Physical and Mechanical Properties of Fiberboard Produced with Shredded Waste Office Paper

Merve Engin * and Arif Caglar Konukcu

This study investigated the effects of shredded waste office paper as a raw material on the physical and mechanical properties of fiberboard. Two amounts of urea formaldehyde (UF) resin (10 and 15%) and five shredded waste office paper/wood fiber mixing ratios (0/100, 25/75, 50/50, 75/25, and 100/0) were selected. The findings showed that all characteristics of boards were improved with an increase in resin content at various wastepaper participation ratios. The 15% UF-bonded board with 100% wood fiber had the highest modulus of rupture (MOR) value, but there was no statistically significant difference between it and the board with 50% wastepaper. The modulus of elasticity (MOE) values of the 15% UF-bonded boards increased as the wastepaper participation ratio increased, and the highest was obtained from the board with 75% wastepaper. The highest internal bond (IB) strength value was also recorded from the 15% UF-bonded board with 50% wastepaper. This was due to the presence of sufficient bonding potential and smoother surfaces in the shredded wastepaper, which allowed for a synergistic interaction between the wastepaper and wood fiber.

DOI: 10.15376/biores.19.4.8642-8653

Keywords: Fiberboard; Shredded wastepaper; Wood fiber; Mechanical properties

*Contact information: Department of Forest Industrial Engineering, Faculty of Forestry, Izmir Katip Celebi University, Izmir 35620, Türkiye; *Corresponding author: merve.engin.demirok@ikcu.edu.tr*

INTRODUCTION

Wood-based panels are widely used in furniture production, interior design, building projects, and so on. In recent years, the demand for wood-based panels has significantly increased due to several factors, including population growth and urbanization (Worldometers 2024). As a result of the growth in the world's population and people's needs, the amount of waste is on the increase. Used paper-based products are one of the most important types of waste in this respect. The global market for wastepaper is significant, with millions of tons generated and traded annually. The consumption of paper and paperboard has increased by 126% over the last 20 years and is expected to reach 476 million tons by 2032. The recycling industry relies on wastepaper, which is collected around 300 to 350 million tons of wastepaper annually (Statista Research Department, 2024). On the other hand, the Food and Agriculture Organization (FAO) (2003) estimates that about 396.3 million m^3/year of wood-based panels are produced worldwide. However, the continued rise of the world population raises questions about the long-term viability of industrial production and natural resource conservation (Shmulsky and Jones 2019). Thus, sustainable forest management and the recycling of wood-based products have been critical in promoting environmentally friendly alternatives (MacDicken *et al.* 2015; Thonemann and Schumann 2018; Bütün *et al.* 2019; Faraca *et al.* 2019; Budzinski *et al.* 2020; Kunttu *et al.* 2020).

Research on fiberboards has concentrated on preserving forest resources through the use of by-products (Saadaoui *et al.* 2013). This subject is closely related to the idea of sustainability, which is gaining importance and is, therefore, the primary goal of numerous research applications. Wood fibers or other lignocellulosic fibers are used to make fiberboards, which are typically bound together with synthetic binders (Domínguez-Robles *et al.* 2020). Fiberboard offers stability and qualities unlike other wood-based panels, making it a superior alternative to particle board or plywood. Its machine-friendly, flat, robust, dense, and free-of knots properties make it a reliable choice. Fiberboard is gap-free, producing sharp edges without tearing out. Its diverse sizes and physical attributes allow for the precise construction of final products, such as insulation material that is commonly used in the building and construction industry with the desired density and fiberboard features (Awang *et al.* 2023; Gonçalves *et al.* 2021; Ormondroyd and Stefanowski 2015).

Numerous publications in the literature have investigated the physical and mechanical qualities of boards made from various wastepapers such as office paper, newspaper, cardboard, decorative coating paper, and cement bags in the current fiberboard production process (Krzysik *et al.* 1993; Hwang *et al.* 2005; Ayrilmis 2012; Olgun *et al.* 2014; Ramezanian Sani and Enayati 2020; De Castro Sales *et al.* 2021; Moezzipour and Moezzipour 2021). In addition to physical and mechanical qualities, research has been undertaken on the thermal conductivity and fire resistance of wastepaper-based fiberboards (Moezzipour and Moezzipour 2021). Ayrilmis (2012) explored resin-impregnated decorative and coating paper waste from dried paper edges as a binder in producing light-medium density fiberboard (MDF). The addition of impregnated paper waste significantly improved the dimensional stability, and coating paper had a more positive effect on the mechanical properties of lightweight MDF. Krzysik *et al.* (1993) studied the mechanical properties of fiberboards made from old newspapers and wood fibers using glue and wax. Results showed improvements in water absorption, thickness swelling, static bending, and tensile strength with increased glue use but decreased mechanical properties with increased newspaper usage. Krzysik *et al.* (1997) conducted a study on the production of medium-density fiberboard (MDF) in three different thicknesses using waste office paper fibers (30/70). The study found that waste office paper fibers can be recycled and used in low-thickness boards. Boards with greater thickness had lower mechanical properties and lower bending strength and elasticity modulus compared to the standards. Hwang *et al.* (2005) developed fiberboard using waste corrugated cardboard and wood fibers, finding that boards with over 40% recycled corrugated cardboard did not meet the standard values in resistance properties. In general, MDF and recycled fibers from paper waste appear to be suitable raw materials for producing insulation boards (Moezzipour and Moezzipour 2021). Relevant works have shown that the produced boards have acceptable mechanical properties and dimensional stability (Grigoriou 2003; Ayrilmis 2012; Moezzipour and Moezzipour 2021).

