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The Effect of Foamed Urea-Formaldehyde Adhesive on Physical and Mechanical Properties of Medium Density Fiberboards (MDF)

Utjecaj upjenjenog urea-formaldehidnog ljepila na fizička i mehanička svojstva srednje guste ploče vlaknatice (MDF)

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ABSTRACT • *In this study, the effect of using foamed urea-formaldehyde (UF) adhesive in the production of medium-density fiberboard (MDF) on the properties of the board was investigated. A commercial foaming agent was used to increase the volume of UF adhesive by approximately 2.5 times. MDFs were produced using 6, 9 and 12 % adhesive and 1 % ammonium chloride hardener relative to the dry weight of the adhesive. The thermal degradation behavior of the foamed and control adhesives was determined by thermal analysis i.e., thermogravimetric (TGA) and derivative thermogravimetric (DTG) analyses. It was found that the foaming agent did not affect the thermal degradation of the adhesive. Scanning electron microscope images showed that the volume of foamed adhesive and blending efficiency increased. It was determined that MDFs produced with foamed adhesive had better water absorption and thickness swelling properties than control boards. However, the internal bond strength (IB) and modulus of elasticity (MOE) were found to be 8-14 % and 3-16 % higher, respectively, compared to the control samples. As a result, it can be concluded that the foaming process had a positive effect on the board properties and had the potential to reduce the amount of adhesive used.*

KEYWORDS: *medium-density fiberboard; foamed urea-formaldehyde adhesive; physical and mechanical properties; foaming agent*

SAŽETAK • *U radu je istraživan utjecaj upotrebe upjenjenog urea-formaldehidnog (UF) ljepila u proizvodnji srednje gustih ploča vlaknatica (MDF) na njihova svojstva. Za povećanje volumena UF ljepila za otprilike 2,5 puta iskorišten je komercijalni dodatak za pjenjenje. MDF ploče proizvedene su uporabom 6, 9 i 12 %-tnog ljepila te 1 %-tnog otvrđivača amonijeva klorida u odnosu prema težini suhih vlakana. Toplinska degradacija upjenjenoga i kontrolnog ljepila utvrđena je termogravimetrijskom (TGA) i diferencijalnom toplinskom (DTG) analizom. Ustanovljeno je da dodatak za pjenjenje nije utjecao na toplinsku degradaciju ljepila. Pretražnim elektronskim mikroskopom uočeno je da se povećao volumen i mješivost upjenjenog ljepila. Rezultati su pokazali da je MDF*

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proizveden s upjenjenim ljepilom imao bolja svojstva upijanja vode i debljinskog bubrenja od kontrolnih ploča. Međutim, čvrstoća raslojavanja (IB) i modul elastičnosti (MOE) bili su 8 – 14 % odnosno 3 – 16 % veći od istih pokazatelja kontrolne ploče. Slijedom toga, može se zaključiti da pjenjenje ljepila pozitivno utječe na svojstva ploče i može pridonijeti smanjenju količine potrebnog ljepila.

KLJUČNE RIJEČI: *srednje gusta ploča vlaknatica; upjenjeno urea-formaldehidno ljepilo; fizička i mehanička svojstva; dodatak za pjenjenje*

1 INTRODUCTION
1. UVOD

Fiberboards have a wide range of applications, including furniture, cladding, doors, flooring, and wall and ceiling coverings (Istek *et al.,* 2012). Urea-formaldehyde (UF) resin is commonly used in the production of fiberboards due to its economic viability, high reactivity, and good adhesive properties (Moslemi *et al.*, 2020). It is emphasized that 1 million tons of UF adhesive are used in wood-based panel production worldwide (Gadhave *et al*., 2017). However, in terms of the current emphasis on human and environmental health, as well as economic considerations, efforts have been directed towards reducing adhesive consumption and promoting its healthy use. For instance, considering a medium-sized factory producing 1000 m^3 per day, it is noted that the daily consumption of solid UF is around 45-50 thousand kg, and a monthly saving of 150 tons of solid UF could be achieved with a 10 % reduction (Kelleci *et al*., 2022). While achieving homogeneous adhesive distribution in practice is challenging, it is observed that the sprayed adhesive surface area is dependent on particle area measurements. Despite the fiber surface area being approximately 260 cm^2 for 1 g weight, the average droplet diameter of adhesive with 7 % solids is 40 µm, covering a total area of 82 cm^2 (Watters, 1974). Istek *et al*. (2019) indicated that an increase in adhesive surface area leads to enhanced internal bond (IB) strength in the board. Achieving the optimum bonding surface area also relies on the significant importance of the sprayed adhesive diameter (Zhan *et al*., 2021).

