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Influences of UF Adhesive Consumption on HDF Properties

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In this study, high-density fiberboards were produced using urea-formaldehyde resin (0.98 mole) at five different consumption rates (12.47%, 11.55%, 11.12%, 10.65%, and 10.1% by weight of dry fiber), and the physical and mechanical properties and formaldehyde contents of the boards were determined. Boards were produced using a continuous through-feed press in a working factory rather than laboratory-type press equipment. For almost all properties, no linear and stable increase or decrease was observed with an increase in adhesive consumption. On the contrary, the values of properties oscillated with the increase in adhesive consumption. Except in the case of surface soundness (SS), the mean values of the physical and mechanical properties presented significant differences. The property that was most improved was SS, which improved by 25.4% when UF consumption was 105 kg/m^3. Among the physical properties, the greatest improvement was in surface abrasion, with a 15.7% improvement for the same consumption rate. For thickness swelling (TS 2 h and 24 h) and water absorption, a consumption rate of 115 kg/m^3 provided the greatest improvement (decreases of 15.3%, 6.8% and 8.7% respectively). Therefore, considering all of the evaluated properties, a common consumption rate leading to the greatest improvement could not be determined. One of the most important properties of the panels was the formaldehyde emission (FE) value. FE decreased by around 17.6% when UF consumption was 115 kg/m^3. However, the FE values were determined to be above the value for class E1, and should be reduced for marketed goods.

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Introduction

Engineering processes not only provide advances in utilization and diversity in types of wood or wood-based materials, but also extend the lifetime of semi-finished or finished products due to improved physical and mechanical properties. Wood-based composites are versatile materials that have a variety of structural and interior design applications. Particleboards and fiberboards are usually finished with veneer, paint, etc. and are used for furniture production or decoration purposes, due to their outstanding properties such as elasticity, strength, and cost-effectiveness (Açık & Tutuş, 2012). Furthermore, particleboard and medium-density fiberboard (MDF) have become fundamental materials for the furniture industry in Europe (Mantanis et al., 2004). However, global resources are dramatically decreasing with the enormous increase in demand due to increased population and consumption. Wood is a renewable and sustainable construction, building, and decorative material, but a balance between harvesting and growing of trees should be achieved by means of

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natural or sylvicultural practices to prevent shortages. In recent years, growing demand for forestry resources for various uses has led to shortages of wood resources (Lee et al., 2011). The traditional approach for producing medium- and high-density fiberboard (MDF and HDF) uses soft- and hardwoods or mixtures of various wood species. However, anticipated wood shortages, forestry rules, and the expected lower cost of non-wood materials have motivated board producers to seek different sources for lignocellulose fibers (Jaber et al., 2016).

Regarding fiberboard, researchers have generally focused on the influence of the fiber mixture (raw or recovered, soft- and/or hardwood species, etc.) on physical and mechanical properties of HDF (Hunt et al., 2008; Kara et al., 2016; Mihajlova & Savov, 2018; Oh, 2010; Sala et al., 2020). Furthermore, physical and mechanical properties of sandwich panels (Labans et al., 2019; Rozins & Iejavs, 2014) or composite products such as parquet (Açık & Tutuş, 2012; Güler et al., 2007) and laminates (Açık & Tutuş, 2012) which contain HDF have been evaluated, as well as mineral utilization (Özdemir, 2016; Özdemir et al., 2016, 2018), combustion properties (Lee et al., 2011; Özdemir et al., 2013), and the influence of dry heat (Döngel et al., 2008) on HDF or HDF-based products. The effects of density (Hernán Poblete & Roque Vargas, 2006), adhesive type (Mamiński et al., 2020), press temperature and pressure (İstek, 2006), lamination (Hızıroğlu, 2008), heat treatment (Korkut et al., 2015), uniform and non-uniform electric fields (Xu et al., 2015), surface coating (Çetin & Kaygın, 2016; Nemli et al., 2004), chemical treatment (Kartal et al., 2003), and formaldehyde content of UF (Antov et al., 2021) have been investigated. Furthermore, Suchsland and Woodson (1986) provided in-depth information (industry, chemicals, raw materials, manufacturing processes, heat treatment, physical and mechanical properties, etc.) concerning fiberboards such as MDF and HDF.

Türkiye has competitive production capability for MDF/HDF (Bayram et al., 2018; İstek et al., 2017) but competition requires continuous research and development efforts. Furthermore, regulations, the mechanical and physical aspects of the material, consumption, and cost-reducing measures are some of the challenging factors in the industry. Considering this, adhesive is one of the critical materials which have an influence on HDF properties. Çamlıbel (2020a, 2020b) determined that using 0.98 mole UF resin provides better performance. Few studies refer to the effect of different adhesive consumption rates on the physical, mechanical, and formaldehyde content of HDF boards. Therefore, in the present work, a case study was carried out in a real panel production line of a commercial company to evaluate the boards' performance in terms of physical and mechanical properties and formaldehyde emission.

Materials and methods

Scots pine (*Pinus sylvestres* L) and Oriental beech (*Fagus orientalis* L) woods were used as raw materials. The contributions of soft- and hardwood species were 80% and 20%, respectively. Woods were obtained from forestry departments located in the West Black Sea Region of Türkiye.

UF resin was manufactured by the Kastamonu Resin Production Plant located in Kastamonu, Türkiye, and the specifications of the adhesive are presented in Table 1.

Ammonium sulfate ($(NH4)_2SO_4$), an inorganic sulfate salt, was used as a catalytic agent for hardening the UF resin. It was obtained from a commercial company located in İstanbul, Türkiye, and was used as a 20% solution. The density and pH of the solution were 0.95 g/cm³ and 6.5, respectively.

