad (6)$$

where F is the failing force of the test piece, in N; h – length of the shear area, in mm; b – width of the shear area, in mm.

Before The shear strength test, the length and width of the shear area of the plywood specimens were measured to the accuracy of 0.1 mm and recorded. After that the specimens were pre-treated as required for non-covered exterior plywood (EN 314-2:1993) – for 4 h in boiling water, then dried in the ventilated drying oven for 16 h to 20 h at 60 ± 3 °C, then immersed in boiling water for 4 h, followed by cooling in water at 20 ± 3 °C for at least 1 h.

3. Results and discussion

3.1. Lignin structure

Absolutely dry (a) and air-dry (b) samples of lignin extracted from alder chips processed by SE for 1, 2, and 3 minutes, respectively, were prepared (Table 4).

Table 4. Moisture content of SE lignin samples, % of mass: a) absolutely dry samples – air-dry samples after being dried in oven at 105 °C and stored in desiccator over phosphorus pentoxide; b) air-dry samples – samples held in air at room temperature to reach equilibrium moistures

Samples	L1	L2	L3
Absolutely dry a	0	0	0
Air-dry b	5.95	5.90	6.17

The glass transition temperature T_g of the alder-wood SE lignin determined by calorimetric test of the samples was found to be in the range of 137–157 °C (Fig. 4). As seen from Fig. 4, the glass transition temperature of air-dry SE lignin (L2b) is higher than that of absolutely dry lignin sample (L2a). The thermo-gravimetric (TG) curves of air-dry lignin samples extracted from steam-exploded masses processed under pressure and high temperature during 1 min (L1b) and 2 min (L2b) are shown in Fig. 5. In case of L1b lignin the loss of mass occurred earlier compared with the L2b lignin suggesting that glass transition temperature of the L2b lignin sample is lower than glass transition temperature of the L1b lignin.

Infrared spectra of lignin, extracted from the steam-exploded mass, and the boards are shown in Figs. 6a, b, c. Intensity of the IR carbonyl band at 1702 cm^{-1} is growing in spectra of the SE lignin samples with the increase of duration of SE treatment of the mass from which lignin is extracted (Fig. 6c).

Vibration bands of the aromatic ring of lignin at 1600 cm^{-1} , 1510 cm^{-1} , and $1420\text{--}1450 \text{ cm}^{-1}$ are more expressed (Sarkanen, Ludwig 1975) in board samples of

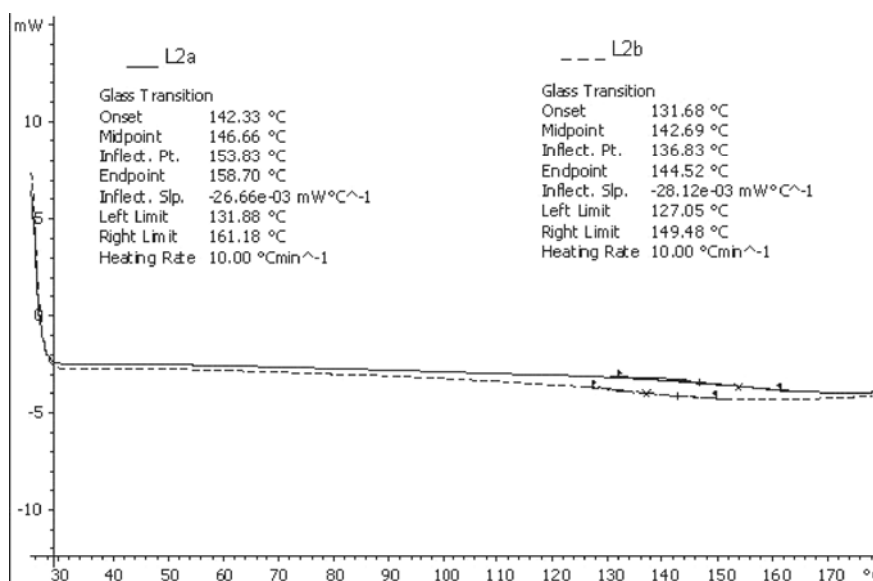


Fig. 4. DSC curves of SE lignin. L2a – oven-dry SE lignin (SE treatment time 2 min); L2b – air-dry SE lignin (SE treatment time 2 min)