The fiberboard sector is struggling to meet rising demand while supplying wood raw materials. Wood-based waste materials may reduce virgin wood usage and production costs, thereby providing financial benefits to the fiberboard industry. Another important problem is the increasing amount of wastepaper generated by the population. In this study, the costs of reprocessing wastepaper were reduced by neglecting the pulping stage. Waste office papers, which were simply shredded to the average length of wood particles, were used in varying concentrations in board production. The mechanical properties of laboratory-made boards were compared using various ratios of wastepaper and resin.

EXPERIMENTAL

Materials

The fibers used in the laboratory-made board production were provided in their natural form, without additives, by Kastamonu Entegre MDF Gebze Factory (Kocaeli, Türkiye), and the fiber furnish consisted of 80% beech and 20% larch wood fiber mixtures. The urea-formaldehyde (UF) resin and ammonium sulfate ($(NH_4)_2SO_4$) hardener were provided by Yıldız Entegre Akhisar Facilities (Manisa, Türkiye). At 23.4 °C, the UF resin with 64.93% solid content had an F/U mole ratio of 1.15, a density of 1.28 g/cm^3, a pH of 7.91, and a viscosity of 84 cps. Waste office paper was also collected at the main campus of Katip Celebi University in Izmir, Türkiye. The shredded office paper was chopped into 2 × 15 mm bits using a paper shredder machine. Figure 1 depicts the shredded waste office paper and wood fibers utilized in the production of each board type. Prior to board production, the moisture level of wood fibers and shredded waste office paper was lowered between 3 to 5%. The items were enclosed in plastic bags to keep the moisture from reacting with the environment. The papers had an average grammage of 80 g/m^2 and a density of 0.75 g/cm^3.

Fig. 1. Shredded waste office paper and wood fiber used in this study

Board Manufacturing

The fiberboards including wastepaper were produced using different ratios of wood fiber mixtures (wt/wt) to shredded waste office paper (0/100, 25/75, 50/50, 75/25, and 100/0). Figure 2 depicts the general manufacturing process of a single-layered fiberboard that contains shredded waste office paper. The production of the boards was planned as 9 mm thick and 750 kg/m^3 density, and these boards were produced using a hydraulic hot press of the laboratory type (CEMILUSTA SSP-180 T Model, Istanbul, Türkiye). The experimental design is displayed in Table 1. The UF resin was combined with each type of board using a mechanical mixer with a 30-rpm rotor. Resin content was applied at two different levels (10 and 15%). The 320 × 360 mm mold was used to manually form the board mats. After that, the mats were heated to 170 °C for five minutes using a hydraulic hot press that was operating at 3 MPa of pressure. Figure 3 displays a general overview of the boards produced for this study. The boards were conditioned for two weeks at 20 °C and 65% relative humidity before testing.

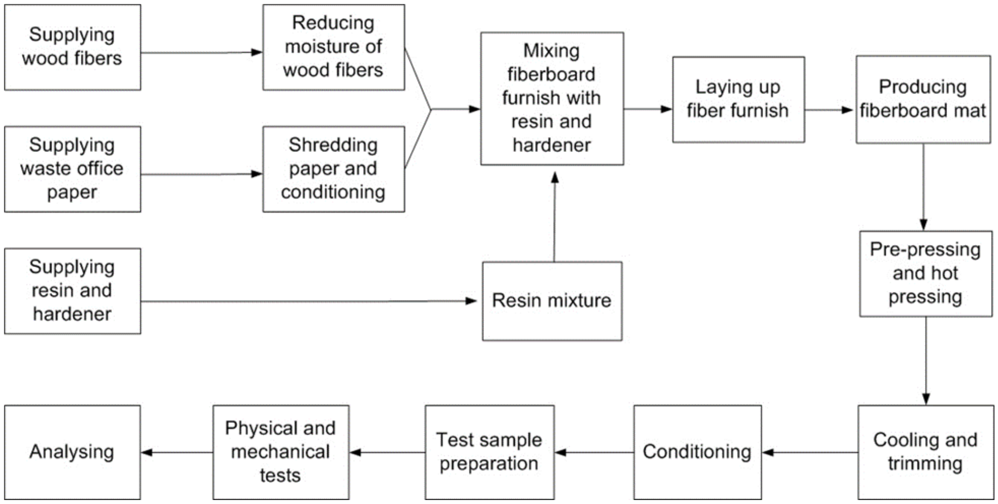

Fig. 2. General manufacturing process of a fiberboard containing shredded waste office paper

