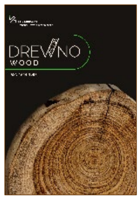
Article citation info:
Çamlibel O., Ayata Ü., Peker H. 2024. Effect of Calcium Lignosulfonate Additive on Some Physical and Mechanical Properties of High-Density Fiberboard. *Drewno. Prace naukowe. Doniesienia. Komunikaty* 67 (214): 00037. https://doi.org/10.53502/wood-195844

Łukasiewicz
Poznań Institute of Technology

Drewno. Prace naukowe. Doniesienia. Komunikaty
Wood. Research papers. Reports. Announcements

Journal website: https://drewno-wood.pl/



Effect of Calcium Lignosulfonate Additive on Some Physical and Mechanical Properties of High-Density Fiberboard

Osman Çamlibel[a]
Ümit Ayata[b *]
Hüseyin Peker[c]

[a] Kırıkkale University, Turkey
[b] Bayburt University, Turkey
[c] Artvin Çoruh University, Turkey

Article info
Received: 29 September 2024
Accepted: 12 November 2024
Published online:
17 December 2024

Keywords
wood fiber
high-density fiberboard
calcium lignosulfonate
bending strength
modulus of elasticity
surface soundness
internal bond strength

Calcium lignosulfonate (CLS) ($C_{20}H_{24}CaO_{10}S_2$) is widely used in various industries today, including wood, construction, food, agriculture, and textiles. There are currently few studies on the addition of CLS chemicals to various fiberboards. This study was designed to explore the outcomes of the interaction between CLS and the boards, with the aim of expanding the potential applications of this chemical. We incorporated CLS at varying percentages (6%, 8%, and 10%) as an adhesive additive in high-density fiberboard (HDF) produced using urea-formaldehyde (UF) resin in a laboratory setting. We assessed its impact on several physical properties – thickness swelling (TS), density, and water absorption (WA) – and mechanical properties: modulus of rupture (MOR), internal bond strength (IB), modulus of elasticity (MOE), and surface soundness (SS). A control group was created using prepared boards, enabling the comparison of results between boards made with and without CLS additives. According to the results of a multivariate analysis of variance, the CLS percentage showed no significant effect on density, MOE, and SS. However, it significantly influenced TS, WA, IB, and MOR, resulting in reductions of 4–12% for SS, 6–12% for MOR, and 2–22% for IB, while increasing TS by 20–130%, WA by 25–84%, and MOE by 1–3%. It was observed that the use of CLS led to differing results in the tests conducted on the produced HDF materials.

DOI: 10.53502/wood-195844

Introduction

Composite wood panels are becoming more popular for enhancing fiber efficiency and maximizing the use of renewable timber resources. These panels are created by thoughtfully combining veneers, wood chips, wood fibers, and slats. Their growing demand is attributed to their ability to be produced in large sizes and their high quality, often matching or exceeding that of other materials. They are mainly used in constructing vehicles, ships, and railway cars, as well as in prefabricated homes, interior finishes, decorative applications, and various carpentry projects, including doors and hidden components of furniture [Hammond et al. 1969].

High-density fiberboard (HDF) is an engineered wood panel categorized within the “fiberboards”

* Corresponding author: umitayata@yandex.com

group, which is subdivided by density into low, medium, and high variations. HDF is produced by compressing fine lignocellulosic fibers and synthetic resin under high pressure and temperature [Irle and Barbu 2010]. HDF is a subtype of fiberboard with a density exceeding 800 kg/m³. One of the challenges in developing new materials for furniture or construction is the high moisture absorption of lignocellulosic fibers, which makes them highly hydrophilic. This issue can be addressed through physical or chemical modifications of the fibers [Mamiński et al. 2020].

Lignosulfonates (LS) are derived from spent sulfite liquor generated during the wood sulfite digestion process, which may contain lignosulfonic acid, and occasionally, hemicellulose and sugars. Currently, lignosulfonate products are utilized as binders in animal feed pellet production, for protein precipitation in wastewater treatment at paper mills, and in the leather tanning process [Windschitl and Stern 1988]. The process of extracting LS is referred to as delignification. During this process, the electrophilic carbocations formed by the cleavage of ester bonds interact with bisulfite ions to create LS, which can include ions such as calcium, sodium, magnesium, and ammonium. Thus, conducting a thorough theoretical study on how these ions influence the properties of LS would be quite intriguing [Salazar Valenciaet al. 2015].

CLS chemical contains various anionic groups, such as sulfonic and carboxylic acids, along with alkyl and phenolic hydroxyl groups. This composition gives it properties like wettability, adsorptivity, and dispersibility, which can have intriguing effects on mineral flotation [Pang et al. 2004; Tan et al. 2012; Bo et al. 2018]. There is a limited amount of research on the addition of CLS in the adhesive as a contributor to the production of fiber-based panels such as high, medium, and low-density fibreboards (HDF, MDF, and LDF). The aim is to ensure that the addition of this substance in varying amounts to different panel types primarily improves formaldehyde emissions while also positively impacting their mechanical and physical properties. Literature reviews indicate that tests on various wood-based panels with different LS ratios have shown notable changes in density, formaldehyde emissions, water absorption (WA), thickness swelling (TS), internal bond strength (IB), modulus of rupture (MOR), modulus of elasticity (MOE), and surface soundness (SS).

