Utilization of Waste Polyethylene and its Effects on Physical and Mechanical Properties of Oriented Strand Board

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The effect of adding waste polyethylene (WPE) was investigated at various ratios on some physical and mechanical properties of oriented strand board (OSB) panels. All of the test panels were bonded with 6% phenol-formaldehyde resin in three layers. The manufacturing parameters was 0/100, 10/90, 20/80, 30/70, 40/60, and 50/50 by weight% of WPE/wood strand. All the boards were manufactured to achieve targeted specific gravity of 0.65 g/cm^3. Polyethylene improved the water resistance of the OSB panels because of its hydrophobicity. Based on the results of this study, thickness swelling, humidity, dimensional stability, water absorption, and screw withdrawal resistance of the samples were improved significantly. However, MOE, MOR, and internal bond strength values of the samples decreased with increasing WPE in the panels when compared to the control panels but met minimum requirements in EN 300 (type 1-2-3-4) control panels. The conclusion was reached that waste polyethylene can be used in the manufacture of OSB panels, resulting in the enhancement of above mentioned physical and mechanical properties, as well as a safe disposal and economical utilization.

Keywords: Oriented strand boards; Wood composite; Waste polyethylene; Physical and mechanical properties; Screw withdrawal; Internal bond; Water absorption; Dimensional change

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INTRODUCTION

Wood composite materials such as plywood, fiberboard, particleboard, and oriented strandboard (OSB) are commonly utilized for various applications in the construction industry (Howard 2000; Hu 2000). Oriented strandboard is a material that is manufactured from thin wood strands bonded together with water-resistant adhesive under heat and pressure (Cai and Ross 2010). Main applications in Turkey include roofs and walls, I-beams, wood and steel construction systems, coatings, and chest for transportation of materials, *etc*.

Because of rapid industrialization and technological development, especially in some developing countries, environmental pollution problems and a shortage of natural resources have occurred. Various types of polyethylene are industrial products that produce a large quantity of waste materials every year (Tayyar and Ustun 2010). Polyethylene (PE) is the most commonly used plastic in the world. Depending on its density, PE can be produced in various viscosity levels because of its low melting temperature, typically between 106 and 130 °C. Additionally, polyethylene is a soft material that enables PE-based composite boards to be nailed, screwed, cut easily, and it shows near-zero moisture absorption (approximately below 0.02% after 24 h of underwater immersion) (Klyosov 2007).

Today, recycling waste products by utilizing them in manufacturing processes is very attractive because it can prevent environmental pollution and lower production costs (Ayrılmis *et al.* 2009). Polyethylene is a material that is not able to biodegrade rapidly in the environment. In order to recycle such materials, different kinds of waste products have been increasingly used (Prideaux 2007). Yilgor *et al*. (2014) manufactured wood based panels using waste Tetra Pak material and evaluated some chemical and physical properties as well as biological, weathering, and fire performance. In their study, Ozdemir and Mengeloglu (2008) showed that thickness swelling and water absorption properties of recycled high density polyethylene (HDPE) based wood plastic composites decreased.

In the literature, there is no information related to the effects of waste polyethylene on the physical and mechanical properties of OSBs. Therefore, this study offers a solution to the waste polyethylene problem by investigating the effects of WPE on some physical (density, humidity, dimensional changes, thickness swelling, and water absorption) and mechanical properties (internal bond, modulus of elasticity, modulus of rupture, and screw withdrawal) of OSB panels produced by adding WPE in different ratios.

EXPERIMENTAL

Materials

In this study, Scots pine wood (*Pinus sylvestris* L.) was used in the manufacture of the OSBs. The strand dimensions were approximately 80 mm long, 20 mm wide, and 0.7 mm thick. Resin, containing 47% liquid phenol-formaldehyde (pH 10.5), was applied at a 6% ratio, based on the weight of the oven-dry wood strands for all boards produced. WPE granules between 0.7 mm and 1.3 mm in thickness were chosen from industrial waste polyethylene. Low-density polyethylene typically has a density value ranging from 0.91 to 0.925 g/cm^3 and Scots pine wood has a density of 0.56 g/cm^3.