Oyster white liquid paraffin (a lubricating and water-repelling agent) was obtained from a commercial company located in Denizli, Türkiye, and technical specifications of the paraffin are presented in Table 2.

At least five HDF boards were produced for each resin content to evaluate the effects of the adhesive consumption rate on the physical and mechanical properties and formaldehyde content of the boards. Raw wood materials were separately chipped according to species, and the chips were stored in individual silos. A mixture of chips containing 80% Scots pine and 20% Oriental beech was obtained using a silo discharge helix. The mixed chips were screened using a roller screen, and non-standard chips were extracted. The chips were cooked with an Andritz defibrillator (Andritz AG, Graz, Austria) using the following processing parameters: 8 bar steam pressure, 185 °C temperature, and 3.5 minutes (digester).

Table 1. Technical specifications of the adhesive

Solid content	Mole ratio (F:U)	Density (g/cm³ @20 °C)	Viscosity (25 °C cPs)	Gel time (100°C) (20% $(NH4)_2SO_4$)	pH	Free formaldehyde (%)	Metilol groups (%)	Shelf time (day)
58 ± 1	0.98	1.227	15-35 s	20-60 s	7-8.5	0.18 (max)	12-15	75

Table 2. Properties of the liquid paraffin

Density (g/cm³)	Solid matter (%)	pH	Viscosity (25 °C cPs)
0.96	60	9-10	13-23

Table 3. Production parameters of the boards

Production Parameters	Groups according to adhesive consumption (kg/m³ solid)				
	115	105	100	95	90
Wood mixture (%) (Scots pine + beech)	80+20				
Hardener (% wt. dry fiber)	1.30				
Adhesive (% wt. dry fiber)	12.47	11.55	11.12	10.65	10.1
UF molar ratio (F:U)	0.98				
Paraffin (% wt. dry fiber)	1.38				
Press temp. (°C)	225				
Press speed (mm/s)	970				
Press duration (s)	57				
Press pressure (kg/cm²)	32				
Dimension (mm)	7.7x2100x2440				

Before the fibrillation process, cooked chips were blended with liquid paraffin (1.35% by weight of dry fiber), and fibrillation was performed using a defibrillator unit. Hardener (1.3 wt.% according to the ratio of adhesive and dry fiber) and adhesive (12.47%, 11.55%, 11.12%, 10.65%, and 10.1% by weight of dry fiber) were added to the fibers sequentially in a Blowline unit. Blended fibers (shown in Fig. 1, left) were dried from 97% to 12% moisture content (MC) using a Büttner single flash dryer (Büttner Energie- und Trocknungstechnik GmbH, Krefeld, Germany) with a length and diameter of 180 m and 2 m, respectively. The inlet and outlet temperatures of the dryer were 240 and 60 °C, respectively. The dried fibers were screened using a fiber shifter unit. A mat forming process was performed using a Siempelkamp Starformer (G. Siempelkamp GmbH & Co. KG, Krefeld, Germany), and then mats were pre-pressed. Mats were trimmed and pressed using a continuous through-feed press (ContiRoll, Siempelkamp, G. Siempelkamp GmbH & Co. KG, Krefeld, Germany). The pressing parameters were 970 mm/s press speed, 225 °C temperature, and 57 s pressing duration. The produced HDF boards were conditioned for 5 days in the acclimatization section (20±1 °C, 65% relative humidity). Boards were sanded using a Steinemann sanding machine (Steinemann Technology AG, St. Gallen, Switzerland) with 40, 80, and 150 grit sandpapers. K-type heads were used in the first two sections, and FS- and NS-type heads in the final six sections. Tests were performed using the samples shown in Fig. 1 (right). Production parameters for the boards are presented in Table 3.

The thickness, density, MC, thickness swelling (TS), water absorption (WA), and surface absorption (SA) of the samples were determined in compliance with TS EN 324-1 (1999), TS EN 323 (1999), TS EN 322 (1999), TS EN 317 (1999), and TS EN 382-1 (1999).

The modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding (IB), and surface soundness (SS) of the samples were determined in compliance with the TS EN 310 (1999), TS EN 319 (1999), and TS EN 311 (2005) standards, respectively. An IB700 Board Property Tester (IMAL Srl, Italy) was used to determine both physical and mechanical properties in compliance with the standards.

The formaldehyde content (FC) of the boards was determined using a perforator method in accordance with the TS EN ISO 12460-5 (2016) standard, which regulates the determination of formaldehyde content of unlaminated and uncoated wood-based panels.

Analysis of variance (ANOVA) was performed to evaluate the influence of the adhesive consumption rate on the boards' physical and mechanical properties and FC. Duncan's multiple range tests were performed to obtain the differences between the mean values of the variables. Coefficients of determination (R^2) between the variables were calculated.

