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Determination of Physical and Mechanical Properties of Waste Paper Boards Supported by Wood Chips and Chopped E-glass Fiber

Određivanje fizičkih i mehaničkih svojstava ploča izrađenih od otpadnog papira i ojačanih drvnim iverjem te usitnjenim staklenim vlaknima

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ABSTRACT • *Today, legal regulations, along with social awareness, have made waste management a necessity. Depending on the type of waste, technological developments have enabled an increase in the number of approaches, e.g., reusing, recycling, and manufacturing of different products. In this study, low-density boards were produced using different proportions of office waste paper, wood chips, and chopped E-glass fiber. Waste paper and glass fiber formed the middle layer of the boards and wood chips comprised the surface layers. The density, water absorption, and thickness swelling properties of the boards were investigated. Among the mechanical properties, the modulus of rupture, modulus of elasticity, and internal bond strength were determined. The use of wastepaper led to a reduction in the modulus of rupture and modulus of elasticity of the boards. An increase in the glass fiber ratio contributed positively to the water absorption and thickness swelling properties, whereas it directly led to decreases in the internal bond strength, and the modulus of rupture and modulus of elasticity values. Nonetheless, the low-density boards were able to meet the minimum modulus of rupture and modulus of elasticity specified in ANSI 208.1 standards, while only one variation met the IB requirements.*

KEYWORDS: *office waste paper; paper board; wood chips; chopped glass fiber*

SAŽETAK • *U današnje je vrijeme zakonska regulativa, uz društvenu svijest, gospodarenje otpadom učinila nužnošću. Ovisno o vrsti otpada, tehnološki je razvoj omogućio povećanje broja pristupa gospodarenju otpadom, npr. pri ponovnoj uporabi, recikliranju i proizvodnji različitih proizvoda. Za ovo su istraživanje izrađene ploče niske gustoće s različitim udjelima otpadnoga uredskog papira, drvnog iverja i usitnjenih staklenih vlakana. Pritom su otpadni papir i usitnjena staklena vlakna iskorišteni za izradu središnjeg sloja, a drvno je iverje upotrijebljeno za vanjske slojeve ploča. Izrađene su ploče ispitane i utvrđena je njihova gustoća, moć upijanja vode i debljinsko bubrenje.*

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Dodatno su određeni modul loma, modul elastičnosti i čvrstoća raslojavanja. Rezultati ispitivanja pokazali su da je uporaba otpadnog papira pridonijela smanjenju vrijednosti modula loma i modula elastičnosti. Istodobno je povećanje udjela usitnjenih staklenih vlakana imalo pozitivan učinak na vrijednosti upijanja vode i na debljinsko bubrenje, ali je izravno utjecalo i na smanjenje čvrstoće raslojavanja, modula loma i modula elastičnosti. Ipak, izrađene ploče niske gustoće zadovoljile su minimalne zahtjeve norme ANSI 208.1 glede modula loma i modula elastičnosti, a samo je jedna skupina eksperimentalno izrađenih ploča zadovoljila uvjete čvrstoće raslojavanja.

KLJUČNE RIJEČI: *otpadni uredski papir; ploče od papira; drvno iverje; usitnjena staklena vlakna*

1 INTRODUCTION
1. UVOD

Today's increasing population, developing economy, rapid urbanization, and rising living standards have accelerated the production of solid waste worldwide, especially in developing countries (Minghua *et al.,* 2009; Guerrero *et al.,* 2013). Many countries are enacting measures and new policies against environmental problems caused by the management of diminishing resources and waste (Kızıltaş *et al.,* 2020). Public awareness of recycling and waste management has recently emerged in many countries. Following this stage, the need arises to integrate materials obtained from recycling into value-added products. Different recycled materials can be used in a variety of ways, revealing the potential of these products to provide benefits to national economies (Sözen and Gündüz, 2021).

Researchers have defined "zero waste" as a new paradigm that promotes the recovery of resources from the overall waste stream, reducing consumption, and applying a life-cycle approach to product design (Dinshaw *et al.,* 2006). The term has been used frequently since its inception and has played a role in creating social awareness, especially in high-income countries. High-income countries, which comprise 16 % of the world's population, account for 34 % (683 million tons) of the total amount of solid waste worldwide (The World Bank, 2020). In addition, awareness of waste recycling is quite high in these countries. The European Paper Recycling Council (EPRC) reported that in 2019, eight European Union countries had recovered 60 % and 15 countries 70 % of their waste paper. The total rate of recycled waste paper has been reported as reaching 72 % (EPRC, 2019).

