Effects of Wastepaper Pulp and Its Level on The Properties of Particleboard

Mehmet Erdal Kara *

The effects of waste pulp fiber on the mechanical, physical, and technological properties of particleboard were investigated. For this purpose, 1.5%, 3%, 4.5%, and 6% were added to the middle layer of the chip blank. As an adhesive, 7% urea-formaldehyde (UF) resin was used in the middle layer and 12% in the top layer, in proportion to the dry chip weight. Chip blanks were pressed in a hydraulic press at 195 ± 5 °C, 30 kg/cm² pressure, and for 300 s, whereby test samples with dimensions of 550 x 550 x 19 mm³ and a density of 630 kg/m³ were produced. The 3% waste pulp fiber utilization provided optimum values, such as 7.3% and 27.2% improvements in bending strength and elastic modulus, respectively. However, 6.6% and 9.7% increases in thickness swelling (24 h) and water absorption (24 h) were observed. Moreover, there was a 24.6% increase in formaldehyde emissions. According to the results, it can be said that waste paper pulp fiber could be an alternative to wood raw material in particleboard production at low levels of addition.

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INTRODUCTION

Particleboard is a large flat material obtained by pressing lignocellulosic-based wood and woody plant chips or small particles with synthetic resins under heat and pressure (Bozkurt and Göker 1990). Particleboards are divided into seven classes according to the TS EN 312 (2012) standard. This classification determines what kind of load-carrying capacity the particleboard has under which conditions. Global production of wood-based materials has been on a continuous upward trend for years. The global production of particleboard, which has a special place among the wood-based materials available in the market, was realized as 102 million m³ in 2020 (Faostat 2020).

In the first quarter of the century, recycling waste generated as a result of rapid industrialization and population growth has been seen as a driving force for economies, and the use of recycling products has increased in many countries (Larney and van Aardt 2009) in a variety of fields.

Davis *et al.* (2003) reported the negative effect of inorganic compounds, such as kaolin clay and calcium carbonate, in pulp on all properties of medium-density fiberboard (MDF). Camlıbel (2021) used 1.5% and 3% calcite ($CaCO_3$) as filler and found optimum values in the physical properties and formaldehyde emission of MDF in experimental samples using 3% calcite. The influence of ammonium chloride (Çamlıbel and Aydın 2022) and ammonium sulfate (Çamlıbel *et al.* 2025) on the physical and mechanical properties of MDF was investigated. The effect of paraffin utilization levels on MDF was evaluated by Çamlıbel and Aydın (2025). Grigoriou (2003) produced particleboards with 5%, 8%, and 10% methylene diphenyl diisocyanate pMDI resin by mixing newspaper, office, and magazine papers (0:100, 15:85, 25:75, 50:50, 75:25, and 100:0) with wood chips. In the study, optimum values were observed in composite boards with 50% waste newsprint. In addition, as the paper ratio increased, tensile strength (internal bond, IB), flexural strength (modulus of rupture, MOR), screw retention resistance, and thickness swelling (TS) decreased.

Roffael *et al.* (2001) mixed thermomechanical pulp (TMP), chemical thermos-mechanical pulp (CTMP), and kraft pulp with wood fiber (0%, 25%, 50%, and 75%) in a pilot plant to test them in MDF production. In the study, (TS, water absorption-WA) and (IB, modulus of elasticity-MOE, and MOR) values decreased with the increase in waste pulp. While similar quality MDF was produced with TMP and CTMP pulp, the lowest values were found in samples produced with kraft pulp. This was explained by the presence of inorganic compounds, such as ash and extractives, in the pulp. It was also found that the sludge content that would not affect the board quality was 25% and met the requirements of the American National Standards Institute (ANSI).

Nicewicz *et al.* (2006) stated that waste paper can be used in particleboard production with urea formaldehyde (UF) and melamine urea formaldehyde (MUF) resins. Taramian *et al.* (2007) produced single and three-layer particleboard with 3%, 4% (pMDI) and 10%, 12% (UF) resins by adding pulp fibers (0%, 15%, 30%, and 45%) to wood chips, and mechanical and physical properties decreased with increase in pulp utilization. In contrast, it was found that particleboards with 15% pulp addition met the requirements of ASTM D1037 (1999) standard for general use. Genk *et al.* (2007) produced MDF by mixing primary and secondary paper sludge fibers with wood fibers in a pilot plant. At the end of the study, it was stated that the mechanical and physical properties of the fiberboards produced with wood fiber / primary sludge fiber (3:7) were higher than the limit values specified in the ANSI standard in terms of mechanical and physical properties, while the ratio of wood fiber / secondary sludge fiber (7:3) met the standard values. Rassam (2008) produced composite boards by mixing waste cardboard particles with wood chips and bonding them with polyphenol resin. It was stated that the mechanical properties increased as the resin ratio increased and the composite board obtained using 50% cardboard fiber and 10% resin met the limit values specified in the standards. Migneault *et al.* (2010) investigated the recycling potential of TMP, CMTP, and kraft pulp sources (0%, 25%, 50%, and 75%) mixed with wood fiber in MDF production. There was a linear decrease in the physical and mechanical properties (TS, WA, IB, MOE, and MOR) of MDF test samples with the increase of waste pulp. This was explained as the ash and polar extractive contents in the composition of waste paper pulp decreased the crosslinking quality of the UF resin between the fibers and negatively affected the mechanical properties and dimensional stability of the boards. It was also stated that the waste pulp content that can be used in MDF production is 25%. Nourbakhsh and Ashori (2010) mixed waste newspaper pieces with wood chips at various ratios (75/25, 50/50, 25/75, and 0/100) and investigated the effect on the properties of particleboards. The TS, IB, MOR, and MOE met the ANSI requirements, and it was stated that waste paper could be a potential filler material for particleboard. Hamzeh *et al.* (2011) stated that the addition of waste paper in composite boards obtained by mixing polyethylene materials with waste paper and wood chips at different ratios caused an increase in MOR and MOE and can be used as a filler. Kara *et al* (2024) reported that the addition of a maximum of 3% waste rock wool to the particle boards (composed of wood chips and waste rock wool in different proportions) did not have a negative effect on the mechanical and physical properties of the boards and likewise stated that waste rock wool could be used as a filler. Lykidis *et al.* (2012) mixed cardboard waste (100:0, 70:30, and 50:50) with wood chips and obtained particleboards with UF and pMDI resins. It was determined that the use of waste paper negatively affected the board properties, and with the increase of pMDI resin, the boards containing 30% waste paper met the limit values of the European Standard EN 312 (2010). Akbulut *et al.* (2021) used waste paper pulp fibers in the surface and middle layer (10%, 20%, and 30%) of the particleboard and found that the optimum values were obtained in the boards with 20% waste paper pulp in the surface layer. Accordingly, there were 50%, 35%, and 15% decreases in TS, WA, and 15% IB, respectively. In contrast, 22%, 24%, and 59% increases in FE, MOR, and MOE were reported. Güler and Üçüncü (2024) obtained particleboards by mixing 0 to 50% waste office paper with wood chips and found optimum results in boards with 10 to 20% waste fiber. The TS and WA decreased 7.71% and 2.2%, IB by 22%, and MOR and MOE by 21% and 42%, respectively.