Table 1. Experimental Design of the Study

Resin Content (%)	Waste office paper ratio (%)	Wood fiber ratio (%)	Board type
10	0	100	A1
	25	75	A2
	50	50	A3
	75	25	A4
	100	0	A5
15	0	100	B1
	25	75	B2
	50	50	B3
	75	25	B4
	100	0	B5

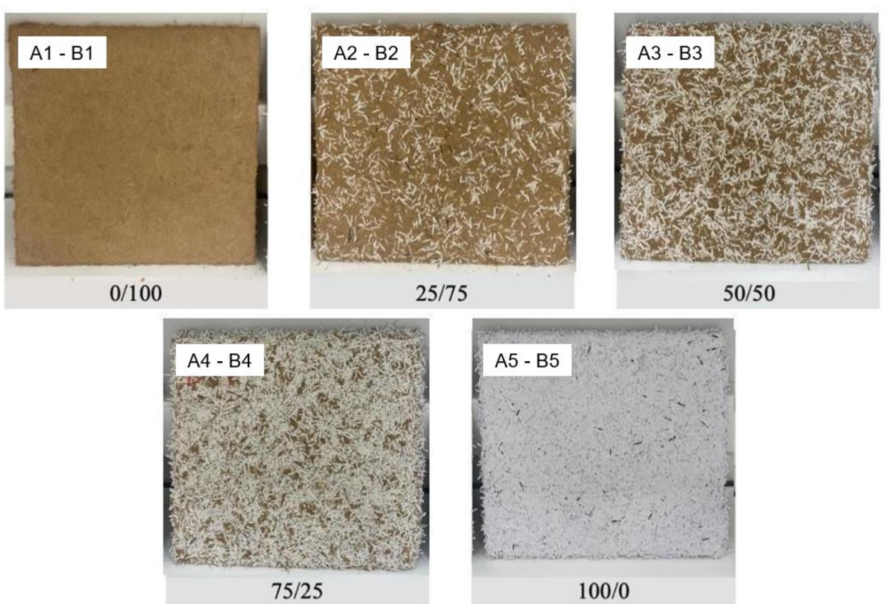

Fig. 3. An overview of the boards showing five different ratios of shredded waste office paper to wood fiber mixtures (wt/wt): 0/100, 25/75, 50/50, 75/25, and 100/0

Physical and Mechanical Testing

After the boards were cut to the necessary test size in compliance with European Norm (EN) guidelines, their mechanical and physical qualities were examined. The EN 322 (1993) and EN 323 (1993) standards were used to determine the moisture content and density of the boards, respectively. Based on the EN 317 (1999) standard, measurements of thickness swelling (TS) and water absorption (WA) were also made following 2 and 24 h of submersion in water. The bending strength (MOR) and modulus of elasticity (MOE) for the mechanical properties were calculated using the EN 310 standard (1994), and the internal bond (IB) strength was calculated using the EN 319 standard (1999). A universal test machine called IMAL IB600 was used to conduct the tests. Ten test specimens of each type of board were used for the physical and mechanical tests.

Statistical Analyses

The statistical software SAS 9.4 was used to conduct statistical analyses. A two-way analysis of variance (ANOVA) with a 95% confidence level was used to assess the effects of the resin content and the ratios of wood fibers to shredded waste office paper on the characteristics of boards. Using Duncan's multiple range test, significant differences between the mean values of the different board types were also determined.

RESULTS AND DISCUSSION

Table 2 shows the physical properties of each type of board, including thickness, density, TS (2 to 24 h), and WA (2 to 24 h) mean values.

Table 2. Mean Values of Physical Properties of the Boards Containing Shredded Waste Office Paper