Paper is most commonly used as a medium for writing and printing. In addition, it is used as a packaging material and actively used in the industrial and construction sectors. These and many other uses make it almost impossible to stop the production of paper. (Thaemngoen *et al.,* 2004). Waste paper is paper that meets production requirements and needs disposal. Waste paper is sourced from offices, homes, public facilities, commercial enterprises, and industrial production facilities (Oriyomi *et al.,* 2015). In particular, 90 % of office waste is recyclable (Okino *et al.,* 2000). The recycling of waste paper in Europe is an excellent example, as it provides economic circulation and significant environmental gains (Adu *et al.,* 2018).

Okino *et al.,* (2000) examined the physical and mechanical properties of low-density boards obtained by using three different types of waste paper (white office waste paper, newspaper, and mixed magazines) and two different thermosetting glues (urea formaldehyde and tannin paraformaldehyde). As a result of the study, the modulus of elasticity (*MOE*), modulus of rupture (*MOR*), and internal bond (*IB*) values of the 0.55 g/cm^3 density boards obtained using 100 % waste paper and urea formaldehyde glue were determined as 2.0 (GPa), 5.3 (MPa) and 137 (kPa), respectively. Moreover, in the same study, the boards obtained from the office paper showed the best thickness swelling properties.

Bringing the waste recovered through recycling into the economy is as important as recycling. Depending on the characteristics of the recycled materials, significant contributions to the economies of local governments and countries can be made by ensuring sustainability and producing high value-added products. The waste paper has advantages as a material in terms of both collection and transformation into different products using various production methods. Many industrial products have also been produced such as fiber-cement composites (Thaemngoen *et al.,* 2004), granular and sheet activated carbon from wood waste (Malikov *et al.,* 2007; Yorgun *et al.,* 2009), paperboard briquettes (Odusote *et al.,* 2016), pine tree bark insulation board (Ozlusoylu and Istek, 2019; Istek and Ozlusoylu, 2019), and particleboard produced from chainsaw dust (Istek *et al.,* 2020) and waste sweet bay wood (Yazici, 2020).

This study aimed to produce low-density board using office waste paper. For this purpose, office waste paper and chopped glass fiber were used in different proportions and the physical and mechanical properties of the boards were then compared with the relevant standards.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Material
2.1. Materijal

In this study, office waste paper (WP), wood particles (P) and chopped E-glass fiber (GF) were used as

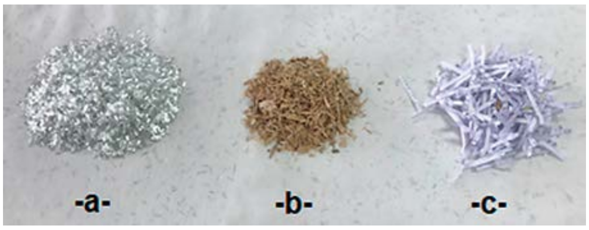

Figure 1 Materials used in the study: (a) chopped glass fiber, (b) wood chips, (c) office waste paper
Slika 1. Materijali upotrijebljeni u istraživanju: a) usitnjena staklena vlakna, b) drvno iverje, c) otpadni uredski papir

Table 1 Properties of urea formaldehyde glue used in the study
Tablica 1. Svojstva urea-formaldehidne smole primijenjene u istraživanju

Properties *Svojstvo*	**Values** *Vrijednost*	**Unit** *Jedinica*
pH / *pH vrijednost*	7.5 – 8.5	-
Solid matter ratio *udio suhe tvari*	54.00 – 56.00	%
Viscosity *viskoznost*	100 – 200	at 20 °C, cps
Density / *gustoća*	1.220 – 1.230	at 20 °C, kg/m³
Gel time *vrijeme želiranja*	15 – 25	at 100 °C, s

materials. Office waste paper, used on both sides, was recycled within the scope of the "zero waste" project of Bartın University (in Turkey). Before being used, the waste paper, weighing 80 g/m², was shredded using an office shredder.

Wood particles in the form of chips were used as the outer layers in the production of the particleboard. These chips were obtained from an industrial production company (Kronospan Forest Products Industry and Trade Inc., Kastamonu, Turkey) and consisted of 50 % coniferous (*Pinus sylvestris*) and 50 % deciduous (*Fagus orientalis* L.) wood chips that varied in size between 2 and 10 mm. The waste paper and wood chips were dried in an oven to a moisture content of 4 - 4.5 % before the boards were produced. During drying, it was observed that the moisture of the wood chips was reduced at a faster rate.