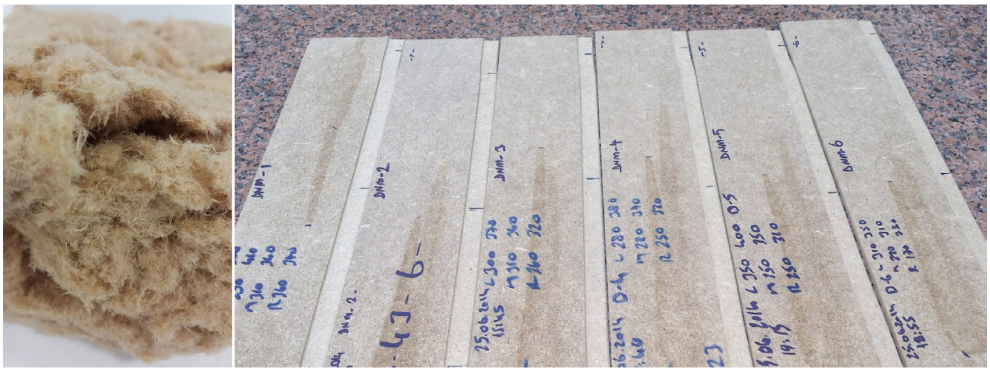

Fig. 1. Fibers (left) and HDF test samples (right)

Results and discussion

1. Physical properties

Average values for the physical properties of the HDF boards are presented in Table 4. The thicknesses of the boards were around 7.7 mm, and there were no statistically significant differences between the groups, except for the boards produced with 115 kg/m³ adhesive.

As seen in Table 4, the average densities of the boards ranged from 867 to 893 g/cm³ and increased (by 2.93%) with an increase in adhesive consumption. Generally, HDF boards have density values in a range of 800 to 1100 kg/m³ (Hong et al. 2017). The experimental values are in agreement with the values obtained by Camlibel (2020a). Çamlıbel (2020b) reported 881.2 kg/m³ density for HDF produced using 0.98-mole UF adhesive with the following production parameters: 1.35% paraffin, 58 s press duration, 215 °C press temperature, and 950 mm/s press speed. Furthermore, the upper bound of the specific gravity for MDF was reported as 0.88 by Kartal and Green (2003). As seen in the table, there are significant differences ($P < 0.05$; superscripts a–e correspond to the results of Duncan's multiple range test, with an ordering of low to high in the mean densities except for the boards produced using 90 and 100 kg/m³ adhesive.

The MC of the boards ranged from 6.3% to 6.8%, and all mean values presented statistically significant differences. Furthermore, there was no linear relation between the adhesive consumption rate and the MC of the boards. MC values decreased and then slightly exceeded the initial values when adhesive consumption increased. The minimum MC value (6.29%) was obtained for 105 kg/m³ adhesive consumption. Çamlibel (2020a) reported 6.7% MC for HDF boards produced using 0.98-mole UF resin (8.6% by weight of dry fiber), with a mixture of hard- and softwoods, which is in line with the results of this study.

Values of TS (2 h and 24 h) obtained for the boards fluctuated as the adhesive consumption rate was increased. As seen in Table 4, all mean values presented statistically significant differences, except for the boards produced using 100 and 105 kg/m³ adhesive with an application time of 24 hours. For both 2- and 24-hour applications, the maximum (4.13% and 8.85%) and minimum (3.23% and 8.17%) TS values were obtained with adhesive consumption rates of 105 and 115 kg/m³ respectively. Çamlibel (2020a) reported almost equal (3.98%) and 2.2 times higher (19.55%) TS values for 7.68 mm-thick HDF boards with 2- and 24-hour applications, respectively. Also, a value of 4.86% for TS (2 h) was reported by Çamlıbel (2020b). Antov et al. (2021) reported values of 12.9% and 18.3% for TS (24 h) in HDF produced using European beech (*Fagus sylvatica* L.) and Turkish oak (*Quercus cerris* L.) woods and UF adhesive (3%). Hernán Poblete and Roque Vargas (2006) reported TS values of 7.6% and 20.1% in 2 and 24 hours respectively for 987 kg/m³ density HDF boards produced by a dry process. Hong et al. (2017) reported an R^2 value of 0.38 between TS and resin content (8%, 10%, 12%, 14%) for MDF boards. In the present study, the R^2 values for TS 2 h vs. UF consumption and TS 24h vs. UF consumption were 0.342 and 0.5 respectively (Fig. 2), indicating no good correlation between the variables.

Average values for the surface absorption (SA) of the boards (Table 4) ranged from 280 to 303 mm. Statistically significant differences were detected between the groups, except in the case of 90 and 95 kg/m³ adhesive consumption. The R^2 value for SA vs. UF is presented in Fig. 2. An SA value around 8.9% higher than the maximum values obtained in this study was reported by Çamlibel (2020a) for HDF boards produced using 970 mm/s press speed, 220 °C press temperature, and 57 s press duration. Consequently, almost all physical properties exhibited unstable increases and decreases with increasing adhesive consumption rates.

Mean values of WA (24 h) reached their maximum (19.7%) and minimum (17.03%) with adhesive consumption rates of 105 and 115 kg/m³, respectively. As seen in Table 4, all mean values presented statistically significant differences. Çamlibel (2020a) reported a WA value of 22.18% for 7.68 mm-thick HDF boards.

Table 4. Physical properties and statistics for the panels in terms of adhesive groups

Properties	Groups	N	Mean	Std. Dev.	Properties	Groups	N	Mean	Std. Dev.
Thickness (mm)	R115	5	7.744b*	0.015	Density (g/cm³)	R115	5	892.60d	2.408
	R105	5	7.676a	0.018		R105	5	880.00c	1.581
	R100	5	7.726b	0.015		R100	5	870.80b	2.775
	R95	5	7.722b	0.013		R95	5	867.20a	2.588
	R90	5	7.726b	0.032		R90	5	871.20b	2.588
TS 2 h (%)	R115	5	3.234a	0.032	TS 24 h (%)	R115	5	8.170a	0.012
	R105	5	4.130e	0.027		R105	5	8.858b	0.035
	R100	5	4.040d	0.046		R100	5	8.470b	0.022
	R95	5	3.976c	0.027		R95	5	8.814d	0.027
	R90	5	3.816b	0.036		R90	5	8.766c	0.023
Moisture (%)	R115	5	6.676e	0.027	WA 24 h (%)	R115	5	17.028a	0.029
	R105	5	6.296a	0.042		R105	5	19.700e	0.079
	R100	5	6.394b	0.030		R100	5	18.838c	0.033
	R95	5	6.536c	0.021		R95	5	18.838d	0.024
	R90	5	6.612d	0.043		R90	5	18.646b	0.032
SA (mm)	R115	5	303.40b	2.074					
	R105	5	327.40d	3.209					
	R100	5	313.00c	2.121					
	R95	5	280.40a	3.847					
	R90	5	283.00a	4.123					

