Potential Use of Textile Dust in the Middle Layer of Three-layered Particleboards as an Eco-friendly Solution

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Textile (cotton) dust, which is harmful to humans and the environment, is one of the largest wastes in the textile industry. The aim of this study was to investigate the potential use of this waste in high value-added materials. Physical and mechanical properties and formaldehyde emissions of the three-layered particleboards with textile (cotton) dust in the middle layer were investigated in this study. A phenol formaldehyde resin was used as the binder in particleboard production. Four different amounts of textile dust (10%, 20%, 30%, and 40%) based on the oven-dried weight of the wood were obtained from a commercial textile manufacturer as industrial waste. The density, thickness swelling, modulus of rupture, modulus of elasticity, internal bond, and formaldehyde emissions of the produced panels were determined. The physical and mechanical properties and formaldehyde emissions of the particleboards were negatively affected, which decreased with the addition of a high amount of textile powder. At low rates, the use of textile dust in the middle layer did not significantly decrease the particleboard properties. Textile dust can be a partial solution for the raw material demand of the wood-based panel industry.

Keywords: Textile dust; Formaldehyde emission; Waste management; Particleboard

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INTRODUCTION

Although the usage of wood-based boards has increased in the last two decades, the source of raw materials is still a major problem. Forests, which are a primary source for wood materials, have decreased by 13 million ha each year (Pirayesh and Khazaeian 2012). Mankind is using abundant amounts of wood and wood products in daily life (Ndazi *et al.* 2006). This need is constantly increasing because of the production of wood composites, such as medium density fiberboard, particleboard, and plywood. Also, hardwood and coating products are becoming increasingly important. Particleboard is one of the most used wood composite boards because of its advantages, such as low production costs and good strength, which makes it ideal for the furniture industry.

There is a growing demand for particleboard furniture production, such as interior decoration and residential construction (Pan *et al.* 2006). However, because of the diminution of forest resources and the degradation of forests, there are serious concerns about the long-term raw material supply in this sector. Therefore, researchers have focused on alternative lignocellulosic materials to produce particleboards to decrease the use of wood materials. For this reason, in previous studies, non-wood plants, such as wheat straw (Nemli *et al.* 2009), sycamore leaves (Pirayesh *et al.* 2015), waste grass (Wang and Sun

2002), and agro-residues, such as coffee husk (Bekalo and Reinhardt 2010), walnut/almond shells (Pirayesh *et al.* 2011) and tea leaves (Yalınkılıç *et al.* 1998), have been used as alternative lignocellulosic materials in particleboard manufacturing.

The textile industry is one of the largest industries in the world. During textile production, waste materials are produced. Textile (cotton) dust is one of the wastes produced in the textile industry (DeLuca 1984). Textile dust has a pure white cotton structure with short fibers (Classen and Baril 1981) and it consists of 60% to 80% fibers, leaves, and crusts, 10% to 30% sand, and some water-soluble substances (Ertaş *et al.* 2010). Textile dust, a non-reusable waste in textile production, is gathered in a collector using dust extraction systems with air circulation during textile production.

Dust can get into the environment during yarn and fabric production and creates a harmful environment for human health (Silverman and Viles 1950). Additionally, dumping organic wastes in landfills is forbidden in the European Union and other countries (Jeihanipour *et al.* 2010). Landfills are the main practice for disposing of textile dust in many countries. Government regulations and legislation require textile manufacturers to find environmentally-friendly recycling or disposal processes for textile dust. A potential use of textile dust could be as a raw material for wood-based panel production, which could be a partial solution for the demand of different raw materials in the wood-based panel industry.

Phenolic resins are the polycondensation products of the reaction of phenol with formaldehyde (Pizzi 1994). Using phenol-formaldehyde (PF) resins as an adhesive was recognized as long ago as the end of the nineteenth century. At the present time it is the most commonly used adhesives in forest products industry (Pizzi 1983). The bond strength of PF resins is high, the deterioration at elevated temperatures in presence of moisture is slight, and formaldehyde emission is low compared with UF. But some disadvantages of PF is its dark color, expensive price, and long curing time (Dunky and Niemz 2002).

Textile dust, which is an industrial waste in particleboard production, has not been studied as an alternative to wood particles in the middle layer of particleboards. Because a large amount of textile dust is produced in textile factories, it is necessary to investigate the potential use of this waste product in high value-added materials. This could also meet the requirements of environmental protection policies that are in place because of the harmful effects of textile dust. As a fiber source, textile dust may play a notable role in the production of particleboards. The purpose of this study was to determine the effect on the physical and mechanical properties and formaldehyde emissions after adding textile dust to the middle layer of three-layered particleboards.

EXPERIMENTAL

Materials

Black poplar wood from the Trabzon city (in the Black Sea region) of Turkey was used as the raw material for the chips. The phenol formaldehyde (PF) resin was supplied from a commercial resin manufacturer (Vezirköprü Forest Products and Paper Industry Inc., Samsun, Turkey) and used as the binder for the wood chips. The technical properties of the PF resin are given in Table 1.