Chopped E-glass fibers were supplied by the Omnis Composite Industry and Trade Inc. (Istanbul, Turkey). As glass fibers do not hold moisture, they were not subjected to any drying process. Images of the materials used in the study are shown in Figure 1.

Urea formaldehyde glue (POLIURE 7455) supplied by Polisan Chemistry Trade Inc. (Istanbul, Turkey) was used. No hardening agent was added to the glue. The amount of glue (solid matter ratio) was 10 % of the total produced board weight. The properties of the urea formaldehyde glue, as listed in the MSDS (Material Safety Data Sheet) catalog of the manufacturer, are given in Table 1.

2.2 Methods
2.2. Metode

The boards produced in the study consisted of three layers: two surface layers and a middle layer. Wood chips alone were used in the surface layers of the boards, which constituted 50 % of the total board weight. Different proportions of waste paper and chopped glass fiber strands were used in the middle layer of the boards. In all variations, the board thickness produced was 12 mm. Table 2 shows the ratios and weights of the board variations created within the scope of the study.

2.3 Production of boards
2.3. Izrada ploča

The wood particles (P) and office waste paper (WP) were brought to 4-4.5 % moisture content in the oven and then held for 2 h to be cooled to room temperature. The production phase was carried out according to the variations given in Table 2. Wood particles alone were used in the production of the control samples. Therefore, the control boards consisted of a single layer. All other variations were composed of three layers, i.e., two surface layers and a middle layer.

Table 2 Ratios and weights of board variations in the study
Tablica 2. Udjeli i mase pojedinih sirovina od kojih su izrađene ispitivane ploče

Variations *Varijacije*	**Surface** *Vanjski sloj*		**Middle layer** *Središnji sloj*				**Surface** *Vanjski sloj*		**Code** *Oznaka*
	Wood chips (Particles) (P) *Drvno iverje (P)*		**Waste paper (WP)** *Otpadni papir (WP)*		**Glass fiber (G)** *Staklena vlakna (G)*		**Wood chips (Particles) (P)** *Drvno iverje (P)*		
	g	%	g	%	g	%	g	%	
P100 (Control)	500	50	-	-	-	-	500	50	P1
P50W50	250	25	500	50	-	-	250	25	P5W5
P50W45G5	250	25	450	45	50	5	250	25	P5W45G5
P50W40G10	250	25	400	40	100	10	250	25	P5W4G1
P50W30G20	250	25	300	30	200	20	250	25	P5W3G2

The wood particles (P) used in the surface layers of all boards except the control samples constituted half of the weight of the mat. The other half consisted of the chopped glass fiber (G) used with waste paper (WP). The production setup for the variations (excluding the controls) is shown in Figure 2. The materials, in their specified weights, for the two surface layers and one middle layer (Figure 2A) were processed in two different concrete mixers, respectively. The materials were glued using urea formaldehyde (solid matter rate, 55±1 %) (Figure 2B). A pressure paint gun was used and care was taken to ensure that the gluing was homogeneous. The glued materials then proceeded to the laying process.

A 400 mm × 400 mm mold was used in the preparation of the mat. This mold was placed on top of a thin metal plate covered by baking paper. In the laying process, first of all, wood particles (25 %) were spread homogeneously and carefully to form the substrate. The material/s (50 %) forming the middle layer was then spread over the substrate. Finally, the same (25 %) wood particles as those used in the lower layer were spread to form the upper layer. Finally, baking paper and a thin metal plate were placed on the mat, respectively. Pre-pressing at up to 10 % of the hot press pressure (3 kg/cm^2) was applied to form the mat in preparation for hot pressing (Figure 2C). The formed mat (Figure 3) was hot pressed for 6 min (Figure 2D). To ensure uniform board thickness, 12 mm-thick metal laths were used at the hot press stage (Figure 2D-e).

The production conditions of the boards are given in Table 3, and the appearance of the board before and after hot pressing is shown in Figure 3.