Panel Manufacture

Six panels, including one control panel (non-WPE) and five panels manufactured with different ratios of WPE (10/90, 20/80, 30/70, 40/60, 50/50) by weight, were tested for physical and mechanical properties. Two boards for each combination of variables and total of 12 boards were produced. Dimensions of the boards were 500 mm x 500 mm x 12 mm. OSB panels were aimed to manufacture with a density of 0.65 g/cm^3. The panels were manufactured with three layers and particle weight ratios of 25:50:25 (face, core, and face, respectively). The core layer was spread perpendicular to the face layers. The waste polyethylene was used in all layers homogeneously. Polyethylene capped the pores among strands when it melted.

The wood strands were dried to 3% moisture content, and then the resin was sprayed straight away once the wood strands got out from the dryer for 3 min. The OSBs were manufactured in the Laboratory of Forestry Faculty, Karabuk University. All mats were pressed in a hot press at a temperature of 180 °C and a pressure of 3.92 N/mm^2 for 9 min to 12 mm- the target thickness.

Evaluation of Physical and Mechanical Properties

After the pressing process, the boards were conditioned at 65 ± 5% relative humidity and at a temperature of 20 ± 2 °C until their weight was stable (ISO 554 (1976)). The moisture content and density, thickness swelling, water absorption, modulus of rupture and elasticity, and internal bond were determined according to the relevant standards TS-EN 322 ; EN 323; EN 317; EN 310; EN 319 respectively.

All physical and mechanical tests were performed in accordance with current Turkish (TS) and European standards (EN). Physical properties (water absorption, (WA 24 h to 48 h), thickness swelling (TS 24 h to 48 h) and dimensional changes (DC 24 h to 48 h)) and mechanical properties (internal bond (IB 24 h to 48 h), screw withdrawal strength (SW 24 h to 48 h), modulus of elasticity (MOE) in static bending, and modulus of rupture (MOR) in static bending) were evaluated. Static bending and dimensional change tests were carried out in parallel (//) and perpendicular (⊥) directions, depending on the surface layer. When testing physical properties such as TS, DC, and WA, distilled water was used.

For screw withdrawal experiments, screws of 3.5 × 40 and 4 × 40 mm dimensions were used, and the screws were applied perpendicular to the surface of the test samples. For each experiment, 10 samples with dimensions of 50 × 50 × 12 mm^3 were tested according to EN 320 (1993). Each screw was inserted into a pre-bored hole and screwed into the board through its depth.

The boards were evaluated according to EN 300 (2006), which classifies and distinguishes boards into four types: 1) OSB/1 – general purpose boards and boards for interior fitments for use in dry conditions; 2) OSB/2 – load-bearing boards for use in dry conditions; 3) OSB/3 – load-bearing boards for use in humid conditions; 4) OSB/4 – heavy duty load-bearing boards for use in humid conditions. Board properties were compared to the requirements of OSB types 1, 2, 3, and 4 (EN 300 2006) and notated in this work in brackets.

Data for each test were statistically analyzed. Analysis of variance (ANOVA) was used ($\alpha < 0.05$) to test for significant differences among factors of all OSB groups. The values were evaluated with the Duncan test to identify which groups were significantly different from other groups.

RESULTS AND DISCUSSION

Density, Moisture Content, and Dimensional Changes

The average and standard deviation values of density (D), moisture content (MC), and dimensional changes (DC) of the treated OSB panels are shown in Table 1.