In recent years, political and economic developments on a global scale have made access to limited forest resources more difficult, and costs have increased. This has increased interest in the use of recyclable lignocellulosic materials as an alternative to wood raw materials. Approximately 4.5 million tons/year of paper and cardboard are produced in Türkiye, and 0.3 million tons/year of waste pulp fiber is generated as a by-product (Akbulut *et al*. 2021). Environmental regulations have forced mills to seek an effective strategy for the recycling and disposal of this waste fiber. Waste paper fibers, which constitute a problem in the environment, are a cheap and indispensable raw material source. It is thought that these resources, which can be used without the need for costly processes, can be brought to the national economy through independent enterprises within the scope of symbiotic projects. Considering the aforementioned issues, the effect of secondary pulp fibers disposed of in cardboard production on the mechanical and physical properties of particleboard was investigated. For this purpose, P3 type particle boards with the properties specified in Turkish Standard TS EN 312 (2012) were produced using 1.5%, 3%, 4.5%, and 6% waste pulp fibers in the middle layer of the particle draft in proportion to the dry particle weight.

EXPERIMENTAL

Wood or Wood-based Materials

In this study, black pine (*Pinus nigra* A.) and aspen *(Populus tremula* L.) tree species and sawdust were obtained from the Taşköprü/Kastamonu region. The wood chips and sawdust (industrial waste) obtained from these tree species were sourced from the Kastamonu Entegre Ağaç Sanayi A.Ş. chipboard plant.

Wastepaper pulp fiber, which was considered an alternative to wood raw material, was supplied from KARTONSAN Karton A.Ş.

Waste fibres contain organic materials such as fines, which are short fibres 1 to 10 μm in diameter and 0.1 to 0.3 mm (100 to 300 μm) in length, as well as microfibrils, and undissolved polysaccharides and lignin fragments formed during the refining process. Inorganic materials include calcium carbonate ($CaCO_3$), titanium dioxide (TiO_2), starch, kaolin, talc pigment, *etc*., in the range of 0.5 to 10 μm, as well as other minerals (silica, barium sulphate) and filler material residues.

Elemental Analysis

The elemental analysis results (Fig. 1) of waste pulp fiber are given in Table 1.

Table 1. Elemental Analysis of Waste Pulp Fiber

Analysis	Analysis Results		Method
	Original base	Dry base	
Total moisture (%)	40.9		ASTM D3302 (2002)
Ash (%)	19.4	32.9	ASTM D3174 (2012)
Gross calorie (kcal/kg)	1222	2067	ASTM D5865 (2001)
Net calorie (kcal/kg)	884	1876	
Volatile matter (%)	37.5	63.4	ASTM D3175 (2008)
Total sulfur (%)	0.04	0.06	ASTM D4239 (1994)
Fixed carbon (%)	2.2	3.7	ASTM D3172 (2002)

Fig. 1. Elemental analysis tests

Microscopic Analysis (SEM)

The microscopic structure of the waste paper pulp fiber was imaged (Fig. 2) using scanning electron microscopy (SEM; ZEISS Ultra Plus, Jena, Germany) at 100x magnification. Particles of inorganic materials were observed on the fiber surface. These particles did not show a regular crystalline structure and were found to be amorphous. The lengths of the pulp fibers varied between 1 to 1.5 mm and thicknesses between 5 to 50 µm.