Table 3 Production conditions of boards
Tablica 3. Parametri izrade ploča

Characteristics *Svojstvo*	**Production conditions** *Parametar*	**Unit** *Jedinica*
Board thickness *debljina ploča*	12	mm
Board width – length *širina i dužina ploča*	400 × 400	mm
Target density *ciljana gustoća ploča*	0.52	g/cm³
Middle layer material/s ratio *udio središnjeg sloja*	50	%
Surface layer chip ratio *udio iverja u vanjskim slojevima*	50	%
Press temperature *temperatura prešanja*	180	°C
Press pressure / *tlak prešanja*	30	kg/cm²
Total press time *ukupno vrijeme prešanja*	180	s
Resin ratio / *nanos smole*	10	%

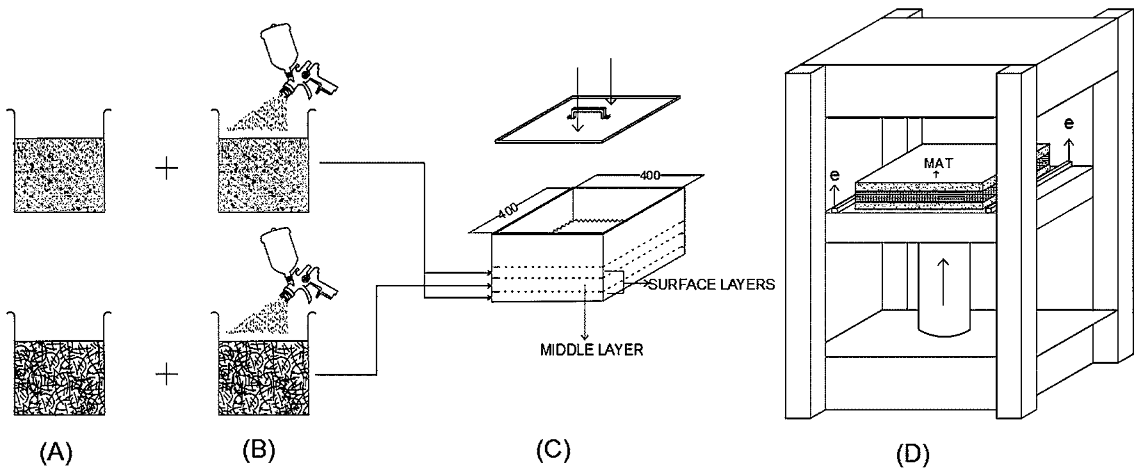

Figure 2 Production stages of boards
Slika 2. Faze izrade ploča

Figure 3 Hot-pressed board: (a) pre-hot pressing, (b) post hot pressing
Slika 3. Eksperimentalne ploče: a) prije vrućeg prešanja, b) nakon vrućeg prešanja

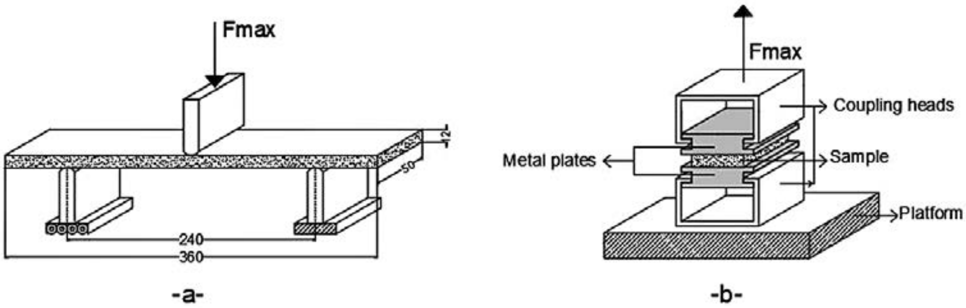

Figure 4 Test configuration: (a) bending strength, (b) internal bond strength
Slika 4. Način ispitivanja: a) savojne čvrstoće, b) vlačne čvrstoće

Boards taken from the hot press were left to cool at room temperature using 20 mm ×20 mm stacking laths. After 48 h, the board edges were evened using a circular saw.

2.4 Preparation of test samples
2.4. Priprema ispitnih uzoraka

Sample preparation processes began 10 days after the production of the boards. Samples were cut from different parts of the produced boards and investigations were carried out in accordance with the TS EN 326-1 (1999) standard. The oven-dry (D_0) and 12 % (air-dry) (D_{12}) density values of the samples were determined in accordance with the TS EN 323 (1999) standard. In order to determine the oven-dry density, the samples cut in accordance with the standards were kept at (103 ±2) °C until their weight was stabilized. Determination of thickness swelling after immersion in water (24 h) was carried out in accordance with TS EN 317 (1999). Modulus of elasticity in bending (MOE) and bending strength tests were carried out in accordance with the principles specified in TS EN 310 (1999). The loads in the elastic region (F2-F1) and the difference in the deformation amounts corresponding to these loads (d2-d1) were used to calculate the MOE. Care was taken to ensure that these values were between 10 % and 40 % of the maximum load.