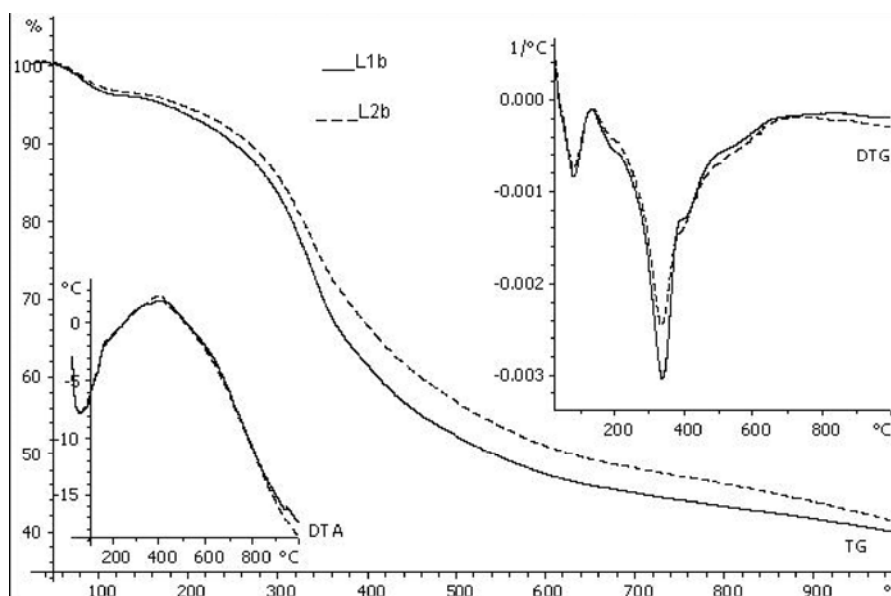


Fig. 5. Thermo-gravimetric (TG) weight loss curves of SE lignin. L1b – air-dry SE lignin (SE treatment time 1 min); L2b – air-dry SE lignin (SE treatment time 2 min)

material containing admixture of lignin (compare curves 2 and 1 in Figs. 6a and 6b). They are more distinct in spectra of chip boards (Fig. 6a) compared with boards pressed of the cellulose residue (Fig. 6b) after extraction of lignin.

3.2. SE fibre parameters

Particle size statistics was studied with fibres of air-dried steam exploded mass (F1), residue of the steam exploded mass after extraction of the components soluble in water and 0.4% solution of NaOH (F2), and ground residue (F3). The obtained results are summarised in Table 5. As seen in the table, the average length and width of the fibres decreases, but the amount of smaller particles increases after farther treatment – rinsing with water and solution of NaOH, grinding (Abolins *et al.* 2008).

Table 5. Determined fibre parameters. Shape – the ratio of the perceptible to the actual fibre length. Fines – fibers less than 0,2 mm. Aspect ratio – AS = average length/average width

Sample	F1	F2	F3
Number of fibres	14502	20042	20014
Temperature at testing, °C	40.5	40	39.3
Average length, µm	855	799	637
Average width, µm	30.9	26.4	29.6
Shape, %	84.8	85.9	86.3
Fines, %	10.2	11.6	29.9
Coarseness, µg/m	339	172	225
Aspect ratio	27.7	30.3	21.5

Since the average ratio of length to width of undamaged fibres in the natural aspen and birch wood are equal to 1.2/0.033 and 1.2/0.024, respectively (Mepcob

