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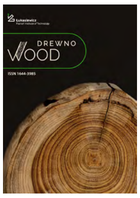

Effects of Formaldehyde Scavenger on Mechanical, Physical, and Emission Test Results in Multi-Layer Pressed Chipboard Production

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This study investigates the effects of different formaldehyde scavenger (FS) ratios on the physical, mechanical, and chemical properties of fiberboard composites. Experimental analyses included measurements of thickness, density, modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB), shear strength (SS), moisture content, thickness swelling (TS), water absorption (WA), and formaldehyde emission (FE) levels. The results indicate that an increase in the FS ratio leads to a significant decline in mechanical properties. Specifically, MOR, MOE, and IB values decreased by 17.97%, 15.65%, and 16.33%, respectively. Changes in TS and WA were also observed, with TS increasing by up to 22.68% and WA decreasing by as much as 16.90%. In terms of formaldehyde emissions, a significant reduction was observed as the FS ratio increased. At a 15% FS ratio, formaldehyde emissions decreased by 43.24%, which is considered a positive outcome in terms of environmental and health impacts. Overall, the use of FS in specific ratios reduces FE while causing certain reductions in mechanical properties. These findings highlight the importance of optimizing FS usage for the production of low-FE fiberboards.

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Introduction

Particleboards (PB) are manufactured by bonding and shaping chips of dried wood or other lignocellulosic plant materials using synthetic resin adhesives, typically under heat and pressure. These boards primarily come in two forms: flat PB and oriented strand boards [Şanıvar and Zorlu 1980].

Common adhesives used in the production of various wood-based panels include urea-formaldehyde (UF) resin and melamine-formaldehyde resin [Nakano et al. 2018]. UF resin is synthesized through a chemical reaction involving coal, water, and air, where urea and formaldehyde undergo polycondensation to form synthetic resin [Şanıvar and Zorlu 1980]. UF adhesives represent the most significant and widely used category of amino resin adhesives. These resins are polymeric condensation products formed through the reaction of aldehydes with compounds containing amine or amide groups, with formaldehyde being the primary

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aldehyde utilized. Key advantages of UF adhesives include: (a) their initial water solubility, which makes them highly suitable for large-scale and cost-effective production, (b) high hardness, (c) flame resistance, (d) excellent thermal properties, (e) colorlessness in cured polymers, and (f) adaptability to various curing conditions [Dinwoodie 1983; Pizzi 1983; Pizzi and Mittal 2003].

Despite all of their favorable properties, the main disadvantages of UF adhesives are formaldehyde emissions (FE) from UF-bonded fiberboard composites and poor durability, especially under the influence of moisture or water at high temperatures. Similarly, the hydrolytic sensitivity of the bond between the carbon of the methylene bridge and the nitrogen of the urea leads to a loss of bond strength during the production of panels and throughout their service life [Baharoğlu et al. 2012; Zhang et al. 2014; Silva et al. 2015; Selakjani et al. 2021; Dorieh et al. 2022].

For more than fifty years, UF resin has been a key adhesive in the wood-based panel industry. Its widespread use is mainly due to its strong bonding ability, reliable stability, cost-effectiveness, and rapid curing time [Roffael 1993; Tohmura et al. 2000; Hassannejad et al. 2020]. The primary effects of formaldehyde exposure in humans are physical symptoms caused by irritation of the mucous membranes in the eyes and upper respiratory tract, along with skin sensitivity. In non-industrial indoor environments, sensory reactions are the most frequently observed effects. Most individuals encounter low levels of formaldehyde in the air, with sensory responses such as odor perception and irritation being the most common. Additionally, symptoms of increased reactivity in the lower respiratory tract may also develop [World Health Organization 1989]. The FE potential from UF-bonded PBs is affected by multiple factors, including the resin's composition (formaldehyde-to-urea molar ratio) and degree of condensation, pressing conditions (duration and temperature), the type of wood used, the moisture content of adhesive-coated wood particles before pressing, the type and amount of hardener, the use of additives such as FS, and the post-production conditioning process [Que et al. 2007].

To meet the lower formaldehyde limits mandated by new and stricter environmental regulations, existing adhesive systems for wood-based panels can be modified, often by incorporating FS, which are commonly referred to as formaldehyde cleansers [Mantanis et al. 2018; Hemmilä et al. 2019; Antov et al. 2020]. FS can be categorized into three primary types: bio-based (natural) scavengers, synthetic scavengers, and nano-scavengers [Kristak et al. 2023]. Common approaches to reducing formaldehyde emissions in engineered wood panels include the use of low-emission or bio-based adhesives, along with the application of FS additives, which help decrease the free formaldehyde content in the adhesive [Antov et al. 2020]. Numerous consumer products that contain formaldehyde-based resins release formaldehyde into indoor air, leading to a range of health issues such as headaches, dizziness, and nausea. These symptoms are commonly referred to as Sick Building Syndrome (SBS) or Sick House Syndrome [Hojo et al. 2020].