2.5 Test method
2.5. Metoda ispitivanja

The setups for the bending strength and IB strength tests applied to the samples are shown in Figure 4a and Figure 4b, respectively. Samples in dimensions of 50 mm × 360 mm ×12 mm were prepared in accordance with the specified standard for bending strength tests. 50 mm × 50 mm ×12-mm samples were used to determine the IB strength (Figure 5). Ten replications were made for each variation of bending strength and internal bond tests. Silicon was used to bond metal plates to the surfaces of these samples. Internal bond strength tests were carried out by attaching these plates to the coupling heads.

Figure 5 Internal bond strength test samples
Slika 5. Uzorci za ispitivanje čvrstoće raslojavanja

Eqs. (1), (2), and (3) were used to calculate bending strength (σ_B), *MOE* (σ_{MOE}) and *IB* (σ_{IB}) strength, respectively.

$$\sigma_B = \frac{3}{2}\frac{F \cdot L_S}{b \cdot h^2} \tag{1}$$

$$\sigma_{MOE} = \frac{\Delta F \cdot L_S^3}{4 \cdot \Delta d \cdot b \cdot h^3} \tag{2}$$

$$\sigma_{IB} = \frac{F}{A} \tag{3}$$

Here, F is the maximum load value, L_S is the distance between the supports (240 mm), b is the width of the sample (50 mm), h is the height of the sample, ΔF is the difference of the two loads within the elastic limits, Δd is the deformation difference corresponding to the two loads within the elastic limits, and A expresses the surface area of the sample (50 mm × 50 mm = 2500 mm²).

2.6 Evaluation of data
2.6. Evaluacija podataka

The one-way analysis of variance (ANOVA) included in the Statistical Package for the Social Sciences (SPSS) software program was used to evaluate the data. Duncan's test was used to determine the differences between the groups.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Density
3.1. Gustoća

The density of the produced boards was measured at oven-dry (D_0) and air-dry (D_{12}) moisture con-

Table 4 Average density and standard deviation values of boards
Tablica 4. Prosječne gustoće ploča i standardne devijacije ispitivanih svojstava

Board codes *Oznake ploča*	**Density (D_{12})** *Gustoća (D_{12}),* g/cm³	**Standard deviation** *Standardna devijacija*	**Density (D_0)** *Gustoća (D_0),* g/cm³	**Standard deviation** *Standardna devijacija*
P1	0.52	0.030	0.49	0.028
P5W5	0.52	0.050	0.49	0.048
P5W45G5	0.53	0.046	0.50	0.045
P5W4G1	0.53	0.049	0.50	0.050
P5W3G2	0.53	0.040	0.50	0.049

tent. To calculate the density of the boards, ten samples were used for each variation. No statistically significant difference was found among the board density values. The average density and standard deviation values of the boards are given in Table 4.

The air-dry density (D_{12}) of the boards was targeted as 0.52 g/cm³ at the production stage. The density measurements demonstrate that this goal was achieved. The variation of 0.01 in the P1 and P5W5 boards was thought to have been a result of chips lost during production. On the other hand, the standard deviation values show that the overlaying process had been carried out as homogeneously as possible. An average decrease of 6 % was observed in the oven-dry density (D_0) values. Istek and Sıradag (2013) stated that density changes of up to 10 % in particleboards do not significantly affect board properties. The decrease in density in the P5W4G1 and P5W3G2 variations containing glass fiber was less than in the other variations. This situation was thought to have been caused by the fact that the water absorption and water holding abilities of E-glass fiber are lower than those of wood chips and waste paper.

Table 5 Minimum requirements of ANSI 208.1 and EN 16368/LP1standards
Tablica 5. Minimalni zahtjevi definirani normama ANSI 208.1 i EN 16368/LP1

Properties *Svojstvo*	**ANSI 208.1**	**EN 16368/LP1**
MOE, N/mm²	500	950
MOR, N/mm²	2.8	7
IB, N/mm²	0.14	0.28

3.2 Modulus of Rupture (*MOR*) and Modulus of Elasticity (*MOE*)
3.2. Modul loma (*MOR*) i modul elastičnosti (*MOE*)

The average *MOR* and *MOE* values of the boards are shown in Figure 6. The *MOR* values show that reducing the amount of chips forming the board to 50 % (in all variations except P1) was effective in reducing the bending strength. Decreases in the *MOE* were in parallel with the decrease in bending strength.