* Duncan homogeneity groups

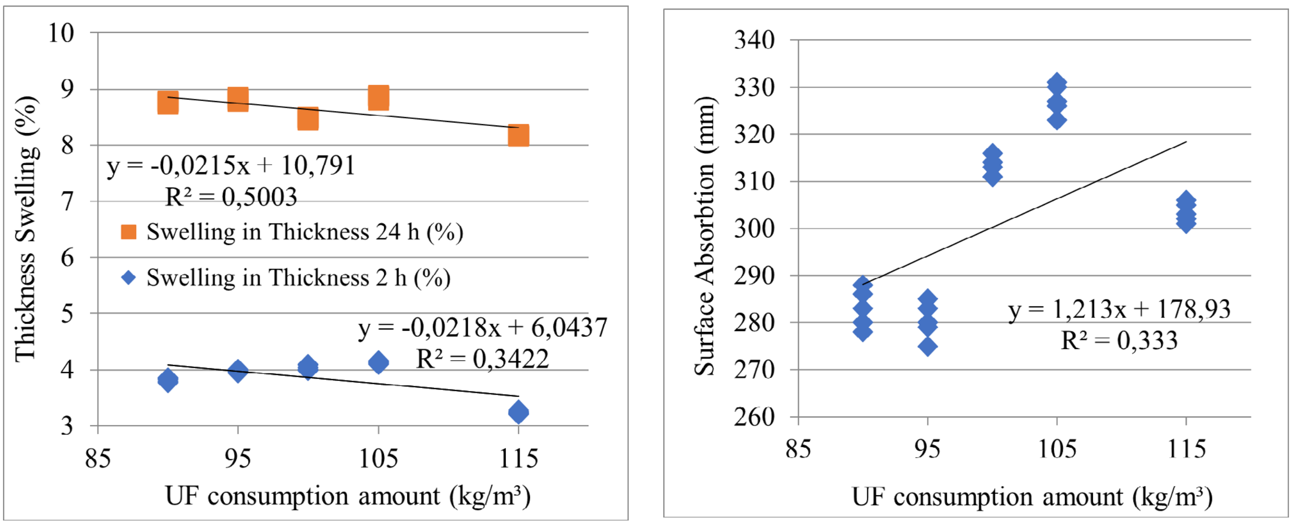

Fig. 2. Linear regression models for TS and WA

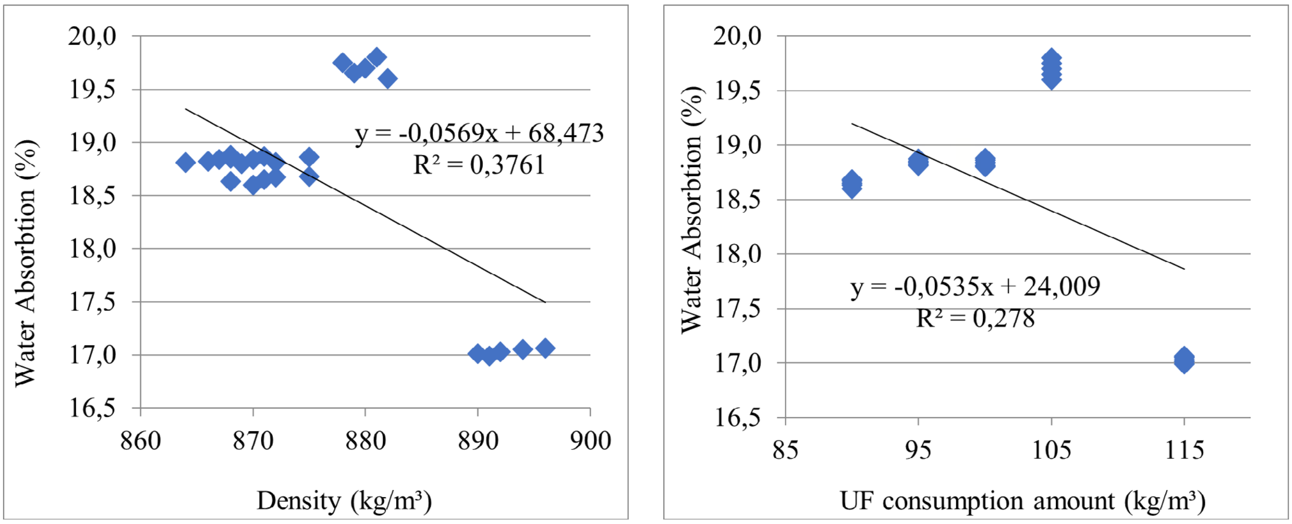

Fig. 3. Linear regression models for TS and WA

Antov et al. (2021) reported WA (24 h) values of 26.1–31.5% for HDF (930 kg/m^3) produced using very low UF resin content (3%). Hernán Poblete and Roque Vargas (2006) reported 10.8% and 27.9% as WA values in 2 and 24 hours respectively for 988 kg/m^3 density HDF boards produced by a dry process. They calculated R^2 values of 0.68 and 0.73 for density vs. WA 2h and density vs. WA 24h, respectively. As seen in Fig. 3, a considerably lower R^2 value was calculated here for WA vs. density. An R^2 of 0.192 was reported for WA vs. resin content in MDF by Hong et al. (2017). As can be seen in Fig. 3, relatively low values were obtained in this study for WA vs. UF consumption rate. Consequently, WA is regarded as an unstandardized technical property (Antov et al., 2021), and a wide range of WA values (for example, higher than 30%) has been reported for HDF board by researchers such as Antov et al. (2021) and Mihajlova and Savov (2018).