The adhesive's drying, hardening, and strength development occur due to a chemical reaction that can be initiated by adding a hardening agent or applying heat. Once fully cured, the adhesive film remains solid in melting liquids, does not soften under heat, and is resistant to water and moisture [Gurtekin and Oguz 2006].

PB and medium-density fiberboard (MDF) production significantly contributes to the global consumption of UF resins, with UF's effectiveness attributed to its high reactivity, excellent wood adhesion, and cost-effectiveness [Dunky 1998; Costa et al. 2013].

Research has been conducted on the use of various additives to mitigate FE in wood-based panels. In a study by Lum et al. [2014], mechanical, physical, and formaldehyde emission tests were conducted on PB panels incorporating different proportions of an FS. The results demonstrated that higher concentrations of the scavenger reduced FE with minimal impact on mechanical properties and TS. Myers [1984] conducted a study that critically reviewed the literature on the impact of the formaldehyde/urea molar ratio (F/U) on FE from PB and plywood bonded with UF adhesives, as well as its effect on other properties of the adhesive and the panels. Lee and Kim [2013] examined how incorporating scavengers like MDF flour, silica powder, rice husk flour, and tannin powder into UF resins influenced curing behavior, the activation energy of the curing process, crosslinking, crystal structure, and free formaldehyde content. Their findings indicated that the addition of scavengers led to a reduction in unreacted free formaldehyde content. Costa et al. [2013] compared the physical and mechanical properties of PB produced using ammonium bisulfite, sodium metabisulfite, and urea in different forms, assessing their formaldehyde emission levels. Ghani et al. [2018] introduced varying amounts of an amine-type FS (0.5%, 0.7%, and 1%) into PBs made from rubberwood particles, followed by tests for TS, water absorption (WA), formaldehyde emissions, modulus of rupture (MOR), internal bond strength (IB), and modulus of elasticity (MOE). Neimsuwan et al. [2017] investigated the effect of adding tannin to PBs and its impact on formaldehyde levels, finding that a 1.2% concentration of tannin led to a 21.35% reduction in formaldehyde content. Kord et al. [2018] examined FE and conducted various performance tests

(WA, TS, MOR, IB, and MOE) on PBs manufactured with additives such as alizarin red sulfonate, alizarin yellow-GG, and chromotropic acid, each at concentrations of 1%, 3%, 5%, and 7%. The study found that PBs with 7% alizarin red sulfonate had significantly lower FE (0.38 mg/l), similar reductions being observed for those with chromotropic acid (0.43 mg/l) and alizarin yellow-GG (0.49 mg/l). In a study by Eom et al. [2006], the effects of addition of volcanic pozzolan on the physicomechanical properties and characteristics of MDF were investigated, focusing on the reduction of formaldehyde and total volatile organic compound (VOC) emissions in furniture materials. Pozzolan was added to UF resin as a cleaner during MDF production. The study examined properties such as WA, TS, MOR, MOE, IB, and formaldehyde emissions. Costa et al. [2014] investigated the performance of scavengers in reducing VOC emissions from wood-based composites. PBs made from maritime pine and poplar were produced using a melamine-modified UF resin and two scavengers, sodium metabisulfite and urea. The particleboards made from pine exhibited significantly higher total VOC emissions than those made from poplar.

FS, also known as formaldehyde capturers, are chemicals added to adhesive mixtures to diminish the release of formaldehyde from finished wood panels; they are extensively used in the European PB and MDF industries [Mantanis et al. 2018].

This study aimed to investigate how varying concentrations of an FS composed of urea and ammonium compounds influence specific mechanical and physical properties of PB panels, along with their FEs. The research goal was to obtain valuable insights that could lead to improvements in the FS and PB industries.

Materials and methods

A composite material was created using 50% Scots pine (*Pinus sylvestris* L.), 20% oak (*Quercus robur* L.), 20% white poplar (*Populus alba* L.), and 10% planer shavings (waste from white poplar planing), sourced from the Western Black Sea region of Turkey.

The adhesive was produced at the Kastamonu adhesive production facility, and had the following properties: a solid content of 62±1%, an upper-lower surface outer layer chips (SL) urea-formaldehyde ratio of 1.35, and a middle layer chips (CL) UF ratio also of 1.35. Other specifications included a density of 1.228 g/cm^3 at 20 °C, a viscosity of 20–38 seconds at 25 °C, a gel time of 35–60 seconds at 100 °C (with a 20% ammonium chloride (NH_4Cl) solution), a pH of 7–8.5, a free formaldehyde content of $\leq$ 0.20%, a methylol groups content of 12–15%, and a shelf life of 80 days.

