Shredded Waste Office Paper as a Component with Wood Particles in the Production of Particleboard

Arif Caglar Konukcu,* and Merve Engin

The effect of shredded waste office paper was considered when producing one-layered particleboard. Five different mixing ratios of shredded waste office paper/wood particles were used (0/100, 25/75, 50/50, 75/25, and 100/0) and two amounts of urea formaldehyde (UF) resin (10% and 15%). The boards were tested for their physical and mechanical properties, including modulus of elasticity (MOE), bending strength (MOR), and internal bond (IB) strength, in accordance with the European Norm (EN) standards. All properties of the boards were found to be improved *via* increasing the resin content. The 15% UF-bonded board with 100% wood particles had the highest MOR, whereas the board containing 100% wastepaper for 15% UF had the highest MOE. However, there was no statistical difference between the board types. Although increasing wastepaper content in the board negatively affected the IB, the usage of wastepaper up to 25% was shown to be acceptable as a raw material in the production of particleboard. None of the prepared boards met the EN 312 (1999) requirements for thickness swelling. The boards made from shredded waste office paper were more suitable for dry and indoor use.

DOI: 10.15376/biores.19.3.5935-5948

Keywords: Particleboard; Shredded wastepaper; Wood particle; Mechanical properties

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

INTRODUCTION

The demand for wood-based boards has experienced significant growth globally in recent years; this trend has been driven by various factors such as urbanization, population growth (Worldometers 2024), and increasing construction activities (Aksel and Çetiner 2020). The versatile and cost-effective particleboards are extensively used in furniture manufacturing, interior design, and construction projects (Radiant Insights 2019). This surge in demand has led to a considerable expansion in particleboard production capacities worldwide (Gupta 2024). According to the Food and Agriculture Organization (FAO), the amount of wood-based board production in the world is approximately 396.3 million m^3/year (FAO 2023). However, the continuous growth of the global population raises concerns about the sustainability of industrial production and the preservation of natural resources (Shmulsky and Jones 2019). Fortunately, environmental awareness and new approaches offer opportunities to reduce natural resource use and slow climate change, which are becoming priorities for global states and institutions. Thus, the issues of sustainable forest management (MacDicken *et al.* 2015) and recycling of wood-based products (Thonemann and Schumann 2018; Bütün *et al.* 2019; Faraca *et al.* 2019; Budzinski *et al.* 2020; Kunttu *et al.* 2020) have been crucial for reducing greenhouse gas emissions and promoting environmentally friendly solutions (Çelik 2020).

Particleboard is a panel product made from lignocellulosic materials, primarily in the form of discrete wood particles, which are mixed with a synthetic resin or other suitable binder and bonded together using heat and pressure (US EPA 2002). To support environmentally friendly approaches, various high-quality waste materials have been used in particleboard production (Sejati *et al.* 2020; Chaydarreh *et al.* 2021; Hidayat *et al.* 2022; de Souza *et al.* 2023). Wastepaper can also be used as a raw material in the production of particleboard (Clad 1970). Wastepaper can yield different results than wood particles as raw materials for wood-based composites. For example, Gerischer (1977) added waste kraft paper pieces to the board to yield better strength properties. Although the produced boards had lower density than wood-based boards, they exhibited higher bending strength.

Many studies have been conducted to investigate the effects of wastepaper and corrugated paper board (OCC) ratios and the resin used as binders, on the properties of boards containing wastepaper and wood particles (Grigoriou 2003; Nicewicz *et al.* 2006; Taramian *et al.* 2007; Rassam 2008; Abdolzadeh and Doosthoseini 2009; Nourbakhsh and Ashori 2010; Eshraghi and Khademieslam 2012; Dukarska *et al.* 2018). In general, increasing the resin ratio in the board content has led to higher modulus of rupture/bending strength (MOR) and modulus of elasticity (MOE) values (Grigoriou 2003; Rassam 2008; Eshraghi and Khademieslam 2012). Except for screw holding strength, substituting wood particles with mixed wastepaper pieces in amounts of up to 50% has been shown to improve the mechanical properties of boards, making them acceptable for special indoor usages (Grigoriou 2003). In terms of properties, nearly all low-density boards containing wastepaper outperformed low-density commercial fiberboards. Furthermore, while magazine paper is thought to be of higher quality than newspaper and office paper, the dense filler content resulted in boards of lower strength (Okino *et al.* 2000). The results of Rassam's research (2008) showed that increasing the amount of old corrugated cardboard (OCC) decreased the thickness, swelling, and internal bond (IB) characteristics, but had no significant effect on bending strength. The boards produced with 50% OCC and 10% resin met the external conditions of use specified in the standards (Rassam 2008).

As can be observed from studies on the production of particleboard containing wastepaper, it is possible to substitute office wastepaper for wood particles in board production. Recycling office wastepaper is a cheaper alternative to wood composite materials because it has lower operating costs than wood and wood-based composite production (Grigoriou 2003; Nourbakhsh and Ashori 2010).

