

# Particle board production using paper mill waste sludge and European black pine (*Pinus nigra* A.) wood chips

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**Abstract.** Paper mills use excessive amounts of water throughout production to produce paper. While mills treat water for reuse, sludge is generated and must be processed as a waste, along with some washing water. In this study, waste sludge from a kraft process mill mixed with up to 40% black pine (*Pinus nigra*) wood chips was investigated for multi-purpose board production using urea formaldehyde resin and ammonium chloride as a hardener. The panels were pressed at 150°C for 7 minutes between 2.4 MPa and 2.6 MPa. The resulting panels were 18 mm thick, with a density of from 0.69 gr/cm<sup>3</sup> to 0.71 g/cm<sup>3</sup>. Measurements of density, moisture, water absorption, thickness swelling, modulus of rupture, modulus of elasticity and internal bond strength to the surface were carried out on the particle board panels. The results indicated that panels could be used for general purposes.

**Keywords:** Paper mill; Waste sludge; Particle board; Physical properties; Mechanical properties

## Introduction

Shortages of wood fiber in some regions have encouraged the use of waste products for panel production (Lee et al. 2022). The increasing need for raw materials in the panel production sector has encouraged exploration of other cellulosic resources including agricultural residues and coconut fiber (Table 1). However, these materials may be less compatible than forest-derived residues. One possible alternative fiber source originates from the pulp and paper industry. The pulping process produces a sizable volume of fibers that are unsuitable for paper production (Naik et al. 2004).

These fibers are often burned in the pulp liquor regeneration process, but they might also be used to supplement fiber supplies for panel production. However, this sludge also contains inorganic substances that may be incompatible with composite production.

The objective of this study was to evaluate the potential for using waste sludge from the pulp and paper industry as a partial substitute for wood chips in particleboards.

## Materials and methods

Waste sludge from kraft paper mill wastewater was provided by Kahramanmaraş Paper Industry and Trade Inc. (KMK Paper, Kahramanmaraş, Türkiye). The mill processed mixed softwood species. The sludge was dried at 70°C and then broken into pieces and pulverized. Black pine (*Pinus nigra* A.) sawdust was dried at 70°C to between 1% and 2% moisture content then mixed with the sludge at five different ratios (Table 2).

Panels were produced with three layers. The 0.8–1.5 mm thick outer layers were composed entirely of black pine sawdust with 10%–11% urea formaldehyde resin (Table 3). The core consisted of the black pine/pulp sludge mixture along with 8%–9% resin (m/m). The resin contained 55% solids urea formaldehyde and 33% ammonium chloride.

The 40 by 40 cm panels were formed and then cold pressed before being hot pressed for 6 to 7 minutes at 150°C and at 2.4 MPa to 2.6 MPa to a target thickness of 18 mm. The den-

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Table 1. The alternative plant sources used by some researchers for particleboard production.

Alternative sources	Researchers
Corn stalk, cotton stalk, pepper stalk, wheat stalk, sunflower stalk	Guler and Ozen (2004); Bektas et al. (2005); Alma et al. (2005); Guler et al. (2006); Oh and Yoo (2011); Bektas et al. (2020)
Peanut, hazelnut husk, peanut shell, yellow pine	Guler et al. (2009); Mankowski and Laskowska (2021)
Sugarcane, hemp grass, flax, hemp, kenaf	Jiaying et al. (2003); Kalaycıoğlu and Nemli (2006)
Licorice root, rice pad	Guler (2015)
Coconut skin and fiber	Khedari et al. (2003); Khedari et al. (2004)
Needle leaves, pine cones	Nemli and Aydın (2007); Buyuksari et al. (2010)
Kiwi pruning waste, grass waste, tea waste, vine waste	Nemli et al. (2003); Nemli et al. (2009)

sity of the resulting panels ranged from 0.69 g/cm<sup>3</sup> to 0.71 g/cm<sup>3</sup>. Ten panels were fabricated for each wood/sludge ratio. The panels were conditioned for 3 weeks at 20°C and 65% relative humidity, in accordance with Turkish Standard (TSE) TS 642 ISO 554 (1997). The conditioned panels were cut into samples for evaluating thickness swelling, water absorption, flexural properties, and internal bond strength, according to EN 326-1:1999 (TSE - TS EN 326-1 1999), Wood-based panels- Sampling, cutting and inspection - Part 1: Sampling test pieces and expression of test results (CEN, Ankara) (Table 4).

Moisture content of the panels was determined using European Standard (EN) 322 (TSE - TS EN 322 1999). Briefly, samples were weighed, oven dried at 104°C and weighed. Density was determined by measuring panel dimensions and weighing each sample according to Standard EN 323 (TSE - TS EN 323 1999).