Among the disadvantages of UF resin are high formaldehyde emissions, low water resistance, and sensitivity to temperature changes (Bekhta *et al*., 2022). Formaldehyde emission is responsible for adverse effects on human health such as cancer, leukemia, genotoxicity, skin, and respiratory tract irritation, nausea, nasopharyngeal and skin sensitization (Chrobak *et al*., 2022; Istek *et al*., 2018; Kristak *et al.,* 2023). Intensive research has been conducted to reduce formaldehyde emissions and improve the mechanical properties in the production of fiber and particleboards. Some of these studies include encapsulated urea (Liu *et al*., 2021), zeolite (Camlibel, 2020), activated carbon (Zamani *et al*., 2022; Ergün *et al*., 2023), and adhesive foaming. The foaming process enhances adhesive homogeneity by reducing resin viscosity. Additionally, it allows for the use of less adhesive by increasing its volume, thereby reducing both cost and formaldehyde emission (Hu *et al*., 2021). Recently, bio-based foaming agents have emerged as a promising alternative to enhance the performance of UF adhesives. These agents are bio-based surfactants that can improve the foam stability and bubble size distribution of UF adhesives, enabling better penetration and distribution in wood structures (Bacigalupe *et al*., 2020). Bio-based foaming agents are considered environmentally and human-health-friendly compared to synthetic agents containing harmful chemicals (Benavides, 2022).

Studies have investigated the properties of low-density particleboards produced with UF adhesive prepared using chemical foaming agents, indicating that results obtained with the use of 2 % less adhesive were similar to control group boards (Boruszewski *et al*., 2022). Jiang *et al*. (2016) reported that particleboards produced with foamed adhesive generally meet international standards in terms of mechanical properties, providing a significant advantage of obtaining a product similar to the control with a lower solid content. Heri Iswanto *et al*. (2018), Nadhari *et al*. (2019), Widyorini *et al*. (2017), and Zhai *et al*. (2021) have conducted studies on the use of foam agents in adhesive foaming. Chemical foaming agents such as azodicarbonamide, sodium dodecyl sulfate, sodium laureth sulfate, commonly used in foam agents, have environmental and human health impacts. In the present world, moving away from products with such effects will likely restrict the use of chemical foaming agents in the near future.

In this study, a commercial foaming agent was used in the production of UF adhesive foamed fiberboard, aiming to produce boards with standard properties while consuming less adhesive. The physical and mechanical properties of the produced boards were examined, along with the thermal and morphological properties of foamed and unfoamed adhesives.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

In this study, fibers obtained from oriental beech (*Fagus orientalis*) and pine (*Pinus brutia*) wood fibers were used as raw materials. The wood fibers were

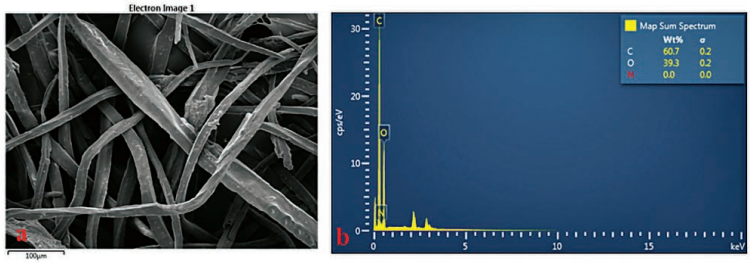


Figure 1 SEM (a) and EDS (b) analyses of neat fiber
Slika 1. SEM (a) i EDS (b) analize čistih vlakana

sourced from the Kastamonu Integrated MDF Plant (Kastamonu, Turkey) and consist of a blend of 55 % beech and 45 % pine wood. SEM and EDS analyses of fiber are given in Figure 1.

The fibers determined the chemical composition, and they contained 60.7 % of carbon (C), 39.3 % of oxygen (O) and 0 % of nitrogen (N). The fibers used in the production were dried up to 2 % moisture content to be prepared for manufacturing. UF adhesive with a density of 1.28 g/cm^3 and a solids content of 65 %, supplied by a commercial wood-based board factory (Kastamonu, Turkey), was employed as the adhesive. The commercial foam agent used has a density of 1.05 and a pH value of 5.5. This foam agent is herbal resin-based and was supplied by ARTRA Construction Landscape Plastic Ltd. (İstanbul, Turkey).