A search of the literature showed that there are many studies on the use of recovered paper in particleboard production. However, in most of them, the wastepaper was used as sludge (Taramian *et al.* 2007) and pulp (Abdolzadeh and Doosthoseini 2009; Eshraghi and Khademieslam 2012) or in the form of particles called flake (Grigoriou 2003; Rassam 2008; Nourbakhsh and Ashori 2010). In this study, the wastepaper was neither pulped, nor subjected to a process that requires extra costs, such as deinking and cleaning, nor was it used in the form of very large pieces. Instead, wood particle size was taken into consideration, such that the wastepaper was chopped into smaller and equal particles. Through filling the areas that would normally form gaps between wood particles, a near-homogeneous paper and wood particle distribution within the thickness and crosswise direction of boards was achieved. Thus, the load transmission within the boards was improved and the mechanical strength values of the boards were increased. As a result, in cases where wood particle and paper sizes are similar, the mechanical strength values of the board obtained from using these two raw materials together in different proportions and the synergistic effect of the raw materials on load transmission were examined.

EXPERIMENTAL

Materials

Wood particles, urea-formaldehyde (UF) resin, and ammonium sulfate $(NH_4)_2SO_4$ hardener were provided by Yıldız Entegre Akhisar Facilities in Manisa, Türkiye. Wood particles were made from a mixture of 100% pine wood species (*Pinus brutia*, *Pinus nigra*, and *Pinus sylvestris*). The bulk density value of a pile of wood particles is given as 0.183 g/cm^3 in Table 1. The UF resin with a solid content of 64.93% had a 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 at 23.4 °C. Waste office paper was also collected from the main campus of Katip Celebi University in Izmir, Türkiye. A paper shredder machine was used to cut the waste office paper into 2 × 15 mm^2 pieces. Figure 1 shows the shredded waste office paper and wood particles used for the manufacturing of each board type. Prior to manufacturing boards, the moisture content of the wood particles and shredded waste office paper was reduced to approximately 3% to 5%. The materials were sealed in plastic bags to prevent their moisture content from interacting with the environment. The papers had an average grammage of 80 gr/m^2 and an apparent density was calculated as approximately 0.6 gr/cm^3 according to ISO 534 (2011) standard. Some characteristics of the materials used in this study are shown in Table 1.

Table 1. Characteristics of Wood Particles and Shredded Waste Office Papers Used in this Study

Material	Length (mm)	Width (mm)	Thickness (mm)	Slenderness Ratio	Bulk Density (g/cm^3)
Wood particles	27.83 (9.25)	3.86 (1.73)	1.32 (0.38)	21.08	0.183 (0.01)
Office papers	15.91 (0.43)	2.44 (0.12)	0.07 (0.01)	214.29	0.058 (0.01)

Mean values of 100 particles and values in parentheses are standard deviations

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

Board Manufacturing

The general manufacturing process of one-layered particleboard containing shredded waste office paper is shown in Fig. 2. One-layered boards with a thickness of 10 mm and a target density of 650 kg/m^3 were manufactured on a laboratory-type hydraulic hot press (Cemilusta SSP-180 T Model, Istanbul, Türkiye). The boards were made of various ratios (0/100, 25/75, 50/50, 75/25, and 100/0) of shredded waste office paper to wood particle mixtures (wt/wt). Table 2 shows the experimental design of the study. Each of the board types in this study was mixed with urea-formaldehyde (UF) resin using a mechanically operated mixer with a rotor speed of 30 rpm. Two levels of resin content (10% and 15%) were used. The board mats were manually formed inside a mould with dimensions of 320 × 360 mm^2. The mats were then pressed for 5 min at 170 °C using a hydraulic hot press with a pressure of 3 MPa. A general view of the boards manufactured in this study is shown in Fig. 3. Before testing, the boards were conditioned at 20 °C and 65% relative humidity for two weeks.

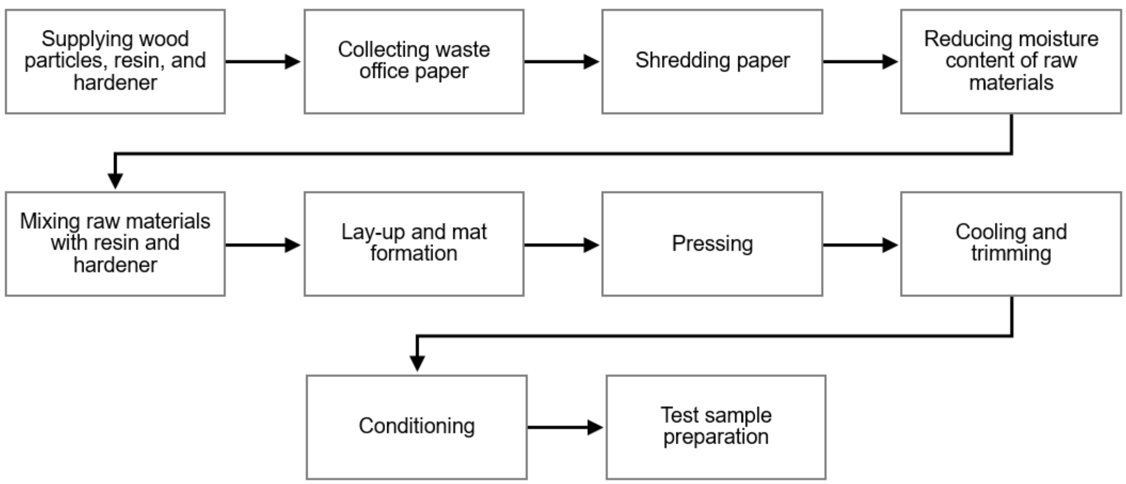

Fig. 2. The general manufacturing process of a one-layered particleboard containing shredded waste office paper