Board type	Thickness (mm)	Density (kg/m^3)	2h TS (%)	24h TS (%)	2h WA (%)	24h WA (%)
A1	8.34 (0.13)	799 (61.22) abc	57.77 (5.07) a	68.14 (4.87) a	98.54 (9.70) a	111.92 (9.39) a
A2	8.43 (0.25)	724 (44.43) d	33.48 (1.52) b	36.23 (2.31) bc	85.86 (9.79) b	95.65 (10.40) bc
A3	8.29 (0.19)	768 (45.57) c	30.97 (2.17) b	33.40 (3.35) bc	83.25 (8.75) bc	89.20 (8.16) cd
A4	8.27 (0.29)	800 (46.73) abc	32.44 (3.79) b	35.01 (4.55) bc	81.04 (3.86) bcd	86.38 (3.43) cde
A5	8.60 (0.37)	779 (20.19) bc	33.98 (2.79) b	38.89 (1.94) b	98.49 (3.05) a	101.16 (3.07) b
B1	8.16 (0.22)	794 (35.36) abc	32.65 (1.17) b	37.10 (1.08) bc	73.92 (4.47) cde	83.71 (4.33) def
B2	8.31 (0.33)	806 (32.60) abc	32.01 (3.38) b	35.02 (4.35) bc	70.01 (4.71) de	80.12 (5.15) def
B3	8.35 (0.33)	819 (46.63) ab	29.06 (2.39) b	31.72 (3.14) c	66.90 (6.38) e	73.33 (6.27) f
B4	8.17 (0.11)	826 (30.15) a	30.15 (1.83) b	32.20 (1.53) c	71.41 (2.63) de	74.85 (1.96) ef
B5	8.61 (0.14)	801 (27.14) abc	33.17 (1.92) b	34.22 (2.51) bc	84.64 (4.28) bc	86.19 (4.29) cde

Values in parentheses are standard deviations; means not followed by a common lowercase letter in the same column are significantly different from another at the 5% significance level

The average densities of the boards ranged from 724 to 826 kg/m^3, whereas their average thicknesses varied from 8.16 to 8.61 mm. The highest thicknesses were observed on the boards containing 100% wastepaper for both resin ratios (10 and 15%). The different compressibility qualities of paper and wood fiber materials are the primary cause of the variation in the thickness of produced boards, even though all boards are subjected to the same variables during the production process. Based on raw material content, 100% paper-based boards have higher thickness values than those containing wood fibers because of the incompressible properties of paper material (Holmstad *et al.* 2001).

Tables 2 and 3 summarize the TS and WA mean values of each board type and their statistical comparison, respectively. Both the resin content and the waste office paper/wood fiber mixing ratios significantly impacted the boards' physical characteristics, according to the findings of the ANOVA test. The interaction between the variables for 2 and 24 hours of TS was also significant, while the interaction was not for 2 and 24 hours of WA. The results show that increasing the resin content from 10% to 15% generally improved the boards' physical characteristics. It can also be clearly stated that when the amount of wastepaper in the board increased, the TS and WA abilities of the boards decreased compared to the boards with 100% wood fiber (A1 and B1). However, the TS values of the board types produced for this study did not meet the requirements of EN 622-5 (2009) (Table 4).

Paper particles interact better with wood fiber particles in comparison to interactions between pairs of wood particles due to their smoother surfaces and higher bonding potential; as a result, a significant portion of the paper surface is covered in wood fibers. The tendency of the paper particles to absorb water is thereby partially reduced. This might also result from the shredded waste papers not being subjected to a deinking process; as a result of the ink and hydrophobic chemicals seen on the surface of the paper material (Bolanča *et al.* 2012). As the rate of paper material usage increased, contrary to expectations, the TS and WA values of the boards decreased (Grigoriou 2003; Nourbakhsh and Ashori 2010).

Table 3. Summary of Two-way ANOVA Test Results on the Effects of Shredded Paper Ratio and Resin Content n on Properties of Fiberboard (p values)

Variable	Density	Physical Properties				Mechanical Properties		
		2h TS	24h TS	2h WA	24h WA	MOR	MOE	IB
Resin content	0.0003*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*
Fiber/Paper ratio	0.0252*	<.0001*	<.0001*	0.0006*	0.0003*	<.0001*	<.0001*	<.0001*
Resin content x Fiber/Paper ratio	0.0409*	<.0001*	<.0001*	0.3724	0.2228	0.0003*	0.0279*	0.0001*

*Indicates significance at 0.05

The mean comparisons of MOR and MOE for each type of board are shown in Figs. 4 and 5, respectively. The boards' average MOR ranged from 12.57 to 31.32 MPa, while their average MOE ranged from 1684 to 3410 MPa. The MOR and MOE values of the boards were significantly affected by the resin content, waste office paper/wood fiber mixing ratios, and their interaction, as indicated by the results of the ANOVA test (Table 3). According to earlier research, higher MOR and MOE values were obtained when the resin content of the boards containing wastepaper increased (Okino *et al.* 2000; Grigoriou

2003; Rassam 2008; Eshraghi and Khademieslam 2012). Due to the increased resin content of the boards, similar results were observed in this study.