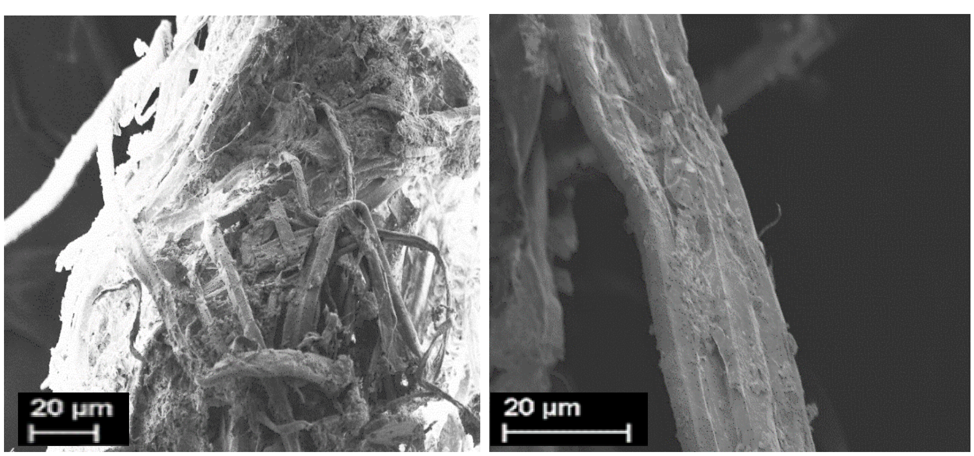


Fig. 2. SEM images of waste paper pulp fiber

Bulk Density

Waste paper pulp fiber, which was considered as a supporting material to reduce the wood raw material utilization, was supplied from KARTONSAN Karton A.Ş. Furthermore, the basic function of the wastepaper pulp would be to provide advanced contact between the wood particles, in combination with the added adhesive, and thereby contribute to the bonding. However, it should be taken into consideration that sometimes the influence would be adverse, since the wastepaper pulp fibers would be diluting the adhesive too much. The dry state bulk weights of larch pine wood (*Pinus nigra*) chips and waste paper pulp fibers (Fig. 3) were determined as 188 kg/m³ and 260 kg/m³, respectively.

Fig. 3. Falling densities of waste pulp fibers and wood chips

Glue and Chemicals

MUF resin with a ratio of 1.10 mol (62% solids content) containing 23% melamine was used in the production of test samples. Ammonium chloride (NH_4Cl) solution with a solids content of 20% was used as a hardener, and paraffin emulsion with a solids content of 60% was used as a water repellent. Wood or wood-based materials and chemicals used in the study were supplied by Kastamonu Entegre Ağaç Sanayi A.Ş. The properties of the chemicals used in the study are given in Table 2.

Table 2. Properties of Glue and Chemicals

Chemicals	Solids Content (%)	Density (g/cm³)	Viscosity (cP)	pH	Molar Ratio (Mr)	Melamine Ratio (%)	Flow Time (sn)	Gel Time (sn)
Glue (MUF)	62	1.270	275	8.6-8.8	1.10	23	63	45-46
Paraffin emulsion	60	0.90-0.94	12-22	9-10	-	-	12	-
Hardener (NH_4Cl)	20	1.03	7.8	8.3	-	-	-	-

Production of Test Boards

The production of the particleboard test samples was carried out in the laboratory environment, and the production parameters of the research are given in Table 3.

Table 3. Production Design

Particle Board Draft	Raw Material Type	Experimental Groups				
		Control (W0)	W1	W2	W3	W4
		Raw materials mix percentage (%)				
Surface layer (SL)	Wood chips	40	40	40	40	40
	Waste pulp fiber	0	0	0	0	0
Core layer (CL)	Wood chips	60	58.5	57	55.5	54
	Waste pulp fiber	0	1.5	3	4.5	6

Gluing and chip drafting

The mixing of wood particles and waste pulp fibers was done with a specially designed mixer (Fiber and Chip Blender 2021; Kastamonu, Türkiye). Glue and chemicals were injected pneumatically on the mixer. Melamine urea formaldehyde (MUF) resin was used to glue the chips at a ratio of 7% in the middle layer and 12% in the upper and lower layers, based on the dry chip weight. Ammonium chloride (NH_4Cl) solution with a solid content of 3% in the middle layer and 0.5% in the top layer with a solid content of 20% was used as hardener in proportion to the glue. Paraffin emulsion with a solids content of 0.5% by weight of fully dry particles and a solids content of 60% was the water repellent.

Preparation of particleboard

As can be seen in Table 3, the surface layer of the particleboard consisted of 40% industrial black pine sawdust. The core layer was composed of 60% wood chips of 1:1 black pine and aspen, respectively. In the middle layer, 1.5%, 3%, 4.5%, 4.5%, and 6% waste pulp fibers were added to the dry chips. The mixture was laid in a 550 × 550 × 300 mm^3 preparation container according to the three-layer particleboard production method.

Pressing

The pressing of the chip drafts was carried out with a German Bürkle brand hydraulic test press (Fig. 4) at a temperature of 195 ± 5 °C and a pressure of 30 kg/cm^2 and a pressing time of 300 s. At the end of this process, test samples with 550 × 550 × 19 mm^3 dimensions and 630 kg/m^3 density were obtained.

Fig. 4. Pressing of chip drafts (Bürkle press)

To prevent delamination during the hot-pressing stage, the veneer blank was conditioned to the appropriate moisture level, and suitable pressing parameters (temperature, pressure and duration) were determined. This ensured complete curing of the resin and optimized the formation of a homogeneous bond between the layers.

Surface treatment

The test specimens were kept at 20 ± 2 °C and 65 ± 5 relative humidity for 4 to 7 days and then sanded with 80 to 100 grit sanding belts with a net thickness of 18 ± 0.1 mm with an EMC Explorer 2RK (model 2010; Türkiye) caliber sanding machine.

Test Methods

Samples were prepared in accordance with the TS EN 312 (2012) standard. Ten samples were taken for each group. Mechanical properties (tensile strength, bending strength, and elasticity modulus) were determined using a ZwickRoell (Zwick GmbH & Co. KG, Ulm, Germany) universal testing machine in accordance with the related standards.

Physical tests (24 h thickness swelling and water absorption) properties were determined. The weight and size of the samples were measured using precise scale and digital caliper, respectively. Free formaldehyde content was determined according to perforator method (TS EN 12460-5 2016). Standards and limit values related to the tests are given in Table 4.