Table 1. Average and Standard Deviation Values of Treated OSB Panels Produced by Adding WPE in Various Ratios

Wood (%)	Polyethylene (%)	Air-dry Density (g/cm^3)	Moisture Cont. (%)	Dimensional changes (%) // 24 h	// 48 h	⊥ 24 h	⊥ 48 h
100	-------	$0.620^{(0.03)}$	$5.79^{(0.25)}$	0.59	0.8	0.98	1.2
90	10	$0.621^{(0.03)}$	$5.34^{(0.27)}$	0.43	0.7	0.64	0.9
80	20	$0.624^{(0.04)}$	$4.87^{(0.32)}$	0.35	0.6	0.32	0.6
70	30	$0.634^{(0.05)}$	$4.22^{(0.29)}$	0.37	0.5	0.23	0.5
60	40	$0.655^{(0.03)}$	$3.37^{(0.21)}$	0.31	0.5	0.24	0.4
50	50	$0.665^{(0.03)}$	$3.34^{(0.19)}$	0.17	0.32	0.12	0.2

Data were statistically analyzed by means of average and standard deviation, respectively.

⊥: perpendicular to major axis of panel, //: parallel to major axis of panel

According to Table 1, the air-dry density values of treated samples ranged from 0.620 to 0.665 g/cm^3. The panels that were manufactured with different ratios of WPE had similar density values. Moisture content values decreased due to increasing WPE amount; similarly, dimensional change values decreased significantly based on increasing WPE amount compared to the control samples. Hydroxyl groups in treated OSB decreased with an increase of WPE amount, thus improving the dimensional change stability. For wood, dimensional changes are commonly assumed to be linearly related to changes in moisture content (Zelinka and Glass 2010). The highest moisture content was obtained (5.79%) from the non-WPE sample, and the lowest value was obtained (3.34%) from the sample with 50% WPE.

The physical and mechanical properties of wood materials, such as MOE, MOR, IB, *etc.*, are affected greatly by moisture content (MC) (Niemz 2010). In this study, dimensional changes after 24 and 48 h were considerably lower than the control values. The greatest dimensional change after 24 h was obtained (0.59%) from the untreated sample, and the lowest value after 24 h was obtained (0.17%) from the sample with 50% WPE parallel to the grain. The greatest dimensional change after 48 h was 0.98% in the untreated sample, and the lowest value of DC after 48 h was 0.12% in the sample with 50% WPE perpendicular to grain. According to these results, using polyethylene in OSB affected the MC value positively. The DC value was also positively affected because of the decrease in MC value. In wood and wood-based materials, swelling occurs because of absorbed water and shrinkage occurs when the absorbed water is released (Niemz 2010).

Thickness Swelling and Water Absorption

Average and standard deviation values of thickness swelling (TS) and water absorption (WA) of treated OSB panels are shown in Table 2.

Table 2. Average Values of Thickness Swelling and Water Absorption Rate in the OSB Panels Produced by Adding WPE in Various Ratios

Wood	Polyethylene	TS (%)		WA (%)	
%	%	24 h	48 h	24 h	48 h
100	-------	27.46$^{(4.84)}$ A [1]	28.85$^{(5.15)}$ A [1]	65.78$^{(8.81)}$ A	70.97$^{(8.25)}$ A
90	10	26.32 $^{(4.06)}$ A [1]	28.06 $^{(5.36)}$ A [1]	64.49$^{(11.95)}$ A	69.93$^{(10.20)}$ AB
80	20	19.24$^{(4.40)}$ B [2]	22.08$^{(3.50)}$ B [2]	53.74$^{(6.24)}$ B	60.39$^{(8.32)}$ B
70	30	13.65 $^{(4.34)}$ C [3]	16.96$^{(4.23)}$ C [3]	45.43$^{(5.94)}$ C	50.01$^{(6.18)}$ C
60	40	8.84 $^{(3.61)}$ D [4]	12.75$^{(4.67)}$ CD[3]	31.68$^{(8.50)}$ D	35.35$^{(8.06)}$ D
50	50	8.11 $^{(3.08)}$ D [4]	9.58$^{(4.26)}$ D [4]	22.47$^{(6.65)}$ E	23.97$^{(5.37)}$ E

*Groups with the same letters in each column indicate that there is no statistical difference (pr < 0.05) between the samples according to the Duncan's multiple range test.
*Data were statistically analyzed by means of average and standard deviation.
*Quality requirements were compared to OSB type 1-2-3-4 (EN 300 OSB minimum property requirement 2006) and are notated in brackets.