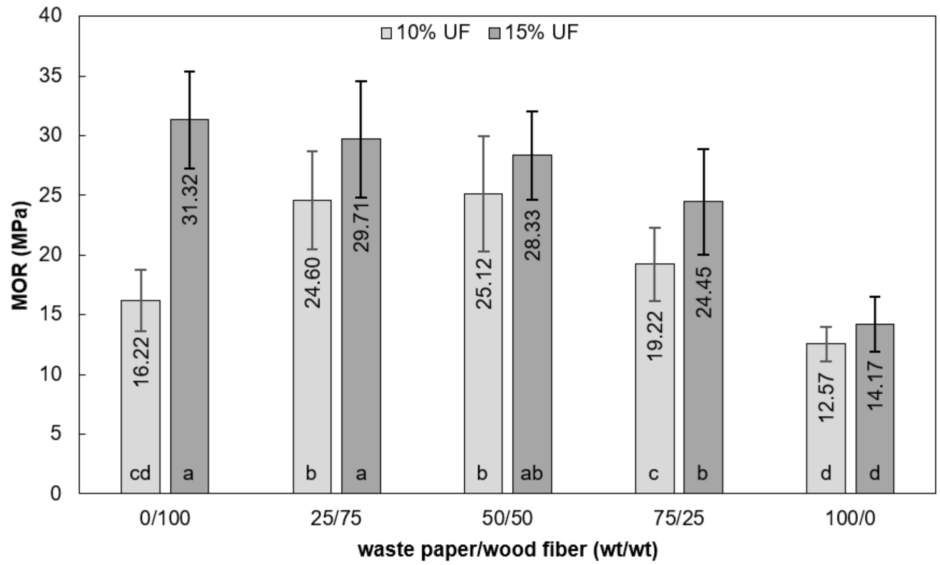

Fig. 4. Bending strength (MOR) comparisons between different board types using five different ratios of shredded waste office paper (0/100, 25/75, 50/50, 75/25, and 100/0) to fiber mixtures (wt/wt). The distinct lowercase letters denote a significant difference at the 5% significance level

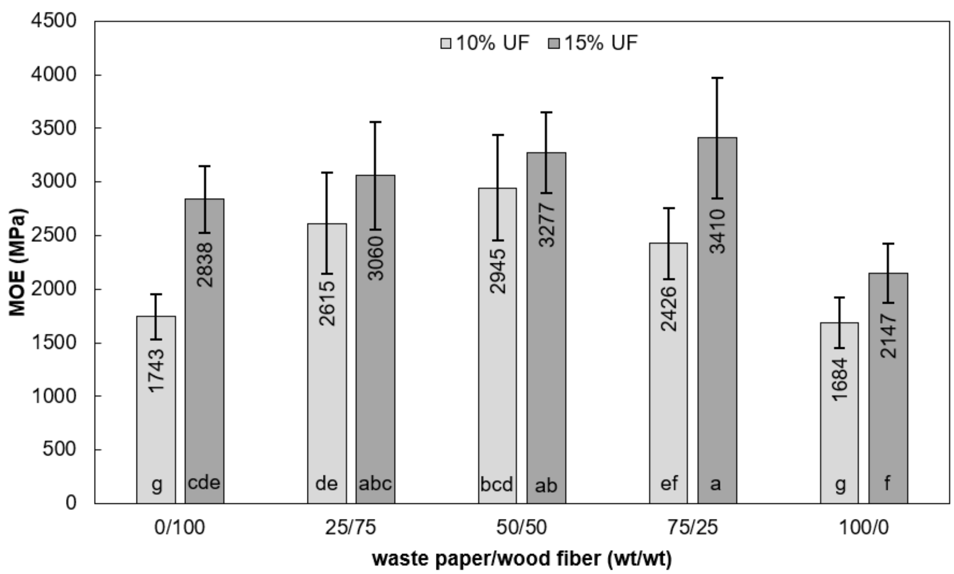

Fig. 5. Modulus of elasticity (MOE) comparisons between different board types using five different ratios of shredded waste office paper (0/100, 25/75, 50/50, 75/25, and 100/0) to fiber mixtures (wt/wt). The distinct lowercase letters denote a significant difference at the 5% significance level

An increment in MOR values was observed when up to 50% wastepaper was added to the 10% UF-bonded board (A2 and A3). Furthermore, the board with 75% wastepaper (A4) had a higher MOR value than the board with 100% wood fiber content (A1), even though their MOR values decreased. No statistically significant difference was found between the board with 100% wood fiber content (A1) and the board with 75% wastepaper (A4). In general, the MOR values of the 15% UF-bonded boards were found to be higher than those of the 10% UF-bonded boards, and the MOR values of the boards decreased as the wastepaper participation ratio increased. Although the 15% UF-bonded board with 100% wood fiber (B1) had the highest MOR value of 31.32 MPa, there was no statistically significant difference between the 15% UF-bonded boards with 100% wood fiber, 25%, and 50% wastepaper (B1, B2, and B3). According to the European Standard (EN 622-5 2009), the minimum requirements for fiberboards are listed in Table 4. The 10% UF-bonded boards with 25% and 50% wastepaper (A2 and A3) and the 15% UF-bonded board with 75% wastepaper (B4) satisfied the minimum requirements for non-load-bearing boards for use in dry conditions, whereas the 15% UF-bonded boards with 25% and 50% wastepaper (B2 and B3) met the minimum requirements for load-bearing boards for use in dry conditions.