Flexural properties were determined according to EN 310 (TSE - TS EN 310 1999). Load was applied at a constant rate throughout the experiment, and the loading head speed was adjusted to reach the maximum force (in 60±30) seconds. Load and deflection were continuously monitored, and the resulting load/deflection curve was used to calculate modulus of elasticity (MOE) and modulus of rupture (MOR).

Thickness swelling and water absorption were determined by weighing and measuring the thickness of samples prior to immersion in distilled water. Sample mass and thickness were measured after 2 and 24 hours of immersion.

Internal bond strength was measured according to Standard EN 319 (TSE - TS EN 319 1999). Samples were glued to aluminum blocks, allowed to cure, and then pulled apart. The load required to fail the specimens was defined as the shear capacity.

The data were averaged and then subjected to an analysis of variance. Differences between means were subjected to a Duncan's mean separation test ( $\alpha = 0.05$ ).

Table 2. Proportions of waste sludge and black pine chips used to fabricate panels.

Board type	Waste sludge (%)	Black pine chips (%)
A	0	100
B	10	90
C	20	80
D	30	70
E	40	60

The densities of the boards obtained with waste sludge and European black pine wood chips were 0.69 g/cm<sup>3</sup>–0.71 g/cm<sup>3</sup>.

Table 3. Properties of the urea formaldehyde resin used to fabricate the panels.

Property	UF
Solids (%)	55±1
Density (g/cm <sup>3</sup> )	1.20
pH	8.5
Viscosity (cps)	160
Ratio of water tolerance	10/27
Reactivity	35
Free formaldehyde (%)	0.15
33% NH <sub>4</sub> Cl content (max, %)	1
Gel point (100°C)	25–30
Storage time (25°C, max day)	90
Flowing point (25°C)	20–40

Table 4. Dimensions and number of replicates per treatment used to assess panel properties.

Test	Dimensions (mm)	Replicates/Treatment	Test standard
Thickness swelling	18	10	TSE - TS EN 317 (1999)
Density	18	10	TSE - TS EN 323 (1999)
Water absorption	18	10	TSE - TS EN 317 (1999)
Flexural properties	18	10	TSE - TS EN 310 (1999)
Internal bond	18	10	TSE - TS EN 319 (1999)

## Results and discussion

Thickness swelling after 2 hours of immersion was lowest in the all-wood panel and steadily increased with increasing pulp sludge content (Table 5). The presence of any sludge produced a significant increase in thickness swelling, with the largest swelling in the 40%/60% sludge/wood panels. Panel thicknesses continued to increase with the additional 22 hours of soaking, but the trends were the same. Standard EN 317 (TSE - TS EN 317 1999) limits swelling to 14% after 24 hours of immersion, meaning that none of the panels met this standard, including the all-wood one.

Water absorption followed trends that were similar to those for swelling, with steadily increasing absorption with increased sludge content. Once again, absorption increased significantly with increased sludge content. The results suggest that any sludge reduces panel properties. This problem might be overcome by adding more resin to the furnish.

Kalaycıoğlu (1992) determined that water intake of panels composed of tobacco stem and tea factory waste was 60%–71%

after 24 h, and thickness increased 22%–37%. Filiz et al. (2011) determined that the low-density particle boards produced from tea plant wastes swelled between 17% and 34.8%, while Sevinçli (2014) reported that swelling of medium density boards composed of lavender plant and red pine chips was between 34.36% and 76.98%.

The addition of pulp sludge also negatively affected flexural properties, with significant losses in both MOR and MOE with increasing pulp content (Table 6). There was a 16% loss in MOR when 10% sludge was substituted and a nearly 60% loss in MOR when 40% sludge was substituted. EN 310 (TSE - TS EN 310 1999) specifies a minimum MOR of 10 MPa for 13 to 20 mm thick boards and 11 MPa for interior equipment such as furniture, meaning that only 10% sludge could be added without reducing this property below acceptable levels. Similarly, MOE significantly declined by 14.8% with 10% sludge and 60.9% when 40% sludge was substituted. EN 310 (TSE - TS EN 310 1999) specifies a minimum MOE of 2300 MPa in dry conditions and 1950 MPa in humid environments for 13 to 20 mm thick panels. Once again, addition of 10%

Table 5. Effect of increasing sludge content on thickness swelling and water absorption of particleboards subjected to EN 317 (TSE - TS EN 317 1999).\*