2. Mechanical properties

Average values for the mechanical properties of the HDF boards are presented in Table 5. The results show that an increase in adhesive consumption did not lead to stable linear increases or decreases in the mechanical properties. As seen in the table, values fluctuated as the adhesive consumption rate increased. The maximum (46.93 MPa) and minimum (40.5 MPa) mean MOR values were obtained for the boards produced using 105 and 100 kg/m^3 adhesive, respectively. An intermediate value (43.37 MPa) was reported by Çamlibel (2020a) for HDF boards. According to Duncan's multiple range tests, differences between the mean values of MOR depending on adhesive consumption were statistically significant. However, there was a weak relationship between the two variables, as indicated by the calculated coefficient of determination (R^2) value of 0.115 (Fig. 4). Antov et al. (2021) reported MOR values in the range 30.99–40.47 MPa for eco-friendly HDF boards; these are lower than the results obtained in this study.

As seen in Table 5, the mean MOE values of the boards ranged from 4244 to 4415 MPa. An MOE of 3990 MPa for HDF board produced using 8.6% UF resin, which is in line with the results of this study, was reported by Çamlibel (2020a). The MOE initially underwent a slight and negligible decrease (0.24%) and then increases of 2.82%, 1.73%, and 4.02% when the UF consumption rate was increased from 90 to 95, 100, 105, 110, and 115 kg/m^3 respectively. It could be concluded that a 1% increase in adhesive consumption might produce a 0.14% increase in MOE if the relationship had been linear. It was found that there was a significant relationship between adhesive consumption and MOE, as indicated by the calculated R^2 value of 0.777 (Fig. 4). In general, the average MOR and MOE values of the panels were higher than those reported by Çamlibel (2020a). Antov et al. (2021) reported MOE values of 3197–4114 MPa for eco-friendly HDF boards; these are lower than the results obtained in this study.

As seen in Table 5, IB values ranged from 1.54 to 1.72 MPa. A considerable increase (11.96%) was observed when adhesive consumption increased from 90 to 115 kg/m^3. There were no statistically significant differences between the mean values for the 90, 95, and 100 kg/m^3 groups. The calculated R^2 value (0.782) indicates a significant relationship between IB and adhesive consumption. Antov et al. (2021) reported IB values of 0.58 to 0.67 MPa for eco-friendly HDF boards; these are considerably lower than the results obtained in this study.

The surface soundness (SS) values ranged from 1.21 to 1.58 MPa. A similar value (1.2 MPa) for the

Table 5. Mechanical properties and statistics for the panels in terms of adhesive groups

Properties	Groups	N	Mean	Std. Dev.	Properties	Groups	N	Mean	Std. Dev.
MOR (MPa)	R115	5	46.324d*	0.034	IB (MPa)	R115	5	1.722c	0.019
	R105	5	46.932e	0.024		R105	5	1.662b	0.038
	R100	5	40.502a	0.029		R100	5	1.544a	0.015
	R95	5	45.114c	0.043		R95	5	1.560a	0.025
	R90	5	44.746b	0.030		R90	5	1.538a	0.024
MOE (MPa)	R115	5	4415.2e	3.114	SS (MPa)	R115	5	1.556a	0.035
	R105	5	4317.8c	1.924		R105	5	1.578a	0.030
	R100	5	4364.0d	2.345		R100	5	1.210a	0.677
	R95	5	4234.2a	2.588		R95	5	1.374a	0.027
	R90	5	4244.4b	2.074		R90	5	1.258a	0.024