Table 4. Minimum Requirements for MDF at a Nominal Thickness of > 6 to 9 mm (EN 622-5 2009)

Classifications	Bending Strength (MOR) MPa	Modulus of Elasticity (MOE) MPa	Internal Bond (IB) MPa	Thickness Swelling (TS) %
Non-load-bearing boards for use				
in dry conditions	23.0	2700	0.65	17
in humid conditions	27.0	2700	0.80	12
Load-bearing boards for use				
in dry conditions	29.0	3000	0.70	17
in humid conditions	34.0	3000	0.80	12

The 10% UF-bonded board with 50% wastepaper (A3) had the highest value at 2945 MPa, whereas the board with 100% wastepaper (A5) had the lowest MOE value. The MOE values increased along with the addition of up to 50% wastepaper to the 10% UF-bonded boards as well, as seen by the MOR values (A2 and A3). Even though their MOE values had dropped with 75% wastepaper content, the board with 75% wastepaper content (A4) had a statistically higher MOE value than the board with 100% wood fiber content (A1). In general, the MOE values of the 15% UF-bonded boards increased as the wastepaper participation ratio increased to 75%. The highest MOE value was observed on the board containing 75% wastepaper with 3410 MPa. However, statistical analysis revealed no significant difference between the 15% UF-bonded boards with 25%, 50%, and 75% wastepaper (B2, B3, and B4). According to the European Standard (EN 622-5 2009), the 10% UF-bonded boards with 50% wastepaper (A3) satisfied the minimum requirements for non-load-bearing boards for use in dry and humid conditions, whereas the 15% UF-bonded boards with 25%, 50%, and 75% wastepaper (B2, B3, and B4) met the minimum requirements for load-bearing boards for use in dry and humid conditions (Table 4).

The mean comparisons of IB for each type of board are shown in Fig. 6. The variables (waste office paper/wood fiber mixing ratios and resin content), as well as their interaction, were found to have a significant effect on the IB value of the boards, according to the ANOVA test results (Table 3). Higher IB values were obtained as the resin content increased. Additionally, the IB value of the boards generally increased with up to 50% in the wastepaper content increment, regardless of the two resin ratios (10% and 15%). This result can be explained by the fact that the smoother surfaces and increased bonding potential of shredded waste office paper, allowing them to interact better with wood fibers and cover the paper surface with many more fibers. However, this had a negative effect when the paper participation ratio was over 50% in the board. Thus, there were relatively higher IB values as paper usage increased up to 50%. The 10% UF-bonded board containing 100% wood fiber had the lowest value with 0.09 MPa, whereas the 15% UF-bonded board containing 50% wastepaper had the highest IB value with 0.29 MPa. It was observed that there was no statistically significant difference found between the boards with 25% and 50% wastepaper (B2 and B3), even though the 15% UF-bonded boards had the highest IB value when the wastepaper content was increased up to 50%. Nevertheless, none of the board types produced for this study met the minimum requirements of EN 622-5 (2009) (Table 4).

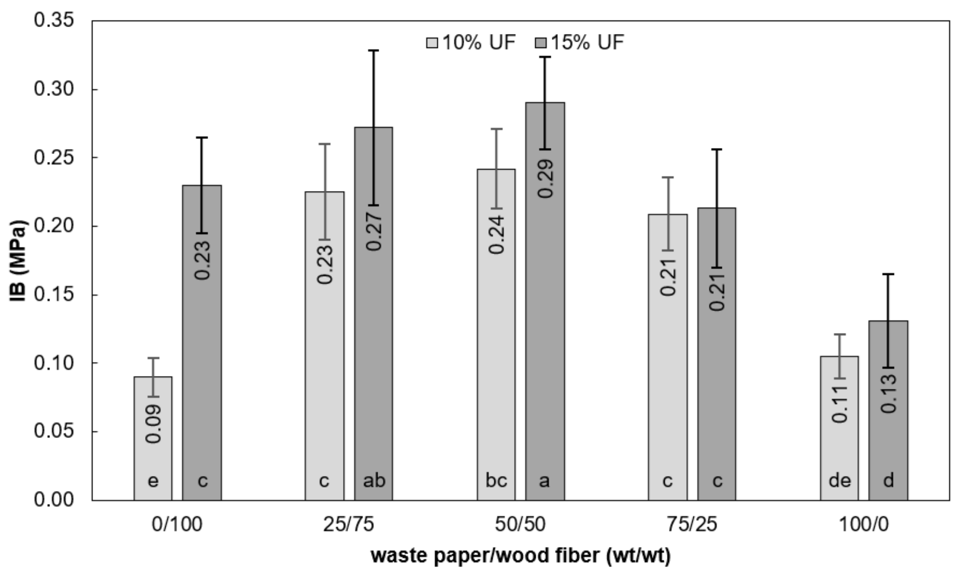

Fig. 6. Internal bond (IB) strength comparisons between different board types using five different ratios of shredded waste office paper (0/100, 25/75, 50/50, 75/25, and 100/0) to fiber mixtures (wt/wt). The distinct lowercase letters denote a significant difference at the 5% significance level