The physical and mechanical properties of the boards were compared with the relevant standards. As the density of these boards was less than 600 kg/m³, they were classified as low-density boards. Thus, the boards were comparable to the American National Standards Institute for particleboard (LD2) for interior application (ANSI 208.1, 2016) and the European standard for lightweight particleboard for interior application (EN 16368/LP1, 2014). Table 5 gives the minimum *MOE*, *MOR*, and *IB* requirements of the relevant standards.

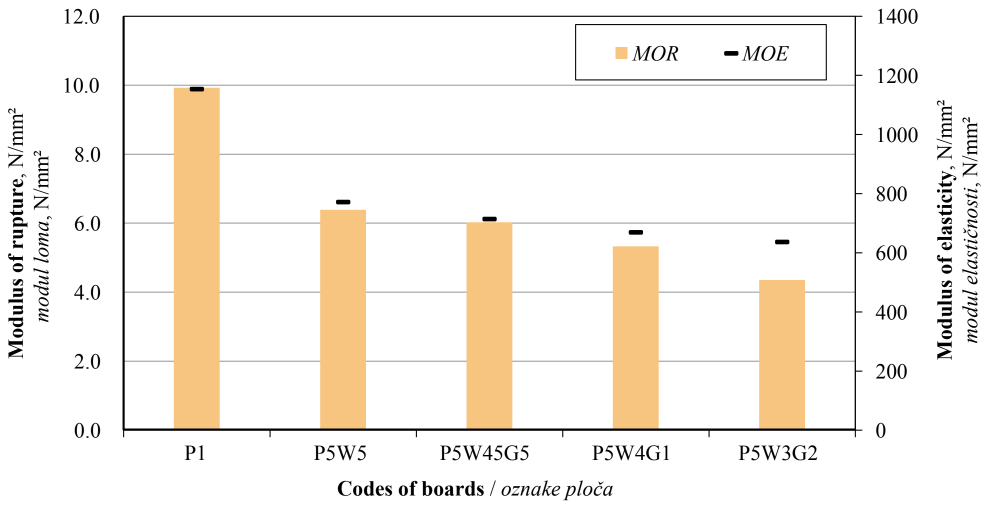

Figure 6 *MOR* and *MOE* values of boards
Slika 6. Vrijednosti modula loma i modula elastičnosti

The P1 variation showed the highest *MOR* (9.93 N/mm²) and *MOE* (1153 N/mm²) values. The use of chips alone in this variation was effective in increasing these values. The compatibility of the surface chips and glue used in particleboard production was an important factor. All of the produced variations met the minimum *MOE* value of 500 N/mm² specified in the ANSI A208.1 standard. On the other hand, except for P1, none of the other variations could reach the *MOE* value of 950 N/mm² specified in the EN 16368/LP1 standard.

The use of waste paper in the boards lowered the bending strength values. This decrease was 35 % in the P5W5 boards (which used the most waste paper) and 56 % in the P5W3G2 boards (which used the least waste paper). The waste paper shredded in an office shredder was a bulkier material than the glass fiber or wood chips. Therefore, it had a larger surface area. This was thought to have reduced the rate of glue per unit area during gluing. The distribution and amount of glue play an important role in board production. Okino *et al.* (2000) used 8 % and 12 % urea formaldehyde glue in low-density boards produced from office waste paper. The bending strength values of these boards were determined as 3.8 N/mm² and 5.3 N/mm², respectively.

The fillers such as $CaCO_3$ used in the production of white office paper were believed to be effective in the adhesion performance of the glue. Consequently, the weakening of the glue performance was effective in the decrease of the bending strength. The importance of glue-material compatibility was therefore revealed in the study. Although paper is manufactured from fibers (wood), additives and fillers cause significant changes in the structure of these fibers. In terms of adhesion performance, it was observed that, except for P1, the compatibility between the chips and the waste paper was not sufficiently achieved in the variations. Ellis *et al.* (1993), Massijaya and Okuma (1996), and Okino *et al.* (2000) reported that the mechanical properties in low-density boards produced using waste paper were boosted by an increase in the glue ratio.

The increase in the ratio of E-glass glass fiber used in the boards caused a decrease in the bending strength. The bending strength, which was 6.39 in the P5W5 board, was reduced to 6.03, 5.33, and 4.35 in the P5W45G5, P5W4G1, and P5W3G2 boards, respectively. The urea formaldehyde glue incompatibility observed with the waste paper was also seen with the E-glass glass fiber. In the literature, it is reported that, when glass fibers are chopped or in fabric form, they are compatible and can be used with epoxy. Valente *et al.* (2011) produced hybrid composites with thermoplastic polymers using wood flour and recycled chopped glass fiber. They reported that the chopped glass fiber increased the mechanical properties of the composites, and emphasized that the particle size and the hardness of the matrix and the bond area were effective in this situation. Various studies have stated that many factors can affect the mechanical properties in board production (Istek *et al.,* 2018; 2019).