* Duncan homogeneity groups

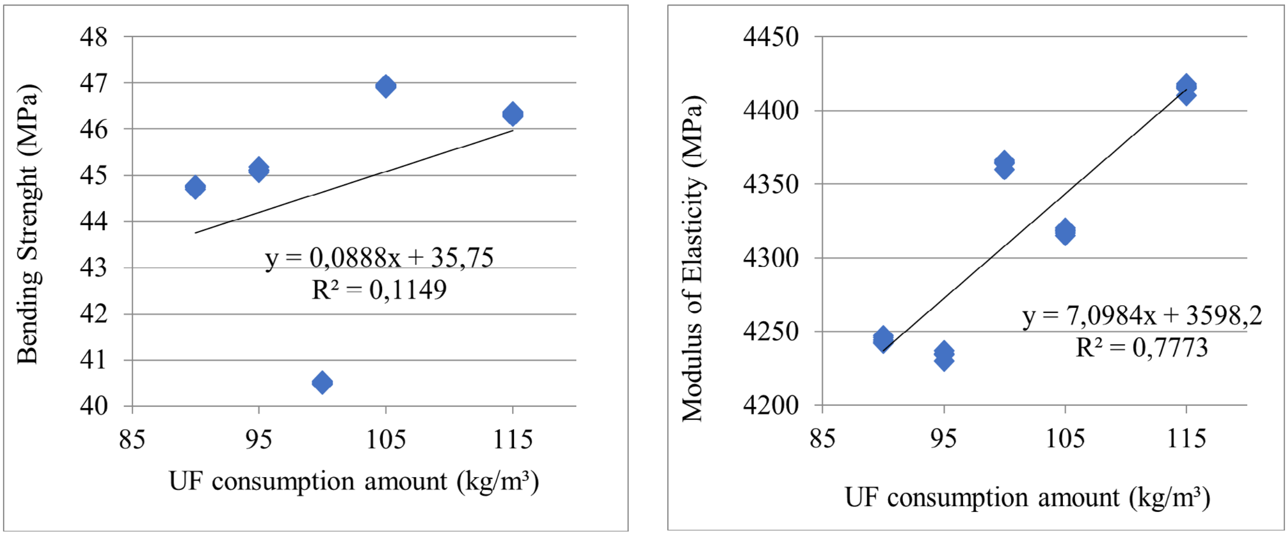

Fig. 4. Linear regression models for IB and MoE

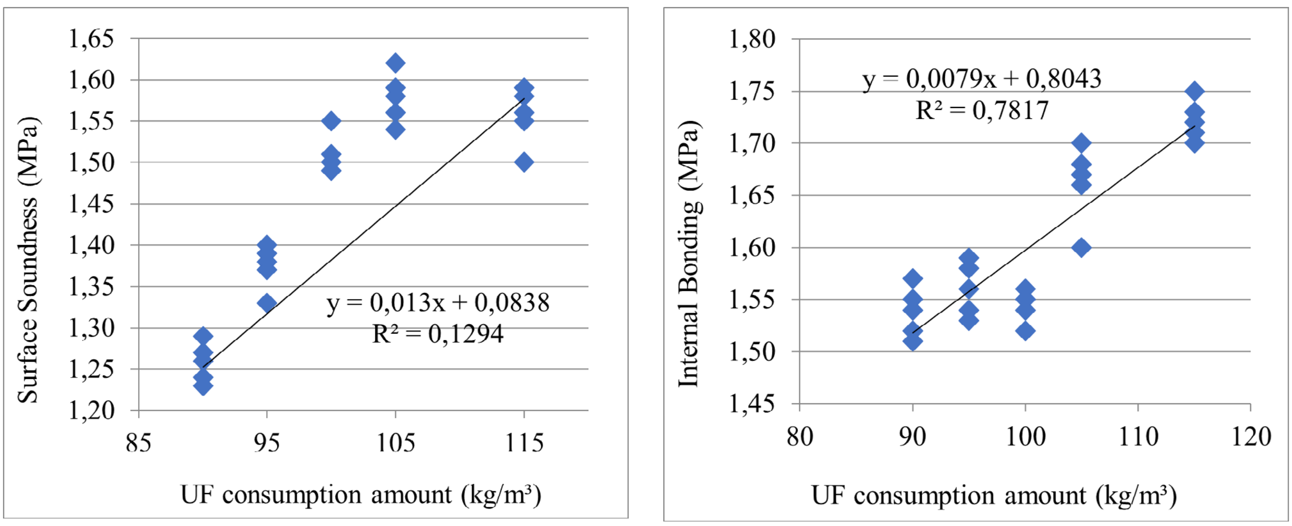

Fig. 5. Linear regression models for SS and IB

IB of HDF panels produced using 8.6% UF resin was reported by Çamlibel (2020a). However, stable and linear behavior was not observed as the adhesive consumption rate was increased from the lowest to the highest value. The lowest and the highest IB values were obtained for the panels produced using 100 and 105 kg/m³ adhesive. There was no statistically significant difference between the groups, and a weak relationship between SS and adhesive consumption was indicated by the calculated R^2 value of 0.129 (Fig. 5).

According to Hong et al. (2017), MOR, MOE, and IB values for MDF boards gradually increased when the resin content was increased from 8% to 14%. In industrial conditions, the variation in adhesive consumption was maintained within certain limits, and as a result the trend was not linear and stable not only for mechanical but also for physical properties. Furthermore, it is not easy to say that any of the groups presented the best physical and mechanical properties.

Density is the principal determinant that influences board properties (Sari et al., 2013). Hernán Poblete and Roque Vargas (2006) reported that MOE and MOR increased from 3035 to 4406 MPa and from 366 to 414 MPa respectively when density increased from 880 to 1041 kg/m³. As other researchers have observed, density has a positive influence on the mechanical properties of boards.

3. Formaldehyde content

Mean FC values for the boards are presented in Table 6. As in the case of physical and mechanical properties, FC oscillated as the adhesive consumption rate increased. It is believed that because of the factory production process, the CoV obtained within each panel was extremely low, as seen in the table. However, such small differences may lead to statistically significant differences between the mean values. The FC of the boards was decreased by around 17.57% when adhesive consumption increased from 90 to 115 kg/m³. Hong also observed that there is not a clear correlation between the adhesive consumption rate and formaldehyde emission, since the FC values vary when the density and resin content are increased. However, as was described above for the mechanical properties, formaldehyde content did not follow a linear and stable trend with the increase in adhesive consumption. All FC values are higher than the standardized value for class E1, namely 8 mg/100 g, which is not appropriate for boards made in industrial conditions.

Conclusions

According to the results, only surface soundness (SS) was insignificantly influenced by UF consumption. The thickness means of the groups were close to each other, and only the 105 kg/m³ group presented a significant difference. The influence of UF consumption on the properties was not linear, either positively or negatively. Fluctuation was observed as the consumption rate was increased from 90 to 115 kg/m³.