Antov et al. [2020a] studied the impact of adding CLS to MDF panels produced with 3%, 4%, and 5% phenol-formaldehyde (PF) resin, using CLS at levels of 5%, 10%, and 15%. They conducted tests on density, TS, WA, MOR, and MOE, comparing the results across the different panel formulations. The data indicated that CLS addition should be limited to a maximum of 10% to avoid negatively affecting the mechanical properties of MDF panels made with lower PF resin content (3%).

Antov et al. [2021a] developed formaldehyde-free fiberboard panels using CLS as a lignin-based adhesive at varying concentrations of 8%, 10%, 12%, and 14%. They conducted tests on WA, MOE, MOR, and TS. The findings indicated that increasing the CLS content resulted in reduced formaldehyde emissions, as well as lower WA and TS values. Conversely, both MOE and MOR values were found to increase with higher CLS ratios.

Antov et al. [2021b] explored the production of HDF panels using a urea-formaldehyde (UF) resin combined with commercial ammonium LS from hardwood fibers. The panels were created with a low UF content of 3% and varying ammonium LS levels at 6%, 8%, and 10%. They assessed properties such as MOE, MOR, IB, WA, and TS. The study concluded that it is possible to produce environmentally friendly HDF panels that meet European standards, featuring acceptable physical-mechanical properties and near-zero formaldehyde emissions, at a low cost by utilizing minimal traditional UF resin alongside ammonium lignosulfonate.

In a study by Çamlıbel and Ayata [2023a], the effects of CLS additives at concentrations of 2% and 3% on the physical properties of HDF were examined. The boards were produced at a pressing speed of 1000 mm/s with a UF adhesive ratio of 1.00. The findings indicated that the addition of 2% CLS resulted in a decrease in thickness, whereas 3% CLS caused an increase in thickness. Both density and moisture content were found to decrease with the addition of CLS, while TS and WA values increased. The study concluded that CLS significantly influenced the performance characteristics of the boards tested.

In the research by Çamlıbel and Ayata [2023b], the mechanical characteristics of HDF were examined, with the boards being manufactured by incorporating CLS chemicals at 2% and 3% concentrations. The production parameters for the HDF included a pressing speed of 1000 mm/s, a pressure of 34 kg/cm², and a pressing duration of 55 seconds. The adhesive used was a UF resin with a molar ratio of F/U: 1.00. The wood fiber blend was composed of 50% pine, 30% fir, and 20% beech. The UF resin had a solid content of 62%, with an adhesive content of 11%, 1.35% hardener, and 0.95% paraffin. The study assessed several mechanical properties, such as MOR, MOE, IB, and SS.

In the work of Gonçalves et al. [2024], three-layer panels were created, with the core layer bonded using polymeric isocyanate (pMDI) and the surface layers bonded with LS. To enhance the distribution of the adhesive, propylene carbonate (PC) was utilized as a solvent for the pMDI. Specifically, the core layer contained 2.2% PC, while the surface layers incorporated 15% LS and 1.3% pMDI. The results indicated that the optimal panels consisted of a core layer with 2.2% PC, along with surface layers made of 15% LS and 1.3% pMDI.

Given the limited research on CLS additives in HDF panels, we conducted this study using standard-produced HDF, incorporating three different levels of CLS in the adhesive. After the measurements and tests conducted on the productions related to the parameters, the aim of the study was to create a new application area for the chemical used. Additionally, it was intended to generate ideas about incorporating this chemical into different adhesive ratios in the production of other wood-based materials.

Materials and methods

In this study, we utilized urea-formaldehyde (UF) adhesive with the following characteristics: solid content of 62%, a formaldehyde-to-urea molar ratio of 1.00, density at 20°C of 1.226 g/cm3, and viscosity at 25°C ranging from 20 to 36 seconds. The gel time at 100°C (with a 20% ammonium sulfate solution) was between 20 and 48 seconds. The adhesive had a pH of 6.8 to 8.4, free formaldehyde content not exceeding 0.20%, a methylol group percentage of 11-15%, and a shelf life of 80 days. This adhesive was commercially produced at the Kastamonu Integrated Wood Industry Adhesive Plant.

The workflow diagram for the panels produced in the study is presented in Figure 1.

