Bulletin of the *Transilvania* University of Brasov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 18(67) No. 3 – 2025
https://doi.org/10.31926/but.fwiafe.2025.18.67.3.3

GLUABILITY OF THERMALLY MODIFIED BIRCH (*Betula pendula* Roth.*)*, ASPEN (*Populus tremula)*, AND POPLAR (*Populus x canadensis* Moench) VENEERS USING COMMERCIAL ADHESIVES

Anete MEIJA[1] Uldis SPULLE[1] Haralds ŠILLERS[2]

Abstract: *With the increasing demand for renewable materials worldwide, the use of wood has become increasingly appealing. However, wood has some drawbacks, and modification is the approach that tries to reduce them. Thermal modification of wood is a sustainable method that enhances its biological durability and dimensional stability. However, it results in diminished mechanical properties, posing challenges for its bonding applications. This study focuses on determining the glueing quality of 3-ply plywood produced from thermally modified aspen (Populus tremula L.), birch (Betula pendula Roth.), and poplar (Populus x canadensis Moench) veneers. Plywood samples were prepared using commercially available adhesives - phenol formaldehyde, melamine urea formaldehyde, hybrid polymer, and polyurethane. The thermal modification was carried out under vacuum (TERMOVUOTO process) and in a water steam environment (WTT – hydrothermal process). Adhesion quality was evaluated in accordance with the EN 314 standard. Results indicated that plywood from the TERMOVUOTO process-modified veneers yielded higher tensile-shear strength than plywood from WTT-modified veneers. Polyurethane and phenol-formaldehyde adhesives proved to be the most suitable for bonding thermally modified veneers, whereas the hybrid polymer is unsuitable for this purpose. The study contributes to optimising the use of thermally modified veneers in producing plywood for outdoor applications or 3rd Service Class, as per EN 1995-1-1:2004/AC:2006 - Eurocode 5.*

Key words: *bonding, plywood, thermal modification, veneers.*

[1] Latvia University of Life Sciences and Technologies, Institute of Civil Engineering and Woodworking, Dobeles Street 41, LV-3001 Jelgava, Latvia;
[2] JSC Stora Enso Latvia, Launkalne Sawmill, Krogzemji, Smiltene County, LV-4718 Launkalne, Latvia;
Correspondence: Anete Meija; email: anete.meija@lbtu.lv.

1. Introduction

Wood is one of Latvia's most significant natural resources, with forests covering 53% of its territory [13]. As a result, the wood processing industry plays a vital role in Latvia's economy. The increasing focus on sustainability, aligned with European Union goals, has led to efforts to improve the longevity and usability of wood products through eco-friendly methods such as thermal modification [7].

Thermal modification enhances wood's resistance to biological agents [26] and its dimensional stability [27], though it reduces its mechanical strength [6]. While the thermal modification of sawn timber is widely studied [8, 21, 23], limited research exists on the bonding of thermally modified veneer. Industrially produced adhesives, such as phenol–formaldehyde (*PF*), melamine-urea-formaldehyde (*MUF*), polyurethane (*PU*), and hybrid polymer (*HB*), are generally designed for large-scale bonding of solid wood elements. They are theoretically not intended for thin materials, and even less so for thermally modified veneers. Two thermal modification methods – water steam-based (*WTT*) [11] and vacuum-based (TERMOVUOTO) [18] – have been explored for veneer modification. Commercially available glues are tested for glueing these veneers. Phenol–formaldehyde is the most commonly used adhesive in plywood manufacturing. Melamine-urea-formaldehyde (*MUF*) is widely used as an adhesive in the wood industry [4], previously tested in a superheated steam environment at 160°C and 190°C, thermally modified beech (*Fagus sylvatica* L.) and birch (*Betula pubescens* Ehrh.) using a shear strength test according to EN 205, mentioned by Boruszweski et al. [5]. For the Plato® process poplar (*Populus* species, I214), birch (*Betula pendula* Roth.) at 165°C was tested according to the EN 392 standard, mentioned by Sernek et al. [19]. *PUR* adhesive is also tested for thermally modified wood glueing [14]. No data is available in the literature about aspen plywood bonded with HB adhesive, which can broaden the use of wood species during the shortage of wood supply.