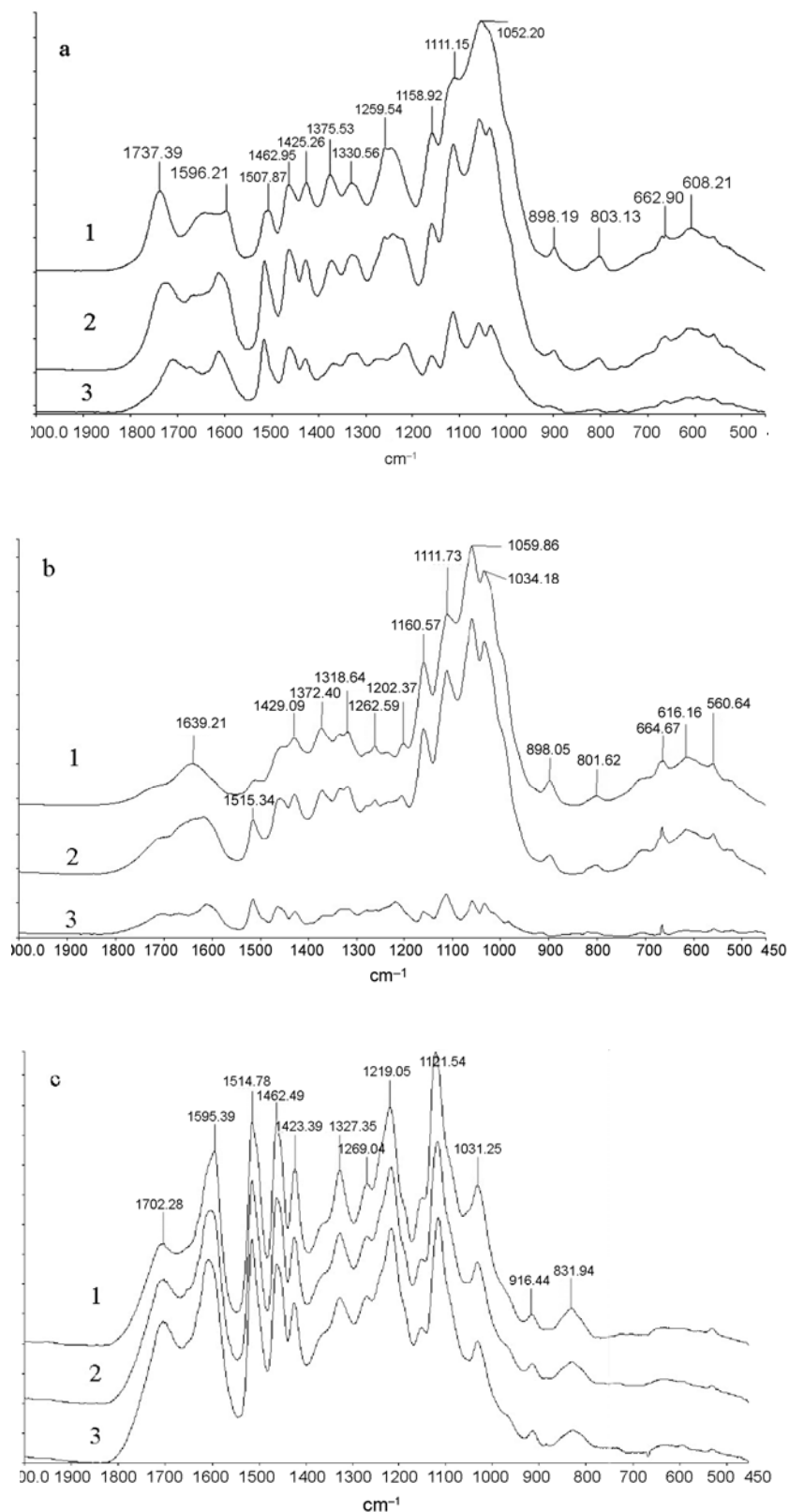


Fig. 6. FTIR spectra of different samples: a) boards of shredded alder chips; 1 – binder-less boards of shredded alder chips (B1); 2 – self-binding boards of shredded alder chips mixed with SE lignin at the proportion 4:1 (B2); 3 – difference between spectra 1 and 2; b) boards of ground SE cellulose; 1 – self-binding boards of ground SE cellulose (B3); 2 – self-binding boards of ground SE cellulose mixed with SE lignin at the proportion 4:1 (B4); 3 – difference between 1 and 2; c) SE air-dry (6%) Lignin; 1 – 1 min treatment time SE Lignin (L1b); 2 – 2 min treatment time SE Lignin (L2b); 3 – 3 min treatment time SE Lignin (L3b)

1989), the length of fibres after SE is smaller the width being the same as of natural fibres.