A statistically significant difference in the bending strength among the variations was demonstrated by the ANOVA (F_{ratio} = 47.716; P_{value} = 0.000 < 0.05). Duncan's test was used to determine differences in *MOR* among the groups, as shown in Table 6.

Table 6 Duncan's test results of *MOR*
Tablica 6. Rezultati Duncanova testa za modul loma

Board codes *Oznake ploča*	**Number of samples** *Broj uzoraka*	**A**	**B**	**C**
P5W3G2	10	636.00		
P5W4G1	10	668.50	668.50	
P5W45G5	10	713.00	713.00	
P5W5	10		771.38	
P1	10			1152.9

3.3 Internal Bond (*IB*) Strength
3.3. Čvrstoća raslojavanja (*IB*)

Internal bond strength directly or indirectly affects the physical and mechanical properties of wood-based boards. The *IB* strength of the produced boards varied between 0.35 N/mm² and 0.04 N/mm². The *IB* strength and standard deviation values of the boards produced within the scope of the study are shown in Table 7.

In the *IB* strength tests, the highest value (0.35 N/mm²) was achieved by the P1 and the lowest (0.04 N/mm²) by the P5W3G2 variation. These values were in

Table 7 Internal bond strength and standard deviation values of boards
Tablica 7. Čvrstoća raslojavanja i standardne devijacije

Board codes *Oznake ploča*	**Number of samples** *Broj ispitanih uzoraka*	**F_{max} Average** *Prosjek maksimalne sile loma (F_{max})*	**Standard Deviation** *Standardna devijacija*	**IB Strength** Čvrstoća *unutarnje veze,* N/mm²
P1	10	904.2	±70.7	0.35
P5W5	10	184.8	±11.3	0.07
P5W45G5	10	172.2	±10.6	0.07
P5W4G1	10	146.2	±14.1	0.06
P5W3G2	10	101.4	±7.1	0.04

accordance with the 0.14 N/mm² and 0.28 N/mm² values specified in the ANSI 208.1 and EN 16368/LP1 standards, respectively. In fact, the P1 variation, which was produced totally from chips, reached a value close to the 0.4 N/mm² required in the TS EN 310 standard for particleboards. There was an 80 % decrease in the IB strength of the P5W5 and P5W45G5 variations. In these variations, the waste paper ratio constituted 50 % and 45 % of the board weight, respectively. The use of waste paper in the middle layer of the board was effective in the *IB* strength decreases. The increase in the amount of glass fiber was in parallel with the decrease in the *IB* strength of the boards. The urea formaldehyde glue used was compatible with the lignocellulosic materials (chips). However, it did not show the same compatibility with the waste paper, which is basically a lignocellulosic material. This was thought to have been caused by the fillers and additives used in the production of the office paper. The same incompatibility applied to the E-glass glass fiber.

Synthetic glass fibers have hydrophobic properties and therefore do not form adhesive bonds with wood. However, when these fibers are used with suitable resins, they give strength to the composite. These fibers are more commonly used with epoxy-based resins/glues (Ashori and Sheshmani, 2010; Gurunathan *et al.,* 2015; Wei and McDonald, 2016). When the failure types formed as a result of the IB strength tests, the ruptures were seen to occur from the middle layer (Figure 7a). Figure 7b shows the failure type resulting from the *IB* strength test.

During *IB* strength tests, if ruptures arise from the surface of the boards, the test is considered invalid. In the tests performed, all the ruptures, including those in the control sample, arose from the middle layer. The incompatibility of the waste paper with the urea formaldehyde glue bolstered the occurrence of breakouts from the middle layer. Okino *et al.* (2000) produced low-density boards using office waste paper, newsprint, and magazine paper. Using 8 % and 12 % urea formaldehyde glue, they determined the *IB* strength of the boards obtained from office paper to be 0.108 and 0.137 N/mm², respectively. They noted that these results could be explained by poor resin dispersion and/or low resin levels.

3.4 Water Absorption (*WA*) and Thickness Swelling (*TS*)

3.4. Upijanje vode (*WA*) i debljinsko bubrenje (*TS*)

The 24-h water absorption and thickness swelling values of the boards are shown in Figure 8.