2.2 Production of MDF
2.2. Proizvodnja MDF ploča

In this study, UF adhesive at usage ratio, 6, 9 and 12 % based on the dry fiber weight, along with a commercial foam agent at a 1.5 % concentration based on adhesive solids, was mixed for 5 minutes at 3000 rpm to foam the adhesive. The viscosity and pH of the foamed adhesive were found to be 41.15 CP and 7.20, respectively, at 22 °C, while the viscosity and pH of the unfoamed adhesive were determined to be 17.67 CP and 8.25 at the same temperature. MDF experimental boards were produced using the obtained foamed adhesive solution. Three groups of boards were manufactured, resulting in a total of 18 experimental boards, including control samples for each group. The experimental boards were produced with dimensions of 250 mm × 250 mm, a thickness of 12 mm, and a target density of 0.8 g/cm^3. The foamed adhesive solution prepared with fibers at 2 % moisture content was sprayed onto the fibers using a rotating drum, internal spray, and single injector system at 5.5 bars of compressed air pressure. The spraying process was completed by mixing the adhesive and fibers for approximately 3 minutes. The adhesive-coated fibers were manually formed in a mat with dimensions of 250×250×300 to form the board layout. Experimental boards were then produced using a hot press (SSP180 Cemil Usta, Turkey) under the conditions of 4.0 N/mm^2 of specific pressure, 175 °C temperature, and a 5-minute duration. Following the hot press, the boards were allowed to cool, and test samples were prepared. The MDFs were conditioned for one week under ambient conditions before preparing the test samples according to the EN 326-1 (1999) standard. Following one week at (20±2) °C and (65±5) % relative humidity, the samples were maintained in a controlled environment chamber.

2.3 Characterization of adhesive and MDF
2.3. Karakterizacija ljepila i MDF ploča

Thermogravimetric (TG) and derivative thermogravimetric (DTG) tests were conducted on the foamed and unfoamed adhesive samples using Hitachi-STA 7300 equipment (Hitachi, Ltd., Tokyo, Japan). The samples were heated at a rate of 10 °C per minute from room temperature to 600 °C while being subjected to a nitrogen environment with a gas flow rate of 50 mL/min. The foamed and unfoamed adhesive morphologies were studied using a scanning electron microscope (SEM) (MAIA3 XMU model, TESCAN, Brno, Czech Republic). To increase the conductivity of the adhesive, a 5 nm thick layer of gold was applied to the samples. The SEM microscope was operated at 20.0 kV voltages during the microstructure image analysis.

The EN 322 (1999) standard was used to measure moisture content (*MC*), while EN 323 (1999) was used to calculate densities. The EN 317 (1999) standard was used to evaluate thickness swelling (*TS*), and ASTM D1037-12 (2020) was followed for water absorption (*WA*). According to EN 319 (1999) and EN 310 (1999), respectively, the internal bond strength (*IB*), modulus of elasticity (*MOE*), and modulus of rupture (*MOR*) were assessed. All tests, except for the SEM and TGA analyses, were conducted on six samples for each group. The effect of foamed and unfoamed adhesives on the mechanical and physical properties of the MDF was statistically analyzed using one-way analysis of variance (ANOVA) within the SPSS 16 software.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Characterization of adhesive and MDF
3.1. Karakterizacija ljepila i MDF ploča

TG and DTG graphs of foamed UF adhesive (UF-F) and unfoamed UF adhesive are given in Figure 2.

The thermal decomposition behavior of UF and UF-F samples was determined through TGA measurements. Figure 1 shows the weight loss (%) ratios as a function of temperature. The weight loss (%) by weight of the resins was computed. At temperatures below 200 °C, surface evaporation and the gradual release of natural moisture and formaldehyde from UF are the main causes of the weight loss during the first stage (Jiang *et al*., 2010; Roumeli *et al*., 2012). The condensation reaction of unreacted amino and hydroxymethyl groups can cause water to evaporate. According to Zorba *et al*. (2008) and Zhao *et al*. (2013), the breakdown of methylene and methylene ether bonds takes place in the second stage, which is between 175 and 350 °C. The final stage involves additional carbonization, performed over a wide temperature range from 350 °C to 800 °C. Lower rates of O, N, and H element elimination are the cause of this stage (Chen *et al*., 2021). Similar studies have also found that TGA analyses of UF adhesives yield similar results (Singha and Thakur, 2009; Chen *et al*., 2017).

The TG and DTG results of UF-F, foamed by adding a commercial foam agent at a 1.5 % ratio based on the dry weight of UF, were found to be quite similar to UF. The amount of foam agent used was observed not to significantly impact the thermal properties of the adhesive either positively or negatively. Figure 3 displays SEM images of foamed and unfoamed (pure) UF adhesives.