Immersion time (Hr)	Sludge/Wood (%)	Thickness swelling (%)		Water absorption (%)	
		Mean	Range	Mean	Range
2	0/100	8.98 (1.07) <sup>a</sup>	8.18-9.77	9.88 (1.18) <sup>a</sup>	9.00-10.75
2	10/90	12.06 (1.36) <sup>b</sup>	11.26-12.86	13.27 (1.50) <sup>b</sup>	12.39-14.14
2	20/80	12.28 (1.03) <sup>b</sup>	11.48-13.07	13.51 (1.13) <sup>b</sup>	12.63-14.38
2	30/70	14.46 (1.35) <sup>c</sup>	13.66-15.25	15.90 (1.49) <sup>d</sup>	15.02-16.77
2	40/60	16.16 (1.37) <sup>d</sup>	15.36-16.95	17.77 (1.51) <sup>e</sup>	16.89-18.65
24	0/100	38.10 (5.76) <sup>e</sup>	34.53-41.67	41.92 (6.33) <sup>f</sup>	37.99-45.84
24	10/90	52.19 (4.90) <sup>f</sup>	48.62-55.75	57.41 (5.39) <sup>g</sup>	53.48-61.33
24	20/80	60.11 (6.19) <sup>g</sup>	56.42-63.67	66.12 (6.81) <sup>h</sup>	62.19-70.04
24	30/70	61.46 (3.90) <sup>g</sup>	57.89-65.68	67.68 (4.29) <sup>h</sup>	63.68-71.53
24	40/60	67.40 (6.79) <sup>h</sup>	63.83-70.97	74.14 (7.48) <sup>i</sup>	70.21-78.07

\* Values represent means of 10 replicates per sludge/wood ratio, while figures in parentheses represent one standard deviation. Values followed by the same letter do not differ significantly by Duncan's Least Significant Difference Test ( $\alpha = 0.05$ ).

Table 6. Effect of increasing sludge content on flexural properties (MOR, MOE) and internal bond (IB) of particleboards subjected to EN 310 (TSE - TS EN 310 1999) and EN 319 (TSE - TS EN 319 1999).\*

Sludge/Wood (%)	Modulus of Rupture (MPa)		Modulus of Elasticity (MPa)		Internal Bond Strength (MPa)	
	Mean	Range	Mean	Range	Mean	Range
0/100	13.34 (1.59) <sup>d</sup>	11.67-15.01	2743.1 (292.1) <sup>d</sup>	2364-3071	0.4335 (0.0482) <sup>e</sup>	0.37-0.48
10/90	11.22 (0.83) <sup>c</sup>	10.35-12.09	2336.7 (105.8) <sup>c</sup>	2211-2497	0.3627 (0.0476) <sup>d</sup>	0.30-0.43
20/80	7.63 (1.09) <sup>b</sup>	6.48-8.78	1753.6 (155.9) <sup>b</sup>	1506-1980	0.2897 (0.0531) <sup>c</sup>	0.24-0.36
30/70	6.62 (0.67) <sup>ab</sup>	5.91-7.33	1688.9 (305.9) <sup>b</sup>	1199-1992	0.2295 (0.0424) <sup>b</sup>	0.20-0.29
40/60	5.50 (0.82) <sup>a</sup>	4.63-6.36	1073.3 (209.9) <sup>a</sup>	810-3071	0.1940 (0.0595) <sup>a</sup>	0.13-0.28

\* Values represent means of six replicates per sludge/wood ratio, while figures in parentheses represent one standard deviation. Values followed by the same letter do not differ significantly by Duncan's Least Significant Difference Test ( $\alpha = 0.05$ ).

sludge resulted in an acceptable panel, while further increases produced unacceptable losses in MOE.

Internal bond (IB) followed similar trends, with significant losses in properties with increasing sludge content. The standard (TSE - TS EN 319 1999) calls for IBs of 0.36 MPa and 0.29 Mpa (Table 6).

Kalaycıoğlu (1992) determined that the MOR values of tobacco stalk and tea factory waste panels were between 12.68 MPa and 16.87 Mpa, while IB values were between 0.360 MPa and 0.438 MPa. Aras et al. (2014) found an MOE of 970 MPa in boards produced from 100% pine nut cones with a density of 0.70 g/cm<sup>3</sup>.

The minimum IB on the surface is 0.24 MPa for 13 mm and 20 mm general purpose particle boards used in dry conditions, while this value increases to 0.35 MPa for panels used in interior equipment (including furniture) or other load bearing panels in dry conditions. In this case, the addition of 20% sludge still resulted in panels that met some of the requirements for some applications, but further sludge addition resulted in significant declines in IB that would make the panels unacceptable for most uses.

## Conclusions

The addition of 10% pulp sludge to the core of black pine particleboard resulted in panels that still met the requirements for thickness swelling/water absorption, flexural properties, and IB, but further sludge content significantly reduced most properties below acceptable levels. The results suggest that pulp sludge could be used as an extender at low concentration. However, the effect of sludge addition on other panel properties needs to be evaluated, including odors and resistance to biodeterioration.

## Authorship contributions

SK: Conceptualization, Data curation, Formal Analysis, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MT: Investigation, resources and Funding acquisition.

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