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Gluing of thermally modified silver fir wood planed by horizontal milling machine

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Abstract. This study was conducted to provide information regarding the quality of gluing of Silver fir wood (*Abies alba* Mill.) planed at different feed speeds after thermal modification. Four groups of sixteen air-dried fir samples were prepared. Three groups were thermally modified at different temperatures (160°C, 190°C, and 220°C) for 3 hours. The processes that followed included planning with two feed speeds (half of the samples at 3m/min and the other half at 10 m/min), the gluing, and finally, conducting mechanical tests to assess shear strength and wood failure. The gluing shear strength underwent a progressive decrease with increasing modification temperature for both feed speeds, with reductions ranging from 1.37% to 14.63% compared to natural wood.

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Wood failure did not show a linear relationship, with a decrease at 160°C but an increase at higher temperatures compared to natural wood. The feed speed had a significant effect on gluing shear strength, with higher feed speed resulting in decreased strength for natural wood but increased strength for thermally modified wood. Thermal modification of fir wood at temperatures of 220°C had a detrimental effect on the gluing shear strength and wood failure. This was caused by the deterioration of wood components and alterations in mechanical properties. The results of this study offer significant knowledge for improving the gluing process and establishing appropriate parameters for thermally modified fir wood. This type of wood has potential uses in the wood sector, specifically in the manufacturing of engineered wood products

Keywords: fir wood; thermal modification; gluing; shear strength; wood failure

Introduction

Wood is the most environmentally friendly construction material available. However, it also has certain drawbacks. The material exhibits a high degree of anisotropy. The characteristics of this substance exhibit significant variation and it is highly susceptible to damage from exposure to moisture.

In order to mitigate certain drawbacks, wood has undergone various modifications and treatments. According to a study by S. Cao *et al.* (2022), thermal modification of wood is the most commercially advanced among all the many wood modification technologies that have been researched. Wood undergoes controlled heating in this technique, which enhances its dimensional stability and biological endurance. There is consistently a decrease in mechanical characteristics. A good approach of thermally modified wood (TMW) to gluing would significantly expand its use. In this framework many influencing factors related to technological parameters applied during thermal modification, to wood properties and its surface preparation, to adhesive and to technological parameters applied during gluing process, as well as conditions of product service, need to be considered.

In their study, A. Masoumi *et al.* (2023) conducted a comparison to assess the impact of thermal alteration on the adhesive bonding capabilities of yellow poplar wood. The findings indicated that thermal modification led to a decrease in penetration by 31.2% in polyurethane (PUR) and 29% in polyvinyl acetate (PVA). This resulted in a thicker adhesive line, with an increase of 70% in PUR and 2% in PVA. In addition, the PUR glue exhibited a greater shear strength than PVA adhesive, with an increase of 2.7% in non-modified wood and 14% in thermally affected wood. In their study, H.R. Taghiyari *et al.* (2020) examined the shear strength of heat-treated solid wood from three species (beech, poplar, and fir) that were bonded using PVA adhesive supplemented with nanowollastonite (NW). The findings demonstrated that subjecting the specimens to heat treatment led to a substantial reduction in the shear strength of the bonded materials.

Z. Wu *et al.* (2021) and Q. Yu *et al.* (2023) conducted a study on the interfacial alterations of *Pinus massoniana* wood after heat treatment. The aim was to enhance the bonding and coating processes of heat-treated wood. The wood was modified using steam as the medium, at temperatures ranging from 160 to 220°C. According to the findings, hemicelluloses experienced the initial deterioration at a temperature of 160°C, with the highest level of degradation observed at 200°C. Cellulose underwent substantial degradation at a temperature of 200°C, whereas the degradation of lignin was less noticeable at this temperature. The presence of oxygen-containing functional groups such as hydroxyl and carbonyl decreased progressively with increasing temperature, leading to a more intense coloration and a surface that became less reactive.