The images reveal that, because of UF foaming, pores with different diameters are formed (Figure 3a), while unfoamed UF exhibits morphology similar to a flat film (Figure 3b). These pores increased the UF volume. The volumes of both foamed and unfoamed adhesive, which had the same amount, were determined through 5 repetitions each. The volume of the unfoamed and foamed adhesive was found to be (1238±25) cm^3 and (3056±99) cm^3, respectively. Chemical composition of neat UF adhesive, determined with EDS analyses, was 48 % C, 30.6 % O and 21.5 % N. Gul and Alrobei (2021) found via EDS analyses that neat UF adhesive had 27 % N content.

The increased volume enhances blending efficiency by allowing UF to come into contact with more fiber surfaces. As will be discussed in the mechanical experiments, foaming the adhesive enables achieving the same mechanical properties with less adhesive. Similar SEM images were obtained by foaming UF adhesive in the

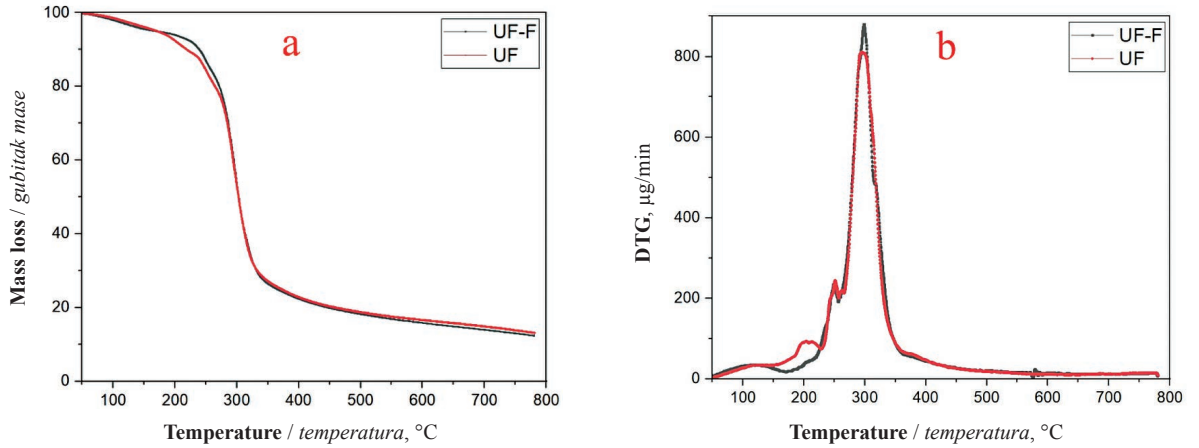
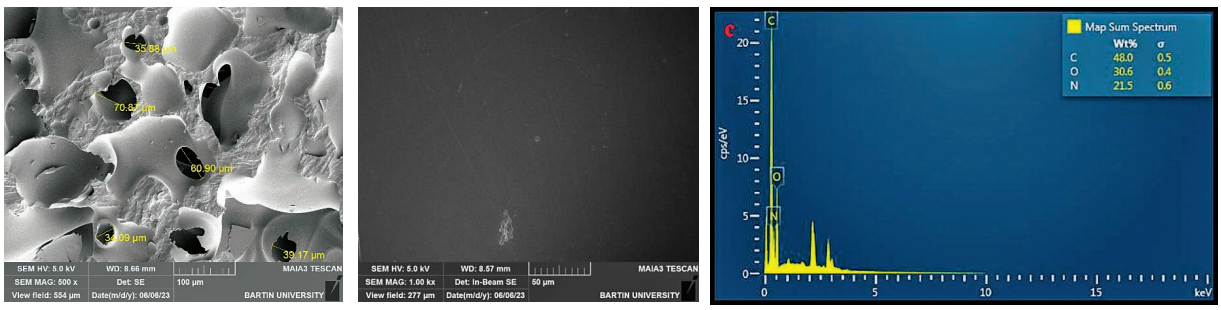


Figure 2 TG (a) and DTG (b) results of foamed (UF-F) and unfoamed (UF) adhesive
Slika 2. TG (a) i DTG (b) rezultati za upjenjeno (UF-F) i neupjenjeno (UF) ljepilo



a) b) c)

Figure 3 SEM images of foamed UF (a) and unfoamed UF (b); EDS analyses of UF (c)
Slika 3. SEM fotografije upjenjenoga (a) i neupjenjenog (b) UF ljepila; EDS analiza UF ljepila (c)

production of particleboards, and it was reported that the same or better mechanical properties could be achieved with less adhesive (Kelleci *et al*., 2022).