Compared with dimensions of industrial fibres (Mecob 1989) the dominating fibre length is 1 mm in both cases the length of industrial fibres reaching 12.8 mm while the length of SE fibres does not exceed 7.5 mm.

3.3. Properties of hot-pressed boards

An illustration of the sequence of procedures used to obtain the board samples is demonstrated in Fig. 7. All the board samples were 7–8 mm in thick.

Density, bending strength (F_m), modulus of elasticity (E_m), and the instant (G_t) and residual swell (G'_t) of thickness of the hot-pressed board samples are presented in Table 6.

Comparing density of the tested samples it obviously increases with the content of lignin in samples B1–B2 and B3–B4.

The highest density, however, is reached in samples (B4) pressed of the steam-exploded cellulose residue with admixture of lignin (20% by mass) extracted from the steam-exploded mass of wood, which is less than the content of lignin in natural wood samples (B1) or in the steam-exploded mass (B5).

The rather considerable difference between the density of samples B1 and B4 may be assigned to the much smaller size of fibrous particles of the steam-exploded cellulose mass compared to the size of shredded wood chips.

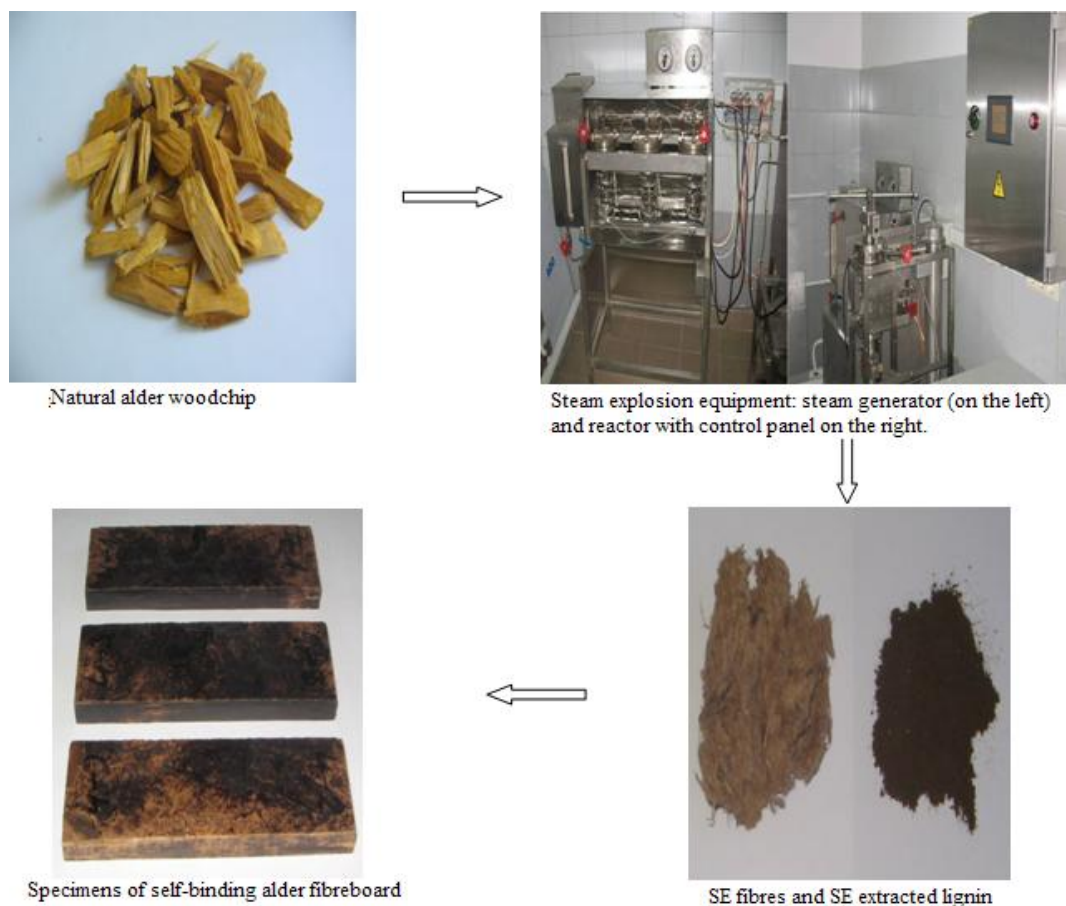


Fig. 7. An illustrative display of processing the hot-pressed boards

Table 6. Properties of hot-pressed sample boards. ± – standard deviation

Sample	Pressing T, °C	Density, g cm ⁻³	f_m , N mm ⁻²	E_m , N mm ⁻²	G_t , %	G'_t , %	