Table 4. Standards and Limit Values for Physical and Mechanical Properties of P3* Type Boards

Mechanical and Physical Tests	Standard No	Sample Dimension (mm)	Limit Values (P3)
Density (kg/m³)	TS EN 323-1 (1999)	50 × 50	630
Tensile strength (N/mm²)	TS EN 319 (1999)	50 × 50	≥ 0.35
Modulus of rupture (N/mm²)	TS EN 310 (1999)	50 × 410	≥ 11
Modulus of elasticity - MOE (N/mm²)	TS EN 310 (1999)	50 × 410	≥ 1600
24h Thickness swelling - TS (%)	TS EN 317 (1999)	50 × 50	Max. 100
24h Water absorption - WA (%)	TS EN 317 (1999)	50 × 50	Max. 20
Free formaldehyde (mg/100 g)	TS EN 12460-5 (2016)	20 × 25 (150 g)	E1 ≤ 8 mg/100 g

*P3: Humid environment and general-purpose particleboard

The descriptives and statistics for the properties were calculated using SPSS v23 software.

Multi-way analysis of variance (ANOVA) and *post-hoc* test (Duncan's multiple range test) were performed to evaluate the effect of factors. The confidence interval was 95%.

RESULTS AND DISCUSSION

The descriptives and statistics for the physical and mechanical properties and free formaldehyde are given in Table 5, and the changes in the properties are illustrated in Figs. 6 and 7 with error bars.

Table 5. Statistical Analysis of Test Results

Sample/Particleboard	Type	N	Mean*	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
						Lower Bound	Upper Bound		
Density (kg/m³)	W0	10	646.25^{a}	22.64	7.15	632.23	660.27	620.00	690.00
	W1	10	655.25^{a}	19.34	6.11	643.28	667.23	634.00	687.00
	W2	10	654.00^{a}	20.01	6.32	641.61	666.39	630.00	685.00
	W3	10	650.25^{a}	23.08	7.29	635.96	664.54	625.00	688.00
	W4	10	648.13^{a}	21.89	6.92	634.57	661.68	610.00	675.00
Tensile Strength (N/mm²)	W0	10	0.41^{d}	0.024	0.008	0.39	0.43	0.38	0.45
	W1	10	0.39^{c}	0.025	0.008	0.37	0.41	0.35	0.43
	W2	10	0.35^{b}	0.018	0.006	0.33	0.36	0.32	0.38
	W3	10	0.30^{a}	0.025	0.008	0.28	0.32	0.26	0.34
	W4	10	0.29^{a}	0.019	0.006	0.28	0.31	0.26	0.32
Modulus of Rupture (N/mm²)	W0	10	14.68^{c}	0.161	0.051	14.57	14.80	14.48	15.03
	W1	10	15.02^{d}	0.245	0.077	14.85	15.20	14.71	15.35
	W2	10	15.75^{e}	0.319	0.101	15.52	15.98	15.35	16.27
	W3	10	11.83^{a}	0.165	0.052	11.71	11.95	11.65	12.14
	W4	10	12.04^{b}	0.219	0.069	11.89	12.20	11.63	12.26
Modulus of Elasticity (N/mm²)	W0	10	2460^{b}	170.7	54.0	2338	2582	2241	2800
	W1	10	3080^{c}	143.8	45.5	2977	3183	2850	3301
	W2	10	3130^{c}	165.9	52.5	3012	3249	2900	3360
	W3	10	2225^{a}	115.1	36.4	2143	2307	2051	2440
	W4	10	2255^{a}	135.9	43.0	2158	2352.2	2101	2500
Thickness Swelling 24 h (%)	W0	10	34.13^{b}	0.96	0.31	33.44	34.82	32.40	35.77
	W1	10	32.14^{a}	0.90	0.29	31.50	32.79	30.19	33.36
	W2	10	31.88^{a}	1.05	0.33	31.13	32.63	30.75	33.53
	W3	10	41.54^{c}	1.12	0.35	40.74	42.34	40.29	43.22
	W4	10	43.88^{d}	1.09	0.35	43.10	44.66	42.13	45.85
Water Absorption 24 h (%)	W0	10	92.11^{c}	2.44	0.77	90.37	93.85	89.50	96.50
	W1	10	88.15^{b}	1.85	0.58	86.82	89.47	85.41	90.80
	W2	10	83.16^{a}	1.21	0.38	82.29	84.02	81.35	85.37
	W3	10	89.60^{b}	1.98	0.63	88.19	91.02	86.82	92.65
	W4	10	98.36^{d}	2.84	0.90	96.33	100.39	94.73	103.32
Free Formaldehyde (mg/100 g)	W0	10	7.31^{b}	0.44	0.14	6.99	7.62	6.58	7.88
	W1	10	5.33^{a}	0.52	0.17	4.96	5.71	4.66	6.05
	W2	10	7.92^{b}	0.31	0.10	7.70	8.14	7.50	8.42
	W3	10	7.56^{b}	0.36	0.12	7.30	7.82	7.05	8.18
	W4	10	10.85^{c}	0.55	0.18	10.45	11.24	10.32	11.94

Duncan's multiple range test results, the same letters mean no significant differences between the means

The densities of the boards were almost the same and no significant differences were observed. Board density is one of the important factors affecting physical and mechanical properties. Çamlıbel and Aydın (2023) reported that TS, IB, MOR, and MOE were statistically significantly influenced by the density; however, IB was the most positively affected property. Considering this, with increasing density, the contact between chip particles increases and has a positive effect on the properties of the board (Göker and Akbulut 1992). Contrary to density, both physical and mechanical properties and free formaldehyde were significantly influenced by waste pulp fiber utilization percentage.

Physical and Technological Properties

The physical properties, including average values of density, 24 h TS, WA, and free formaldehyde tests, and technological properties of the test samples, are shown in Fig. 5.