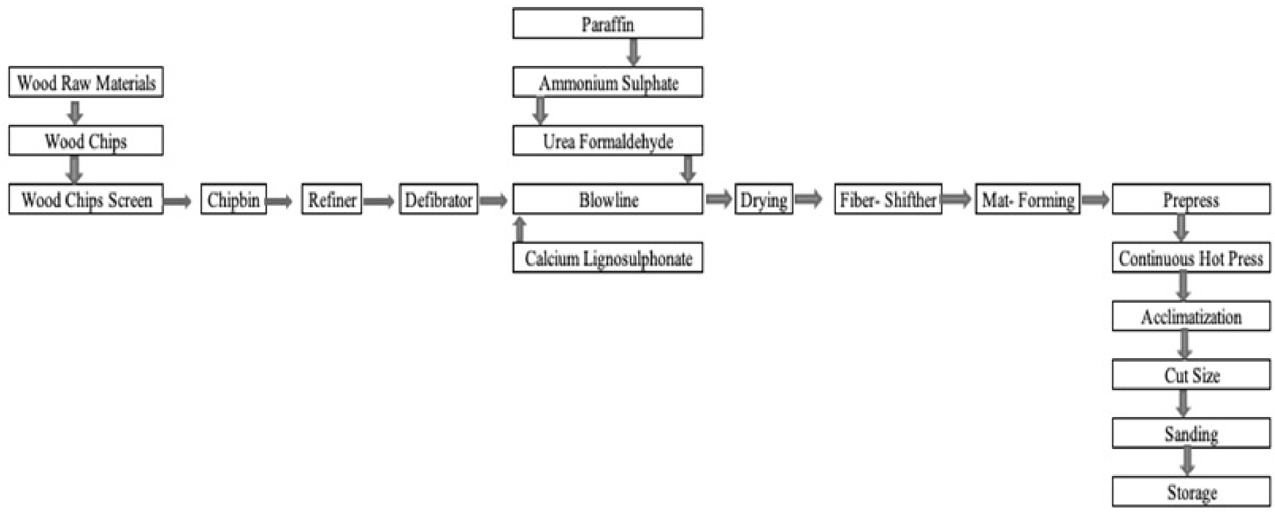


Fig. 1. Workflow diagram for the panels produced in the study

Table 1. Parameters of produced fiberboard panels

Wood mixture	50% pine + 30% fir + 20% beech
Hardener (% amount based on dry weight)	1.35
UF (% amount based on dry weight)	11
UF molar percentage (F:U)	1.00
CLS (50% Solution)	0% (control), 6%, 8%, and 10%
Paraffin (% amount based on dry weight)	0.95
Continuous press temperature (°C)	220
Continuous press speed (mm/s)	780
Continuous press time (s)	70
Continuous press pressure (kg/cm^2)	34
HDF board dimensions (mm)	7.4 x 2097 x 7365

Fig. 2. Preparation method of materials with calcium lignosulfonate additives

Paraffin was included as a liquid emulsion with a solid content of 60%, a pH of 9-10, viscosity between 12 and 24 seconds, and a density of 0.96 g/cm^3. Ammonium sulfate ($(NH_4)_2SO_4$) was utilized in a 20% solution (density: 0.96 g/cm^3, pH: 6.6) to function as a catalyst for curing the UF adhesive during hot pressing. Additionally, commercial CLS was obtained in powder form from a supplier in İzmir, Turkey, and prepared as a 50% solution with a pH range of 3-5. Table 1 outlines the parameters relevant to the produced HDF panels.

The preparation method of materials with calcium lignosulfonate additive is shown in Figure 2.

The cooked chips were transformed into pulp using a defibrator and then directed to the blow line for additional processing (Andritz defibrillator (2008 model; Andritz AG, Graz, Austria). The UF adhesive had a dry solid percentage of 11%, the hardener was at 1.35%, and the liquid paraffin's dry solid percentage was 0.95%. CLS was added at varying levels of 0%, 6%, 8%, and 10%. The UF, hardener, and CLS adhesives were manufactured in adhesive plants and transported to the HDF production line via tanks, while liquid paraffin was stored in a dedicated tank on-site.

The fibers were dried to a moisture content of 12% and then placed in a forming unit to create 7 mm HDF panels. Following formation, a pre-pressing process applied a pressure of 200 bars to the mat. In the hot pressing phase, the press temperature was set at 220°C, with a continuous press speed of 780 mm/s, a pressing time of 70 seconds, and a pressure of 34 kg/cm^2, resulting in panels measuring 7.40 x 2097 x 7365 mm. The MDF boards were produced in a single layer press (Siempelkamp laboratory single hot press model; Siempelkamp, Krefeld, Germany). A total of 40 panels were produced and rested in an intermediate storage area for 5 days after cooling in the star cooler.

The top and bottom surfaces of the panels were sanded using 40, 80, 120, and 180-grit sandpaper. After sanding, the panels were conditioned according to the TS 642 ISO 554 [1997] standard at 20±2°C and 65±5% relative humidity. Panels with 0%, 6%, 8%, and 10% CLS were then tested for physical properties (density per TS EN 323 (1999), thickness swelling (TS) and water absorption (WA) per TS EN 317 [1999]) and mechanical properties (internal bond strength (IB) per TS EN 319 [1999], modulus of rupture (MOR) and modulus of elasticity (MOE) per TS EN 310 [1999], and surface soundness (SS) per TS EN 311 [2005]). A universal tester (Imal Mobiltemp shc 22, model IB700; San Damaso, Italy) was used to assess mechanical properties.

Data analysis was performed using statistical software, which allowed for the calculation of various parameters, including means, identification of homogeneity groups, determination of maximum and minimum values, assessment of standard deviations for data dispersion, execution of multivariate analysis of variance to explore relationships among multiple variables, and calculation of percentage change rates.