This study aims to evaluate the bonding quality of plywood made from thermally modified veneers using different commercially available adhesives.

2. Materials and Methods

2.1. Materials

Aspen (*Populus tremula* L.) 2.5 mm, birch (*Betula pendula* Roth) 1.5 mm, and poplar (*Populus* x *canadensis* Moench) 1.5 mm veneers underwent thermal modification under TERMOVUOTO (*TV*) (vacuum) conditions at varying temperatures and durations, as well as under *WTT* (water steam) conditions. Table 1 presents the thermal modification process temperatures and the maximum holding duration at the highest temperature, and Table 2 presents the mass loss during the process.

The adhesives used included phenol formaldehyde resin (*PF*) (SFŽ-3014), melamine urea formaldehyde resin (MUF) (Casco Adhesives *MUF* system 1257/7557), hybrid polymer glue (*HB*) (Soudal *HB* Construct), and polyurethane glue (*PUR*) (*PURBOND HB* S159).

2.2. Plywood Manufacture

Two three-layer plywood samples were

produced using both untreated and thermally modified veneers. Plywood bonding was carried out using a hydraulic press, "Joos LAP 150," equipped with heated pressing plates measuring 600 x 600 mm. The plywood was pressed under specific pressure and temperature conditions (Table 3), following the manufacturer's instructions for each adhesive type.

Veneer modification conditions Table 1

Modification conditions	Time (t) [min]	Temperature (T) [°C]	Modification type
WTT 160/50	50	160	WTT
TV 160/50	50	160	TV
TV 204/120	120	204	TV
TV 214/120	120	214	TV
TV 217/180	180	217	TV
TV 218/30	30	218	TV

Veneer mass loss Table 2

Modification conditions	Aspen mass loss [%]	Birch mass loss [%]	Poplar mass loss [%]
WTT 160/50	5.28±1.15	6.66±0.87	5.58±0.74
TV 160/50	1.24±1.89	1.08±0.24	0±0.69
TV 204/120	2.94±0.61	2.77±0.46	2.94±0.61
TV 214/120	4.77±1.28	5.70±0.51	6.50±1.44
TV 217/180	6.61±0.97	7.77±1.13	8.57±0.76
TV 218/30	4.24±0.90	4.72±0.57	5.46±0.93

Glueing conditions Table 3

Glue	Pressing parameters		
	Pressure [MPa]	Time (t) [min]	Temperature (T) [°C]
PF	1.8	7	145
HB	1.8	20	room (20)
MUF	1.8	116	room (20)
PUR	1.8	90	room (20)

2.3. Testing

During plywood manufacture, the plywood compression ratio (*CR*) was determined. Two thickness measurements of the plywood sample were taken – before and after pressing – using the electronic calliper KS Tools 300.05. The *CR* was calculated using Equation (1) [22].

$$CR = \frac{(T_v - T_b)}{T_v} \cdot 100 \qquad (1)$$

where:

CR is the compression ratio [%];

T_v – thickness of the plywood before pressing [mm];

T_b – thickness of the plywood after pressing [mm].

Following manufacturing, the plywood specimens underwent three separate pre-treatment (*PT*) regimes:

a) 24h: immersion in water at 20±3°C for 24 hours;
b) 4h+16h+4h+1h: immersion in boiling water for 4 hours, drying in a ventilated oven at 60±3°C for 16 hours, repeated immersion in boiling water for 4 hours, followed by cooling in water at 20±3°C for 1 hour;
c) 72h+1h: immersion in boiling water for 72±1 hours, followed by cooling in water at 20±3°C for 1 hour.

The bonding quality of the adhesive was assessed in accordance with the EN 314-1 [10] standard. Six samples were tested for tensile-shear strength using the universal testing machine Zwick Z100/TL3S, and the percentage of wood failure was measured for all samples after the tensile-shear test.

Additionally, the plywood samples were evaluated for their conformance to bonding Class 3 according to the EN 314-2 standard [9].

2.4. Data analysis

The tensile-shear strength value and the wood failure percentage were determined for each plywood test specimen. The mean tensile-shear strength and the standard deviation were calculated for each sample set using Microsoft Excel data processing software.