Both 24 and 48 h thickness swelling values were considerably lower than the control values. The highest value of TS after 24 h was 27.46% in the non-WPE panel sample, of TS after 48 h was 28.85% in the non-WPE sample, and the lowest value of TS after and the lowest value of TS after 24 h was 8.11% in the sample with 50% WPE. The highest value 48 h was 9.58% in the sample with 50% WPE. According to Table 2, minor differences were obtained between 24 h and 48 h TS values but as seen, the variance from

24 h to 48 h was much bigger in manufactured OSB because wood absorbs the most amount of water especially in 24 h; manufactured OSB that were produced using polyethylene does not absorb water as rapidly as wood. Because of the hydrophobic properties of polyethylene, the TS values of OSB panels manufactured using WPE decreased with an increasing amount of WPE.

These results were in agreement with a study carried out by Ayrılmıs *et al.* (2009). In the cited study, by increasing the rubber content to 30% in OSB, TS values decreased from 21.1% to 14.3%. Linear results have been obtained between moisture content and thickness swelling in particleboard (Watkinson and Gosliga 1990). Additionally, Linville (2000) stated that board properties and TS are influenced by resin level. Yapici (2008) researched TS values of OSBs depending on the amount of adhesive and observed that with an increase in the adhesive amount from 3% to 6%, TS values decreased 49%. In the present study, although the amount of adhesive was fixed (6%) in OSB panels manufactured with WPE, TS values decreased from 27.46% to 8.11%, depending on the WPE used in OSB. This may result in reduction of costs and contribute to greater recycling of WPE.

The quality requirements were compared to OSB types 1-2-3-4 (EN 300 2006), and the results are shown in brackets in Table 2. According to these results, the control panel met the minimum requirements of type 1, and 40-50% polyethylene-containing panels met the minimum requirements of type 4, regarding TS. Homogeneous groups for TS are shown by Duncan's multiple comparison tests (Table 2). It was observed that there was a statistical difference among the average TS values of the panels. WA values followed a similar pattern to the values of TS. Accordingly, WA values after 24 and 48 h were considerably lower than the control values. The highest value of WA after 24 h was 65.78% in the non-WPE panel sample, and the lowest value of WA after 24 h was 22.47% in the sample with 50% WPE. The highest value of WA after 48 h was 70.97% in the non-WPE sample, and the lowest value of WA after 48 h was 23.97% in the sample with 50% WPE. Homogeneous groups for WA were shown by Duncan's multiple comparison tests (Table 2). It was observed that there was a statistical difference among the average WA values of the panels.

Similar results were obtained by (Yilgor *et al*. 2014). According to his study, water may have penetrated through the small cracks and fractures occurred during panel manufacturing process using waste Tetra Pak. In his study, fibers were not coated enough by melted LDPE in Tetra Pak so the penetration of water could not have been prevented wholly.

Modulus of Elasticity, Modulus of Rupture, and Internal Bond

Average and standard deviation values of MOE, MOR, and IB of OSB panels are shown in Table 3.

MOR and MOE have important roles when describing the mechanical properties of OSB panels. Average values of modulus of rupture (MOR) and modulus of elasticity (MOE) at static bending in the parallel and perpendicular directions, as well as the internal bond (IB) for each OSB panel are given in Table 3. According to the results, there was a significant difference among the manufactured panels for both parallel and perpendicular MOR. As shown in Table 3, MOE and MOR values of the OSB panels decreased with increasing WPE amount when compared to the control panels. Similar trends and results between the MOE and MOR values were obtained. For MOE and IB, when the WPE amount in OSB panels exceeded 30%, the minimum quality requirements of EN 300 could not be met. In addition, differences between parallel and perpendicular MOE/MOR values decreased depending on the increasing WPE amount. The reason for the decrease in IB values can be explained with the weak adhesion between wood strands and WPE. This situation leads decrease of MOE/MOR values. In this case, by increasing resin level IB strength of OSBs can be enhanced depending on increased WPE amount (Maloney 1977). Therefore, the more WPE is used in boards, the more isotropic they become. Similar results were obtained in a study by Ayrılmıs *et al.* (2009). In his study, MOE/MOR values decreased depending on increasing waste tire rubber amount.