Table 2. Experimental Design of the Study

Resin Content (%)	Waste Office Paper Ratio (%)	Wood Particles 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

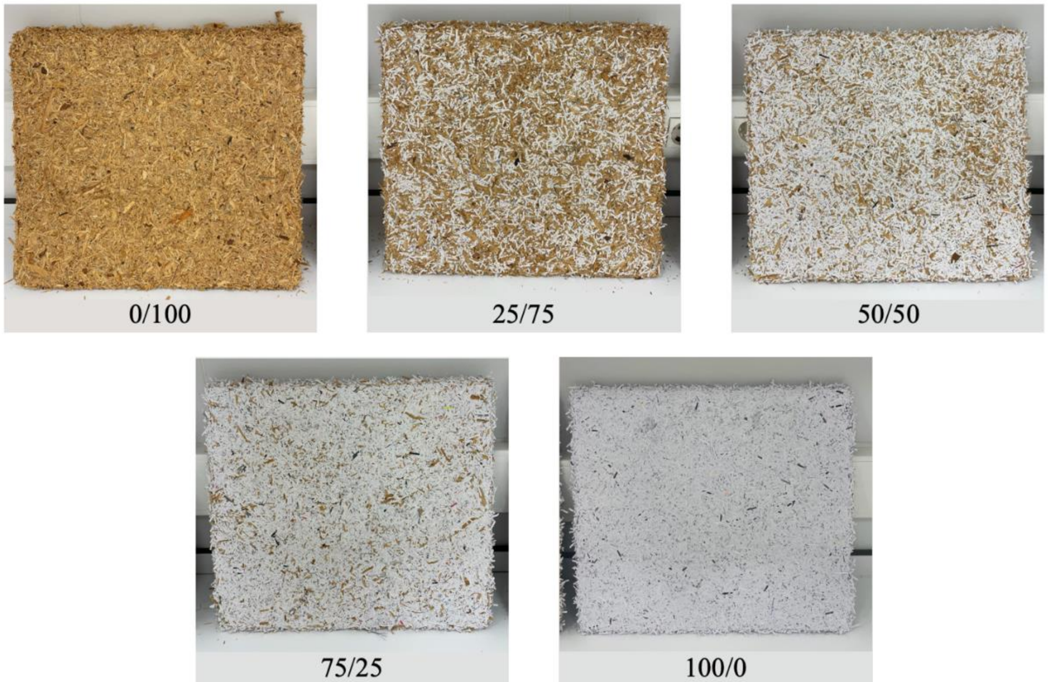

Fig. 3. A general view of the boards with five ratios (0/100, 25/75, 50/50, 75/25, and 100/0) of shredded waste office paper to wood particle mixtures (wt/wt)

Physical and Mechanical Testing

The manufactured boards were tested for physical and mechanical properties after being cut to the required test size in accordance with the European Norm (EN) standards. Moisture content and density of the boards were determined according to the EN 322 (1993) and EN 323 (1993) standards, respectively. Thickness swelling (TS) and water absorption (WA) after 2 h and 24 h of immersion in water were also measured based on the EN 317 (1999) standard. For the mechanical properties, the EN 310 (1994) standard was used to determine the bending strength MOR and MOE; and the IB strength was determined according to the EN 319 (1999) standard. The tests were performed on an IMAL IB600 universal test machine. In this study, ten replicate specimens of each board type were used to provide a mean value for each type of physical and mechanical test.

Statistical Analyses

Statistical analyses were performed with the SAS 9.4 statistical software. The effects of resin content and mixing ratios of wood particles to shredded waste office paper on the properties of the boards were evaluated by a two-way analysis of variance (ANOVA) at a 95% confidence level. Significant differences among the mean values of board types were also carried out using Duncan's multiple range test.

RESULTS AND DISCUSSION

The physical properties of each board type are presented in Table 3. The average densities of the boards ranged from 628 to 843 kg/m^3. In general, the density of the boards increased with an increasing participation ratio of the wastepaper. This can be explained by the fact that the paper material has a thin profile and a smooth surface that can be analyzed in two dimensions: machine direction (MD) and crosswise direction (CD), and when pressed, it compresses easily due to its structural properties. As a result, when wastepaper material is converted into manufacturing boards, it is easily compressed and has fewer pores along the thickness direction. This results in lower thickness values for distances between the surface boundaries of paper boards, as seen in the board types containing 100% wastepaper (A5 and B5 in Table 3). The lower thickness values lead to higher density values at a given board weight. However, as the pores between wood particles along the board thickness direction increase, the thickness value of the board increases at a given weight and smaller values are observed in the density value of the boards, similar to the board types containing 100% wood particles (A1 and B1 in Table 3).