Results and discussion

The findings from the multivariate analysis of variance are shown in Table 2. These results indicate that the CLS ratio had no significant effect on thickness, density, modulus of elasticity (MOE), surface soundness (SS), and moisture tests. However, it was found to be significant for thickness swelling (TS), water absorption (WA), internal bond strength (IB), and bending strength (MOR) tests. This data is crucial for understanding the properties of the produced materials.

The test measurement results for the physical properties of the produced boards are presented in Table 3.

The application of CLS was found to lead to a reduction in thickness values, while TS and WA values showed an increase (Table 3).

The control samples exhibited the greatest thickness, measuring 7.72 mm, while the experimental samples with 8% and 10% CLS ratios showed the lowest thickness at 7.62 mm. The most significant reduction in thickness, at 0.65%, occurred in the experimental samples with a 6% CLS ratio, whereas the smallest decrease of 0.52% was observed in the samples with 8% and 10% CLS ratios (Table 3).

Table 2. The results of the multivariate analysis of variance (*: significant)

Source	Dependent Variable	Sum of Squares	Degrees of Freedom	Mean Square	F Value	Sig.
CLS Ratio	Thickness	0.007	3	0.002	1.142	0.362**
	Density	1525.978	3	508.659	1.887	0.173**
	MOR	72.468	3	24.156	4.619	0.016*
	MOE	74016.820	3	24672.273	0.527	0.670**
	IB	0.485	3	0.162	17.351	0.000*
	SS	0.120	3	0.040	1.251	0.324**
	Moisture	0.060	3	0.020	1.309	0.306**
	TS	630.693	3	210.231	347.899	0.000*
	WA	1275.201	3	425.067	408.060	0.000*
Error	Thickness	0.031	16	0.002		
	Density	4313.457	16	269.591		
	MOR	83.680	16	5.230		
	MOE	749173.763	16	46823.360		
	IB	0.149	16	0.009		
	SS	0.513	16	0.032		
	Moisture	0.245	16	0.015		
	TS	9.669	16	0.604		
	WA	16.667	16	1.042		
Total	Thickness	1181.991	20			
	Density	15506249.920	20			
	MOR	31116.729	20			
	MOE	279015844.819	20			
	IB	44.294	20			
	SS	35.086	20			
	Moisture	1100.098	20			
	TS	6355.942	20			
	WA	24175.833	20			
Corrected Total	Thickness	0.038	19			
	Density	5839.435	19			
	MOR	156.149	19			
	MOE	823190.582	19			
	IB	0.634	19			
	SS	0.633	19			
	Moisture	0.305	19			
	TS	640.361	19			
	WA	1291.868	19			

Table 3. Measurement results for physical tests

Test	CLS (%)	Mean	Change (%)	*HG*	*SD*	Minimum	Maximum	COV
Thickness (mm)	0	7.72	-	A*	0.06	7.62	7.77	0.75
	6	7.67	↓0.65	A	0.02	7.64	7.69	0.31
	8	7.68	↓0.52	A**	0.02	7.65	7.71	0.31
	10	7.68	↓0.52	A**	0.06	7.63	7.78	0.75
Density (kg/m³)	0	875.43	-	A	9.19	861.44	887.03	1.05
	6	868.51	↓0.79	A**	18.04	853.20	893.14	2.08
	8	888.54	↑1.50	A	21.25	858.47	908.76	2.39
	10	888.94	↑1.54	A*	14.73	874.33	904.85	1.66
Moisture (%)	0	7.39	-	A	0.22	7.14	7.69	2.91
	6	7.41	↑0.27	A	0.10	7.29	7.52	1.29
	8	7.50	↑1.49	A*	0.07	7.40	7.57	0.92
	10	7.36	↓0.41	A**	0.03	7.31	7.40	0.43
TS (%)	0	10.38	-	D**	0.19	10.10	10.59	1.81
	6	12.55	↑20.91	C	0.41	11.99	12.99	3.28
	8	23.97	↑130.92	A*	1.17	22.58	25.11	4.89
	10	20.72	↑99.61	B	0.92	19.34	21.55	4.42
WA (%)	0	23.26	-	D**	0.74	22.14	23.99	3.20
	6	29.09	↑25.06	C	0.11	29.02	29.28	0.37
	8	42.90	↑84.44	A*	1.83	40.74	44.97	4.27
	10	40.04	↑72.14	B	0.49	39.51	40.40	1.22

SD: Standard Deviation, *HG*: Homogeneity Group, COV: Coefficient of Variation,
Number of Measurements: 5, *: Highest Result, **: Lowest Result

When a 6% CLS percentage was used, a decrease in density of 0.79% was observed. Conversely, using 8% and 10% CLS resulted in increases of 1.50% and 1.54%, respectively. The highest density was recorded in the samples with 10% CLS (888.94 kg/m^3), while the lowest was found in the 6% CLS samples (868.51 kg/m^3) (Table 3).