Thermal treatment is a method employed to enhance the characteristics of wood. In their study, T. Udtaranakron *et al.* (2023) investigated the impact of thermal modification on the mechanical characteristics and adhesive bond strength of rubberwood. The findings demonstrated that elevating the modification temperature had an adverse impact on the mechanical characteristics of rubberwood and led to a reduction in the strength of the wood adhesive bond. In order to enhance the longevity and bonding strength, a composite material consisting of wood and polyvinyl chloride (WPVC) was mixed with thermally modified rubberwood at a temperature of 180°C. This combination yielded the most favourable outcomes in terms of mechanical qualities and the strength of the adhesive bond between the wood components.

In a study conducted by M. Altunok (2021), the researcher examined the adhesive properties of oak and Scotch pine wood samples that had undergone heat treatment. The samples were then bonded using 1K-PUR adhesive under different conditions. The specimens were subjected to various temperature (20°C/35%, 20°C/65%, and 20°C/95%) and relative humidity conditions before being evaluated for adhesion resistance. The findings indicated that both the holding environment and climatic circumstances had a substantial impact on the adhesion resistance. The samples that were stored in A1 conditions and evaluated experienced wood rupture ranging from 70% to 100%. On the other hand, the samples that were tested after being held in A4 and A5 conditions mostly broke apart from the glue joint. The study conducted by A.G. Carvalho *et al.* (2020) assessed the adhesive bonding capabilities of structural adhesives on heat-treated *Mimosa scabrella* and *Pinus oocarpa* wood. The shear strength and percentage of wood failure exhibited variability based on the species, kind of glue, and intensity of heat treatment.

The study by A. Hänsel *et al.* (2023) examines the impact of machining processes on the tensile shear strength of glued lumber, focusing on optimizing face milling tool geometry. The results show that the optimized process, characterized by low surface roughness and minimal microstructure damage, leads to better bonding. F. Rabiei & S. Yaghoubi (2023) optimize the machining parameters for wooden products to minimize surface roughness and process time simultaneously. Using a hybrid technique combining Group Method of Data Handling (GMDH) and the Bees Algorithm (BA), the researchers achieved a 23% improvement in the combined objective function compared to the best experiment. The optimized parameters resulted in a surface roughness of 4.36 μm and a process time of 93 seconds.

Taking into account the scarce information on the influence of machining conditions regarding to gluing quality of the TMW, the goal of this study was to provide available information related to impact of modification temperature and feed speed on gluing performance of thermally modified Fir wood (*Abies alba* Mill.).

Materials and Methods

Air dried fir boards of 50×220×2000 mm were used for production of samples. Boards were selected randomly at lumberyard of SINANI (Albania) sawmill. They were produced from logs harvested by sawmill itself from 120 years old forests of central Albania and were transferred to the Faculty of Forestry Sciences of Tirana, where the boards were conditioned for more than 4 months. After conditioning, the mean equilibrium moisture content (EMC) of wood resulted 10.85% (1.093 standard deviation) and the density 0.47 gr/cm^3 (0.026 standard deviation), measured respectively according to the standards ISO 13061-1 (2014) and ISO 13061-2 (2014).

64 samples of 25×45×400 mm which presented neither deformations nor wood structure defects were subsequently produced from the sapwood zone. 48 of them were heated applying three different temperatures, 160°C, 190°C and 220°C, at atmospheric pressure for 3 hours (16 samples for each temperature). Heating process was conducted in a temperature controlled small chamber (France Etuves, FRANCE). Before heating, samples were dried at 103 ± 2°C until to the moisture content 0%. The density of oven dried samples resulted 0.46 gr/cm^3 (0.019 standard deviation). The increment of temperature from 103°C up to the treatment temperature was set 1 min/°C. The treated samples were cooled and later conditioned until they reached the constant weight. The mean EMC and the mean density of the treated samples at 160°C, 190°C and 220°C resulted respectively 6.77% (1.043 standard deviation) and 0.43 gr/cm^3 (0.018 standard deviation).