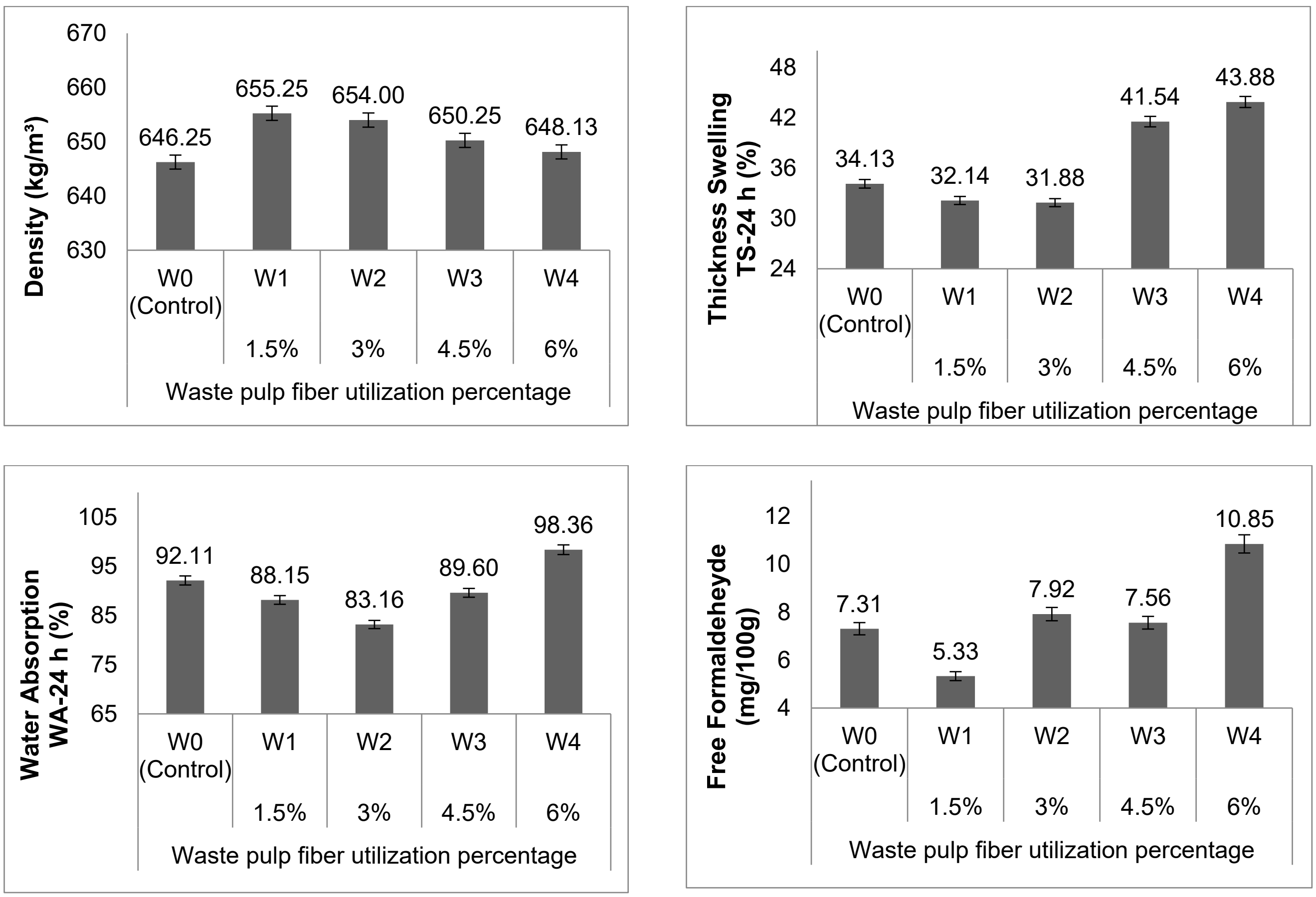


Fig. 5. Mean values of physical and technological properties

The lowest TS and WA 24 h values were found in the W2 (3% pulp fiber), which showed decreases of 6.60% and 9.72% compared to the control samples, respectively. This situation can be explained by the fact that inorganic compounds detected in the waste pulp fiber in the elemental analyses buffer the resin between the chips, reducing its pH and bonding ability. In the literature, there are similar and contrary expressions. Davis *et al.* (2003) stated that inorganic compounds in the pulp content are the primary factor negatively affecting the dimensional stability of the panels. Camlıbel (2021) mentioned the positive effect of 3% calcite ($CaCO_3$) used as filler on the physical properties of MDF. Akbulut *et al.* (2021) stated that the use of 20% waste sludge fiber led to a 35 to 50%

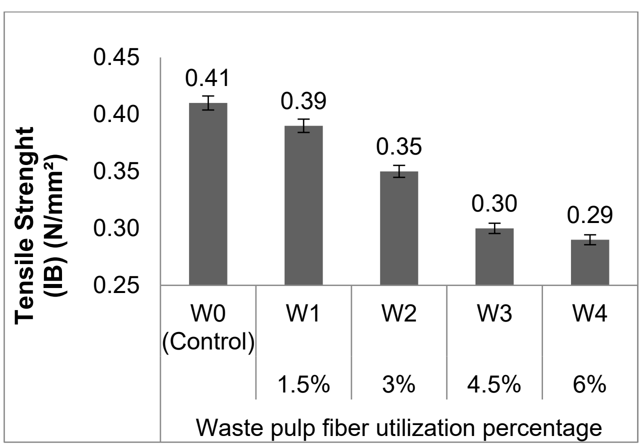
decrease in the TS and WA values of particleboards. Güler and Üçüncü (2024) observed a 0 to 10% decrease in the TS and WA values of particleboards produced by mixing wood chips and office papers. Roffael *et al.* (2001) found that the use of waste kraft pulp in MDF production caused a decrease in the TS and WA values. The negative effect of inorganic materials, such as ash and extractives in the pulp content, was shown as the reason for this situation. Taramian *et al.* (2007) investigated the negative potential of the increase in waste paper pulp on the dimensional stability of particleboard and stated that the increase in waste paper pulp negatively affected the dimensional stability of MDF. Migneault *et al.* (2010) stated that TMP, CMTP, and kraft pulp were recycled. This situation was explained by the fact that inorganic compounds in the pulp reduced the bonding ability of the resin.