Table 1. Technical Properties of the PF Resin

Technical Properties	Value
Mole Ratio of Phenol / Formaldehyde (%)	1.2
Density (g/cm^3)	1.27
Gel Time (s)	40
pH	7
Solid Content (%)	63
Viscosity (cps)	60

The textile dust was obtained from a textile manufacturer in Kahramanmaras City, Turkey. The average particle size of the textile dust was 0.20 mm. The dust was dried in an oven until the moisture content was 1 wt.%.

Methods

Production of the particleboards

The chips for the particleboards were prepared from black poplar wood without bark using a ring type flaker (Robert Hildebrand, Germany) in the laboratory. The middle and surface particles were produced using a hammer mill (Robert Hildebrand, Germany). The resulting surface and middle layer chips were dried in an oven at 103 °C until a 3% moisture content was reached, based on the oven-dried weight of the wood. The chips were glued with a laboratory type pneumatic glue machine. Based on the oven-dried chip weight, a 11-wt.% PF resin was used for the surface layer particles and a 9-wt.% PF resin was used for the middle layer particles. For the resin hardener, a 1% ammonium sulfate solution was used, which was based on the oven-dried weight of the solid resin. The shelling ratio of the particleboard mat was 40%. The mats were hot pressed at a temperature of 150 °C for 5 min at 2.5 N/mm^2 with a panel thickness of 12 mm (all of the parameters were kept constant). Any hydrophobic materials and other additive materials were used during panel production. Two particleboard panels were produced for each of the production parameters. The resulting particleboards had the dimensions 550 mm × 550 mm × 12 mm and were conditioned at 20 °C and a 65% humidity for three weeks. The experimental design is presented in Table 2.

Table 2. Experimental Design for Particleboard Production

Particleboard Code	Amount of PF (%)		Surface Layer Wood Chip Amount (wt.%)	Amount of Textile Dust Powder in Core Layer (wt.%)
	Surface Layer	Core Layer		
A	11	9	100	0
B	11	9	90	10
C	11	9	80	20
D	11	9	70	30
E	11	9	60	40

Test methods

The flexural properties (modulus of rupture (MOR) and modulus of elasticity (MOE)) were determined according to EN 310 (1993). A total of 12 specimens were used when determining the bending properties. As for the internal bond (IB) strength, 20 specimens were tested according to EN 319 (1993). The thickness swelling (ThS) (24-h) of the 20 particleboard specimens was tested according to EN 317 (1993).

The formaldehyde emission test was performed on the test samples according to EN 120-1 (1994). The formaldehyde emission was measured *via* the perforator method. The formaldehyde test was repeated in triplicate for each parameter.

Statistical analysis

A simple variance analysis with a 95% confidence level was used to determine the significant effects of the textile dust on the properties of the particleboard. A Newman Keuls test was conducted to compare the board groups that showed a significant difference.

RESULTS AND DISCUSSION

Mechanical Properties

The average physical and mechanical properties of the test panels, formaldehyde emissions, and statistical analysis results are shown in Table 3. Particleboards with up to 10 wt.% textile dust met the minimum requirements for the MOR (11 N/mm^2) and MOE (1800 N/mm^2) for interior fitments (including furniture), as specified in EN 312-2 (1996). The MOR and MOE of the particleboard with 10 wt.% textile dust were found to be 13.0 N/mm^2 and 1814 N/mm^2, respectively. The MOR and MOE values of the control group were found to be 13.4 N/mm^2 and 1885 N/mm^2, respectively. The MOR of the specimens with 20 wt.% textile dust (12.9 N/mm^2) met the MOR requirement given in EN 312-2 (1996), while the MOE (1755 N/mm^2) was slightly lower than the MOE requirement. As the amount of textile dust increased to 30 wt.%, the MOR and MOE values showed a sharp decrease, which was significantly different from the control group. The reason for the decrease in these properties was partly because the increased amount of textile dust used in the middle layer negatively affected heat transfer during pressing of the particleboard mat. A similar result was reported by Nemli *et al.* (2007).

The minimum IB value for particleboards used for interior fitments (including furniture) specified in EN 312-2 (1996) is 0.40 N/mm^2. The IB strength of the specimens with 10 wt.% textile dust (0.40 N/mm^2) met the standard value, but the other groups with different textile dust amounts did not. The highest IB values were found in the control sample (0.42 N/mm^2), while the lowest value was obtained from the boards with 40 wt.% textile dust (0.17 N/mm^2). The use of textile dust adversely affected the IB resistance. However, up to 20 wt.% textile dust had no significant effect on the IB strength. As the amount of textile dust reached 30 wt.% in the middle layer, the IB strength significantly decreased. This decrease was similar to the decrease in the MOR and MOE of the samples. Similar results were observed in previous studies for particleboards produced using agricultural waste (Grigoriou 2003; Nemli and Çolakoğlu 2005; Nemli *et al.* 2009). The improvement in the IB strength with up to 20 wt.% textile dust showed that the textile dust filled the porosity in the middle layer of the particleboard. However, above 20 wt.%, the decrease in the IB strength was mainly because the inclusion of textile dust decreased the interaction/bonding between the wood particles. This is due to the fact that the textile powder has shorter fibers than wood. Khanjanzadeh *et al.* (2014) made a similar statement in their study.