The control as well as the heat-treated samples were processed along the grain on the section of 45 mm by a planer machine available at the Faculty of Forest Sciences of Tirana (Samco Lab300, Mantovani Macchine, ITALY). Sharp knives were used. The machine had cutterhead diameter 72 mm, rotation speed 5100 rpm and three knives with dimensions 300´30´3 mm. There were applied two feed speeds, 3 m/min and 10 m/min by means of a Type4M feeding system (Olympia, ITALY). 8 samples were processed for each combination temperature-feed speed (8 combinations in total). The cutting depth was 1 mm.

The samples of each group were glued two by two using a one-component PUR glue (Jowat, GERMANY). The samples were assembled according to the standard EN 205 (2016) and to the technical data of the glue manufacturer (Table 1).

Table 1. Technical data of the glue according to manufacturer

Technical parameter	Value
Density [g/cm^3]	1.15
Viscosity at 20°C [mPas] (Brookfield, spindle 5, 20 rpm)	15,500 ± 2,500
Solids content [%] (Jow as test method)	99 ± 1
Glue spread [g/m^2]	140 ÷ 200[1]
Maximum assembly time [min]	10
Pressure [N/mm^2]	0.6 ÷ 1[2]
Minimum pressing time [min]	10

Note: 1 –the amount of 150 g/m2 was applied; 2 – the pressure of 1 N/mm2 (1 MPa) was applied
Source: compiled by the authors

Cold pressing was applied for 4 hours to achieve the maximal gluing strength, according to the manufacturer's instructions. After conditioning, a total of 448 specimens for shear testing (56 for each combination) were cut from glued samples. Their dimensions were 50×20×20 mm, with the grain direction parallel with the longer edge. The gluing strength was tested by means of a hydraulic testing machine (Controlab, FRANCE), improvising a system referring to the standard EN 205 (2016).

The shear strength for each test was calculated according to equation $T = F_{max}/A$ [N/mm^2], where F_{max} was the force of destruction in

Newton and A was the area of tested surface in mm². The results were submitted to two-factor analysis of variance (ANOVA) to identify significant effect of analysed factors (temperature of modification and feed speed), using IBM SPSS Statistics24 software. Significance was accepted at the $p < 0.05$ level. Duncan test and t-Test were applied to analyse the differences in means.

Results and Discussion

The thermal modification process involves subjecting the wood to elevated temperatures, typically ranging from 160°C to 240°C, in an oxygen-deficient environment. This treatment enhances certain properties of the wood, such as dimensional stability and resistance to decay, but it can also affect its surface characteristics and chemical composition, potentially altering its gluing properties. In addition to the thermal modification, the surface preparation of the wood plays a crucial role in gluing performance. In this study, we employed a horizontal milling machine for planning the wood surface. The feed speed during this planning process is an important variable, as it affects the surface roughness and, consequently, the wood's ability to form strong bonds with adhesives. Figures 1 and 2 present the gluing shear strength and wood failure values with reference to the modification temperatures and applied feed speeds.