The hardener used for curing the urea formaldehyde adhesive was ammonium chloride (NH_4Cl), sourced from a specialized company in Gebze, Turkey. This catalyst was prepared as a 20% solution with a density of 0.95 g/cm^3 and a pH of 6.5.

Paraffin, an off-white liquid obtained from a facility in Denizli, Turkey, had a solid content of 60%, a pH of 9–10, a viscosity of 14–24 seconds, and a density of 0.96 g/cm^3.

The specific formula of the scavenger chemical, which includes components such as amine groups and urea, remains confidential. This FS is produced through the expertise of a specialized company (Kastamonu Entegre, Turkey).

The wood materials were processed into coarse chips using a chipping machine and transported via a belt conveyor system to different silos designated for the outer and middle layers. Large-sized chips were produced in Pallman-type mills, with sizes designated as SL (0.12–0.26 mm) for the upper-lower layers and CL (0.30–0.47 mm) for the middle layer. The chips were then dried in rotary drum dryers to achieve a moisture content of 1.4–2.2%.

Following drying, the chips were classified using a three-stage mechanical shaking sieve. The adhesive for the CL layer contained a solid content of 62%, with the following chemical composition: 8% UF, 2.2% hardener, varying percentages of catcher (0%, 0.93%, 1.86%, and 2.73%), and 0.30% paraffin. After chemical treatment, the moisture content was adjusted to 5.3% for the CL. For the SL layer, the adhesive UF had a solid content of 50%, with 13% urea-formaldehyde, 2.8% hardener, varying percentages of catcher (0%, 0.93%, 1.86%, and 2.73%), and 0.30% paraffin. After chemical treatment, the moisture content was adjusted to 14.5% for the SL outer layer chips.

The glued chips were then formed into chipboard using a spreading station, mixing the CL and SL layers in a ratio of 67% to 33%. The prepared chipboard was subjected to a 7-layer hot press with a pressing time of 200 seconds, a temperature of 200 °C, and a pressure of 32 kp/cm^2, resulting in boards with the dimensions 18 x 1830 x 3660 mm. After pressing, the boards were cooled to room temperature (25 °C) in a star cooler and subsequently trimmed. The finished products were stored in a temporary area for 5 days before sanding with 40-60-80-100 grit sandpaper.

Test boards were conditioned in a controlled environment with no airflow and a smooth floor, adhering to the TS 642-ISO 554 [1997] standard, at 20±2 °C and 65±5% relative humidity (RH) until they reached 12% moisture content. The study involved conducting physical, mechanical, and FE tests on the boards.

Testing was performed according to several standards, including TS 642 ISO 554 [1997] for standard atmospheric conditions, TS EN 309 [1999] for PB classification, TS EN 317 [1999] for measuring thickness swelling after water immersion, TS EN 310 [1999] for evaluating bending strength and elasticity, TS EN 311 [1999] for surface soundness, TS EN 319 [1999] for tensile strength perpendicular to the board plane, TS EN 323 [1999] for density assessment, and TS 4894 EN 120 [1999] for formaldehyde content measurement in wood-based panels. Additional standards included TS EN 312-1 [1999], TS EN 312-2 [1999], TS EN 312-3 [1999], and TS EN 325 [1999] for general PB characteristics. Measurements were taken with a digital micrometer with a precision of 0.01 mm, and testing was conducted using the Imal IB700 laboratory testing machine.

Data analysis was performed using statistical software, enabling the determination of various parameters, including the identification of homogeneity groups and the calculation of means and maximum and minimum values. The analysis also included assessment of standard deviations to evaluate data dispersion, the use of multivariate analysis of variance to examine relationships between multiple variables, and the calculation of percentage change rates.

Results and discussion

Table 1 presents the findings from the multivariate analysis of variance. The results indicate that the thickness test did not show a significant effect with respect to the catcher addition rate. However, all other tests were identified as statistically significant.

The results of mechanical, physical, and emission tests for chipboards produced with varying ratios of FS additive are summarized in Table 2. The thickness measurements (in mm) remained consistent across all panels, indicating that the addition of FS at different ratios resulted in a uniform distribution of panel thicknesses during production. Despite the variations in chemical proportions, the uniform thickness results suggest that the FS did not affect the thickness, which is viewed positively.

In the case of density, the highest value (636.10 kg/m^3) was recorded for panels with a 10% addition of FS, and the lowest (631.60 kg/m^3) for panels with a 5% addition. The use of 5% catcher resulted in a density decrease of 0.08%, while 10% and 15% additions led to increases of 0.63% and 0.47%, respectively (Table 2).

In the modulus of rupture (MOR) test, the control group gave the highest value of MOR (15.80 N/mm^2), and the panels with 15% FS the lowest (12.96 N/mm^2). The MOR results indicated decreases of 12.66%, 8.86% and 17.97% respectively at catcher addition rates of 5%, 10% and 15% (Table 2).