3.2 Chemical and morphological properties of MDF
3.2. Kemijska i morfološka svojstva MDF ploča

The SEM, mapping, and EDS analyses of MDFs produced with adhesives containing 12 % foam and adhesive without foam are given in Figure 4, aiming to identify the distribution of adhesive within the manufactured MDF.

The SEM image of MDF produced with 12 % foamed adhesive (Figure 4a) shows that the adhesive uniform distribution results in enhanced fiber binding (a tighter structure). In Figure 4d, MDFs manufactured with unfoamed adhesive exhibit distinct fibers with less interconnection (a looser structure). Additionally, the nitrogen distribution within the adhesive used in the manufactured MDFs was scrutinized using mapping images. The mapping image of MDF produced with foamed adhesive (Figure 4b) reveals a more homogeneous distribution, whereas MDFs produced with unfoamed adhesive show a more clustered nitrogen distribution with areas devoid of nitrogen (Figure 4e). Conducting EDS analyses on the SEM-imaged areas of the produced MDFs yielded disparate results despite the equal adhesive quantities used in MDF production. In Figure 4c, MDF manufactured with foamed adhesive contains 11.4 % nitrogen, while in MDF produced with unfoamed adhesive (Figure 4f), the nitrogen content attributed to the adhesive is 7.6 %. Although both samples used 12 % adhesive, a 3.8 % difference is observed in the analyzed part. The more heterogeneous distribution of adhesive in MDFs produced with unfoamed adhesive is also shown in the SEM images. These findings from SEM, mapping, and EDS analyses suggest that foamed adhesive ensures a more homogeneous distribution within the produced MDF. The concentration of total nitrogen in the wood is under 0.5 % by dry weight (Cowling and Merrill, 1966; Khanina *et al.*, 2023). So, this amount of N is negligible. In the study conducted by Fletes and Rodrigue (2021), the nitrogen content was neglected in the analysis of wood fiber using EDS, similar to our study (Figure 1b), due to its significantly low concentration. On the other hand, the ultimate analysis, which provides more precise information about the chemical composition of wood, has indicated that the nitrogen (N) content in various wood species ranges from 0.1 % to 0.5 % (Telmo *et al.,* 2010). On the other hand, the low signals observed are considered normal and expected. This situation is related to the addition of adhesive in proportions of 6, 9 and 12 % by weight of the fiber content. The detection of 7.6 % and 11.4 % nitrogen (N) attributed to UF adhesive is in line with the expected results, considering that neat UF contains 21.5 % N as determined by EDS analysis. Similar studies have also reported low signal intensities for nitrogen (N) (Hashim *et al.,* 2005). Additionally, Gul *et al.* (2019) found that the UF adhesive filled the gaps between the fibers in the manufactured MDF, and the presence of nitrogen (N) was confirmed through EDS analysis. In another study, the distribution and chemical composition of the adhesive in wood-based panels were examined, and it