The experimental samples with a 10% CLS ratio showed the lowest moisture content at 7.36%, while the highest moisture content was found in samples with an 8% CLS ratio at 7.50%. Increases in moisture were observed in the samples with 6% and 8% CLS ratios, with values rising by 0.27% and 1.49%, respectively, while a decrease of 0.41% was noted in the samples with a 10% CLS ratio (Table 3).

WA results in Table 3 indicate that the CSL8 samples absorbed the most water on average, at 42.9%, while the control samples absorbed the least at 23.26%. The samples with 6% and 10% CLS absorbed 29.09% and 40.04%, respectively. This finding contrasts with research by Savov and Mihajlova [2017b], which reported a decrease in WA values as the CLS ratio increased from 5% to 20%. Similarly, Çamlıbel and Ayata [2023a] found that WA increased with 2% and 3% CLS additives. Hu and Gua [2015] conducted a study in which they created wood fiber biocomposites reinforced with polylactic acid (PLA) through a traditional hot pressing production method. They explored the effects of incorporating ammonium lignosulfonate (AL) on the mechanical and dimensional characteristics of these biocomposites. Their findings revealed that the addition of AL had a detrimental impact on the dimensional properties of the biocomposites.

The control samples exhibited the lowest TS at 10.38%, while the highest TS was noted in the samples with 8% CLS at 23.97%. The most significant increase in TS (130.92%) occurred with the 8% CLS samples, whereas the smallest increase (20.91%) was with the 6% CLS samples (Table 3).

This finding is at odds with the report by Savov and Mihajlova [2017b], which indicated that increasing the CLS ratio from 5% to 20% decreased TS. Antov et al. [2020a] also reported that the incorporation of 5%, 10%, and 15% CLS into MDF panels led to a decrease in density, while simultaneously increasing TS and WA. In a separate study, Antov et al. [2021b] found that TS for HDF panels varied significantly with different additives.

The test results related to physical characteristics are presented in graphical form in Figure 3.

The results of the tests on the mechanical properties of the produced boards are displayed in Table 4. It was found that the application of CLS resulted in a decrease in IB, SS, and MOR values, while an increase was observed in MOE values (Table 4).

For MOR, the control samples had the highest value at 41.80 N/mm^2, while the lowest was in the samples with 6% CLS at 36.50 N/mm^2. The largest decrease in MOR (12.68%) was in the 6% CLS samples, while the smallest (4.50%) occurred in the 8% CLS samples. The highest MOE was recorded in the 10% CLS samples (3790.90 N/mm^2), compared to the control samples (3649.22 N/mm^2). The greatest increase in MOE was 3.88% with the 10% CLS samples, while the lowest increase (1.18%) was seen with the 6% CLS samples (Table 4).

Regarding IB, the highest value was in the control samples (1.65 N/mm^2), and the lowest was in the samples with 8% CLS (1.28 N/mm^2). The most significant decrease in IB was 22.42% in the 8% CLS samples, while the smallest was 2.42% in the 10% CLS samples (Table 4).

For SS, the control samples recorded the highest value (1.42 N/mm^2), whereas the lowest was in the samples with 6% and 8% CLS (1.24 N/mm^2). The largest decrease in SS was 12.68% for the 6% and 8% CLS samples, while the smallest decrease (4.93%) was in the 10% CLS samples (Table 4).