The modulus of elasticity (MOE) test gave the highest results for the control group (2847.90 N/mm^2), with the lowest observed in the panels with 15% FS (2402.18 N/mm^2). The MOE results indicated decreases of 10.04%, 7.89% and 15.65% respectively at catcher addition rates of 5%, 10% and 15% (Table 2).

The surface soundness (SS) test indicated that the lowest value (1.20 N/mm^2) occurred in samples with 5% FS, while the control group gave the highest result (1.28 N/mm^2). Although the addition of FS reduced SS values, the reduction ranged only from 2% to 6% (Table 2).

Regarding moisture content, the panels with 10% FS exhibited a decrease of 4.62%, while those with 5% and 15% additions showed increases of 1.34% and 3.87%, respectively. The highest moisture content (6.97%) was found in samples with a 15% addition, and the lowest (6.40%) in those with 10% catcher chemical (Table 2).

In the case of formaldehyde emissions, the highest values were measured for the control group (14.50), and the lowest (8.23) for samples with a 15% addition of FS. As the catcher ratio increased from 5% to 15%, the percentage drop in FE increased from 8.97% to 43.24% (Table 2).

The IB test returned the highest value in the control group (0.49 N/mm^2) and the lowest in the samples with 15% catcher (0.41 N/mm^2). An increase in the catcher proportion led to decreased IB values, with the largest reduction (16.33%) recorded in the 15% group and the smallest (8.16%) in the 5% group (Table 2).

The SS test showed that the value increased with increasing catcher content (by 7.82%, 9.14% and 22.68% respectively for contents of 5%, 10% and 15%). The control samples yielded the lowest SS result at 15.21%, while the highest (18.66%) was observed in the group with 15% catcher (Table 2).

For FS contents of 5% and 10%, WA values decreased by 16.90% and 11.14% respectively. However, a 15% content produced a 5% increase. The highest WA value was therefore recorded in the experimental group with a 15% addition of FS (see Table 2).

Lum et al. [2014] conducted a study on PBs with FS and found that higher dosages of formaldehyde scavengers led to a more significant reduction in FE. They concluded that applying the FS post-process was highly effective in reducing emissions in three-layer PBs, while minimally affecting mechanical properties and thickness swelling. In research by Puttasukkha et al. [2015], the impact of adding an FS to UF resin on its curing behavior, bonding strength, FE, and chemical properties was examined for PB production. The FS was incorporated into the UF resin at concentrations of 0%, 6%, 12%, 18%, and 24% by weight. The study concluded that the inclusion of the FS could enhance the bonding strength of the panels and significantly reduce FE. Costa et al. [2013] reported decreases in IB and FE for PBs made with ammonium bisulfite, sodium metabisulfite, and urea compared with control samples. Ghani et al. [2018] reported reductions in formaldehyde emissions, MOR, IB, and MOE in PBs with methylamine, ethylamine, and propylamine added at rates of 0.5%, 0.7%, and 1%. The literature indicates that the primary purpose of FS is to

Table 1. The results of the multivariate analysis of variance (*: Significant)

Source	Dependent Variable	Sum of Squares	Degree of Freedom	Mean Square	F Value	Sig.
FS Rate	Thickness	0.000	3	0.000	0.058	0.981**
	Density	146.875	3	48.958	8.044	0.000*
	MOR	43.043	3	14.348	923.825	0.000*
	MOE	1022488.763	3	340829.588	6987.092	0.000*
	IB	0.039	3	0.013	30.975	0.000*
	SS	0.029	3	0.010	12.308	0.000*
	Moisture	1.681	3	0.560	77.466	0.000*
	TS	61.424	3	20.475	1901.364	0.000*
	WA	1850.378	3	616.793	3072.080	0.000*
	Emission	239.862	3	79.954	1556.082	0.000*
Error	Thickness	0.014	36	0.000		
	Density	219.100	36	6.086		
	MOR	0.559	36	0.016		
	MOE	1756.076	36	48.780		
	IB	0.015	36	0.000		
	SS	0.028	36	0.001		
	Moisture	0.260	36	0.007		
	TS	0.388	36	0.011		
	WA	7.228	36	0.201		
	Emission	1.850	36	0.051		
Total	Thickness	12677.530	40			
	Density	16064661.000	40			
	MOR	8156.984	40			
	MOE	273267134.200	40			
	IB	7.957	40			
	SS	61.338	40			
	Moisture	1807.606	40			
	TS	11240.135	40			
	WA	218619.918	40			
	Emission	5582.433	40			
Corrected Total	Thickness	0.014	39			
	Density	365.975	39			
	MOR	43.602	39			
	MOE	1024244.839	39			
	IB	0.054	39			
	SS	0.057	39			
	Moisture	1.942	39			
	TS	61.811	39			
	WA	1857.606	39			
	Emission	241.712	39			