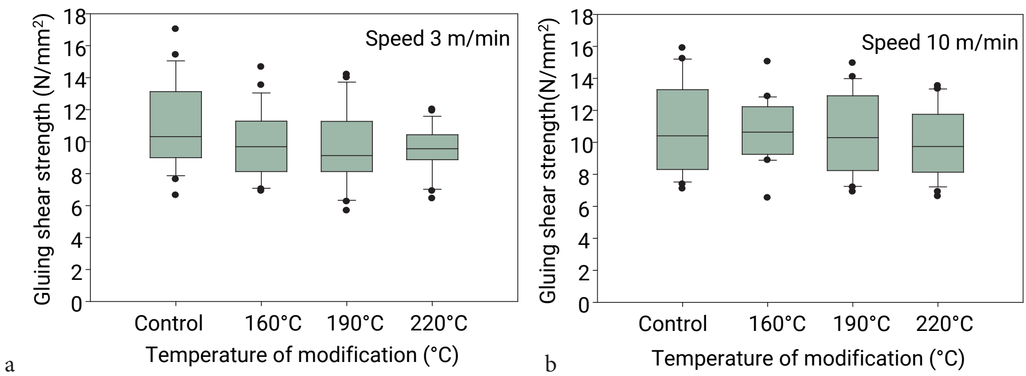

Figure 1. The relation between modification temperature and gluing shear strength
Note: a – referring to feed speed 3 m/min; b – referring to feed speed 10 m/min
Source: compiled by the authors

The gluing shear strength underwent a progressive decrease with reference to that of natural glued wood for all three modification temperatures as well as the two feed speeds. At the lower speed, the control group exhibits a broader range of strengths, while increasing the temperature to 190°C results in a higher median strength and reduced variability, suggesting optimal adhesive performance. At 220°C, although the variability narrows, the strength slightly decreases, indicating diminishing returns at higher temperatures. Comparatively, at the faster speed of 10 m/min, the median strength generally increases across all temperatures, with the most consistent and highest performance observed at 190°C. It suggests that while higher temperatures improve the consistency of adhesive results, the optimal temperature for achieving peak shear strength without compromising consistency appears to be around 190°C, regardless of the application speed.

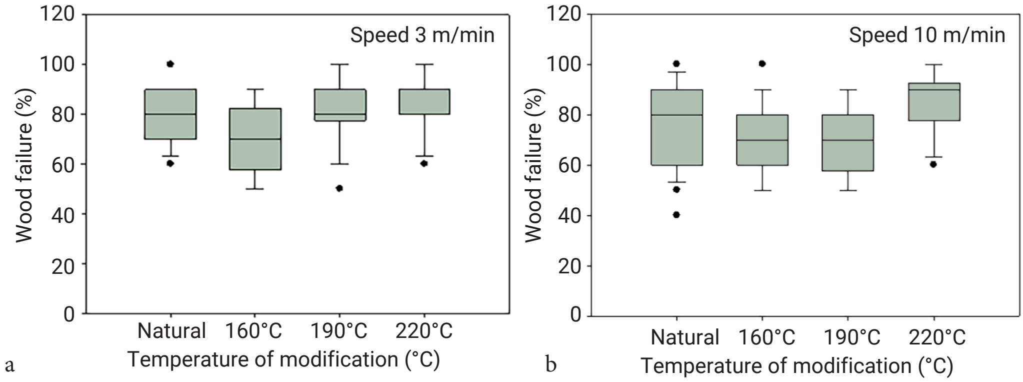

Figure 2. The relation between modification temperature and percent wood failure
Note: a – referring to feed speed 3 m/min; b – referring to feed speed 10 m/min
Source: compiled by the authors

Wood failure did not show a linear relationship like shear strength. For both feed speeds, the failure at the temperature 160°C was lower than that of natural wood, respectively 13.55% for the speed of 3 m/min and 6.55% for the speed of 10 m/min. As for the other temperatures, the failure was bigger than that of natural wood, with the exception of the 190°C temperature for the speed of 10 m/min, where it decreased by 9.52% referring to the failure of natural wood. Regarding the feed speed of 3 m/min, the failure was 1.7% bigger than that of natural wood with reference to the temperature 190°C and 2.83% at the temperature 220°C, whereas for the speed of 10 m/min there was an increase in wood failure, only at the temperature 220°C by11.32%.

Table 2 presents the results of two-factors analysis of variance (ANOVA) of the gluing strength and wood failure for unmodified and thermally modified fir wood at different temperatures, planed with two feeding speeds. The results indicated non-significant effect of the modification temperature for both measured properties, while for the feed speed, a significant effect was noted only for gluing shear strength. The interaction between two analysed factors resulted to be significant at the level 0.05 only for the wood failure.