Depending on the material used, quantity and production parameters, inorganic materials can have both positive and negative effects on the particle size distribution. Improved fire resistance, durability, dimensional stability, and sometimes strength (at low loadings) can be assumed as positive effects. However, reduced internal bonding, higher density, brittleness, and possible resin incompatibility at high loadings can be assumed as negative effects. Therefore, it may be incorrect to express the pure effect of inorganic materials without considering the impact of wood particles.

The lowest values for the formaldehyde were seen in the W1 control samples, which showed a 27% decrease compared to the control sample with 5.33 mg/100 g and used 1.5% pulp. A slight increase was detected in free formaldehyde values due to the increase in waste pulp. This situation can be explained by the release of formaldehyde depending on the bonding ability of the chips. Camlıbel (2021) mentioned the positive effect of calcite ($CaCO_3$) used as a filler on the free formaldehyde values of MDF. Akbulut *et al.* (2021) stated that the addition of waste sludge caused a 22% increase in the free formaldehyde values of particleboard and that this was an important issue to be solved. Mengeloğlu *et al.* (2018) recommended that amine-based formaldehyde removal chemicals could be used to solve the problem.

Mechanical Properties

The average values of tensile strength, bending resistance and MOE of the mechanical properties of the test specimens are given in Fig. 6.



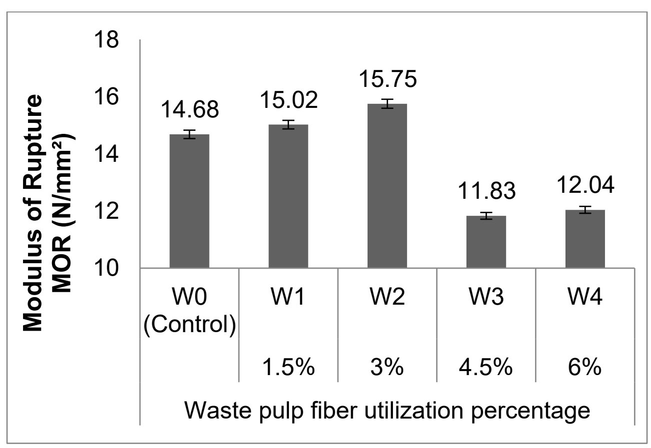


Fig. 6 (a & b). Average values of mechanical properties

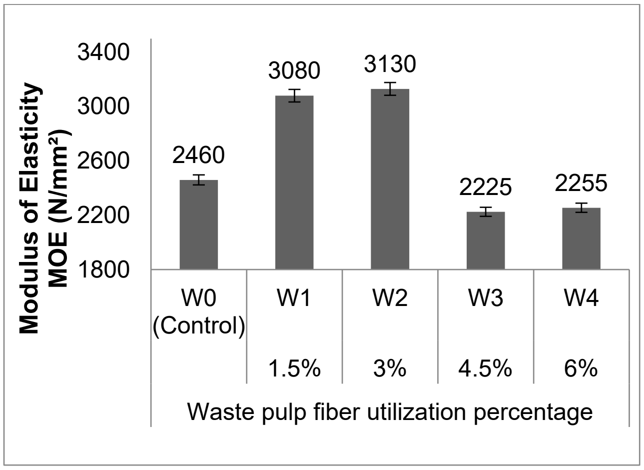


Fig. 6 (c). Average values of mechanical properties

It was seen from the test results that all tensile strength values were above the upper limit for P3 class particleboards presented in TS EN 312 (2012). According to Fig. 6, the highest tensile strength was determined for W0 control samples. The lowest was seen in W4 experimental groups, which showed a 29.1% decrease compared to the control samples. As shown in Fig. 6, a linear-like decrease was observed when the waste utilization rate increased. This situation is explained as the inorganic structures detected as a result of elemental analysis in the pulp negatively affecting the bonding ability of the resin between the chips. In the literature, there are similar expressions. Davis *et al.* (2003) stated in their study that inorganic compounds, such as kaolin coating clay and calcium carbonate, in the pulp were the most important factors negatively affecting the tensile strength. In the study by Akbulut *et al.* (2021), where waste pulp fiber was added to the middle layer and surface of the particleboard, a 15% decrease in the optimum tensile strength values was detected in experimental samples using 20% waste pulp in the surface layer. Roffael *et al*. (2001) mentioned that the significant decreases in tensile strength were strongly related to the ratio of inorganic materials, such as ash and extractives, in the pulp. In addition, it was stated that the usage level that would not affect the board quality was 25%. Taramian *et al.* (2007) stated that the increase in pulp negatively affected the tensile strength in the particleboard experimental samples obtained by adding waste pulp fiber to wood chips, whereas the use of 15% pulp met the requirements specified in the standards. Migneault *et al.* (2010) investigated the recycling possibilities of pulp sources with different properties and found a linear decrease in the tensile strength of MDFs parallel to the increase in pulp. This situation was explained as the inorganic compounds in the waste pulp composition reducing the bonding ability of the resin.