B1	Chips, 2 mm mesh	221	1.18±0.04	21±3	3570±600	35±5	16±3
		227	1.17±0.04	20±5	3650±820	43±9	23±4
B2	Chips :L 4:1	196	1.24±0.01	15±6	3330±430	18±11	10±7
		192	1.27±0.02	14±5	3420±410	12±11	6±8
B3	SE cellulose	225	1.12±0.02	13±2	2400±250	39±3	18±2
B4	SE cell:L 4:1	187	1.29±0.04	22±4	5080±485	25±8	12±5
		196	1.33±0.04	17±2	4230±375	19±5	9±3
B5	Dried SE mass	170	1.34±0.04	30±5	4700±1250	9±1	3±1
		190	1.24±0.06	15±4	3000±750	11±2	3±1

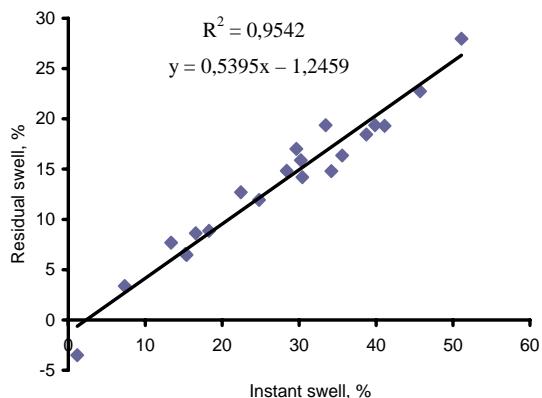


Fig. 8. Correlation between the instant and residual swell of hot-pressed board samples

Enhanced resistance to moisture is another obvious effect of lignin content in the hot-pressed boards. As seen from Table 6, swelling of the board samples in water decreases in the same order as increases the density, the board containing 20% of additional lignin (B2) compared with natural wood (B1) or mixture of cellulose with 20% of the extracted lignin (B4) and pulp (B5) being most resistant. As might be expected, there is a strong correlation between the instant and residual swell (Fig. 8).

Correlation of mechanical properties with the content of lignin is not as unambiguous as in case of density or resistance to moisture. Nevertheless, the board of hot-pressed cellulose residue (B3) has the lowest value of the modulus of elasticity (Table 6). The samples of the mixture of 80% cellulose and 20% lignin (by mass) showed the highest values of the modulus of elasticity (Table 6).