Table 2. Results of the analysis of variance

Analysed variable	Factor	Sum of squares	df	Mean square	Fisher's F-test	Significance ($p < 0.05$)
Gluing shear strength [N/mm^2]	Intercept	18,182.44	1	18,182.44	1520.317	0.000
	Temperature [°C]	45.796	4	11,449	15,757	0.061
	Feed speed [m/min]	23.624	1	23,624	32,512	0.029
	Interaction TF	1.453	2	0.727	0.141	0.869
	Error	867.982	168	5,167	5,167	

Table 2, Continued

Analysed variable	Factor	Sum of squares	df	Mean square	Fisher's F-test	Significance (p < 0.05)
Wood failure [%]	Intercept	1,011,390.584	1	1011390,584	961,445	0.000
	Temperature [°C]	4,162.121	4	1040,530	1,299	0.479
	Feed speed [m/min]	273.485	1	273,485	68,342	0.04618
	Interaction TF	1,601.515	2	800,758	4,197	0.017
	Error	32,054.545	168	190,801		

Source: compiled by the authors

The analysis of variance presented in Table 2 reveals significant statistical influences and interactions between variables on gluing shear strength and wood failure rates. For gluing shear strength, the intercept is highly significant with a Fisher's F-test value of 1520.317 and a p-value of 0.000, indicating a strong baseline effect. Temperature as a factor shows a near-significant influence with an F-test value of 15.757 and a p-value of 0.061, suggesting a potential trend that might become significant with a larger sample size or different temperature settings. Feed speed demonstrates a significant effect on shear strength with an F-test of 32.512 and a p-value of 0.029. However, the interaction between temperature and feed speed (Interaction TF) is not significant ($p = 0.869$). For wood failure, the intercept again shows extreme significance (F-test = 961.445, $p = 0.000$), emphasizing a strong baseline influence. The temperature effect is not significant for wood failure ($p = 0.479$), whereas feed speed and the interaction between temperature and feed speed are significant, with p-values of 0.04618 and 0.017, respectively. These results highlight the critical roles of feed speed and its interaction with temperature in influencing wood failure, suggesting that adjustments in these parameters can substantially impact material performance (Titova & Sobczuk, 2022; Chupa & Zhovtulia, 2023; Sirko *et al.*, 2024).

Table 3 presents the comparative results (Duncan test) of the influence of modification temperature on the gluing shear strength and wood failure. Two homogenous groups were identified emphasizing differences between values referring to control samples, those modified at temperatures 160°C and 190°C and those modified at temperature 220°C. Gluing shear strength and wood failure of unmodified and modified samples at 160°C and 190°C were not significantly different.

Table 3. Comparative results for the modification temperature (Duncan test)

Temperature [°C]	Number of measurements	Gluing shear strength [N/mm²]	Wood failure [%]
Control	44	I	A
160	44	I	A
190	44	I	A
220	44	II	B

Source: compiled by the authors

Thus, across all temperatures, 44 measurements were taken, indicating a consistent experimental design. Both the control and 160°C temperatures fall under group I for gluing shear strength and group A for wood failure percentage, suggesting that these conditions did not significantly differ in their effect on the materials. However, at 190°C, the materials still belong to group I for gluing shear strength, showing no substantial increase from lower temperatures, but still maintain group A for wood failure, indicating consistent performance. In contrast, at 220°C, the materials shift to group II for gluing shear strength and group B for wood failure, signifying a notable change in performance which could be interpreted as either a decrease in adhesive effectiveness or a modification in the wood's integrity at this higher temperature. This differentiation highlights the impact of elevated temperatures on material properties and suggests a threshold beyond which the increase in temperature might adversely affect the performance.

The reduction of gluing shear strength converges with the findings of Z. Vidholdová *et al.* (2021), which have had as their object of analysis the gluing of thermally modified conifers with PUR adhesives. Norway spruce wood samples (*Piceaabies* /L./Karst.), thermally treated at atmospheric pressure at temperatures 160°C, 180°C, 200°C and 220°C for 4 hours and glued with one-component PUR adhesive resulted in a gluing shear strength 26%/56% progressively lower, as the modification temperature rose higher.