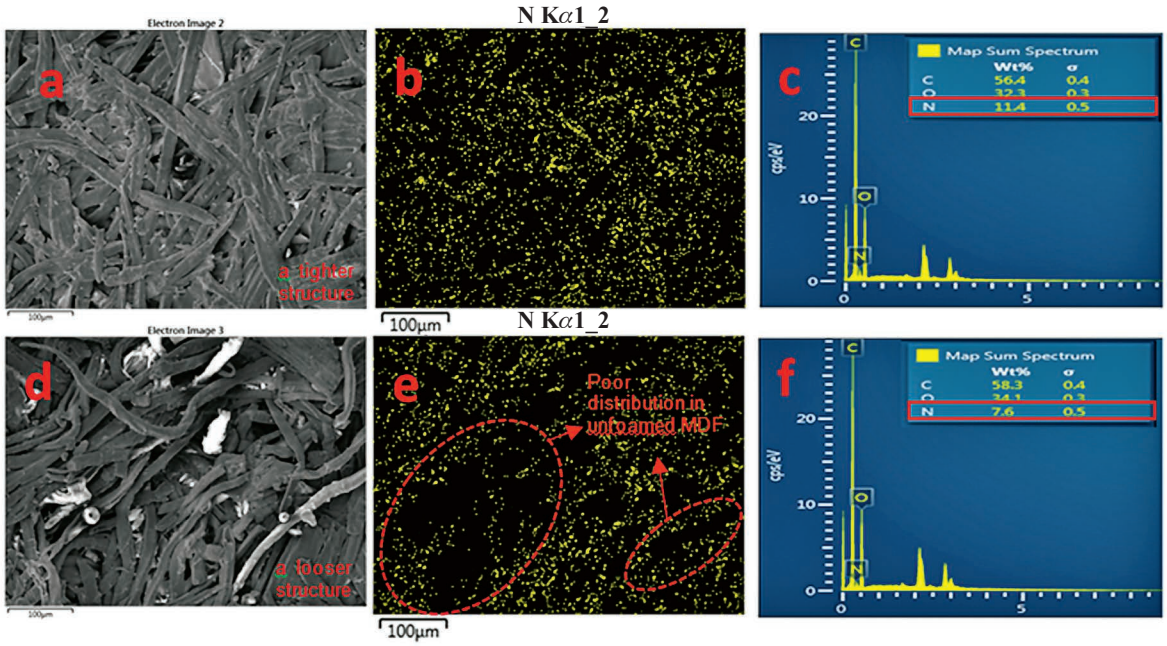


Figure 4 SEM, mapping, and EDS analyses of 12 % foamed MDF (a, b, c) and unfoamed MDF (d, e, f)
Slika 4. SEM, mapiranje i EDS analiza 12 %-tnog upjenjenog MDF-a (a, b, c) i neupjenjenog MDF-a (d, e, f)

was emphasized that the nitrogen (N) element originated from the adhesive. The distribution of the adhesive and the nitrogen (N) element were visualized using SEM-mapping (Lin *et al.,* 2023).

3.3 Physical properties of MDF
3.3. Fizička svojstva MDF ploča

In this study, MDF was produced by adding a commercial foam agent to urea-formaldehyde adhesive at concentrations of 6, 9 and 12 %, and by using adhesive with added foam. The water absorption (*WA*), thickness swelling (*TS*), moisture content (*MC*), and density values of the produced MDFs are provided in Table 1.

The highest density among the produced MDFs is observed in the 12 % unfoamed MDF. On the other hand, the *MC* values of the produced MDFs varied between 4.13 % and 4.58 %. Both the increased adhesive content and foaming of the adhesive resulted in a decrease in *MC* values. However, statistically, no significant differences were observed in density and *MC* values. Due to the manual production of MDFs, some density fluctuations are inevitable. As shown in Table 1, the foaming process reduced the *WA* and *TS* values of the MDFs. For instance, the 24-hour *WA* value for 6 % unfoamed MDF was 43.61 %, whereas the 24-hour *WA* value for 6 % foamed MDF was 42.76 %. Similarly, the 24-hour *TS* value for 6 % unfoamed MDF was 23.35 %, while the 24-hour *TS* value for 6 % foamed MDF was 22.71 %. This result indicates that the foaming process fills the voids between the fibers with adhesive, thereby enhancing the resistance of MDFs to water, influenced by the foam agent used. Additionally, *WA* and *TS* values decreased as the adhesive addition ratio increased. For example, the 24-hour *WA* value for 6 % unfoamed MDF was 43.61 %, whereas the 24-hour *WA* value for 12 % unfoamed MDF was 30.75 %. Similarly, the 24-hour *TS* value for 6 % unfoamed MDF was 23.35 %, while the 24-hour *TS* value for 12 % unfoamed MDF was 18.47 %. This result indicates that the commercial foam agent used strengthens the bonding between the fibers, allowing the foaming process to penetrate the fibers more effectively and prevent moisture absorption. Statistically significant differences were found in the *TS* and *WA* values of the produced MDFs. In previous studies, MDFs produced using urea-formaldehyde adhesive at concentrations of 10-13 % had 24-hour *TS* and *WA* values ranging from 12-23 % and 42-92 %, respectively (Ashori *et al*., 2009; Selakjani *et al*., 2021). On the other hand, in a study conducted by Kelleci *et al*. (2022), different ratios of UF adhesives were foamed and used in the production of particleboards. An increase in adhesive content and foaming resulted in a reduction in the 24-hour TS and WA values of the particleboards, creating a trend similar to that of the current study.

3.4 Mechanical properties of MDF
3.4. Mehanička svojstva MDF ploča

The *IB* results of MDFs containing foamed and unfoamed UF adhesive at 6, 9 12 % ratios are presented in Figure 5.