3. Results and Discussion

3.1. Glue Consumption

Table 4 shows the actual glue consumption, in g/m^2, compared to the nominal values from the data sheet of each glueing system. The most significant deviation is observed in the case of *PUR*. This phenomenon could be attributed to the water-spraying treatment applied to specimens bonded with *PUR* due to the low water content of the thermally modified specimens. This increases process complexity and consequently leads to a higher probability of deviation from nominal parameters.

The spread quantity of *PF* resin was based on the manufacturer`s recommendations and was less than what Xiong et al. used in their research [25] (200 and 240 g/m^2, respectively, for poplar veneer glueing) but more than Bekhta et al. [3] and Bastani et al. [1] used (100 g/m^2 for birch veneer glueing). The control panels in Bekhta et al. 's research [3] had the same spread quantity, 150 g/m^2, as the ones used in this research.

The slightest deviation was observed in specimens bonded with *MUF*, representing a negligible deviation from the nominal consumption. The standard deviations (*SD*) were comparable for all adhesives.

Actual adhesive consumption Table 4

Glue	Consumption [g/m^2]		Deviation [%]
	Nominal	Actual ± SD	
PF	150	156±11	4.0
HB	300	317±13	5.7
MUF	340	343±16	0.9
PUR	150	162±15	8.0

3.2. Compression Ratio

The compression ratio results are presented in Table 5. During the manufacturing of 3-ply plywood specimens, the highest average compression was observed with PF adhesive, where poplar was compressed by approximately one-third (37.4%). This increased compression can be attributed to the elevated pressing temperature of 145°C used with this adhesive, which facilitated more significant material degradation, leading to enhanced compression.

Compression ratio Table 5

Glue	Compression ratio [%]		
	Aspen	Birch	Poplar
PF	15.3±7.1	12.4±6.1	37.4±1.8
HB	2.7±2.6	0.3±1.3	2.5±4.0
MUF	3.8±3.5	0.0±1.0	4.7±2.1
PUR	2.1±2.2	0.2±0.5	3.0±1.0

In contrast, other adhesives were pressed at room temperature (20°C). Concerning the effects of the wood species, specimens made from poplar veneers exhibited the highest compression, while those produced from birch veneers displayed the lowest compression ratio. Bekhta et al. [2] reported that birch plywood glued with urea-formaldehyde resin had a compression ratio of 8.2±1.4%, which is comparable to the PF results obtained in this research. Additionally, the method of thermal modification influenced compression characteristics: specimens made from steam-modified (*WTT*) veneers demonstrated greater compression compared to those manufactured from vacuum-modified veneers (*TV*). However, the thermal modification *TV* regime did not significantly affect the compression ratio.

3.3. Gluability with PF Adhesive

After *PT* 24h, all of the tested samples met the bonding Class 3 (BC3) requirements. For the unmodified samples, the tensile-shear strength (*TSS*) reached high values (above 1 MPa) – 1.74±0.45 MPa for aspen, 2.66±0.1 MPa for birch, and 1.77±0.57 MPa for poplar, respectively.

Also, after *PT* 4h+16h+4h+1h, all of the samples met the BC3 requirements, except the *WTT* 160/50 birch, which had 0.20±0.02 MPa *TSS* with 75% cohesive wood failure. Wei et al. [24] stated that for poplar veneers bonded with *PF* after *PT* 4 h+20 h+4 h+1 h, *TSS* was around 1 MPa. In this research, we have obtained a better result – 1.49±0.14 MPa.

The *TSS* test results after *PT* 72h+1h can be seen in Figure 1. Comparable high results were unmodified and *TV* 160/50 samples, which can be explained by the fact that at 160 °C and 50 minutes duration in the *TV* process chemical changes - acetyl group cleavage and others occurred a much lower extent than in the *WTT* process under the same treatment regime [12]. Consequently, the maximal *TSS* reduction can be observed in the case of *WTT* 160/50 birch plywood, which is the least suitable for plywood production.

Mean wood failure (*MWF*), in percente, was determined for all tested specimens, and compliance with BC3 was clarified (Table 6).