Table 3. Average Modulus of Elasticity, Modulus of Rupture and Internal Bond Values at Static Bending of OSB Panels Produced by Adding WPE in Various Ratios

Wood	Polyethylene	Modulus of elasticity (MOE) (N/mm^2)		Modulus of rupture (MOR) (N/mm^2)		Internal bond (IB) (N/mm^2)	
%	%	//	⊥	//	⊥	Untreated	24 h
100	-----	5728$^{(358)}$ A[4]	3355$^{(353)}$ A[4]	33$^{(2)}$ A[4]	24$^{(5)}$A[4]	0.43$^{(0.03)}$ A[3]	0.07$^{(0.02)}$ A
90	10	5034$^{(340)}$ B[4]	3019$^{(315)}$AB[4]	30$^{(4)}$ A[4]	21$^{(4)}$AB[4]	0.40$^{(0.02)}$ B[3]	0.09$^{(0.01)}$ B
80	20	4034$^{(371)}$ C[3]	2717$^{(297)}$ B[4]	22$^{(2)}$ B[3]	19$^{(1)}$BC[4]	0.34$^{(0.04)}$ C[3]	0.11$^{(0.02)}$ C
70	30	2751$^{(296)}$ D[1]	1833$^{(258)}$ C[3]	18$^{(1)}$ C[2]	16$^{(3)}$ C[4]	0.27$^{(0.05)}$ D[*1]	0.12$^{(0.02)}$ D
60	40	2208$^{(226)}$ E[*]	1277$^{(261)}$ D[1]	15$^{(2)}$ D[1]	13$^{(2)}$DE[3]	0.21$^{(0.03)}$ E[*]	0.16$^{(0.03)}$ E
50	50	1506$^{(242)}$ F[*]	1040$^{(167)}$ D[*]	14$^{(1)}$ D[1]	11$^{(2)}$E[3]	0.19$^{(0.04)}$ E[*]	0.16$^{(0.04)}$ E

*Groups with the same letters in each column indicate that there is no statistical difference (pr < 0.05) between the samples according to the Duncan's multiple range test.
*Data were statistically analyzed by means of average and standard deviation.
*Quality requirements were compared to OSB type 1/2/3/4 (EN 300 OSB minimum property requirement 2006) and are notated in brackets.

The results of Duncan's multiple range tests are also shown in Table 3 using letters. The average MOE parallel to the major axis of the OSBs containing WPE ranged from 5728 to 1506 N/mm^2, and values perpendicular to the major axis ranged from 3355 to 1040 N/mm^2. The average MOR parallel to the major axis values of the OSBs containing WPE ranged from 33 to 14 N/mm^2, and values perpendicular to the major axis ranged from 24 to 11 N/mm^2.

Ayrılmıs *et al.* (2009) stated that the MOE and MOR values of the OSBs with tire rubber can be enhanced by increasing the amount of resin. Wilson (1980) researched the correlation between resin amount and mechanical properties and observed that mechanical properties (MOR, MOE, and IB) improved with an increase in the amount of resin. Therefore, in this study, the decrease in the values of some mechanical properties due to an increase of WPE can be compensated by adding extra resin. According to the results of Table 3, the IB values of unsubmerged OSBs diminished from 0.43 to 0.19 N/mm^2 with the increase of WPE amount; however IB values of panels that are exposed to water submersion for 24 h increased from 0.07 to 0.16 N/mm^2 with the increase of WPE amount;

whereas OSB panels are exposed to submersion in water, internal forces are weakened, which results in swelling of the panels. These results may be explained with the existence of WPE. In addition, there was a statistical difference among the average IB values of the panels. The bond strength values showed similar trends to the results of MOR and MOE tests.