Table 2 The results of mechanical, physical, and emission tests for chipboards produced with and without FS additive at different ratios

Test	FS (%)	Mean	Change (%)	HG	SD	Minimum	Maximum	COV
Thickness (mm)	0	17.80	-	A	0.03	17.77	17.85	0.15
	5	17.80	-	A	0.01	17.78	17.83	0.08
	10	17.80	-	A	0.02	17.77	17.83	0.11
	15	17.80	-	A	0.02	17.78	17.82	0.09
Density (kg/m^3)	0	632.10	-	B	2.33	629.00	636.00	0.37
	5	631.60	↓0.08	B**	2.32	628.00	635.00	0.37
	10	636.10	↑0.63	A*	1.52	633.00	638.00	0.24
	15	635.10	↑0.47	A	3.35	630.00	641.00	0.53
(MOR (N/mm^2)	0	15.80	-	A*	0.03	15.76	15.85	0.19
	5	13.80	↓12.66	C	0.02	13.77	13.84	0.15
	10	14.40	↓8.86	B	0.01	14.38	14.42	0.10
	15	12.96	↓17.97	D**	0.25	12.38	13.21	1.90
MOE (N/mm^2)	0	2847.90	-	A*	2.13	2845.00	2851.00	0.07
	5	2562.10	↓10.04	C	1.73	2560.00	2564.00	0.07
	10	2623.20	↓7.89	B	3.19	2620.00	2628.00	0.12
	15	2402.18	↓15.65	D**	13.32	2374.60	2414.60	0.55
IB (N/mm^2)	0	0.49	-	A*	0.02	0.47	0.52	3.15
	5	0.45	↓8.16	B	0.01	0.42	0.47	3.34
	10	0.43	↓12.24	B	0.02	0.40	0.47	5.34
	15	0.41	↓16.33	C**	0.03	0.37	0.44	6.38
SS (N/mm^2)	0	1.28	-	A*	0.01	1.25	1.29	1.12
	5	1.20	↓6.25	C**	0.02	1.18	1.23	1.42
	10	1.22	↓4.69	C	0.02	1.19	1.25	1.59
	15	1.25	↓2.34	B	0.05	1.16	1.29	3.78
Moisture (%)	0	6.71	-	C	0.17	6.40	6.90	2.48
	5	6.80	↑1.34	B	0.02	6.77	6.82	0.25
	10	6.40	↓4.62	D**	0.02	6.38	6.43	0.28
	15	6.97	↑3.87	A*	0.03	6.92	6.99	0.37
TS (%)	0	15.21	-	D**	0.03	15.18	15.27	0.18
	5	16.40	↑7.82	C	0.02	16.37	16.44	0.14
	10	16.60	↑9.14	B	0.05	16.49	16.65	0.30
	15	18.66	↑22.68	A*	0.20	18.49	18.97	1.06
WA (%)	0	78.10	-	B	0.06	78.02	78.20	0.08
	5	64.90	↓16.90	D**	0.04	64.85	64.95	0.06
	10	69.40	↓11.14	C	0.01	69.38	69.42	0.02
	15	82.06	↑5.07	A*	0.89	81.12	84.19	1.09
Formaldehyde emission	0	14.50	-	A*	0.03	14.44	14.54	0.24
	5	13.20	↓8.97	B	0.03	13.16	13.24	0.21
	10	10.30	↓28.97	C	0.02	10.28	10.33	0.17
	15	8.23	↓43.24	D**	0.45	7.90	8.90	5.48

SD: Standard Deviation, *HG*: Homogeneity Group, COV: Coefficient of Variation,
Number of Measurements: 10, *: Highest Result, **: Lowest Result