Results showed that all of the tested samples met the BC3 requirements, except birch *WTT* 160/50, due to a very low *TSS* value after *PT* 4h+16h+4h+1h.

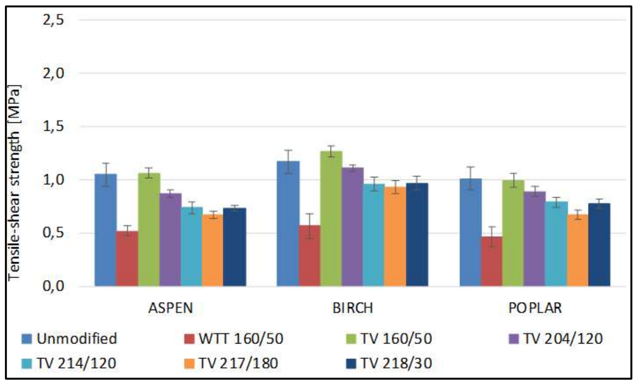

Fig. 1. *Tensile-shear strength after PT 72h+1h with PF glued plywood*

Wood failure after PT 72h+1h Table 6

Modification conditions	Aspen		Birch		Poplar	
	MWF [%]	BC3	*MWF* [%]	BC3	*MWF* [%]	BC3
Unmodified	65	yes	85	yes	65	yes
WTT 160/50	95	yes	90	no*	65	yes
TV 160/50	55	yes	20	yes	75	yes
TV 204/120	90	yes	90	yes	70	yes
TV 214/120	75	yes	85	yes	85	yes
TV 217/180	65	yes	80	yes	60	yes
TV 218/30	60	yes	80	yes	85	yes

*Note: * After PT 4h+16h+4h+1h WTT 160/50 birch plywood has a mean tensile-shear strength of 0.2 MPa and a cohesive wood failure mean of 75%.*

3.4. Glubility with HB Adhesive

Initial results for the gluability of the *HB* adhesive were promising. Therefore, it was decided to test the BC3 conformity. Unfortunately, already after the first *PT* 24h – unmodified aspen failed to meet the requirements due to a very poor *MWF*. *WTT* 160/50 birch failed due to a low *TSS*; all of the *TV* 160/50 and *TV* 204/120 samples failed due to a low *MWF* and the *TV* 214/120 birch, *TV* 217/180 poplar and aspen samples failed due to a low *MWF* and *TSS* combination. Poplar *TV* 218/30 failed due to a low *MWF*.

After *PT* 4h+16h+4h+1h, all aspen and poplar samples failed to meet the BC3 requirements, as well as *WTT* 150/50 birch and *TV* 204/120 birch. The results of *TSS* after *PT* 72h+1h can be seen in Figure 2. As all the results are below 1MPa, the *MWF* is very important. The *MWF* results are presented in Table 7. From all the samples tested, only unmodified birch met the BC3 requirements. Therefore, this glue is not suitable for bonding thermally modified veneers.

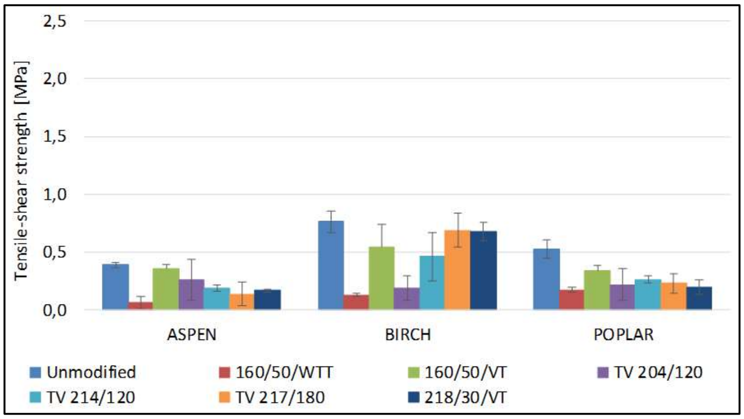

Fig. 2. *Tensile-shear strength after PT 72h+1h with HB glued plywood*

Wood failure after PT 72h+1h Table 7

Modification conditions	Aspen		Birch		Poplar	
	MWF [%]	BC3	*MWF* [%]	BC3	*MWF* [%]	BC3
Unmodified	30	no	70	yes	30	no
WTT 160/50	75	no	75	no	75	no
TV 160/50	35	no	35	no	30	no
TV 204/120	35	no	20	no	40	no
TV 214/120	45	no	50	no	55	no
TV 217/180	30	no	35	no	30	no
TV 218/30	35	no	35	no	20	no