Thickness Swelling

The 24-h ThS of the particleboard samples increased from 18.7% to 26.7% as the textile dust increased from 0 wt.% to 40 wt.% in the middle layer. The minimum amount of swelling was found in the A boards (control), while the maximum amount of swelling was found in the boards with 40 wt.% textile dust. Therefore, the ThS was adversely affected by the incorporation of textile dust into the middle layer of the particleboards (Table 3). The maximum allowable 24-h ThS value for particleboards is 17%, according to EN 312-2 (1996). However, none of the test boards met this specified value. The ThS did not significantly increase when the textile dust content was lower than 20 wt.%, but it considerably increased with a textile dust content above 20 wt.%. This was mainly related to the hydrophilic property of the textile dust and its negative effect on the interfacial bonding of the wood particles. When a high amount of textile dust was incorporated into the middle layer of the particleboard, the surface of the wood particles was covered by textile dust, which negatively affected the IB strength between the particles. This was because the textile dust increased the total contact area between the adhesive and wood, which decreased the mechanical interlocking effect that may trap the adhesive in the cavities and act like an anchor (Ayrılmış *et al*. 2017). The ThS of the particleboards containing textile dust can be reduced by overlaying the surfaces and edges of the boards, increasing the resin content in the middle layer, and using the optimum textile dust content.

Table 3. Physical and Mechanical Properties of the Particleboards

Code	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	ThS (%)
A	13.4 a (1.08)	1885 a (146)	0.42 a (0.08)	18.7 a (0.49)
B	13.0 a (0.74)	1814 a (114)	0.40 a (0.05)	18.9 a (0.87)
C	12.9 a (0.82)	1755 a (103)	0.38 a (0.06)	19.0 a (0.58)
D	10.2 b (0.64)	1417 b (97)	0.25 b (0.05)	22.9 b (0.74)
E	8.0 c (0.93)	1109 c (106)	0.17 c (0.03)	26.7 c (0.61)

The values in parentheses are the standard deviation; different letters in the same column indicate statistical differences at the 95% confidence level

Formaldehyde Emissions

The formaldehyde emissions slightly increased with the addition of up to 20 wt.% textile dust in the middle layer of the particleboard (Fig. 1). There was no significant difference between the control sample (6.45 mg/100 g) and when 20 wt.% textile dust was added into the middle layer of the particleboard (6.54 mg/100 g). However, as the amount of textile dust increased above 20 wt.%, the formaldehyde emissions significantly increased when compared with that of the control samples. The maximum permissible formaldehyde content for E1-grade formaldehyde emissions is 8 mg of CH_2O/100 g for oven-dried particleboard samples, according to EN 312-2 (1996). Because of the molecular characteristics of the PF resin, the formaldehyde emissions from all of the test samples were below the maximum values specified in EN 312-2 (1996). During particleboard production, the amount of textile dust in the middle layer did not have a statistically significant effect on the formaldehyde emissions for boards B and C, but it was found that there were significant differences for boards D and E.

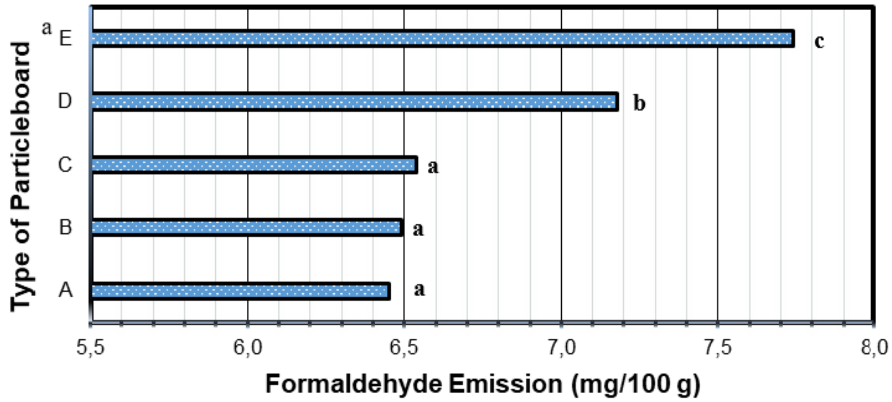

Fig. 1. Average values of the formaldehyde emissions from the different particleboard types (Letters indicate the statistical differences at the 95% confidence level)

CONCLUSIONS

1. Textile dust additions of up to 20 wt.% did not significantly affect the thickness swelling (ThS), internal bond (IB) strength, and bending properties.
2. The physical and mechanical properties of the particleboards were negatively affected by the addition of up to 30 wt.% textile dust.
3. Because a phenol-formaldehyde (PF) resin with a low solid content was used for particleboard production, all of the particleboard groups were found to have an E1-grade formaldehyde emission, which is suitable for internal use.
4. The particleboard industry has faced problems relating to decreased forest resources and increased wood prices. Affordable wood material availability continues to be a major concern for the wood-based panels industry because of the increased number of factories. Textile dust (20 wt.%), which is a by-product from textile mills, can be considered to be an alternative to wood materials for particleboard manufacturing.

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