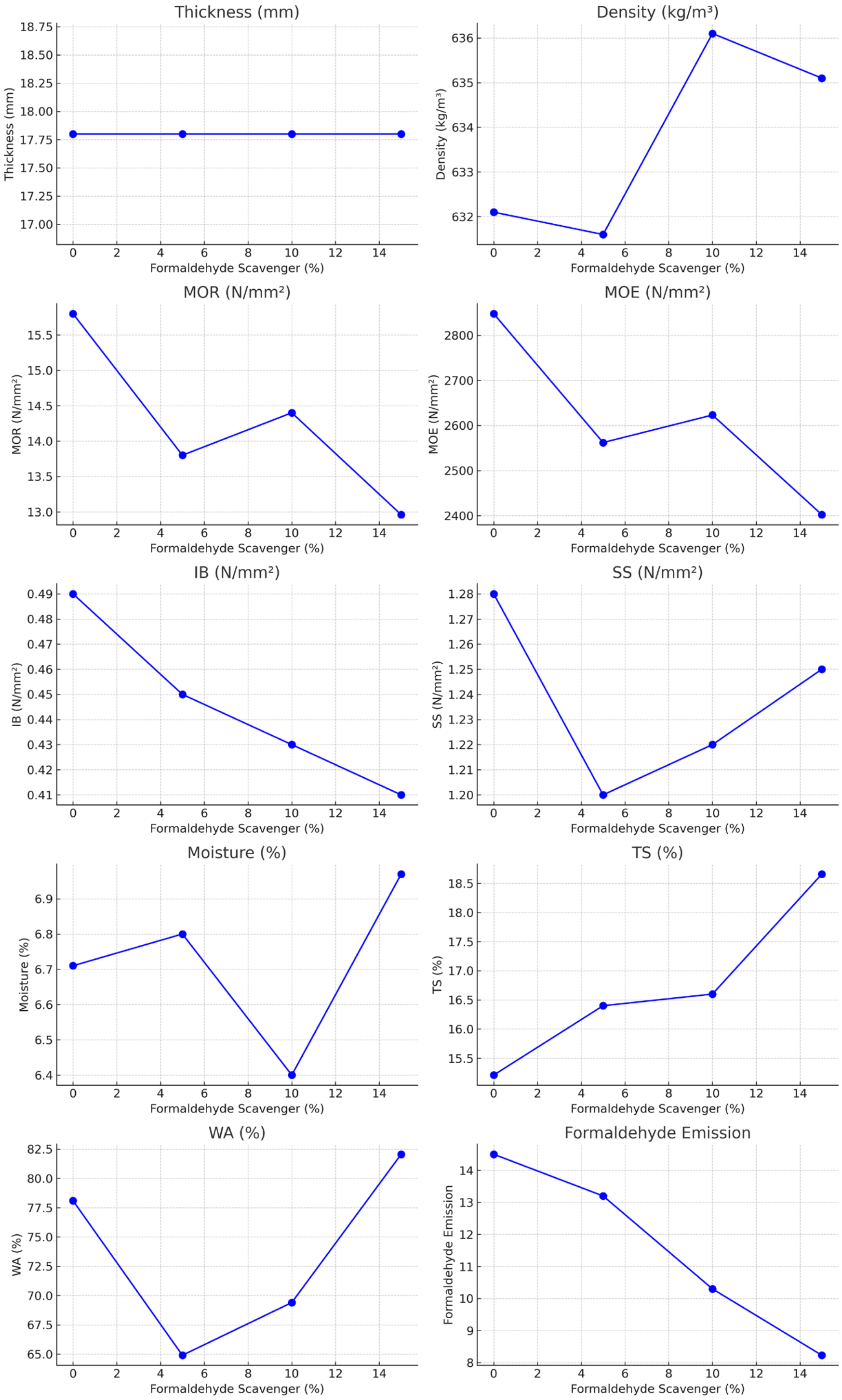

Fig. 1. Graphical representation of the results obtained from the tests

lower FE from wood-based panels, and the results of this study align with previous findings, demonstrating similar reductions in emission values. In a study by Park et al. [2018], the impact of two FS on the thermal curing behavior of modified UF resins and the bonding performance of PB bonded with these resins was explored. It was observed that the FE from particleboards bonded with the modified UF resin decreased as the scavenger concentration increased. UFP proved to be more effective than US in reducing FE and ensuring better adhesion to the UF resin. The findings indicated that the ideal concentration of UFP in UF resin to achieve a balance between FE and PB adhesion was 20%, and that both the thermal curing behavior of scavenger-modified UF resins and the characteristics of the bonded PBs should be taken into account when evaluating an FS system.

A graphical representation of the results obtained from the tests is shown in Figure 1.

Conclusions

The analysis has shown that the FS additives have significant effects on the mechanical and physical properties of wood materials. As the additive concentration increased, there was a reduction in values of density (which ranged from approximately 632 to 636 kg/m^3), MOR (12.96–15.80 N/mm^2), MOE (2402.18–2847.90 N/mm^2), and IB (0.41–0.49 N/mm^2). This indicates a decline in the hardness and durability characteristics of the wood material. Furthermore, an increase in WA and TS rates was observed. The water absorption rate increased from 64.90% to 82.06%, while the swelling rate increased from 15.21% to 18.66%. This suggests that FS additives may increase the wood material's sensitivity to water. Formaldehyde emission, on the other hand, decreased as the additive concentration increased: from an initial 14.50 mg/kg, it dropped to 13.20, 10.30 and 8.23 mg/kg respectively with additive concentrations of 5%, 10% and 15%. This indicates that the FS additives are effective in reducing the FE of the wood material. In conclusion, while FS additives may negatively impact the water absorption, swelling, and mechanical properties of wood material, they are effective in reducing FE. These findings suggest that FS additives can be used to mitigate environmental impacts, but a careful balance should be maintained in their application.

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References

Antov P., Savov V., Neykov N. [2020]: Reduction of formaldehyde emission from engineered wood panels by formaldehyde scavengers—A review. In Proceedings of the 13th International Scientific Conference Wood EMA 2020 and 31st International Scientific Conference ICWST (pp. 7-11).