3.5. Glubability with MUF Adhesive

After *PT* 24h, all of the tested samples met the BC3 requirements. After *PT* 4h+16h+4h+1h, birch and poplar met the BC3 requirements, as well as aspen, except unmodified aspen, *WTT* 160/50 and *TV* 160/50 due to a low *MWF*. The *TSS* results after *PT* 72h+1h can be seen in Figure 3. Only unmodified birch, *TV* 160/50, *TV* 204/120, and aspen *TV* 204/120 results were above 1 MPa; the *MWF* results are crucial and can be found in Table 8.

The results suggest that *MUF* adhesive is unsuitable for poplar plywood used outdoors. Of the birch samples tested, only *TV* 217/180 failed, which can be explained by the fact that this was the most severe regime. It is a bit unclear why untreated and in the mildest regime treated aspen *TV* 160/50 and *WTT* 160/50 failed both the *PT* 72h+1h and the *PT* 4h+16h+4h+1h.

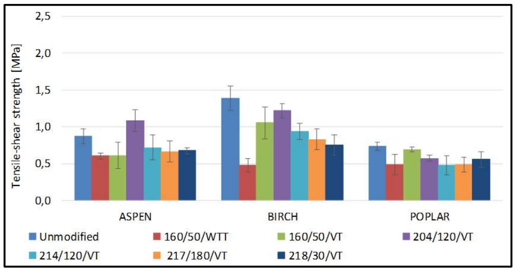

Fig. 3. *Tensile-shear strength after PT 72h+1h with MUF glued plywood*

Wood failure after PT 72h+1h Table 8

Modification conditions	Aspen		Birch		Poplar	
	MWF [%]	BC3	*MWF* [%]	BC3	*MWF* [%]	BC3
Unmodified	25	no	30	yes	25	no
WTT 160/50	35	no	65	yes	45	no
TV 160/50	25	no	60	yes	30	no
TV 204/120	45	yes	75	yes	45	no
TV 214/120	50	yes	45	yes	35	no
TV 217/180	45	yes	30	no	20	no
TV 218/30	45	yes	50	yes	20	no

3.6. Gluability with PUR Adhesive

PUR adhesive is widely used in the wood industry [16, 20]. Similarly to *PF*, after *PT* 24h, all tested samples met the BC3 requirements.

This is the same as all birch samples after *PT* 4h+16h+4h+1h. Aspen samples failed *TV* 214/120 and *TV* 217/180, which were the most severe regimes in the *TV* process. It is hard to explain why the poplar *WTT* 160/50 failed due to a combination of *TSS* and *MWF* while *TV* 160/50 and *TV* 218/30 failed due to *MWF*.

The *TSS* results after *PT* 72h+1h can be seen in Figure 4. The results for unmodified samples were high – 1.70±0.14 MPa for aspen, 1.96±0.11 MPa for birch and 1.35±0.11 MPa for poplar. The *MWF* and the compatibility with BC3 are listed in Table 9.

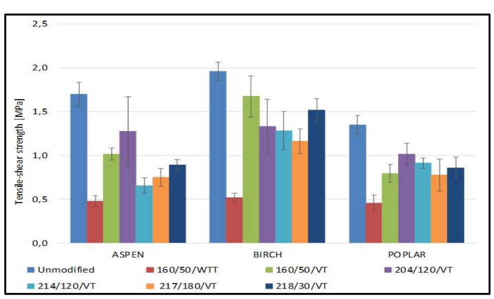

Fig. 4. *Tensile-shear strength after PT 72h+1h with PUR glued plywood*

Wood failure after PT 72h+1h Table 9

Modification conditions	Aspen		Birch		Poplar	
	MWF [%]	BC3	*MWF* [%]	BC3	*MWF* [%]	BC3
Unmodified	20	yes	75	yes	40	yes
WTT 160/50	45	no	45	no	45	no
TV 160/50	45	yes	45	yes	45*	no
TV 204/120	20	yes	45	yes	35	yes
TV 214/120	45**	no	40	yes	45	yes
TV 217/180	35	no	30	yes	20	no
TV 218/30	25	no	30	yes	35	no