The results partly compare to requirements of the European Standard for commercial boards. The hot-pressed boards of raw alder chips (B1) meet the requirements for general purpose particleboard types P1 and P2 for use in dry conditions (type P1) and for interior fitments including furniture under dry conditions (type P2) (EN 312:2003). Admixture of SE lignin to alder chips improves the hot-pressed board (B2) form stability to resist moisture while reducing mechanical strength (Table 6). The properties of B2 samples are close to non load-bearing boards for use under humid conditions (EN 312:2003). Admixture of lignin binder to the cellulose residue improved the quality of hot-pressed boards B4 compared to B3 (Table 6). The properties of board samples B3 do not meet the minimum requirements for any board type of the EU Standard 622-2:2004. The form stability of hot-pressed boards B4 complies with type HB (hard board) of the Standard for use

under dry conditions while bending strength is below the required minimum. The board samples of SE wood (B5 in Table 6) show best results of the tested properties complying with requirements for load-bearing boards for use in dry conditions (EN 622-2:2004). The form stability properties of these samples meet the requirements for use in humid conditions while mechanical properties fail to meet the requirements.

Test results of board samples B5 obtained from hot-pressed air-dry steam-exploded wood suggest that mechanical strength may depend on the temperature at which the boards are pressed. More studies are necessary to obtain the evidence and data revealing the effect of hot-pressing temperature on the board properties.

The board samples of dried SE mass show the best results of all the obtained samples and compete with commercial wood fibreboards. However, if samples are removed from the press unit before having cooled below 60 °C, cavities are formed in the bulk material.

3.4. Plywood properties

Results of plywood sample tests are presented in Table 7. As seen from the results of testing shear strength, admixture of SE lignin to commercial phenol-formaldehyde resin up to 10% does not affect the quality of adhesion. Using the sodium hydroxide solvent for better mixing of lignin into the resin has not improved cohesion, as one may see comparing shear strength of samples P1 and P5 (Table 7). Shear strength of all the samples exceeds the value of 1 N mm⁻² and satisfies the mean apparent cohesive failure (Fig. 9, EN 314-2:1993). As seen from Table 7, adhesion in all the samples comply with the requirements for products of the Joint Stock Company “Latvijas Finieris”. More studies are necessary to find conditions for rational use of SE lignin as substitute for PF resins in plywood production.

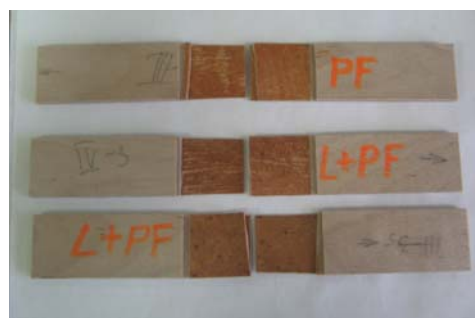


Fig. 9. Plywood specimens after shear strength test. Dark brown square – apparent cohesive wood failure

Table 7. Shear strength and elasticity of plywood samples. * Requirements of Joint Stock Company “Latvijas Finieris”

Sample	Adhesive	Shear strength, N mm ⁻²	Bending strength, N mm ⁻²		Modulus of elasticity, N mm ⁻²	
			along fibres	across fibres	along fibres	across fibres
*	PF _{comm}	≥ 1	23	75	500	10 000
P1	PF _{comm}	1.83±0.34	30±2	163±7	1 284± 86	17 940±840
P2	PF _{comm.} + SE lignin	1.86±0.30	32±2	133±23	1 200±70	16 370±1340
P3	PF _{comm} + hardener	1.66±0.22	28±5	132±6	1 290±440	14 240±990
P4	PF _{comm} +hardener+SE lignin	1.52±0.44	28±1	148±7	1 170±70	17 700±1220
P5	PF _{comm} + SE lignin:NaOH	1.33±0.22	31±2	153±14	1 275±110	18 200±1020

4. Conclusions

1. Lignin extracted from steam-exploded alder wood (*Alnus incana* (L.) Moench) acts as binder in wood particle and fibre boards improving form stability.

2. The hot-pressed boards of raw alder chips (B1) meet the requirements for general purpose particleboard types P1 and P2 for use in dry conditions (type P1) and for interior fitments including furniture under dry conditions (type P2) (EN 312:2003). (EN 312).

3. The properties of hot-pressed board samples (B2) of mixture of raw alder chips and SE lignin are close to non load-bearing boards for use under humid conditions (EN 312:2003).