All MOR and MOE values were above the upper limit of the P3 class particle boards presented in TS EN 312 (2012). As shown in Fig. 6, the highest MOR and MOE were determined in W2 test samples, which showed an increase of 7.29% and 27.24% compared to the control samples, respectively. The W3 test samples presented the lowest values (a decrease of 19.43% and 9.55% compared to the control samples). Significant decreases in MOR and MOE can be expressed because pulp fiber has a different morphological structure compared to wood chips and the inorganic structures it contains negatively affect the bonding between the chips. Considering the literature, Davis *et al.* (2003) mentioned the negative effect of inorganic compounds in the pulp content on the MOR and MOE. Akbulut *et al.* (2021) stated that when waste pulp was added to the surface layers of particleboard, the MOR and MOE increased 24% and 59%, respectively. Hamzeh *et al.* (2011) stated that the use of wastepaper particles as filler in composite boards increased the MOR and MOE. Rafael *et al.* (2005) observed decreases in the MOR and MOE of the test samples due to the increase in kraft pulp fiber. In contrast, Genk *et al.* (2007) stated that the MOR and MOE of MDF obtained by mixing primary and secondary wastepaper sludge fibers with wood fibers (7:3) met the limit values specified in the standards. Migneault *et al.* (2010) investigated the recycling potential of TMP, CMTP, and kraft pulp sources by mixing them with wood fibers, and less decrease was detected in the MOR and MOE values of MDF test samples compared to other properties. This situation was explained by the fact that the MOR of the test samples was less dependent on the adhesive performance.

The tensile strength of internal bonding measures the particleboards' ability to resist layers pulling apart. It defines the bonding quality. For example, low value means poor adhesion, voids, or resin starvation. Therefore, tensile strength is crucial because it directly indicates the integrity of bonding within particleboard. Without sufficient tensile strength, even boards with high bending strength or stiffness can become delaminated, fail in service, or not meet the industry standard. As can be seen in Fig. 6, tensile strength gradually decreased with the wastepaper pulp utilization. Although there were some improvements in certain physical and mechanical properties, a decrease in tensile strength may be considered undesirable for a material intended for structural use.

The fine cellulose particles and microfibrils in wastepaper pulp may increase mechanical bonding by reducing porosity between fibers or between fibers and particles in the matrix, thereby enabling sufficient bonding with less adhesive. However, this can be explained by the formation of a thick film layer of inorganic compounds (fillers) on the resin fiber surface due to the increased use of waste fibers, which negatively affects fibre-fibre bonding.

CONCLUSIONS

In this study, the effect of the utilization of pulp fiber wastes obtained by paper and paperboard production on the mechanical, physical, and formaldehyde properties of particleboard was investigated, and the following conclusions were obtained.

1. The wastepaper pulp in the particleboard had statistically significant effects on the mechanical, technological, and physical properties.
2. The particleboards met the minimum requirements specified in the TS EN 312 (2012) standard.
3. For the bending properties, 3% wastepaper fiber utilization provided the highest value. However, at this ratio, tensile strength has significantly decreased, which is not desirable for material intended for structural purposes.
4. While there was a respective 6.60% and 9.7% decrease in TS and WA 24 h among physical properties, there was a 27% decrease in free formaldehyde emission value among technological properties. In mechanical properties, MOR and MOE increased 7.29% and 27.24%, respectively, while no increase was observed in tensile strength.

5. In the elemental analysis, it was understood that the ash content of the waste pulp fiber was approximately 20%. In addition, when the microscopic structure of the pulp fiber was examined *via* SEM, particles of amorphous inorganic compounds were detected on the fiber surface. These compounds negatively affected the bonding ability of the glue, causing decreases in tensile strength and other properties accordingly.

As a result, it was determined that waste pulp fiber can be used at low levels as a supporting material to reduce the wood raw material in particleboard production. Therefore, materials such as lignocellulose deserve to be recycled and provided to the market as supporting material not only to protect the reduced forest presence but also to contribute to the local or global economy.

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REFERENCES CITED

Akbulut, T., Ayrılmış, N., Özden, Ö., and Avcı, E. (2021). "Potential application of fibrous sludge waste from paper mills in particleboard production," *Forestist* 71(1), 54-61. DOI: 10.5152/forestist.2020.20051

ANSI A208.2 (2002). "Medium density fiberboard (MDF) for interior applications," American National Standards Institute, Composite Panel Association, Gaithersburg, MD, USA.

ASTM D1037 (1999). "Standard test methods for evaluating properties of wood-base fiber and particle panel materials," ASTM International, West Conshohocken, PA, USA.

ASTM D3172 (2002). "Standard practice for proximate analysis of coal and coke," ASTM International, West Conshohocken, PA, USA.

ASTM D3174 (2012). "Standard test method for ash in the analysis sample of coal and coke from coal," ASTM International, West Conshohocken, PA, USA.

ASTM D3175 (2008). "Standard test method for volatile matter in the analysis sample of coal and coke," ASTM International, West Conshohocken, PA, USA.

ASTM D3302 (2002). "Standard test method for total moisture in coal," ASTM International, West Conshohocken, PA, USA.

ASTM D4239 (1994). "Standard test method for sulfur in the analysis sample of coal and coke using high-temperature tube furnace combustion," ASTM International, West Conshohocken, PA, USA.

ASTM D5865 (2001). "Standard test method for gross calorific value of coal and coke," ASTM International, West Conshohocken, PA, USA.

Bozkurt, Y., and Göker, Y. (1990). "Yongalevha endüstrisi (Particleboard industry)," *Ders Kitabı,* İ.Ü. Yayın No:3614, O.F. Yayın No: 413, İstanbul, 14-170.