*Note: *After PT 4h+16h+4h+1h TV 160/50 poplar plywood has a mean tensile-shear strength of 0.92MPa and a cohesive wood failure mean of 35%.*
***After PT 4h+16h+4h+1h TV 214/120 aspen plywood has a mean tensile-shear strength of 0.76 MPa and a cohesive wood failure mean of 35%.*

All the birch samples tested, except *WTT* 160/50, complied with BC3 requirements, which can be attributed to the more severe treatment conditions of *WTT*. Therefore, the veneers were more hydrophobic, which is crucial for gluability with adhesives. Both poplar and aspen regimes, *TV* 217/180 and *TV* 218/30, failed to comply with BC3. *PUR* These are the three regimes with the higher mass loss that have been published before, and, subsequently, the more hydrophobic. Therefore, their gluability with *PUR* adhesives was poor. The birch samples were compatible with BC3 due to the higher initial density of birch wood compared to aspen and poplar.

Thermal modification using the TERMOVUOTO method proved superior to *WTT* due to its gentler treatment process, resulting in better preservation of wood's structural integrity. This aligns with previous findings [15, 17] that TERMOVUOTO leads to lower mass loss and higher mechanical properties than *WTT*. Additionally, the compatibility of polyurethane and phenol-formaldehyde adhesives with thermally modified veneers supports their application in industrial production. There are sustainable alternatives to the commercially available glues, for example, suberinic acid adhesive (*SA*) [16, 20]. In this paper, it is concluded that with the *WTT* modification method modified veneers delaminate and are not suitable for plywood production. If we compare the *SA* adhesive performance with the performance of commercially available glues, the *SA* tensile-shear test results are comparable with the *MUF* adhesive results for poplar (0.74±0.06 and 0.65±0.04 MPa for unmodified samples; 0.69±0.03 and 0.55±0.10 MPa for *TV* 160/50; 0.57±0.04 and 0.48±0.08 MPa for *TV* 204/120; 0.47±0.13 and 0.47±0.04 MPa for *TV* 214/120; 0.49±0.10 and 0.42±0.04 MPa for *TV* 217/180; 0.56±0.11 and 0.53±0.02 MPa for *TV* 218/30). The same tendency can be observed with aspen (0.87±0.10 and 0.77±0.20 MPa for unmodified samples; 0.61±0.18 and 0.66±0.15 MPa for *TV* 160/50; 1.08±0.14 and 0.54±0.11 MPa for *TV* 204/120; 0.72±0.17 and 0.66±0.09 MPa for *TV* 214/120; 0.66±0.14 and 0.49±0.08 MPa for *TV* 217/180; 0.68±0.14 and 0.53±0.05 MPa for *TV* 218/30). However, the birch wood bonding quality with *MUF* is higher than with *SA* (1.39±0.17 and 0.90±0.05 MPa for unmodified samples; 1.06±0.22 and 0.87±0.16 MPa for *TV* 160/50; 1.22±0.10 and 0.76±0.07 MPa for *TV* 204/120; 0.94±0.11 and 0.66±0.14 MPa for *TV* 214/120; 0.83±0.14 and 0.54±0.04 MPa for *TV* 217/180; 0.75±0.14 and 0.66±0.09 MPa for *TV* 218/30). For all the wood species investigated, the *PF* and *PUR* bonding quality was better than the *MUF* and *SA*, but the *HB* was the worst.

However, the reduced mechanical properties of thermally modified wood, especially under *WTT*, remain a challenge. Further research is required to refine the EN 314 methodology for evaluating cohesive wood failure, including steps for determining wood failure specifically in thermo-veneers.