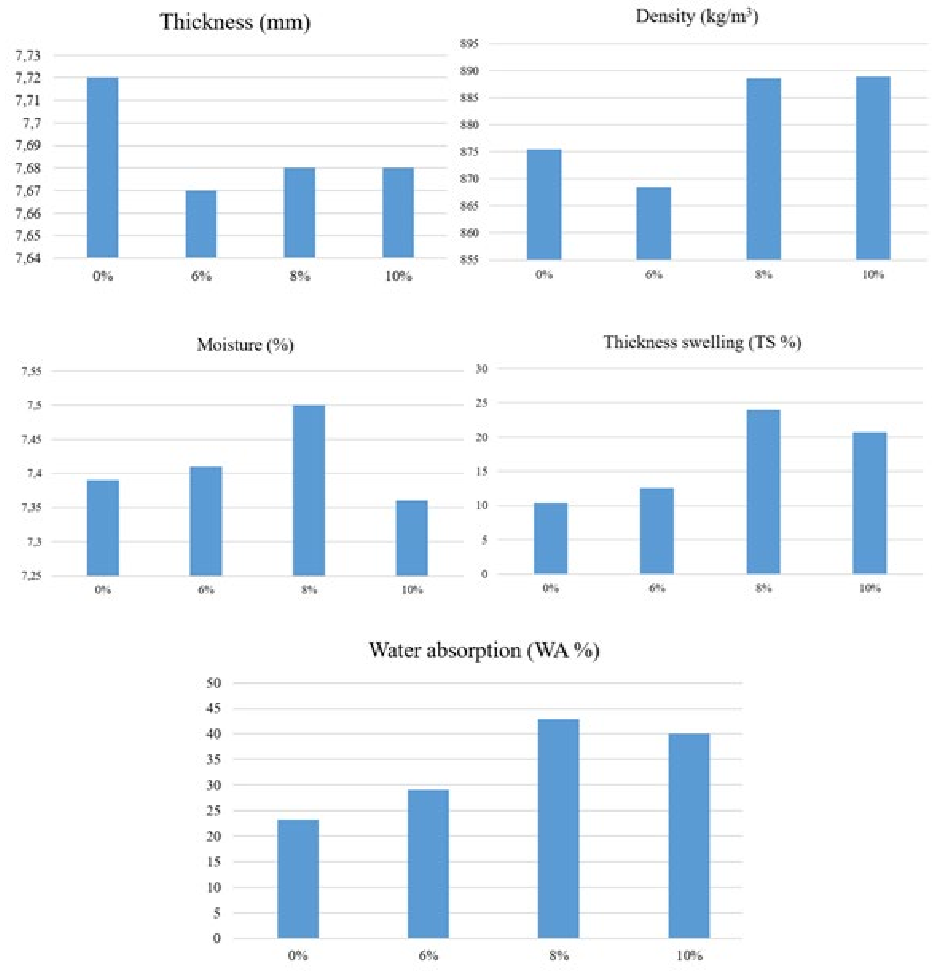


Fig. 3. Graphical representation of the results of physical tests

Table 4. Measurement results for mechanical tests

Test	CLS (%)	Mean	Change (%)	*HG*	*SD*	Minimum	Maximum	COV
MOR (N/mm^2)	0	41.80	-	A*	1.28	39.81	43.35	3.05
	6	36.50	↓12.68	B**	2.07	34.64	39.22	5.67
	8	39.92	↓4.50	A	1.96	37.34	41.87	4.92
	10	39.17	↓6.29	AB	3.34	36.38	42.90	8.53
MOE (N/mm^2)	0	3649.22	-	A**	232.42	3451.34	4019.96	6.37
	6	3692.13	↑1.18	A	232.29	3497.09	3996.82	6.29
	8	3786.00	↑3.75	A	208.40	3573.19	3991.18	5.50
	10	3790.90	↑3.88	A*	189.43	3599.40	4078.15	5.00
IB (N/mm^2)	0	1.65	-	A*	0.05	1.59	1.70	3.06
	6	1.37	↓16.97	B	0.08	1.28	1.48	5.58
	8	1.28	↓22.42	B**	0.17	1.10	1.44	12.98
	10	1.61	↓2.42	A	0.03	1.55	1.64	2.17
SS (N/mm^2)	0	1.42	-	A*	0.08	1.36	1.55	5.72
	6	1.24	↓12.68	A**	0.06	1.17	1.29	5.16
	8	1.24	↓12.68	A**	0.07	1.14	1.32	5.93
	10	1.35	↓4.93	A	0.33	1.07	1.71	24.87

SD: Standard Deviation, *HG*: Homogeneity Group, COV: Coefficient of Variation,
Number of Measurements: 5, *: Highest Result, **: Lowest Result

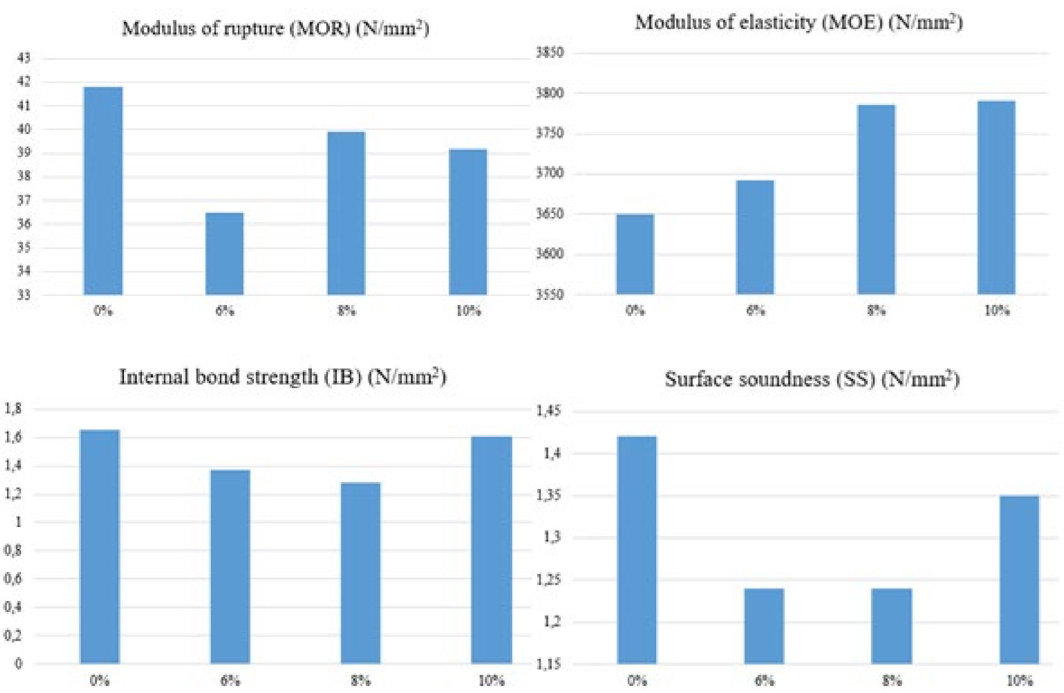


Fig. 4. Graphical representation of the results of mechanical tests

Table 5. Comparison of the results obtained in this study with the standard values