Table 3. Mean Values of Physical Properties of the Boards Containing Shredded Waste Office Paper

Board Type	Thickness (mm)	Density (kg/m^3)	2 h TS (%)	24 h TS (%)	2 h WA (%)	24 h WA (%)
A1	10.96 (0.21)	628 (27.98)	21.46 (0.67) f	25.48 (1.28) e	82.53 (1.54) c	89.91 (2.91) b
A2	9.99 (0.23)	710 (35.64)	41.16 (2.46) cb	48.67 (4.58) b	90.74 (5.56) b	98.78 (6.09) a
A3	9.46 (0.43)	707 (28.56)	51.74 (2.28) a	58.55 (5.84) a	95.35 (3.61) ab	101.10 (2.33) a
A4	9.38 (0.28)	770 (34.02)	44.41 (1.67) b	54.87 (3.65) a	91.31 (1.72) b	98.44 (3.60) a
A5	8.51 (0.19)	809 (25.82)	33.98 (2.79) d	38.89 (1.94) d	98.49 (3.05) a	101.16 (3.07) a
B1	9.58 (0.26)	734 (31.07)	25.91 (0.37) e	35.04 (3.28) d	49.57 (1.39) f	63.80 (1.77) e
B2	10.05 (0.41)	712 (21.45)	32.93 (1.35) d	40.79 (2.34) cd	66.06 (1.71) e	80.39 (0.62) cd
B3	9.45 (0.18)	760 (24.70)	39.06 (1.48) c	45.72 (3.04) bc	73.99 (3.58) d	84.95 (5.92) bc
B4	9.26 (0.33)	771 (41.08)	33.86 (3.32) d	40.44 (4.19) cd	70.99 (2.22) de	77.68 (4.55) d
B5	8.52 (0.11)	628 (27.98)	33.17 (1.92) d	34.22 (2.51) d	84.64 (4.28) c	86.19 (4.29) bc

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

The TS and WA mean values of each board type and their statistical comparisons are shown in Tables 3 and 4, respectively. Based on the ANOVA test results, both variables, waste office paper/wood particle mixing ratios and resin content, had a significant effect on the physical properties of the boards. The interaction between the variables was also significant for each physical property except for 24 h of WA. However, none of the board types made in this study met the EN 312 (1999) requirements for the TS (Table 5). In general, the results indicate that the TS and WA values of the boards increased with an increasing participation ratio of the wastepaper. This occurred because shredded paper had a substantially larger surface area per unit of weight than wood particles because of its wide and thin structures. As a result of wastepaper containing less adhesive per surface area compared to wood particles, the swelling of the board increased (Grigoriou 2003; Nourbakhsh and Ashori 2010).

Table 4. Summary of Two-way ANOVA Test Results on the Effects of Shredded Paper Ratio and Resin Content on Properties of Particleboard (*P* values)

Variable	Physical Properties				Mechanical Properties		
	2h TS	24h TS	2h WA	24h WA	MOR	MOE	IB
Resin content	<0.0001*	0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
Wood/Paper ratio	<0.0001*	<0.0001*	<0.0001*	<0.0001*	0.0017*	0.0311*	<0.0001*
Resin content × Wood/Paper ratio	<0.0001*	<0.0001*	0.0008*	0.1434	0.2723	0.9946	<0.0001*

*Indicates significance at 0.05

Figures 4 and 5 show the mean comparisons of MOR and MOE values for each board type, respectively. In general, the average MOR for the boards ranged from 10.02 to 15.16 MPa, whereas the average MOE ranged from 1445 to 2147 MPa. According to the ANOVA test results, both variables, waste office paper/wood particle mixing ratios and resin content, had a significant effect on the MOR and MOE values of the boards. However, the interaction of the variables was not significant (see Table 4). Previous studies also reported that increasing the resin content in the board material resulted in higher MOR and MOE values (Okino *et al.* 2000; Grigoriou 2003; Rassam 2008; Eshraghi and Khademieslam 2012).

The 10% UF-bonded board with 25% wastepaper (A2) had a minimum MOR of 10.02 MPa; however, no statistically significant difference was found for the 10% UF-bonded boards with 25%, 50%, and 75% wastepaper (A2, A3, and A4). Although the 15% UF-bonded board with 100% wood particles (B1) had the highest MOR value of 15.16 MPa, there was no statistically significant difference between the 15% UF-bonded boards with 100% wood particles, 75%, and 100% wastepaper (B1, B4, and B5). According to the European Standard (EN 312 1999), the minimum requirements for particleboards are listed in Table 5. The MOR of the boards containing different amounts of wastepaper satisfied the minimum requirements for general purpose (P1) and interior fitments (including furniture) (P2).

The minimum MOE value was obtained from the board containing 50% wastepaper for 10% UF (A3) with 1445 MPa. However, no statistically significant difference was found between the 10% UF-bonded boards. In general, increasing the amount of UF resin resulted in much higher MOE values for the boards. The board containing 100% wastepaper for 15% UF (B5) had the highest MOE value, 2147 MPa. Even though the MOE values decreased in 15% UF-bonded boards containing 25% and 50% wastepaper (B2 and B3) at 1897 and 1889 MPa, respectively, it was observed that there was no statistical difference between the 15% UF-bonded board types. According to the European Standard (EN 312 1999) the MOE of the 10% UF-bonded boards only met the minimum requirements for general purpose (P1), whereas the 15% UF-bonded boards satisfied the requirements for general purpose (P1), interior fitments (including furniture) (P2), and non-load-bearing boards (P3).