Screw Withdrawal Resistance

Screw withdrawal resistance (SWR) has an important role when describing mechanical properties of OSB panels because OSB panels are generally fixed with screws in various construction works. Strength values obtained in experiments for 3.5 and 4 mm screws, as well as average and standard deviation values of SWR-treated OSB panels are shown in Table 4.

Table 4. Average Screw Withdrawal Resistance Values of OSB Panels Produced by Adding WPE in Various Ratios

Wood	Polyethylene	**3.5 × 40**		**4 × 40**	
%	%	Untreated (N)	24 h (N)	Untreated (N)	24 h (N)
100	------	584(45) A	258(35) A	690(42) A	302(55) A
90	10	639(77) A	313(45) B	761(81) AB	352(43) AB
80	20	707(75) B	345(45) B	814(90) B	418(77) B
70	30	835(68) C	396(68) C	943(88) C	504(62) C
60	40	926(69) D	421(35) C	1019(66) C	601(87) D
50	50	975(71) D	481(57) D	1138(94) D	614(78) D

*Groups with the same letters in each column indicate that there is no statistical difference (pr < 0.05) between the samples according to the Duncan's multiple range test.
*Data were statistically analyzed by means of average and standard deviation.

Homogeneous groups for SWR are shown by Duncan's tests (Table 4). It was observed that there was a statistical difference among the average SWR values of the panels. SWR values after 24 h were considerably lower than the control values. It was observed that the greater the increase of WPE, the greater the increase in SWR values when compared to control samples. The highest value of SWR (3.5 × 40) was 975 (N) for 50% WPE sample, and the lowest value was 258 (N) for the non-WPE control sample after 24 h. The highest value of SWR (4 × 40) was 1138 (N) for 50% WPE sample, and the lowest value was 302 (N) for the non-WPE control sample after 24 h. Eckelman (1990) studied the SWR properties of wood composite materials using various processing variables. He observed that SWR and IB values have an interaction, and that the density of boards improves SWR values.

CONCLUSIONS

1. This study investigated the physical and mechanical properties of OSBs manufactured with waste polyethylene. According to the results, the amount of waste polyethylene influenced the mechanical and physical properties of the OSB panels.
2. By using WPE materials in OSB panels, thickness swelling, humidity, dimensional stability, water absorption, and screw withdrawal resistance of the samples were

improved significantly. However, the MOE, MOR, and internal bond strength values of the samples decreased with increasing WPE amount in the panels when compared to control panels but met the minimum requirements of EN 300 (type 1-2-3-4). By increasing PF resin levels, weak adhesion between wood strands and WPE can be improved.

3. Optimum results for MOR, MOE, and IB mechanical properties were obtained from the samples with 30% waste polyethylene. They met the minimum requirements for OSB type 1 (EN 300).
4. Based on these results, it is suggested that OSB panels should be manufactured with WPE in order to contribute to recycling WPE, which is industrial waste material. This will also help protect the environment and reduce the manufacturing costs of OSB panels.

REFERENCES CITED

Ayrilmis, N., Buyuksari, U., and Avci, E. (2009). "Utilization of waste tire rubber in manufacture of oriented strand board," *Waste Management* 29(9), 2553-2557. DOI: 10.1016/j.wasman.2009.05.017

Cai, Z., and Ross, R. J. (2010). "Mechanical properties of wood based composite materials," *Wood Handbook- Wood as an Engineering Material*, Forest Products Laboratory, Madison, WI. DOI: 10.1016/j.wasman.2009.05.017

Eckelman, C. (1990). *Fasteners and Their Use in Particleboard and MDF*, National Particleboard Association, Purdue University, West Lafayette, IN.