Test	Standard	Unit	Limit value	This study		
IB	TS EN 319, (1999)	N/mm^2	> 1.20	Control	1.65	Positive
				6% CSL	1.37	
				8% CSL	1.28	
				10% CSL	1.61	
MOR	TS EN 310, (1999)	N/mm^2	> 40	Control	41.80	Positive
				6% CSL	36.50	Negative
				8% CSL	39.92	Negative
				10% CSL	39.17	Negative
MOE	TS EN 310, (1999)	N/mm^2	> 2700	Control	3649.22	Positive
				6% CSL	3692.13	
				8% CSL	3786.00	
				10% CSL	3790.90	
SS	TS EN 311, (2005)	N/mm^2	>1.00	Control	1.42	Positive
				6% CSL	1.24	
				8% CSL	1.24	
				10% CSL	1.35	
Moisture	TS EN 322, (1999)	%	4-11	Control	7.39	Positive
				6% CSL	7.41	
				8% CSL	7.50	
				10% CSL	7.36	
Thickness	TS EN 324-1, (1999)	mm	8±0.3	Control	7.72	Positive
				6% CSL	7.67	Negative
				8% CSL	7.68	
				10% CSL	7.68	
Density	TS EN 323, (1999)	kg/m^3	870 Net	Control	875.43	Positive
				6% CSL	868.51	Negative
				8% CSL	888.54	Positive
				10% CSL	888.94	
TS	TS EN 317, (1999)	%	> 11	Control	10.38	Positive
				6% CSL	12.55	Negative
				8% CSL	23.97	
				10% CSL	20.72	
Water absorption	TS EN 317, (1999)	%	Maximum 35	Control	23.26	Positive
				6% CSL	29.09	
				8% CSL	42.90	Negative
				10% CSL	40.04	

Antov et al. [2020a] found that the addition of 5%, 10%, and 15% CLS to MDF panels decreased MOR and MOE.

In the investigation carried out by Çamlıbel and Ayata [2023b], the addition of CLS chemicals at concentrations of 2% and 3% to HDF panels was found to significantly impact all mechanical properties, based on multivariate variance analysis. The inclusion of CLS resulted in decreased performance in MOR, MOE, and IB tests. However, for the SS test, an improvement was observed with 2% CLS, while a decrease was noted at the 3% concentration.

Additionally, the test results related to physical characteristics are presented in graphical form in Figure 4.

In the study by Pereira et al. [2024], the researchers investigated the viability of using sugarcane bagasse, eucalyptus wood particles, tannin, and LS as adhesives for producing MDF panels. The results from the moisture tests indicated that panels made with only tannin in the adhesive formulation displayed lower rates of TS and WA. On the other hand, panels that included LS were generally inadequate compared to the performance metrics of conventional panels.

Table 5 presents a comparison of the results from this study with the standard values. However, the table lacks clarity regarding the specific values and the type of analysis performed, making it challenging to assess whether the outcomes are "positive" or "negative". Based on the available data, it can be noted that incorporating 6% CSL in HDF boards aligns with the standard requirements.

Conclusions

This research yielded the following findings:

– The use of CLS results in decreased IB, thickness, SS, and MOR, while TS and WA values increase.
– Comparisons with established panel production standards show that incorporating 6% CSL in HDF boards meets the required standards.
– Although the SS and IB values from the 10% CLS addition comply with European standards, the MOR and MOE values do not show favorable results, indicating that exceeding 6% CLS is not advantageous.
– Future studies should focus on exploring the effects of nanocellulose-based materials and varying ratios of CSL to enhance outcomes. It is also recommended to use CSL chemical in various wood-based materials produced with different adhesives, and to conduct tests on the produced materials for formaldehyde emissions, biological properties, mechanical, physical, and technological performance.

Acknowledgments

We would like to express our gratitude to the Kastamonu Entegre Ağaç A.Ş. factory director and managers for their assistance.

References

Antov P., Savov V., Mantanis G.I., Neykov N. [2020a]: Medium-density fibreboards bonded with phenol-formaldehyde resin and calcium lignosulfonate as an eco-friendly additive. Wood Material Science & Engineering, 1-7. DOI: 10.1080/17480272.2020.1751279.

Antov P., Mantanis G.I., Savov V. [2020b]: Development of wood composites from recycled fibres bonded with magnesium lignosulfonate. Forests, 11(6): 613. DOI: 10.3390/f11060613.

Antov P., Krišták L.U., Reh R., Savov V., Papadopoulos A.N. [2021a]: Eco-friendly fiberboard panels from recycled fibers bonded with calcium lignosulfonate. Polymers, 13(4), 639. DOI: 10.3390/polym13040639.