4. Conclusions

1. Plywood from veneers thermally modified in a vacuum environment under identical modification conditions exhibit 50% higher shear strength compared to plywood from veneers thermally modified in a water steam environment; therefore, TERMOVUOTO veneers are more suitable for plywood production.
2. Increased pressing temperature enhances the plywood compression ratio. When using phenol formaldehyde resin adhesive under elevated temperatures, the compaction rates are 15.3±7.1% for aspen, 12.4±6.1% for birch, and 37.4±1.8% for poplar. In contrast, with other adhesives used at room temperature, the compression ratio ranges from 0.3% to 4.7%.
3. The most suitable adhesives for manufacturing plywood intended for bonding Class 3 (outdoor use) from thermally modified veneers are phenol formaldehyde resin adhesive and polyurethane adhesive.
4. After 72h+1h *PT*, the highest shear strength (1.96 ± 0.11 MPa) was observed in plywood made from non-thermally modified birch veneers bonded with polyurethane adhesive, with wood failure of 73%.
5. Birch veneers thermally modified in a vacuum environment under the modification regime *TV* 218/30 and poplar veneers modified under the regime *TV* 214/120 are the most suitable for plywood production when using polyurethane adhesive.

Acknowledgements

This research was conducted within the Latvian State research program project No. VPP-ZM-VRIIILA-2024/2-0002 “Innovation in Forest Management and Value Chain for Latvia's Growth: New Forest Services, Products and Technologies (Forest4LV)”.

References

1. Bastani, A., Militz, H., Rohumaa, A., 2016. Development of bonding strength of modified birch veneers during adhesive curing. In: Wood Research, vol. 61(2), pp. 205-214.
2. Bekhta, P., Pipička, T., Gryc, V. et al., 2023. Properties of plywood panels composed of thermally densified and non-densified alder and birch veneers. In: Forests, vol. 14(1), ID

article 96. DOI: 10.3390/f14010096.
3. Bekhta, P., Sedliačik I., Jones, D., 2018. Effect of short-term thermomechanical densification of wood veneers on the properties of birch plywood. In: European Journal of Wood and Wood Products, vol. 76(4), pp, 549-562. DOI: 10.1007/s00107-017-1233-4.
4. Bono, A., Yeo, K.B., Siambun, N.J., 2003. Melamine–Urea–Formaldehyde (MUF) resin: The effect of the number of reaction stages and mole ratio on resin properties. In: Jurnal Teknologi, vol. 38(1), pp. 43-52. DOI: 10.11113/jt.v38.508.
5. Boruszewski, P.J., Borysiuk, P., Mamiński, M.Ł. et al., 2011. Gluability of thermally modified beech (*Fagus sylvatica* L.) and birch (*Betula pubescens* Ehrh.) wood. In: Wood Material Science and Engineering, vol. 6(1), pp. 185-189. DOI: 10.1080/17480272.2011.598239.
6. Boruvka, V., Zeidler, A., Holeček, T. et al., 2018. Elastic and strength properties of heat-treated beech and birch wood. In: Forests, vol. 9(4), ID article 197. DOI: 10.3390/f9040197.
7. Brischke, C., 2020. Wood protection and preservation. In: Forests, vol. 11(5), ID article 549. DOI: 10.3390/f11050549.
8. Bytner, O., Drożdżek, M., Laskowska, A. et al., 2022. Influence of thermal modification in nitrogen atmosphere on the selected mechanical properties of black poplar wood (*Populus nigra* L.). In: Materials, vol. 15(22), ID article 7949. DOI: https://doi.org/10.3390/ma15227949.
9. CEN/CENELEC, 1993. Plywood - Bonding quality - Part 2: Requirements. EN 314-2:1993 standard.
10. CEN/CENELEC, 2004. Plywood - Bonding quality - Part 1: Test method. EN 314-1:2004 standard.
11. Grīniņš, J., 2016. Bērza saplākšņa īpašību uzlabošana ar hidrotermiskās modifikācijas paņēmienu (Improvement of birch plywood properties using the hydrothermal modification method). PhD Thesis. Riga Technical University, Riga, Latvia.
12. Hill, C., Altgen, M., Rautkari, L., 2021. Thermal modification of wood - A review: chemical changes and hygroscopicity. In: Journal of Materials Science, vol. 56(11), pp. 6581-6614. DOI: 10.1007/s10853-020-05722-z.
13. Latvian Forest Owners' Association. About us. Available at: https://mezaipasnieki.lv/en. Accessed on : January 27, 2025.
14. Mamoňová, M., Ciglian, D., Reinprecht, L., 2022. SEM analysis of glued joints of thermally modified wood bonded with PUR and PVAc Glues. In: Materials, vol. 15(18), ID article 6440. DOI: 10.3390/ma15186440.
15. Meija, A., Irbe, I., Morozovs, A. et al., 2020. Properties of *Populus* genus veneers thermally modified by two modification methods: Wood treatment technology and vacuum-thermal treatment. In: Agronomy Research, vol. 18(3), pp. 2138-2147. DOI: 10.15159/AR.20.184.
16. Meija, A., Spulle, U., Ramata, L. et al., 2025. Glaubility of thermally