4. The properties of hot-pressed board samples (B3 and B4) of SE cellulose and a mixture of SE cellulose with SE lignin do not meet the minimum requirements for any board type of the EU Standard 622-2:2004.

5. Self-binding board samples hot-pressed from SE grey alder fibres (B5) comply with requirements for application in loaded construction in dry environment (EN 622-2:2004).

6. Results obtained with admixture of lignin extracted from steam-exploded wood to plywood binder are promising for more laboratory tests applying higher lignin concentrations in the adhesives and varying the binding regimes.

7. Properties of the obtained hot-pressed board samples and adhesives demonstrate the feasibility of using waste to make value-added products representing an efficient way of protection of the environment.

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LIGNINAS IŠ GARO SPROGDINIMO BŪDU APDIRBTOS MEDIENOS KAIP RIŠAMOJI MEDŽIAGA MEDIENOS KOMPOZITUOSE

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Santrauka

Ligninas, išgautas garo sprogdinimo būdu, atstoja rišamąją medžiagą medienos plaušo plokštėse ir dedamas kaip dalinis pakaitalas į fenolformaldehido klijus, gaminant klijuotą fanerą. Tai beatliekės technologijos pavyzdys įgyvendinant bendrąją beatliekės gamybos koncepciją. Analizuojamos eksperimentinių medienos plaušo plokščių, kurioms naudota skirtingas lignino kiekis, savybės, palyginti su Europos Sąjungos standartizuotų medienos plaušo plokščių savybėmis. Nustatyta gera eksperimentinių plokščių su lignino priedu tankio ir atsparumo vandeniui koreliacija. Bandymų rezultatai rodo plokščių stiprio priklausomybę nuo medienos dalelių dydžio ir presavimo temperatūros. Išanalizavus akivaizdu, kad taikant minėtąją technologiją galima didelės pridėtinės vertės produktų gamyba iš nekokybiškos medienos ir medienos apdirbimo atliekų. Šių technologijų taikymas lėptjūvėse būtų integruotų technologijų grupės, veikiančios pagal beatliekės gamybos principą, pavyzdys. Bandant klijuotą fanerą, kurią gaminant kaip dalinis pakaitalas fenolformaldehido klijams paruošti naudojamas garo sprogdimo procese išgautas ligninas, nustatyta patenkinama kohezija.

Reikšminiai žodžiai: beatliekės technologijos, medienos kompozicinės medžiagos, garo sprogdimas, garo sprogdimo procese išgautas ligninas, adhezivai.

ЛИГНИН ИЗ ДРЕВЕСИНЫ, ОБРАБОТАННОЙ ПАРОВЫМ ВЗРЫВОМ, В КАЧЕСТВЕ СВЯЗУЮЩЕГО КОМПОНЕНТА

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Резюме

Изучено применение лигнина, выделенного из древесной массы после парового взрыва, в качестве связующего компонента в древесноволокнистых плитах и добавки к фенолоформальдегидным клеям для производства многослойных фанер, что является примером безотходных технологических решений в рамках общей концепции безотходного производства. Сравнены свойства образцов плит, полученных горячим прессованием древесной массы с разным содержанием лигнина, и их соответствие техническим требованиям к изделиям. Обнаружена хорошая корреляция плотности и водостойкости плит с содержанием лигнина. Испытания механических свойств полученных образцов свидетельствовали о зависимости прочности от размера древесных частиц и температуры при прессовании. Используемые технологии выявили потенциальные возможности для создания ценных продуктов из низкокачественной древесины и отходов деревообработки. В дополнение к лесопильням они представляют собой образец кластера интегрированных технологий по принципу безотходного производства. Смесь фенолоформальдегидных смол, содержащих 10% лигнина, выделенного из древесной массы после парового взрыва, показывает удовлетворительную адгезию в условиях производства.

Ключевые слова: безотходные технологии, древесные композиты, паровой взрыв, лигнин от парового взрыва, адгезивы.

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