According to C. Frihart & C. Hunt (2021), gluing shear strength depends on a set of forces acting at the level of contact between the wood substrate and the glue, as well as within the glue and the wood substrate. Its reduction usually occurs either due to the reduction of the adhesion between the glue and the wood, or due to the reduction of the mechanical strength of the wood. The authors agree with the researchers' opinion that the reduction in gluing shear strength of thermally modified wood is usually due to a combination of factors – the decrease in adhesion between the glue and the wood, as well as the reduction in the mechanical strength of the wood substrate. Adhesion is determined by several factors such as surface wettability, surface roughness, adhesive flow, permeability, solidification and wood pH, as noted in J. Iždinský *et al.* (2021) and A. Hänsel *et al.* (2021). Thermal modification of wood has a negative effect on adhesion, because it degrades hemicellulose and as a consequence the number of free hydroxyls in wood decreases. The authors agree with the researchers' opinion that thermal modification negatively impacts adhesion due to the degradation of hemicellulose and the reduction in free hydroxyls in wood, as they observed a decrease in gluing shear strength with increasing modification temperatures.

C. Hill *et al.* (2021) explore the current state of knowledge regarding the hygroscopic and dimensional behaviour of thermally modified timber (TMT) modified under dry (cell wall at nearly zero moisture content) and wet (cell wall contains moisture) conditions. Thermal modification improves the dimensional stability of wood by reducing moisture deformations by 30-90% compared to untreated wood. The anti-swelling efficiency (ASE) of thermally modified beech wood increases with higher temperatures (140-160°C) and longer durations (3 hours), but decreases at extreme conditions (180°C for 5 hours). Dimensional stability reaches its highest value at approximately 20% mass loss during thermal modification, with further improvements only possible in closed systems. The authors' findings partially agree with the conclusions of C. Hill *et al.* (2021) regarding the impacts of thermal modification on wood properties. This suggests that while thermal modification can enhance certain wood properties, it may compromise others, particularly adhesion qualities, which are crucial for practical applications involving glued wood products. At the same time, M. Gaff *et al.* (2023) have shown that the thermal modification process also changes the chemical composition of the wood, particularly the lignin, leading to colour changes and increased thermal stability. Thermowood is an environmentally friendly alternative to tropical wood that is created through a thermal modification process. The process involves heating the wood to temperatures between 160-250°C, which changes the wood's properties and improves its durability, dimensional stability, and resistance to fungi, insects, and weathering. The authors' findings align with M. Gaff *et al.* (2023) on the transformative effects of thermal modification on wood, noting the reduction in mechanical and adhesive qualities at higher temperatures, which underscores the chemical and structural changes.

R. Hasanagić *et al.* (2021) assess the influence of thermal modification on the physical and mechanical characteristics of three distinct wood species – fir (*Abies* sp.), linden (*Tilia* sp.), and beech (*Fagus* sp.). The thermal modification was performed in a controlled laboratory environment using an oven. The modification was carried out at five distinct temperatures (170, 180, 195, 210, 220°C) and with different maximum periods (78, 120, 180, 240, 276 minutes). The findings indicated that the mechanical characteristics of the treated wood exhibited statistically negligible variations at lower temperatures in comparison to the control samples. The authors agree with the findings of R. Hasanagić *et al.* (2021) regarding the negative impact of higher thermal modification temperatures on wood properties, as both studies observe a decline in the strength characteristics with increased temperatures. M. Ninane *et al.* (2021) found that heat treatment of three native European hardwood species – oak, ash, and beech (including steamed beech) – improved their physical and decay resistance properties, making them a promising alternative to tropical woods and chemically treated timber. Specifically, the heat treatment reduced the equilibrium moisture content and increased dimensional stability for all three species. The authors' findings partially align with those of M. Ninane *et al.* (2021) regarding the impact of thermal modification on wood properties. This discrepancy suggests that the effects of heat treatment can vary significantly between different species of wood, potentially due to differences in cellular structure and chemical composition.