CONCLUSIONS

1. The physical and mechanical properties of boards made from a mixture of shredded paper and wood fiber showed improvements with an increase in resin content at various wastepaper participation ratios.
2. The 15% urea-formaldehyde (UF)-bonded board with 100% wood fiber (B1) had the highest modulus of rupture (MOR) value, but the 15% UF-bonded boards with 100% wood fiber, 25%, and 50% wastepaper (B1, B2, and B3) did not differ statistically significantly from one another.
3. The modulus of elasticity (MOE) values of 15% UF-bonded boards increased with a 75% wastepaper participation ratio, but no significant difference was found between the boards with 25%, 50%, and 75% wastepaper (B2, B3, and B4).
4. The internal bond (IB) values of the boards significantly increased up to 50% wastepaper participation ratio regardless of the two resin ratios (10% and 15%). This outcome can be explained by the harmonious bond between wood fiber material and

wastepaper, facilitated by the smoother surfaces and increased bonding potential of shredded waste papers.

5. When the proportion of shredded wastepaper was increased by up to 50%, the resulting boards' IB values increased. Possible explanations for this shift included changes in bonding interactions and structural surface variations of the raw materials made from wastepaper and wood fiber. Shredded wastepaper interacted better with wood fiber particles due to their smoother surfaces and higher bonding potential, resulting in a significant portion of the paper surface being covered in wood fibers. This partially reduced the thickness swelling (TS) and water absorption (WA) values.
6. All board types had higher TS and WA values, and these boards did not meet the minimum requirements of EN 622-5 standard, even though the study's variables had a statistically significant impact on the boards' physical characteristics. It was concluded that dry indoor use was more appropriate for them.

ACKNOWLEDGMENTS

The authors thank Kastamonu Entegre Gebze Factory in Kocaeli, Türkiye for the wood fibers and Yıldız Entegre Akhisar Facilities in Manisa, Türkiye for the resin and hardener utilized in the board preparation. The authors are also grateful for the support of the Scientific Research Project Fund of Izmir Katip Celebi University, Project No: 2022-GAP-ORMF-0028.

REFERENCES CITED

Awang, R., Wahab, N. A., Ibrahim, Z., and Aziz, A. A. (2023). "Medium density fibreboard (MDF) from oil palm fibre: A review," *Malaysian Journal of Analytical Sciences* 27(3), 626-640.

Ayrilmis, N. (2012). "Enhancement of dimensional stability and mechanical properties of light MDF by adding melamine resin impregnated paper waste," *International Journal of Adhesion and Adhesives* 33, 45-49. DOI: 10.1016/j.ijadhadh.2011.11.001

Bolanča Mirković, I., Majnarić, I., and Bolanča, S. (2012). "Recycling optimisation of the electrophotographic prints," in: *8th International Conference of DAAAM Baltic Industrial Engineering*, Tallin, Estonia, pp. 119-124.

Budzinski, M., Bezama, A., and Thrän, D. (2020). "Estimating the potentials for reducing the impacts on climate change by increasing the cascade use and extending the lifetime of wood products in Germany," *Resources, Conservation & Recycling: X* 6, article 100034. DOI: 10.1016/j.rcrx.2020.100034

Bütün, F. Y., Sauerbier, P., Militz, H., and Mai, C. (2019). "The effect of fibreboard (MDF) disintegration technique on wood polymer composites (WPC) produced with recovered wood particles," *Composites Part A: Applied Science and Manufacturing* 118, 312-316. DOI: 10.1016/j.compositesa.2019.01.006

De Castro Sales, D., Cabral, A. E., and Medeiros Jr., M. S. (2021). "Development of fiberboard panels manufactured from reclaimed cement bags," *Journal of Building Engineering* 34, article 101525. DOI: 10.1016/j.jobe.2020.101525

Domínguez-Robles, J., Tarrés, Q., Alcalà, M., El Mansouri, N. E., Rodríguez, A., Mutjé,