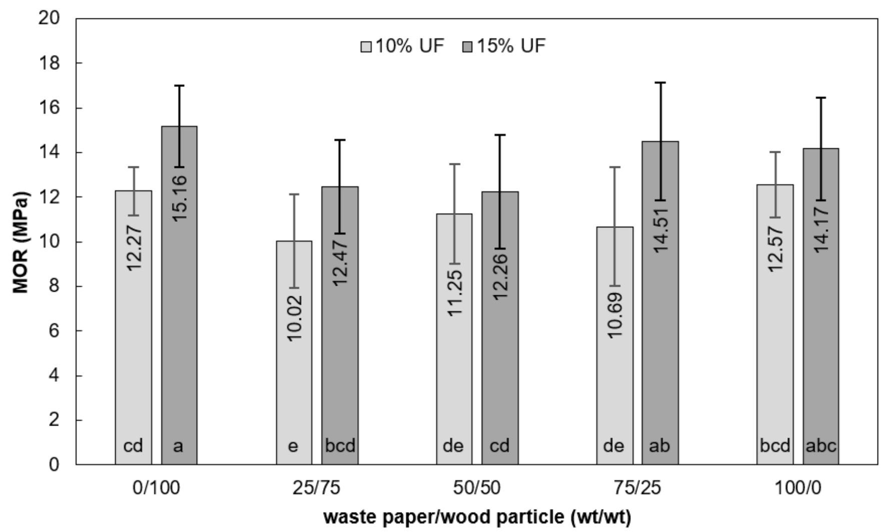

Fig. 4. Comparisons of bending strength (MOR) of board types made with five ratios (0/100, 25/75, 50/50, 75/25, and 100/0) of shredded waste office paper to wood particle mixtures (wt/wt). Different lowercase letters indicate a significant difference one from another at the 5% significance level.

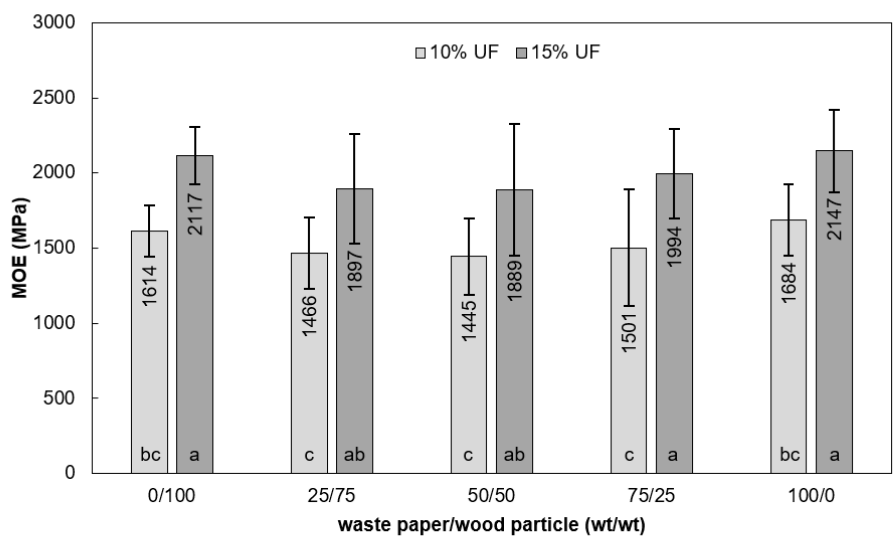

Fig. 5. Comparisons of modulus of elasticity (MOE) of board types made with five ratios (0/100, 25/75, 50/50, 75/25, and 100/0) of shredded waste office paper to wood particle mixtures (wt/wt). Different lowercase letters indicate a significant difference one from another at the 5% significance level.

Figure 6 shows the mean comparisons of IB for each board type. Based on the ANOVA test results, it was found that both variables (waste office paper/wood particle mixing ratios and resin content) and their interaction had a significant effect on the IB value of the boards (see Table 4). Based on the European Standard (EN 312 1999), the IB of the 15% UF-bonded boards only met the minimum requirements for general purpose (P1), whereas the boards containing 25% wastepaper for both resin ratios (10% and 15%) satisfied the requirements for general purpose (P1), interior fitments (including furniture) (P2), non-load-bearing (P3), and load-bearing boards (P4 and P5). The IB value of the boards generally decreased with increasing wastepaper content, regardless of the two resin ratios (10% and 15%). This result is explained by the fact that shredded paper had a lower resin coverage and less bonding ability than wood particles due to its larger surface area. Similar results were observed in other boards that included OCC and wood particles (Rassam 2008). Resin absorption showed differences in its effect on the material, even when the same amounts were used for boards with different material contents. Due to the higher amount of paper particles, the total surface area of the paper materials was higher than the total surface area of the wood particles. Therefore, the amount of resin corresponding to the surface area of one unit of paper particle in the board was less than the amount of resin corresponding to one unit of wood particle. Therefore, it is expected that internal bond values will decrease as the paper content on the board increases.