It may not be reasonable to indicate a common UF consumption rate that would lead to better performance of panels when all of the evaluated properties are considered. However, the boards with rates of 105 and 115 kg/m³ presented better performance in terms of physical and mechanical properties and formaldehyde content. Despite this, the FC of the industrially produced boards exceeded the limit for emission class E1 (≤ 8 mg/100 g) but met the requirements for class E2 (8–30 mg/100 g). Even though the emission values are close to the 8 mg/100 g limit, the boards produced must be enhanced to meet the E1 requirements laid down in health safety standards.

Product properties depend strongly on the component materials and production parameters. Temperature, press time, and pressure are some of the basic production parameters that are widely evaluated especially in MDF production. However, for HDF production, there are issues that remain to be clarified. In this study the production parameters were fixed, but their influence on the evaluated properties should be investigated in a future study. However, particularly for the temperature parameter, it should be taken into account that there is a blow-out risk due to too rapid steam generation when the press temperature is increased excessively (Suchsland & Woodson, 1986).

Table 6. Formaldehyde content (FC) and statistics for the panels in terms of adhesive groups

Properties	Groups	N	Mean	Std. Dev.
FC (mg/100g)	R115	5	9.158a*	0.031
	R105	5	9.862b	0.038
	R100	5	10.578c	0.055
	R95	5	9.900b	0.016
	R90	5	11.110d	0.016

* Duncan homogeneity groups of the means

Conflict of interest

The author(s) declare(s) that there is no conflict of interest concerning the publication of this article.

References

Açık, C., & Tutuş, A. (2012). Effects of Various Synthetic Surface Coatings on Thermal Conductivity of Fiberboard. *Duzce Universitesi Ormancılık Dergisi*, *8*(2), 1–8.

Antov, P., Savov, V., Krišťák, L., Réh, R., & Mantanis, G. I. (2021). Eco-friendly, high-density fiberboards bonded with urea-formaldehyde and ammonium lignosulfonate. *Polymers*, *13*(2), 1–13. https://doi.org/10.3390/polym13020220

Bayram, B. Ç., Ersen, N., Akyüz, İ., Üçüncü, T., & Akyüz, K. C. (2018). An analytical Hierarchy Process application: Determining the most important board type of Turkey regarding exportation in recent years. *International Journal of Environmental Trends*, *2*(2), 53–58.

Çamlıbel, O. (2020a). Investigation of the Physical Properties and Mechanical Properties of Hight Density Fiberboard (HDF) Board Produced with Low Mole Urea Formaldehyde Resin. In Ö. C. Hergül & P. Göker (Eds.), *3rd. International Congress of Academic Research* (pp. 629–635). Asos Press.

Çamlıbel, O. (2020b). Investigation of the Physical Some Properties of HDF Boards Produced with Urea Formaldehyde Different Moles Ratios. In Ö. Çakır (Ed.), *8th International Scientific Research Congress-Science and Engineering* (pp. 25–36). Asos Press.

Çetin, F., & Kaygın, B. (2016). Three dimensional plating of wooden fibrous composite materials by using the technique of pyrolytic plating. *Journal of Bartın Faculty of Forestry*, *18*(1), 93–102.

Döngel, N., Küreli, İ., & Söğütlü, C. (2008). Kuru Sıcaklığın Ahşap ve Ahşap Esaslı Döşeme Kaplama Malzemelerinde Parlaklık ve Renk Değişimine Etkisi. *Politeknik Dergisi*, *11*(3), 255–263.

Güler, C., Çöpür, Y., Taşcıoğlu, C., & Büyüksarı, Ü. (2007). Utilization potential of HDF (High Density Fiberboard) in Laminated Parquet Production. *Duzce Universitesi Ormancılık Dergisi*, *3*(2), 16–32.

Hernán Poblete, W., & Roque Vargas, C. (2006). Relationship between density and properties of HDF manufactured by a dry process. *Maderas: Ciencia y Tecnología*, *8*(3), 169–182. https://doi.org/10.4067/S0718-221X2006000300004

Hızıroğlu, S. (2008). Internal Bond Strength of Laminated Flooring as Function of Water Exposure. *51st International Convention of Society of Wood Science and Technology*, 4.

Hong, M. K., Lubis, M. A. R., & Park, B. D. (2017). Effect of panel density and resin content on properties of medium density fiberboard. *Journal of the Korean Wood Science and Technology*, *45*(4), 444–455. https://doi.org/10.5658/WOOD.2017.45.4.444

Hunt, J. F., O'Dell, J., & Turk, C. (2008). Fiberboard bending properties as a function of density, thickness, resin, and moisture content. *Holzforschung*, *62*(5), 569–576. https://doi.org/10.1515/HF.2008.083

İstek, A. (2006). Effects of pressure and temperature on physical and mechanical properties of high density fiberboard. *ZKÜ Bartın Orman Fakültesi Dergisi*, *8*(10), 29–35.

İstek, A., Özlüsoylu, İ., & Kızılkaya, A. (2017). Turkish Wood Based Panel Sector Analysis. *Journal of Bartin Faculty of Forestry*, *19*(1), 132–138.

Jaber, M. A., Hammadi, K. J., Karem, A. A. A., & Abd-Alrazak, M. (2016). Physical and Mechanical Properties of Medium Density Fiberboard Made of Palm Fronds and Trunks. *Asian Journal of Applied Sciences*, *4*(4), 972–978.

Kara, M. E., Yerlikaya, Z., Ateş, S., & Olgun, Ç. (2016). Effect of pressing conditions on some surface properties of HDF laminate parquets. *Indian Journal of Engineering and Materials Sciences*, *23*(4), 274–278.