Baharoğlu M., Nemli G., Sarı B., Bardak S., Ayrılmış N. [2012]: The influence of moisture content of raw material on the physical and mechanical properties, surface roughness, wettability, and formaldehyde emission of particleboard composite. Composites Part B: Engineering, 43(5), 2448-2451. DOI: 10.1016/j.compositesb.2011.10.020.

Costa N.A., Ohlmeyer M., Ferra J., Magalhães F.D., Mendes A., Carvalho L. [2014]: The influence of scavengers on VOC emissions in particleboards made from pine and poplar. European Journal of Wood and Wood Products, 72, 117-121. DOI: 10.1007/s00107-013-0761-9.

Costa N.A., Pereira J., Ferra J., Cruz P., Martins J., Magalhães F.D., Mendes A., Carvalho L.H. [2013]: Scavengers for achieving zero formaldehyde emission of wood-based panels. Wood Science and Technology 47: 1261-1272. DOI: 10.1007/s00226-013-0573-4.

Dinwoodie J. M. [1983]: Wood adhesives chemistry and technology (A. Pizzi, Ed., Vol. 1, pp. 1-58). Marcel Dekker.

Dorieh A., Selakjani P.P., Shahavi M.H., Pizzi A., Movahed S.G., Pour M.F., Aghaei R. [2022]: Recent developments in the performance of micro/nanoparticle-modified urea-formaldehyde resins used as wood-based composite binders: A review. International Journal of Adhesion and Adhesives, 114, 103106. DOI: 10.1016/j.ijadhadh.2022.103106.

Eom Y.G., Kim J.S., Kim S., Kim J.A., Kim H.J. [2006]: Reduction of formaldehyde emission from particleboards by bio-scavengers. Journal of the Korean Wood Science and Technology 34(5): 29-41.

Ghani A., Ashaari Z., Bawon P., Lee S.H. [2018]: Reducing formaldehyde emission of urea formaldehyde-bonded particleboard by addition of amines as formaldehyde scavenger. Building and Environment 142: 188-194. DOI: 10.1016/j.buildenv.2018.06.020.

Gurtekin A., Oguz M. [2006]: Mobilya ve dekorasyon gereç bilgisi, mesleki ve teknik öğretim okulları, Milsan Basın San A.Ş., Istanbul, Turkey.

Hassannejad H., Shalbafan A., Rahmaninia M. [2020]: Reduction of formaldehyde emission from medium density fiberboard by chitosan as scavenger. The Journal of Adhesion. DOI: 10.1080/00218464.2018.1515631.

Hemmilä V., Adamopoulos S., Karlsson O., Kumar A. [2017]: Development of sustainable bio-adhesives for engineered wood panels—A review. RSC Advances 7, 38604-38630.

Hojo H., Fukai K., Nanjo F. [2000]: Application of green tea catechins as formaldehyde scavengers. Journal of the Japan Wood Research Society, 46(3), 231-37.

Kord B., Movahedi F., Adlnasab L., Ayrilmis N. [2022]: Effect of novel scavengers based on phenolic compounds on formaldehyde emission and physical-mechanical properties of particleboard. Wood Material Science & Engineering, 17(6): 954-964. DOI: 10.1080/17480272.2021.1978542.

Kristak L., Antov P., Bekhta P., Lubis M. A. R., Iswanto A.H., Reh R., Sedliacik J., Savov V., Taghiyari H.R.,

Papadopoulos A.N., Pizzi A., Hejna A. [2023]: Recent progress in ultra-low formaldehyde emitting adhesive systems and formaldehyde scavengers in wood-based panels: A review. Wood Material Science & Engineering, 18(2), 763-782. DOI: 10.1080/17480272.2022.2056080.

Lee Y.K., Kim H.J. [2013]: Relationship between curing activation energy and free formaldehyde content in urea-formaldehyde resins. Journal of Adhesion Science and Technology, 27(5-6), 598-609. DOI: 10.1080/01694243.2012.690620.

Lum W.C., Lee S.H., H'ng P.S. [2014]: Effects of formaldehyde catcher on some properties of particleboard with different ratio of surface to core layer. Asian Journal of Applied Sciences 7(1): 22-29. DOI: 10.3923/ajaps.2014.22.29.

Mantanis G.I., Athanassiadou E.T., Barbu M.C., Wijnendaele K. [2018]: Adhesive systems used in the European particleboard, MDF and OSB industries. Wood Material Science & Engineering, 13(2): 104-116. DOI: 10.1080/17480272.2017.1396622.

Mantanis G.I., Athanassiadou E.T., Barbu M.C., Wijnendaele K. [2018]: Adhesive systems used in the European particleboard, MDF and OSB industries. Wood Material Science and Engineering 13(2), 104-116. DOI: 10.1080/17480272.2017.1396622.