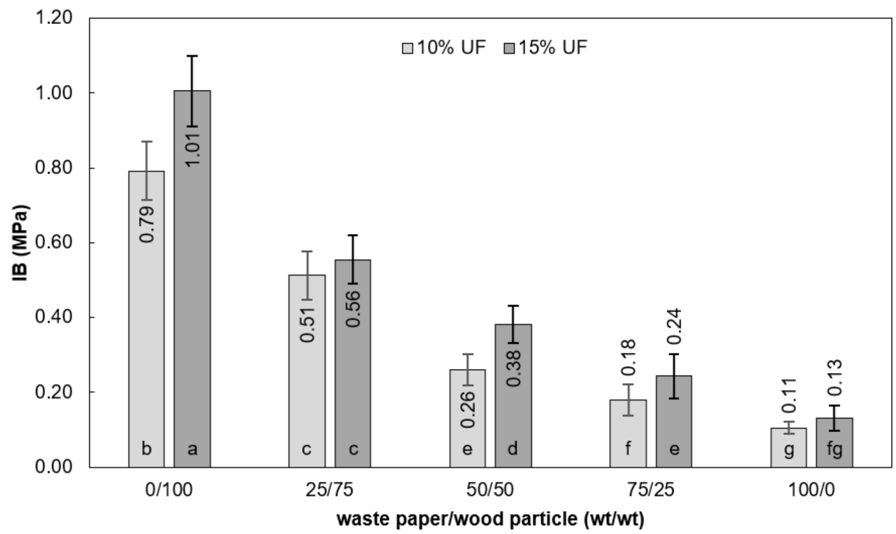

Fig. 6. Comparisons of internal bond (IB) strength of board types made with five ratios (0/100, 25/75, 50/50, 75/25, and 100/0) of shredded waste office paper to wood particle mixtures (wt/wt). Different lowercase letters indicate a significant difference one from another at the 5% significance level.

Figure 7 shows general representative views of wood particles, wastepaper, and pore distribution across the thickness section of the board types with five ratios (0/100, 25/75, 50/50, 75/25, and 100/0) of shredded waste office paper to wood particle mixtures (wt/wt). It is apparent that pore sizes significantly decreased while the wastepaper content of the board increased. As shown in the enlarged figures of the thickness sections of the produced boards, the height and distribution of the pores between the wood particles was greater than the pores between the paper particles. However, in the boards made entirely or primarily of wood particles (Figs. 7a and 7b) the width and height of the pores were more visible. These pores not only reduce the board's density values but also reduce the stress distribution within the board, influencing its mechanical properties such as MOR and MOE. The wastepaper has a flat and larger surface area than wood particles, thus it helps in the uniform distribution of stresses generated by mechanical loading within the board by filling the pores between the wood particles. As a result, boards containing 25%, 50%, and 75% wastepaper had lower mechanical properties than those containing 100% wastepaper or 100% wood particles, but the differences were not statistically significant.

Table 5. Minimum Performance Requirements for All Particleboard Types According to EN 312 (1999)

Classifications	Bending Strength (MOR) MPa	Modulus of Elasticity (MOE) MPa	Internal Bond (IB) MPa	Thickness Swelling (TS) %
General-purpose boards for use in dry conditions (P1)	10.5	-	0.28	-
Boards for interior fitments (including furniture) for use in dry conditions (P2)	11.0	1800	0.40	-
Non-load-bearing boards for use in humid conditions (P3)	15.0	2050	0.45	17
Load-bearing boards for use in dry conditions (P4)	16.0	2300	0.40	19
Load-bearing boards for use in humid conditions (P5)	18.0	2550	0.45	13
Heavy-duty load-bearing boards for use in dry conditions (P6)	20.0	3150	0.60	16
Heavy-duty load-bearing boards for use in humid conditions (P7)	22.0	3350	0.75	10