Camlibel, O. (2021). “Effect of calcite addition on technical properties and reduction of formaldehyde emissions of medium density fiberboard,” *BioResources* 16(2), 3718-3733. DOI: 10.15376/biores.16.2.3718-373

Çamlıbel, O., and Aydın, M. (2022). “Influences of hardening agent on some physical and mechanical properties of medium-density fiberboard,” *Turkish Journal of Forestry* 23(2), 128-134. DOI: 10.18182/tjf.1099700

Çamlibel, O., and Aydin, M. (2023). “Influence of density on medium-density fiberboard properties at industrial scale experimental,” *ProLigno* 19(2), 11-20.

Çamlibel, O., and Aydin, M. (2025). “Influence of paraffin on MDF properties at industrial scale,” *Wood Research* 70(1), 127-138. DOI: 10.37763/wr.1336-4561/70.1.127138

Çamlıbel, O., Aydın, M., and Koç, E. (2025). “Influence of hardener type on the particleboard properties at industrial scale,” *Proceedings of the Mational Academiy of Sciences, India Section A: Physical Scieces* 95, 33-40. DOI: 10.1007/s40010-025-00910-5

Davis, E., Shaler, S. M., and Goodell, B. (2003). “The incorporation of paper deinking sludge into fiberboard,” *Forest Products Journal* 53(11/12), 46-54.

FAOSTAT (2020). “Forestry production and trade,” FAO of the United Nations, Available online: (http://www.fao.org/faostat/en/#data/FO), Accessed 07 July 2020.

Geng, X., Deng, J., and Zhang, S.Y. (2007). “Characteristics of pulp and paper sludge and its utilization for the manufacture of medium density fiberboard,” *Wood and Fiber Science* 39(2), 345-351.

Göker, Y., and Akbulut, T. (1992). “Factors affecting the properties of particleboard and plywood,” in: *Orenko’92: I. National Forest Industry Product Symposium*, Trabzon, Turkey.

Grigoriou, A. (2003). “Waste paper–wood composites bonded with isocyanate,” *Wood Science and Technology* 37(1), 79-90. DOI: 10.1007/s00226-003-0164-x

Güler, C., and Üçüncü, B. (2024). “Board production experiments from waste paper,” *Artvin Coruh University Journal of Forestry Faculty* 25(2), 238-248.

Hamzeh, Y., Ashori, A., and Mirzaei, B. (2011). “Effects of waste paper sludge on the physico-mechanical properties of high density polyethylene/wood flour composites,” *Journal of Polymers and the Environment* 19(1), 120-124. DOI: 10.1007/s10924-010-0255-3

Kara, M. E., Yazıcı, H., Koç, E., and Aykan, R. (2024). “The effect of using waste stone wool on some mechanical and physical properties of particleboards,” *Journal of Bartin Faculty of Forestry* 26(4), 448-457. DOI: 10.24011/barofd.1542421

Larney, M., and Aardt Van, A. M. (2009). “Case study: Apparel ındustry waste management: A focus on recycling in South Africa,” *Waste Management & Research* 28, 36-43. DOI: 10.1177/0734242X09338729

Lykidis, C., Parnavela, C., Goulounis, N., and Grigoriou, A. (2012). “Potential for utilizing waste corrugated paper containers into wood composites using UF and PMDI resin systems,” *European Journal of Wood and Wood Products* 70(6), 811-818. DOI: 10.1007/s00107-012-0618-7

Mengeloğlu, F., Başboğa, İ. H., Atar, İ., Karakus, K., and Yüce, Ö. (2018). “The usage of ABCM as a formaldehyde scavenger during particleboard manufacturing with melamine impregnated paper waste (MIPW),” *Pro Ligno* 14(3), 19-28.

Migneault, S., Koubaa, A., Nadji, H., Riedl, B., Zhang, T., and Deng, J. (2010). "Medium-density fiberboard produced using pulp and paper sludge from different pulping processes," *Wood and Fiber Sciences* 42(3), 292-303.

Nourbakhsh, A., and Ashori, A. (2010). "Particleboard made from waste paper treated with maleic anhydride," *Waste Management & Research* 28(1), 51-55. DOI: 10.1177/0734242X09336463

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

Roffael, E., Dix, B., and Schneider, T. (2001). "Thermomechanical (TMP) and chemo-thermomechanical pulps (CTMP) for medium density fibreboards (MDF)," *Holzforschung* 55(2), 214-218. DOI: 10.1515/HF.2001.035

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

TS EN 310 (1999). "Wood-based panels-determination of modulus of elasticity in bending and of bending strength," Turkish Standards Institute (TSE), Ankara, Türkiye.

TS EN 312 (2012). "Particle boards-properties," Turkish Standards Institute (TSE), Ankara, Türkiye.

TS EN 317 (1999). "Particle boards and fibreboards – Determination of swelling in thickness after immersion in water," Turkish Standards Institute (TSE), Ankara, Türkiye.

TS EN 319 (1999). "Particleboards and fibreboards – Determination of tensile strength perpendicular to the plane of the board," Turkish Standards Institute (TSE), Ankara, Türkiye.

TS EN 322 (1999). "Wood-based panels- determination of moisture content," Turkish Standards Institute (TSE), Ankara, Türkiye.

TS EN 323-1 (1999). "Wood-based panels- determination of density," Turkish Standards Institute (TSE), Ankara, Türkiye.

TS EN 325 (1999). "Wood-based panels-determination of dimensions of test pieces," Turkish Standards Institute (TSE), Ankara, Türkiye.

TS EN 326-1 (1999). "Wood-based panels – Sampling, cutting and expression of test results," Turkish Standards Institute (TSE), Ankara, Türkiye.

TS EN ISO 12460-5 (2016). "Wood-based panels-determination of formaldehyde release- extraction method (perforator method)," Turkish Standards Institute (TSE), Ankara, Türkiye.

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