Antov P., Savov V., Krišták L., Réh R., Mantanis G.I. [2021b]: Eco-friendly, high-density fiberboards bonded with urea-formaldehyde and ammonium lignosulfonate. Polymers 13(2): 220. DOI: 10.3390/polym13020220

Bo F., Wei G., Peng J.X., Zhang W.P. [2018]: Separation of scheelite and calcite using calcium lignosuiphonate as depressant. Separation and Purification Technology, 199: 346-350. DOI: 10.1016/j.seppur.2018.02.009.

Çamlıbel O., Ayata Ü. [2023a]: The effects of calcium lignosulfonate chemical on some physical properties of high-density fiberboards, Academy Global far East Asia 2nd International Conference on Applied Sciences, October 20-22, 2023 Manila.

Çamlıbel O., Ayata Ü. [2023b]: Investigation of some mechanical properties in high-density fiberboards produced using different ratios of calcium lignosulfonate chemical, Avrasya 9th International Conference on Applied Sciences, 26th International Group Exhibition, November 24-26, 2023, Tbilisi, 258-265.

Gonçalves S., Paiva N.T., Martins J., Carvalho L.H., Magalhães F.D. [2024]: Fast-curing 3-layer particleboards with lignosulfonate and pMDI adhesives. Forests, 15(6): 948. DOI: 10.3390/f15060948.

Hammond J.J., Donnelly E.T., Harrod W.F., Rayner N.A., Özden F. [1969]: Ağaç işleri teknolojisi, Mesleki and Teknik Öğretim Kitapları, Editör: İrfan Zorlu, Ajans Türk Matbaacılık Sanayi, 554 pages.

Hu J., Guo M. [2015]: Influence of ammonium lignosulfonate on the mechanical and dimensional properties of wood fiber biocomposites reinforced with polylactic acid. Industrial Crops and Products 78: 48-57. DOI: 10.1016/j.indcrop.2015.09.075.

Irle M., Barbu M.C. [2010]: "Wood-based panel technology," in: Wood-based Panels – An Introduction for Specialists, H. Thoemen, M. Irle, and M. Sernek (eds.) Brunel University Press, London, pp. 1-94.

Mamiński M.Ł., Trzepałka A., Auriga R., H'Ng P.S., Chin K.L. [2020]: Physical and mechanical properties of thin high density fiberboard bonded with 1,3-dimethylol-4,5-dihydroxyethyleneurea (DMDHEU). The Journal of Adhesion, 96(7): 679-690. DOI: 10.1080/00218464.2018.1500280.

Pang Y.X., Qiu X.Q., Yang D.J., Liu L.H. [2004]: Research on complexation property of calcium lignosulfonate. Chemistry and Industry of Forest Products, 24(4): 28-32.

Pereira H.M.L., Lelis R.C.C., Gomes F.J.B., Lopez Y.M., Gonçalves F.G., Chaves I.L.S., Brito A.S. [2024]: Effect of tannin and calcium lignosulfonate-based adhesives on particleboards production. International Journal of Adhesion and Adhesives, 132: 103722. DOI: /10.1016/j.ijadhadh.2024.103722.

Salazar Valencia P.J., Bolívar Marinez L.E., Pérez Merchancano S.T. [2015]: Molecular modeling of ammonium, calcium, sulfur, and sodium lignosulphonates in acid and basic aqueous environments. Brazilian Journal of Physics, 45: 567-574. DOI: 10.1007/s13538-015-0364-5.

Savov V., Mihajlova J. [2017a]: Influence of the content of lignosulfonate on mechanical properties of medium density fiberboard. Pro Ligno 13(4): 252-256.

Savov V., Mihajlova J. [2017b]: Influence of the content of lignosulfonate on physical properties of medium density fiberboard. Pro Ligno 13(4): 247-251.

Tan Z., Yang Z., Ni X., Chen H., Wen R. [2012]: Effects of calcium lignosulfonate on the performance of zinc–nickel battery. Electrochimica Acta, 85: 554-559. DOI: 10.1016/j.electacta.2012.08.111.

Windschitl P.M., Stern M.D. [1988]: Evaluation of calcium lignosulfonate-treated soybean meal as a source of rumen protected protein for dairy cattle. Journal of Dairy Science, 71(12): 3310-3322.

List of standards

TS 642 ISO 554:1997 Standard atmospheres for conditioning and/or testing; specifications. Turkish Standards Institution, Ankara, Turkey.

TS EN 310:1999 Wood- Based panels- determination of modulus of elasticity in bending and of bending strength, Turkish Standards Institution, Ankara, Turkey.

TS EN 311:2005 Wood-based panels - Surface soundness - Test method, Turkish Standards Institution, Ankara, Turkey.

TS EN 317:1999 Particleboards and fibreboards – Determination of swelling in thickness after immersion in water, Turkish Standards Institution, Ankara, Turkey.

TS EN 319:1999 Particleboards and fibreboards- Determination of tensile strength perpendicular to the plane of the board, Turkish Standards Institution, Ankara, Turkey.

TS EN 323:1999 Wood - based panels - determination of density, Turkish Standards Institution, Ankara, Turkey.