Kartal, S. N., Burdsall, H. H., & Green, F. (2003). *Accidental mold/termite testing of high density fiberboard (HDF) treated with boric acid, borax and N'N-aphthoylhydroxylamine (NHA)*.

Kartal, S. N., & Green, F. (2003). Decay and termite resistance of medium density fiberboard (MDF) made from different wood species. *International Biodeterioration and Biodegradation*, *51*(1), 29–35. https://doi.org/10.1016/S0964-8305(02)00072-0

Korkut, S., Çabukoğlu, F., & Özdemir, H. (2015). Effects of Post Heat-Treatment on Certain Characteristics of High Density Fiberboard. *Duzce Universitesi Ormancılık Dergisi*, *11*(1), 83–87.

Labans, E., Kalnins, K., & Bisagni, C. (2019). Flexural behavior of sandwich panels with cellular wood, plywood stiffener/foam and thermoplastic composite core. *Journal of Sandwich Structures and Materials*, *21*(2), 784–805. https://doi.org/10.1177/1099636217699587

Lee, B. H., Kim, H. S., Kim, S., Kim, H. J., Lee, B., Deng, Y., Feng, Q., & Luo, J. (2011). Evaluating the flammability of wood-based panels and gypsum particleboard using a cone calorimeter. *Construction and Building Materials*, *25*(7), 3044–3050. https://doi.org/10.1016/j.conbuildmat.2011.01.004

Mamiński, M., 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). *Journal of Adhesion*, *96*(7), 679–690. https://doi.org/10.1080/00218464.2018.1500280

Mantanis, G., Athanassiadou, E., Nakos, P., & Coutinho, A. M. J. (2004). A New Process for Recycling Waste Fiberboards. In R. J. Tichy & V. Yadama (Eds.), *38th International Wood Composites Symposium* (pp. 119–122). Washington State University.

Mihajlova, J., & Savov, V. (2018). Physical Indicators of High-Density Fibreboards (HDF) Manufactured from Wood of Hard Broadleaved Species. *8th Hardwood Conference – New Aspects of Hardwood Utilization – From Science to Technology*, 142–143.

Nemli, G., Öztürk, I., & Aydın, A. (2004). Laminates. *Artvin Orman Fakültesi Dergisi*, *1–2*, 55–60.

Oh, Y. S. (2010). Effects of recycled fiber addition on high-density fiberboard for laminated flooring bonded with phenol-formaldehyde resin adhesive. *Journal of Applied Polymer Science*, *115*(2), 641–645. https://doi.org/10.1002/app.30435

Özdemir, F. (2016). Investigate on effect of dolomite mineral on some properties of high density fiberboard (HDF). *KSU. Journal of Engineering Sciences, 19*(2), 93–98.

Özdemir, F., Özyurt, H., Dalgıç, E., Ramazanoğlu, D., & Tutuş, A. (2018). Investigation of Surface Quality of High Density Fiberboard (HDF) Boards Produced by Adding Muscovite Mineral. *Kahramanmaras Sutcu Imam University Journal of Engineering Sciences*, *21*(2), 166–171.

Özdemir, F., Tutuş, A., & Bal, B. C. (2013). Effect of fire retardants on thermal conductivity and limited oxygen index of high density fiberboard. *Turkish Journal of Forestry*, *14*(2), 121–126. https://doi.org/10.18182/tjf.40528

Özdemir, F., Tutuş, A., & Çiçekler, M. (2016). Effect of dolomite mineral on surface roughness of high density fiberboard (HDF). *International Furniture Congress*, 498–501.

Rozins, R., & Iejavs, J. (2014). Evaluation of thermal properties of wood based composite panel walls. *Research for Rural Development*, *2*, 109–114.

Sala, C. M., Robles, E., & Kowaluk, G. (2020). Influence of adding offcuts and trims with a recycling approach on the properties of high-density fibrous composites. *Polymers*, *12*(6). https://doi.org/10.3390/POLYM12061327

Sari, B., Nemli, G., Baharoğlu, M., Bardak, S., & Zekoviç, E. (2013). The role of solid content of adhesive and panel density on the dimensional stability and mechanical properties of particleboard. *Journal of Composite Materials*, *47*(10), 1247–1255. https://doi.org/10.1177/0021998312446503

Suchsland, O., & Woodson, G. E. (1986). Fiberboard manufacturing practices in the United States. In *USDA Forest Service, Agriculture Handbook No 640*. USDA Forest Service.

TS EN ISO 12460-5 (2016). *Wood based panels – Determination of formaldehyde release – Part 5: Extraction method (called the perforator method).*

TS EN 310. (1999). *Wood-based panels – Determination of modulus of elasticity in bending and of bending strength.*

TS EN 311. (2005). *Wood-based panels – Surface soundness – Test method.*

TS EN 317. (1999). *Particleboards and fibreboards – Determination of swelling in thickness after immersion in water.*

TS EN 319. (1999). *Particleboards and fibreboards – Determination of tensile strength perpendicular to the plane of the board.*

TS EN 322. (1999). *Wood-based panels – Determination of moisture content.*

TS EN 323. (1999). *Wood-based panels – Determination of density.*

TS EN 324-1. (1999). *Wood-based panels – Determination of dimensions of boards – Part 1: Determination of thickness, width and length.*

TS EN 382-1. (1999). *Fibreboards – Determination of surface absorption part 1: Test method for dry process fibreboards.*

Xu, B., Chen, Z., & Ma, Q. (2015). Experimental Study of Formaldehyde Diffusion with in Building Materials in Different High-Voltage Electric Field. *Procedia Engineering*, *121*, 256–261. https://doi.org/10.1016/j.proeng.2015.08.1066