The lowest *TS* rate (27 %) was that of the P1 board. No statistically significant difference was found among the *TS* ratios in the other variations. The reason that the P1 boards exhibited higher (negative) values than those specified in the standard was attributed to the fact that chips were not used in the middle layer. On the other hand, water was more effective among the chips distributed homogeneously within the outer layers. The 20 % increase in the E-glass fiber in the board content caused a 2 % decrease in the *TS* ratio. The water-resistant structure of the glass fiber was effective in this situation. Ranakoti *et al.* (2019) used epoxy resin as glue in boards composed of wood flour and glass fiber. As a result of the study, they reported a linear relationship between the wood flour ratio and *WA* rate.

When the *WA* samples were examined visually after the experiment, the majority of the *TS* were observed in a line between the layers. Figure 9 shows the separations between the layers after the *WA*-*TS* test.

Wood particles are hydrophilic because of the cellulose in their structure. This feature had a significant effect on the *WA* rate. In office paper formed of cellulosic fibers, additives and fillers, such as $CaCO_3$ incorporated at the production stage, caused changes in the properties of the cellulose. Thus, the *TS* ratios of the surface layers were higher than those of the middle layer.

Figure 7 Results of internal bond strength test: (a) middle layer, (b) failure type after rupture
Slika 7. Prikaz loma uzoraka pri ispitivanju čvrstoće raslojavanja: a) pukotina u središnjem sloju ploča, b) lomne površine nakon razdvajanja iskidanog uzorka

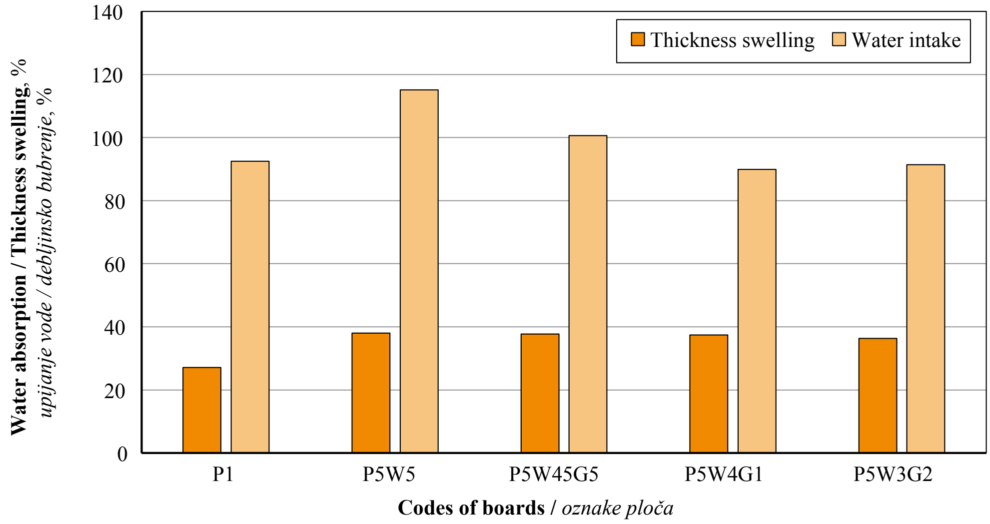

Figure 8 24-hour water absorption and thickness swelling values of boards
Slika 8. Vrijednosti upijanja vode i debljinskog bubrenja ploča nakon 24-satnog izlaganja djelovanju vode

Figure 9 Separation between layers after water absorption-thickness swelling test
Slika 9. Razdvajanje na granici srednjega i vanjskih slojeva ploča nakon izlaganja djelovanju vode

4 CONCLUSIONS
4. ZAKLJUČAK

In this study, in which the physical and mechanical properties of low-density boards obtained from wood particles, office waste paper and chopped glass fiber strands were examined, the following conclusions were reached.

It is possible to produce low-density boards using office wastepaper. Additives can be incorporated into these boards to give them different properties. However, the properties and compatibility of the materials used, as well as the areas of use, should be carefully determined.

The wood particles interacted better with office wastepaper, whereas E-glass, a synthetic fiber, did not exhibit sufficient interaction. The urea formaldehyde glue had a great impact on this situation. The use of resins or glues compatible with synthetic fibers would be especially effective in increasing mechanical properties.

All variations produced met the minimum *MOR* and *MOE* requirements specified in ANSI 208.1 standards (2016), while only variation P1 met the *IB* requirements.

In this study, low-density boards produced in a layered format may reveal physical and mechanical properties differing from boards produced in a homogeneous form.

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