modified aspen, birch, and poplar rotary cut veneers with suberinic acids adhesive. In: Sustainability, vol. 17(5), ID article 1990. DOI: 10.3390/su17051990.

17. Meija-Feldmane, A., Cuccui, I., Irbe, I. et al., 2020. Properties of modified wood according to treatment technology and thermo-vacuum process for birch (*Betula pendula* Roth) veneers. In: BioResources, vol 15(2), pp. 4150-4164. DOI: 10.15376/biores.15.2.4150-4164.
18. Sandak, A., Sandak, J., Allegretti, O., 2015. Quality control of vacuum thermally modified wood with near infrared spectroscopy. In: Vacuum, vol. 114, pp. 44-48. DOI: 10.1016/j.vacuum.2014.12.027.
19. Sernek, M., Boonstra, M., Pizzi, A. et al., 2008. Bonding performance of heat treated wood with structural adhesives. In: Holz als Roh - und Werkstoff, vol. 66, pp. 173-180. DOI: 10.1007/s00107-007-0218-0.
20. Shirmohammadli, Y., Pizzi, A., Raftery, G.M. et al., 2023. One-component polyurethane adhesives in timber engineering applications: A review. In: International Journal of Adhesion and Adhesives, vol 123. DOI: 10.1016/j.ijadhadh.2023.103358.
21. Sosins, G., Grinins, J., Brazdausks, P. et al., 2024. Aspen wood characteristics following thermal modification in closed process under pressure in nitrogen. In: Materials, vol. 17(23), ID article 5930. DOI: 10.3390/ma17235930.
22. Spulle, U., Meija, A., Kūliņš, L. et al., 2021. Influence of hot pressing technological parameters on plywood bending properties. In: BioResources, vol. 16(4), pp. 7550-7561. DOI: 10.15376/biores.16.4.7550-7561.
23. Torniainen, P., Dagbro, O., Morén, T., 2011. Thermal modification of birch using saturated and superheated steam. In: Proceedings of the 7th Meeting of the Nordic-Baltic Network in Wood Material Science and Engineering (WSE), October 27-28, 2011, Oslo, Norway, pp. 43-48.
24. Wei, Q., Wang, W.H., 2018. Properties of phenol formaldehyde resin modified with silane coupling agent (KH550). In: International Journal of Adhesion and Adhesives, vol. 84, pp. 166-172. DOI: 10.1016/j.ijadhadh.2018.03.006.
25. Xiong, G., Hong, L., Ju, Z. et al., 2023. Curing process of phenol formaldehyde resin for plywood under vacuum conditions. In: Journal of Renewable Materials, vol. 11, no. 9, pp. 3447-3461. DOI: 10.32604/jrm.2023.027430
26. Zanuttini, R., Castro, G., Cremonini, C. et al., 2019. Thermo-vacuum treatment of poplar (*Populus* spp.) plywood. In: Holzforschung, vol. 74(1). DOI: 10.1515/hf-2019-0049.
27. Zdravković, V., Lovrić, A., Stanković, B., 2013. Dimensional stability of plywood panels made from thermally modified poplar veneers in the conditions of variable air humidity. In: Drvna Industrija. vol. 64(3), pp. 175-181. DOI: 10.5552/drind.2013.1223.