EN 300 (2006). "Oriented strand boards (OSB) – Definitions, classification specifications," European Committee for Standardization, Brussels, Belgium.

EN 310 (1993). "Determination of bending strength and modulus of elasticity," European Committee for Standardization, Brussels, Belgium.

EN 317 (1993). "Particleboards and fiberboards – Determination of swelling in thickness after immersion in water," European Committee for Standardization, Brussels, Belgium.

EN 319 (1993). "Particleboards and fiberboards; Determination of tensile strength perpendicular to the plane of the board," European Committee for Standardization, Brussels, Belgium.

EN 320 (1993). "Particleboards and fibreboards - Determination of resistance to axial withdrawal of screws," European Committee for Standardization, Brussels, Belgium.

EN 323 (1993). "Wood-based panels-Determination of density," European Committee for Standardization, Brussels, Belgium.

Howard, J. L. (2000). "U.S. forest products annual market review and prospects," *FPL-RN- 0278*, USDA Forest Service, Forest Prod. Lab., Madison, WI, USA.

Hu, P.-J. (2000). "Bending stiffness prediction for oriented strandboard by classical lamination theory," MSc Dissertation, University of Toronto, pp 1-2.

ISO 554 (1976). "Standard atmospheres for conditioning and /or testing- Specifications," International Organization for Standardization, Geneva, Switzerland.

Klyosov, A. A. (2007). *Wood-Plastic Composites*, John Wiley & Sons, Hoboken, NJ. DOI: 10.1002/9780470165935

Linville, J. D. (2000). *The Influence of a Horizontal Density Distribution on Moisture-Related Mechanical Degradation of Oriented Strand Composites*, M.S. thesis, Washington State University, Pullman, WA.

Maloney, T.M., (1977). *Modern Particleboard and Dry-Process Fiberboard Manufacturing*, Miller Freeman Publications, San Francisco-California.

Niemz, P. (2010). "Water absorption of wood and wood-based panels – Significant influencing factors," in: *Wood-Based Panels: An Introduction for Specialists*, Thoeman, N., Irle, M., and Sernek, M. (eds.), Brunel University Press, London, UK, pp. 95-123.

Ozdemir, T., and Mengeloglu, F. (2008). Some properties of composite panels made from wood flour and recycled polyethylene, *Int. J. Mol*. Sci. 9, 2559-2569. DOI: 10.3390/ijms9122559

Prideaux, E. (2007). "Plastic incineration rise draws ire," *Japan Times*, retrieved 10 January 2015.

Tayyar, A. E., and Üstün, S. (2010). "Usage of recycled PET," *Pamukkale Universities Engineering Sciences Journal* 16(1), 53-62.

TS-EN 322 (1993). ''Wood-based panels- Determination of moisture content,'' Ankara, Turkey.

Watkinson, P. J., and van Gosliga, N. L. (1990). "Effect of humidity on physical and mechanical properties of New Zealand wood composites," *Forest Products Journal* 40(7-8), 15-20.

Wilson, J. B. (1980). "Isocyanate adhesives as binders for composition board," *Wood Adhesives Research, Application, and Needs Symposium*, University of Wisconsin, Madison, WI, September 23-25.

Yapici, F. (2008). *The Effect of Some Production Factors on the Properties of OSB Made from Scotch Pine (Pinus sylvestris* L.*) Wood*, Ph.D. dissertation, Zonguldak Karaelmas University, Zonguldak, Turkey.

Yilgor, N., Köse, C., Terzi, E., Kantürk Figen, A., Ibach, R., Kartal, S.N., and Pişkin, S. (2014). "Degradation behavior and accelerated weathering of composite boards produced form waste Tetra Pak packaging materials," *BioResources* 9(3), 4784-4807. DOI: 10.15376/biores.9.3.4784-4807

Zelinka, S., and Glass, S. V. (2010). *Wood Handbook – Wood as an Engineering Material*, General Technical Report FPL-GTR-190, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.

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