When evaluating the *IB* values, it was observed that foamed MDF samples generally had higher *IB* values compared to unfoamed samples. This observation was particularly pronounced in the foamed samples at 9 % and 12 % concentrations. The *IB* values of MDF ranged from 0.11 N/mm² to 0.16 N/mm². Although there was an increase in *IB* values due to the foaming process allowing better penetration of the adhesive into the fibers, statistically, there was no significant difference in *IB* values among the groups. MDFs produced using UF adhesive at concentrations of 10-13 % had *IB* values ranging from 0.10 to 0.32 N/mm² (Mohebby *et al*., 2008; Ashori *et al*., 2009).

The *MOR* and *MOE* results of MDFs containing foamed and unfoamed UF adhesive at 6, 9 and 12 % ratios are given in Figure 6.

As seen in Figure 6, the *MOR* value of 6 % unfoamed MDF was 15.62 N/mm², while the *MOR* value of 6 % foamed MDF was 18.08 N/mm². On the other hand, an increase in adhesive content also resulted in an increase in *MOR* values (23.33 N/mm² for 12 % Foamed MDF). When examining *MOR* values, it was generally observed that foamed MDF samples had

Table 1 Physical test results of produced MDFs
Tablica 1. Rezultati mjerenja fizičkih svojstava proizvedenih MDF ploča

Codes *Oznaka*	**Density, g/cm³** *Gustoća,* g/cm³	***MC*, %**	***TS*, % (2 h)**	***TS*, % (24 h)**	***WA*, % (2 h)**	***WA*, % (24 h)**
% 6 Unfoamed	0.78±0,07a	4.58±0.01a	11.53±1.91b	23.35±1.79c	21.17±5.06bc	43.61±9.20c
% 6 Foamed	0.79±0.03a	4.45±0.01a	11.08±1.99b	22.71±0.91c	22.10±7.63c	42.76±9.12c
% 9 Unfoamed	0.79±0.05a	4.54±0.06a	9.94±2.20ab	18.79±2.39b	20.96±5.21bc	40.35±5.31bc
% 9 Foamed	0.80±0.04a	4.37±0.1a	9.83±0.74ab	18.84±1.16b	17.40±2.74abc	32.19±4.17ab
% 12 Unfoamed	0.82±0.05a	4.29±0.7a	9.71±2.41ab	18.47±3.50b	14.86±2.94ab	30.75±5.31a
% 12 Foamed	0.80±0.05a	4.13±0.02a	8.23±0.97a	15.28±1.99a	11.39±3.26a	27.20±6.91a

Means followed by the same letters (*a*, *b*, *c*) in the same column are not significantly (p <0.05) different; ± Standard deviation.
Srednje vrijednosti iza kojih su ista slova (a, b, c) u istom stupcu nisu značajno različite (p < 0,05); ± označuje standardnu devijaciju.

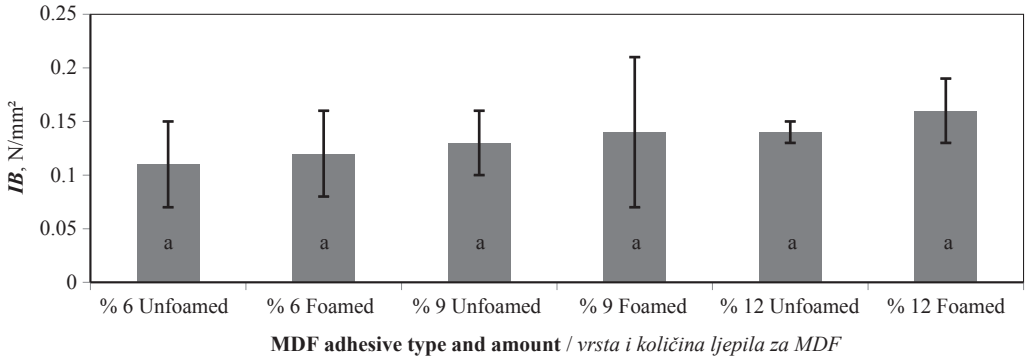


Figure 5 *IB* values of MDFs containing varying amounts of foamed and unfoamed adhesives (means with the same letters (a) in columns are not significantly ($p < 0.05$) different; standard deviation is given with error bars)
Slika 5. *IB* vrijednosti MDF ploča koje sadržavaju različite količine upjenjenoga i neupjenjenog ljepila; srednje vrijednosti s istim slovom (a) u stupcima nisu značajno različite ($p < 0,05$); trake pogrešaka predočuju standardnu devijaciju