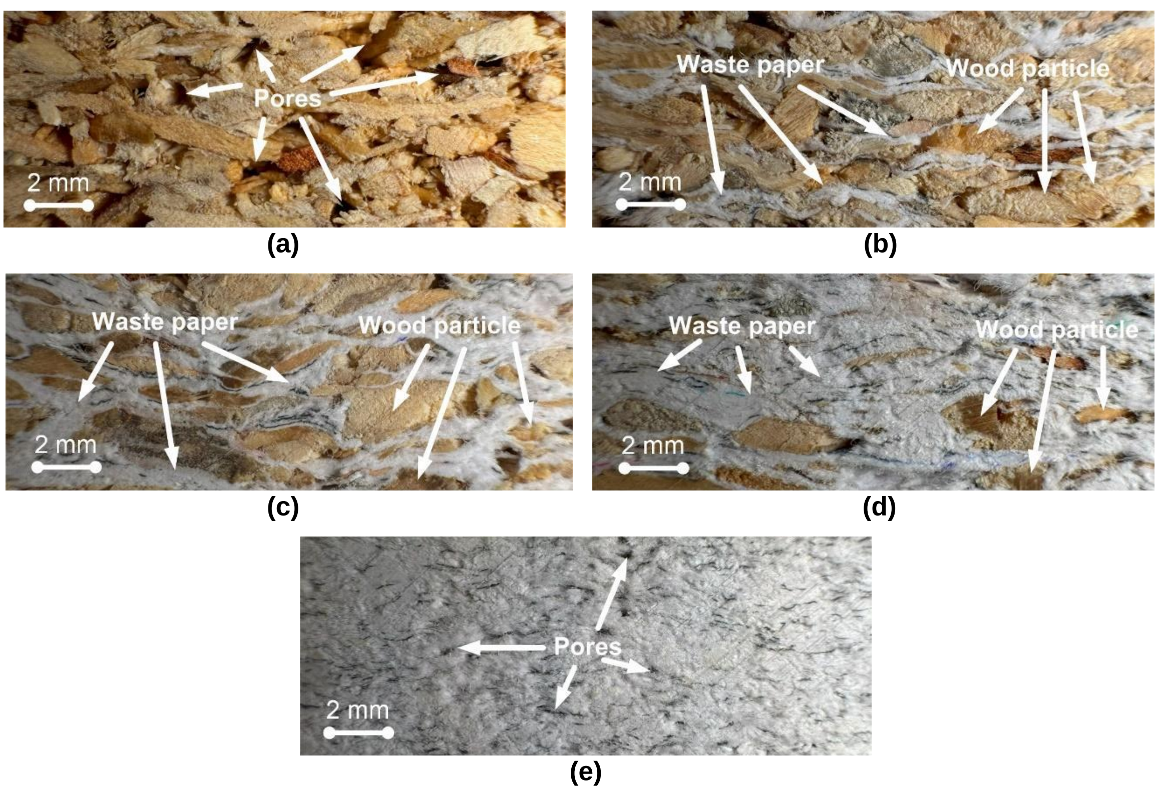

Fig. 7. The general representative views of wood particles, wastepaper, and pore distribution across the thickness section of laboratory-made boards: 0/100 (a), 25/75 (b), 50/50 (c), 75/25 (d), and 100/0 (e) of shredded waste office paper to wood particle mixtures (wt/wt)

CONCLUSIONS

In this study, laboratory-made boards were prepared into two groups with five different mixing ratios and urea-formaldehyde (UF) resin contents of 10% and 15%, and their structural and mechanical properties were investigated. Based on the results, the following conclusions were drawn:

1. In general, the physical and mechanical properties of the board improved with an increase in resin content.
2. The thickness swelling (TS) and water absorption (WA) values of the boards increased in the boards containing a combination of paper and wood particles (25/75, 50/50, and 75/25). Although the variables used in this study had a statistically significant effect on the physical properties of the boards, none of the boards met the EN 312 (1999) requirements. Therefore, it was determined that they were more suitable for dry and indoor use.
3. Although the board containing 100% wood particles for 15% UF (B1) had the highest modulus of rupture (MOR) value, there was no statistically significant difference between 15% UF-bonded boards with 100% wood particles, 75%, and 100% wastepaper (B1, B4, and B5).
4. The board containing 100% wastepaper for 15% UF (B5) had the highest modulus of elasticity (MOE) value, even though the boards containing a combination of paper and wood particles (25/75, 50/50, and 75/25) had lower MOE values. Nevertheless, no statistically significant difference was seen between the 15% UF-bonded board types.
5. The study demonstrated, in an approximate fashion, the importance of the distribution of pores between paper and wood particles within boards. Changes in mechanical values have been linked to variations in load transfer inside the boards, depending on their content.
6. As the wastepaper ratio increased, the internal bond (IB) values of the boards decreased, regardless of the two resin ratios (10% and 15%). This outcome can be explained by the fact that, because of its larger surface area, shredded paper has less resin coverage and bonding ability than wood particles.
7. Even though adding more wastepaper to the board had a negative impact on the IB, using up to 25% of the wastepaper as a raw material for particleboard production was found to be acceptable. When the importance of IB values is neglected, the boards containing up to 75% wastepaper can be preferred for insulation and decorative applications.

ACKNOWLEDGMENTS

The authors would like to thank Yıldız Entegre Akhisar Facilities in Manisa, Turkey, for providing wood particles, resin, and hardener used in the preparation of the boards. The authors are also grateful for the support of the Scientific Research Project Fund of Izmir Katip Celebi University, Project No: 2022-GAP-ORMF-0022.

REFERENCES CITED

Abdolzadeh, H., and Doosthoseini, K. (2009). "Evaluation of old corrugated container and wood fiber application on surface roughness of three-layer particleboard," *BioResources* 4(3), 970-978. DOI: 10.15376/biores.4.3.970-978

Aksel, H., and Çetiner, İ. (2020). "Construction waste management practices on-sites: A case study of Istanbul city," *Environmental Research and Technology* 3(2), 50-63. DOI: 10.35208/ert.723002

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 and Recycling: X* 6, article ID 100034. DOI: 10.1016/j.rcrx.2020.100034

Bütün, F. Y., Sauerbier, P., Militz, H., and Mai, C. (2019). "The effect of fiberboard (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

Chaydarreh, K. C., Lin, X., Guan, L., Yun, H., Gu, J., and Hu, C. (2021). "Utilization of tea oil camellia (*Camellia oleifera* Abel.) shells as alternative raw materials for manufacturing particleboard," *Industrial Crops and Products* 161, article ID 113221. DOI: 10.1016/j.indcrop.2020.113221