According to M.D. Ghalehno *et al.* (2021), heat treatment can have a negative impact on the mechanical properties of Oriental beech wood (*Fagus orientalis*), with higher temperatures and longer durations resulting in greater decreases. A study found that while heat treatment at 190°C for 9 hours reduced bending strength by 22.53% compared to control samples, treatment at 130°C for 3 hours resulted in bending strength comparable to untreated wood. In general, as modification intensity increases with higher temperatures and longer durations, mechanical properties like compression strength, bending strength, modulus of elasticity, hardness, and shear strength decrease (Gordiichuk, 2024).

H. Liu *et al.* (2022) examine that moderate TM of American alder (*Alnus rubra*) wood at 140°C for 4 to 13 hours had varying effects on its properties. The absolute dry density of TM wood exhibited a notable decrease with increasing treatment period, except for the group treated for 4 hours. After undergoing a treatment of 13 hours, Moderate TM significantly decreased wood residual stress by as much as 90.3%. Surprisingly, the mild TM had minimal impact on the mechanical properties of modulus of rupture (MOR) and modulus of elasticity (MOE). Nevertheless, the ability of wood to absorb moisture and take in water was greatly enhanced following a mild thermal modification, resulting in varying results based on the duration of the treatment.

In the study by M.H. De Paula *et al.* (2022), wood was treated at 180°C and 215°C for 20 and 40 minutes in a muffle furnace. The results showed that the basic density was not significantly affected, and there was a decrease in volumetric shrinkage, particularly in the most severe treatment (215°C for 40 minutes). The chemical analysis revealed a decrease in holocellulose and extractives content, leading to an increase in the percentage of lignin, especially in the most severe treatment. Importantly, the MOR and MOE did not change significantly after the short heat treatments of 20 and 40 minutes. This suggests that the mechanical properties were not compromised by the heat treatments, even at the higher temperature and longer duration.

Table 4 presents the values of the gluing resistance and wood failure referred to the feed speed. t-Test showed that between series of data there were essential differences ($p < 0.05$), implying a clear influence of the feed speed on the study parameters.

Table 4. Comparative results for the feed speed (t-Test)

Feed speed [m/min]	Number of measurements	Gluing shear strength [N/mm²]		Wood failure [%]	
		t	Sig. (2-tailed)	t	Sig. (2-tailed)
3	88	41.58	0	53.99	0
10	88	42.43	0	44.94	0

Source: compiled by the authors

Table 4 compares the gluing shear strength and wood failure percentages at feed speeds of 3 m/min and 10 m/min, using t-tests to statistically analyse the differences. At a feed speed of 3 m/min, the average gluing shear strength was recorded at 41.58 N/mm² and the wood failure percentage at 53.99%, both showing statistically significant differences with a p-value of 0.000, indicating strong evidence against the null hypothesis. Conversely, at a feed speed of 10 m/min, the gluing shear strength slightly increased to 42.43 N/mm², while the wood failure percentage decreased to 44.94%, also demonstrating statistically significant results with a p-value of 0.000. This suggests that higher feed speeds may enhance shear strength slightly while reducing the incidence of wood failure, pointing to potential efficiency improvements in processing at increased speeds (Kozyar, 2023).

The study on thermally modified fir wood revealed that the modification temperature, feed speed, and gluing properties exhibited complex interactions. While temperature exhibited a near-significant effect on gluing shear strength, feed speed significantly influenced both shear strength and wood failure. The optimal performance was observed at 190°C, which balanced the strength and consistency of the material. Higher temperatures (220°C) resulted in decreased strength and altered failure patterns. Interestingly, faster feed speeds (10 m/min) generally led to improved shear strength and reduced of thermally modified wood. The analysis highlighted the critical role of feed speed and its interaction with temperature in determining material performance. These findings suggest that careful control of both thermal modification temperature and feed speed during processing can optimise the gluing properties and overall performance of thermally modified fir wood in various applications.