P., and Delgado-Aguilar, M. (2020). "Development of high-performance binderless fiberboards from wheat straw residue," *Construction and Building Materials* 232, article 117247. DOI:10.1016/j.conbuildmat.2019.117247
EN 323 (1993). "Wood-based panels – Determination of density," European Committee for Standardization, Brussels, Belgium.
EN 310 (1994). "Wood-based panels – Determination of modulus of elasticity in bending and of bending strength," European Committee for Standardization, Brussels, Belgium.
EN 322 (1993). "Wood-based panels – Determination of moisture content," European Committee for Standardization, Brussels, Belgium.
EN 622-5 (2009). "Fibreboards – Specifications - Part 5: Requirements for dry process boards (MDF)," European Committee for Standardization, Brussels, Belgium.
Eshraghi, A., and Khademieslam, H. (2012). "Waste paperboard in composition panels," *Cellulose Chemistry and Technology* 46(9–10), 637-642.
FAO. (2023). *World Food and Agriculture – Statistical Yearbook 2023*, Rome. DOI: 10.4060/cc8166en
Faraca, G., Boldrin, A., and Astrup, T. (2019). "Resource quality of wood waste: The importance of physical and chemical impurities in wood waste for recycling," *Waste Management* 87, 135-147. DOI: 10.1016/j.wasman.2019.02.005
Gonçalves, D., Bordado, J. M., Marques, A. C., and Galhano dos Santos, R. (2021). "Non-formaldehyde, bio-based adhesives for use in wood-based panel manufacturing industry—A review," *Polymers* 13(23), 4086. DOI: 10.3390/polym13234086
Grigoriou, A. H. (2003). "Waste paper-wood composites bonded with isocyanate," *Wood Science and Technology* 37(1), 79-89.
Holmstad, R., Antoine, C., Silvy, J., Costa, A. P., and Antoine, J. (2001). "Modelling the paper sheet structure according to the equivalent pore concept," *Proceedings from the Cost Action E11–Characterisation Methods for Fibres and Paper* 15, 25.
Hwang, C. Y., Hse, C. Y., and Shupe, T. F. (2005). "Effects of recycled fiber on the properties of fiberboard panels," *Forest Products Journal* 55(11), 60-64.
Krzysik, A. M., Youngquist, J. A., and Bowers, H. (1997). "Medium density fiberboard panels from waste wood and paper," *Drewno-Material Ekologiczny Warszawa* 18-19.
Krzysik, A. M., Youngquist J. A., Rowell R. M., Muehl J. H., Chow P., and Shook S. R., (1993). "Feasibility of using recycled newspapers as a fiber source for dry-process hardboards," *Forest Products Journal* 43(7-8), 53-58.
Kunttu, J., Hurmekoski, E., Heräjärvi, H., Hujala, T., and Leskinen, P. (2020). "Preferable utilisation patterns of wood product industries' by-products in Finland," *Forest Policy and Economics* 110, article 101946. DOI: 10.1016/j.forpol.2019.101946
MacDicken, K., Jonsson, Ö., Piña, L., Maulo, S., Contessa, V., Adikari, Y., and D'Annunzio, R. (2015). "Global forest resources assessment 2015: How are the world's forests changing?," (https://openknowledge.fao.org/server/api/core/bitstreams/29b8ae23-99f9-4a05-b796-9a35d02af29d/content), Accessed 01 March 2024.
Moezzipour, B., and Moezzipour, A. (2021). "Thermal behavior of insulation fiberboards made from MDF and paper wastes," *Wood Industry/Drvna Industrija* 72(3), 245-254.
Nourbakhsh, A., and Ashori, A. (2010). "Particleboard made from waste paper treated with maleic anhydride," *Waste Management and Research* 28(1), 51-55. DOI: 10.1177/0734242X09336463

Okino, E. Y. A., Santana, M. A. E., and de Souza, M. R. (2000). "Utilization of wastepaper to manufacture low density boards," *Bioresource Technology* 73(1), 77-79. DOI: 10.1016/S0960-8524(99)00146-7

Ormondroyd, G. A., and Stefanowski, B. (2015). "Fibreboards and their applications," in: *Wood Composites,* Woodhead Publishing, Amsterdam, Netherlands. DOI: 10.1016/B978-1-78242-454-3.00005-6

Rassam, G. (2008). "Use of soy/PF resin for old corrugated container (OCC)-wood composites," *Materials Letters* 62(17-18), 3236-3239. DOI: 10.1016/j.matlet.2008.02.030

Saadaoui, N., Rouilly, A., Fares, K., and Rigal, L. (2013). "Characterization of date palm lignocellulosic by-products and self-bonded composite materials obtained thereof," *Materials & Design* 50, 302-308. DOI: 10.1016/j.matdes.2013.03.011

Shmulsky, R., and Jones, P. D. (2019). *Forest Products and Wood Science: An Introduction,* Wiley-Blackwell, England.

Statista Research Department. (2024). "Global paper and paperboard consumption 2021-2032", (https://www.statista.com/statistics/1089078/demand-paper-globally-until-2030/#statisticContainer), accessed 8 August 2024.

Thonemann, N., and Schumann, M. (2018). "Environmental impacts of wood-based products under consideration of cascade utilization: A systematic literature review," *Journal of Cleaner Production* 172, 4181-4188. DOI: 10.1016/j.jclepro.2016.12.069

Worldometers. (2024). "World Population," (https://www.worldometers.info/world-population), Accessed 01 March 2024.

Article submitted: July 8, 2024; Peer review completed: August 2, 2024; Revised version received: August 23, 2024; Accepted: September 13, 2024; Published: September 25, 2024.
DOI: 10.15376/biores.19.4.8642-8653