Clad, W. (1970). "Über die Mitverwendung von Altpapier für die Herstellung von Spanplatten (About the use of waste paper for the production of chipboard)," *Holz als Roh-und Werkstoff* 28(3), 101-104. DOI: 10.1007/BF02615705

Çelik, S. İ. (2020). "Yerküremiz ısınırken bireysel inisiyatiflerin gücü (The power of individual initiatives as our planet warms)," *Tübitak Bilim ve Teknik* 53632, 14-31.

de Souza, M. J. C., de Melo, R. R., Guimarães Junior, J. B., Mascarenhas, A. R. P., de Oliveira Paula, E. A., Pedrosa, T. D., Maskell, D., Mensah, P., and Rodolfo Junior, F. (2023). "Eco-friendly particleboard production from coconut waste valorization," *Environmental Science and Pollution Research* 30(6), 15241-15252. DOI: 10.1007/s11356-022-23273-5

Dukarska, D., Buszka, K., and Modzelewska, I. (2018). "Kraft scrap paper pulp as a substitute of wood chips in manufacture of particleboards resinated with hybrid PF/pMDI resin," *Maderas: Ciencia y Tecnologia* 20(2), 161-170. DOI: 10.4067/S0718-221X2018005002101

EN 310 (1994). "Wood-based panels – Determination of modulus of elasticity in bending and of bending strength," European Committee for Standardization, Brussels, Belgium.

EN 312 (1999). "Particleboards – Specifications," European Committee for Standardization, Brussels, Belgium.

EN 317 (1999). "Particleboards and fiberboards – Determination of swelling in thickness after immersion in water," European Committee for Standardization, Brussels, Belgium.

EN 319 (1999). "Particleboards and fiberboards – Determination of tensile strength perpendicular to the plane of the board," European Committee for Standardization, Brussels, Belgium.

EN 322 (1993). "Wood-based panels – Determination of moisture content," European Committee for Standardization, Brussels, Belgium.

EN 323 (1993). "Wood-based panels – Determination of density," 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.

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

Gerischer, G. (1977). "Structural particleboard from waste materials," *Holzforschung* 31(4), 129-133. DOI: 10.1515/hfsg.1977.31.4.129

Grigoriou, A. H. (2003). "Wastepaper-wood composites bonded with isocyanate," *Wood Science and Technology* 37(1), 79-89.

Gupta, S. (2024). "Particle board market research report information by raw material," (https://www.marketresearchfuture.com/reports/particle-board-market-8650), Accessed 01 March 2024.

Hidayat, W., Aprilliana, N., Asmara, S., Bakri, S., Hidayati, S., Banuwa, I. S., Lubis, M. A. R., and Iswanto, A. H. (2022). "Performance of eco-friendly particleboard from agro-industrial residues bonded with formaldehyde-free natural rubber latex adhesive for interior applications," *Polymer Composites* 43(4), 2222-2233. DOI: 10.1002/pc.26535

ISO 534 (2011). "Paper and board - Determination of thickness, density and specific volume," International Organization for Standardization, Geneva, Switzerland.

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 ID 101946. DOI: 10.1016/j.forpol.2019.101946

MacDicken, K., Jonsson, Ö., Piña, L., Maulo, S., Contessa, V., Adikari, Y., and D'Annunzio, R. (2016). "Global forest resources assessment 2015: How are the world's forests changing?," (https://agris.fao.org/agris-search/search.do?recordID=XF2017001127), Accessed 01 March 2024.

Nicewicz, D., Pawlicki, J., Borysiuk, P., and Zado, A. (2006). "Application of wastepaper in manufacturing of particleboards," *Acta Scientiarum Polonorum, Silvarum Colendarum Ratio et Industria Lignaria* 5(1), 163-171.

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

Radiant Insights (2019). "Particle board market is expected to witness significant growth attributed to increasing opportunities and prospects by 2022," (www.prnewswire.com), Accessed 01 March 2024.

Sejati, P. S., Kusumah, S. S., Dwianto, W., and Surjasa, D. (2020). "Modification of rice biomass wastes for eco-friendly particleboard," in: *IOP Conference Series: Earth and Environmental Science* 572, article ID 012005. DOI: 10.1088/1755-1315/572/1/012005

Shmulsky, R., and Jones, P. D. (2019). *Forest Products and Wood Science: An Introduction*, 6th Ed., Wiley-Blackwell, England.

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

Taramian, A., Doosthoseini, K., Mirshokraii, S. A., and Faezipour, M. (2007). "Particleboard manufacturing: An innovative way to recycle paper sludge," *Waste Management* 27(12), 1739-1746. DOI: 10.1016/j.wasman.2006.09.009

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

US EPA (2002). "Particleboard manufacturing," in: *Wood Products Industry*, AP 42, Vol. I, 5th Ed., United States Environmental Protection Agency, Washington D.C., USA.

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

Article submitted: June 4, 2024; Peer review completed: June 30, 2024; Revised version received and accepted: July 8, 2024; Published: July 16, 2024.
DOI: 10.15376/biores.19.3.5935-5948