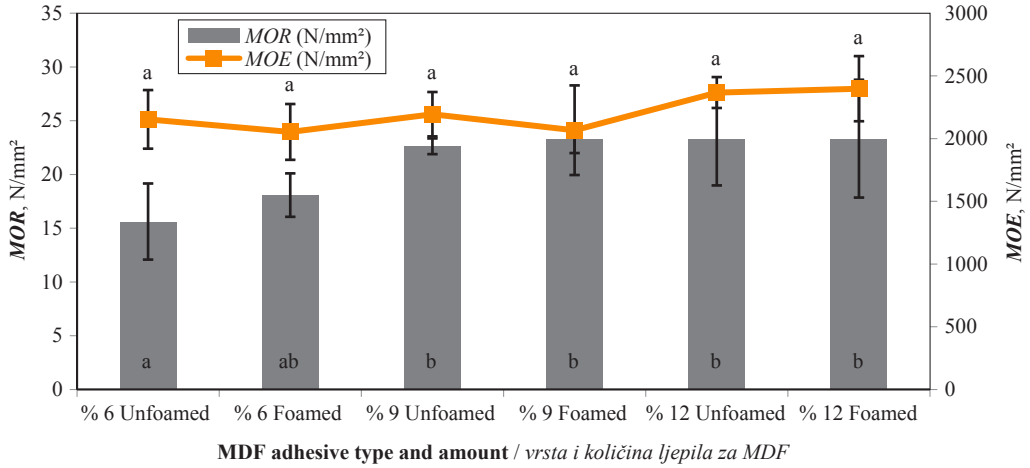


Figure 6 *MOR* and *MOE* values of MDFs containing varying amounts of foamed and unfoamed adhesives (means with the same letters (a, b) in columns are not significantly ($p < 0.05$) different; standard deviation is given with error bars)
Slika 6. *MOR* i *MOE* vrijednosti MDF ploča koje sadržavaju različite količine upjenjenoga i neupjenjenog ljepila; srednje vrijednosti s istim slovima (a, b) u stupcima nisu značajno različite ($p < 0,05$); trake pogrešaka označuju standardnu devijaciju

higher bending strength than unfoamed samples. There was a statistically significant difference among the groups, with the group produced with 6 % unfoamed adhesive showing the lowest result. Especially, it was observed that bending strength of foamed samples was increased at concentrations of 6, 9 and 12 %.

When evaluating *MOE* values, it was observed that foamed MDF samples generally had lower *MOE* values compared to unfoamed samples. This suggests that foamed MDF samples have slightly lower flexibility than unfoamed samples. However, statistically, there was no significant difference between them. This result indicates that the adhesive foamed with a commercial foam agent, by increasing its volume, strengthens the bonding between the fibers, thereby improving the mechanical properties of MDFs. In previous studies, MDFs produced using urea-formaldehyde adhesive at concentrations of 10-13 % had *MOR* and *MOE* values ranging from 12-21 N/mm² and 1400-2650 N/mm², respectively (Mohebby *et al*., 2008; Gul and Alrobei, 2021; Zamani *et al*., 2022). Foaming UF adhesives at different ratios in particleboard production led to an increase in *MOR* and *MOE* values, similar to the findings in the present study (Kelleci *et al*., 2022).

4 CONCLUSIONS
4. ZAKLJUČAK

This study investigated the effects of foamed and unfoamed versions of urea-formaldehyde (UF) adhesive at different ratios on Medium Density Fiberboard (MDF) production. Foamed and unfoamed MDF samples were produced by adding a commercial foam agent to UF adhesive at various ratios. The physical and mechanical properties of the produced MDF samples were examined. In terms of physical properties, unfoamed MDF samples exhibited higher density; however, the addition of the commercial foam agent and the foaming process reduced water absorption and thickness swelling. Foamed MDF samples showed increased resistance to water and exhibited less swelling thickness. Additionally, the addition of the commercial

foam agent contributed to enhanced water resistance in the produced MDFs. Regarding mechanical properties, foamed MDF samples generally demonstrated higher internal bond strength and bending strength compared to unfoamed samples. This suggests that the foamed adhesive strengthened the bonding between fibers, improving the mechanical durability of the MDF. However, the modulus of elasticity (*MOE*) of foamed MDF samples was generally lower than that of unfoamed samples, indicating a higher flexibility of the foamed samples.

In conclusion, the addition of a commercial foam agent and the use of foamed adhesive contributed to improvements in various physical and mechanical properties in MDF production. These results could facilitate the development of more efficient and environmentally friendly products in the MDF manufacturing industry. However, further studies and optimization efforts may help better understand the commercial applicability of this method.

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