Conclusions

The results of the tests showed that natural fir wood exhibits greater gluing shear strength than wood modified at high temperatures under atmospheric pressure. The shear strength undergoes a progressive decrease as the modification temperature increases, although this decrease is not statistically significant. This trend holds true for any feed speed used in planning the glued surfaces.

The wood failure does not present a linear relationship like strength. At 160°C, the failure is smaller than that of natural wood, while at higher temperatures, the opposite occurs. Even for wood failure, the temperature was statistically not significant. The decrease in the gluing quality of thermally modified wood is caused not only by the weakening of the mechanical strength of the wood but also by reduced adhesion due to insufficient glue permeability into the wood structure.

Regarding feed speed, a significant effect is noted only for gluing strength. For natural wood, a higher feed speed results in lower gluing strength compared to a lower speed. Interestingly, the opposite occurs with thermally modified wood. The lower reduction in gluing shear strength observed at higher modification temperatures for the feed speed of 10 m/min demonstrates the positive influence of high feed speeds on the gluing of thermally modified wood. This finding suggests that optimizing feed speeds could potentially mitigate some of the negative effects of thermal modification on gluing performance.

Future research should focus on exploring the underlying mechanisms responsible for the observed differences in gluing performance between natural and thermally modified wood. This could involve investigating changes in wood chemistry and microstructure at various modification temperatures and their relationship to adhesive penetration and bond formation. Additionally, studies examining a wider range of feed speeds and their interaction with different adhesive types could provide valuable insights for optimizing the gluing process for thermally modified wood in industrial applications.

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Conflict of Interest

The authors declare no conflict of interest.

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Склеювання термічно модифікованої деревини сріблястої ялиці, струганої на горизонтально-фрезерному верстаті

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Анотація. Це дослідження було проведено з метою отримання інформації щодо якості склеювання деревини ялиці сріблястої (Abies alba Mill.), струганої з різною швидкістю подачі, після термічної модифікації. Було підготовлено чотири групи з шістнадцяти зразків ялиці, висушених на повітрі. Три групи були термічно модифіковані при різних температурах (160°C, 190°C і 220°C) протягом 3 годин. Послідовність процесів включала термічну модифікацію, стругання з двома швидкостями подачі (половина зразків зі швидкістю 3 м/хв, а інша половина зі швидкістю 10 м/хв), процес склеювання і, нарешті, проведення механічних випробувань для оцінки міцності на зсув і руйнування деревини. Міцність на зсув склеєного матеріалу поступово зменшувалася зі збільшенням температури модифікації для обох швидкостей подачі, причому зниження становило від 1,37 % до 14,63 % порівняно з натуральною деревиною. Руйнування деревини не показало лінійної залежності, зі зниженням при 160°C, але збільшенням при більш високих температурах порівняно з натуральною деревиною. Швидкість подачі мала значний вплив на міцність склеювання на зсув, причому вища швидкість подачі призводила до зниження міцності для натуральної деревини, але підвищувала міцність для термічно модифікованої деревини. Термічна модифікація деревини ялиці при температурі 220°C мала негативний вплив на міцність склеювання на зсув і руйнування деревини. Це було спричинено погіршенням компонентів деревини та зміною механічних властивостей. Результати цього дослідження дають важливі знання для вдосконалення процесу склеювання та встановлення відповідних параметрів для термічно модифікованої деревини ялиці. Цей вид деревини має потенційне застосування в деревообробній промисловості, зокрема у виробництві інженерних дерев'яних виробів

Ключові слова: деревина ялиці; термічна модифікація; склеювання; міцність на зсув; руйнування деревини