Myers G.E. [1984]: How mole ratio of UF resin affects formaldehyde emission and other properties: a literature critique. Forest Products Journal, 34(5), 35-41.

Nakano K., Ando K., Takigawa M., Hattori N. [2018]: Life cycle assessment of wood-based boards produced in Japan and impact of formaldehyde emissions during the use stage. The International Journal of Life Cycle Assessment 23: 957-969. DOI: 10.1007/s11367-017-1343-6.

Neimsuwan T., Siramon P., Hengniran P., Punsuvon V. [2017]: Effect of tannin addition as a bio-scavenger on formaldehyde content in particleboard. Journal of Tropical Forest Research 1(2): 45-56.

Park B.D., Kang E.C., Park J.Y. [2008]: Thermal curing behavior of modified urea-formaldehyde resin adhesives with two formaldehyde scavengers and their influence on adhesion performance. Journal of Applied Polymer Science, 110(3), 1573-1580. DOI: 10.1002/app.28748.

Pizzi A. [1983]: Wood adhesives chemistry and technology (A. Pizzi, Ed., Vol. 1, pp. 59-104). Marcel Dekker.

Pizzi A., Mittal K.L. [2003]: Urea-formaldehyde adhesives. In Handbook of adhesive technology (2nd ed.). Marcel Dekker.

Puttasukkha J., Khongtong S., Chaowana P. [2015]: Curing behavior and bonding performance of urea formaldehyde resin admixed with formaldehyde scavenger. Wood Research, 60(4), 645-654.

Que Z., Furuno T., Katoh S., Nishino Y. [2007]: Evaluation of three test methods in determination of formaldehyde emission from particleboard bonded with different mole ratio in the urea-formaldehyde resin. Building and Environment, 42(3), 1242-1249. DOI: 10.1016/j.buildenv.2005.11.026.

Roffael E. [1993]: Formaldehyde release from particleboard and other wood based panels (pp. ix+-281). ISBN. 978-983-9592-15-3.

Sanivar N., Zorlu I. [1980]: Ağaçişleri Gereç Bilgisi Temel Ders Kitabı, Mesleki ve Teknik Eğitim Öğretim Kitapları [Woodworking Materials Knowledge Basic Textbook, Vocational and Technical Education Teaching Books], Milli Eğitim Basımevi, İstanbul, Turkey.

Selakjani P.P., Dorieh A., Pizzi A., Shahavi M.H., Hasankhah A., Shekarsaraee S., Ashouri M., Movahed S.G., Abatari M.N. [2021]: Reducing free formaldehyde emission, improvement of thickness swelling and increasing storage stability of novel medium density fiberboard by urea-formaldehyde adhesive modified by phenol derivatives. International Journal of Adhesion and Adhesives, 111, 102962.

Silva D.A.L., Lahr F.A.R., Varanda L.D., Christoforo A.L., Ometto A.R. [2015]: Environmental performance assessment of the melamine-urea-formaldehyde (MUF) resin manufacture: A case study in Brazil. Journal of Cleaner Production, 96, 299-307. DOI: 10.1016/j.jclepro.2014.03.007.

Tohmura S.I., Hse C.Y., Higuchi M. [2000]: Formaldehyde emission and high-temperature stability of cured urea-formaldehyde resins. Journal of Wood Science, 46, 303-309.

World Health Organization, [1989]: Formaldehyde/published under the joint sponsorship of the United Nations Environment Programme, the International Labour Organisation, and the World Health Organization.

Zhang J., Kang H., Gao Q., Li J., Pizzi A., Delmotte L. [2014]: Performances of larch (*Larix gmelini*) tannin modified urea–formaldehyde (TUF) resin and plywood bonded by TUF resin. Journal of Applied Polymer Science, 131(22). DOI: 10.1002/app.41064.

List of standards

TS 4894 EN 120:1999 Wood based panels – Determination of formaldehyde content – Extraction method called the perforator method, Turkish Standards Institution, Ankara, Turkey.

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

TS EN 309:1999 Particleboards – Definition and classification, 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 311:1999 Wood-based panels – Surface soundness – Test method, Turkish Standards Institution, Ankara, Turkey.

TS EN 312-1:1999 Particle boards – Specification – Part 1: General requirements for all board types, Turkish Standards Institution, Ankara, Turkey.

TS EN 312-2:1999 Particleboards – Specifications – Part 2: Requirements for general purpose boards for use in dry conditions, Turkish Standards Institution, Ankara, Turkey.

TS EN 312-3:1999 Particleboards – Specifications – Part 3: Requirements for boards for interior fitments (including furniture) for use in dry conditions, 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.

TS EN 325:1999 Wood-based panels – Determination of dimensions of test pieces, Turkish Standards Institution, Ankara, Turkey.