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INFLUENCE OF RESIDUE TYPE ON QUALITY PROPERTIES OF PARTICLEBOARD MANUFACTURED FROM FAST-GROWN TREE OF HEAVEN (*AILANTHUS ALTISSIMA* (MILL.) SWINGLE)

In this study, the effect of residue types (soundwood, branchwood and bark) on the quality properties of particleboards made from the tree of heaven (Ailanthus altissima (Mill.) Swingle) was investigated. For this purpose, the soundwood, branchwood and bark mixed at different ratios were used in the production of particleboards. Modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB), thickness swelling (TS) and formaldehyde emission (FE) of the specimens were then tested. The chemical and anatomical properties of the residue types were also determined. Residue type was found to have an impact on the properties of particleboards. The addition of bark and branchwood improved the thickness swelling (2 h immersion) and formaldehyde emission. However, use of branchwood negatively affected the thickness swelling for 24 h immersion. Based on the findings of this study, it can be concluded that different parts of Ailanthus altissima (Mill.) Swingle can be used to manufacture particleboard panels. The branchwood and bark contents significantly affected the quality properties of the manufactured particleboards. The chemical and anatomical properties of the branchwood and bark were also found to be parameters influencing the quality properties of the particleboards. The results indicate that the contents of added bark and branchwood should not exceed 10% and 20% respectively.

Keywords: particleboard, type of wood, residue type, mechanical properties, water resistance, formaldehyde emission

Introduction

Ailanthus altissima, a genus of trees belonging to the family Simaroubaceae, is a fast growing species commonly known as tree of heaven. It is native to both northeast and central China, as well as Taiwan. The tree grows rapidly and is capable of reaching heights of 15 meters in 25 years [Collin and Dumas 2009; Sladonja et al. 2015].

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Particleboard is a wood-based composite material commonly used for various applications, including floor underlayment, insulation, and the production of furniture, cabinets, and veneer substrates. It appears that particleboard production from wood-based wastes is one of the most commonly used methods to assess waste materials [Wang and Sun 2002; Wang et al. 2008]. In this regard, intensive investigations have been undertaken with the aim of manufacturing particleboard panels using recycled industrial and agricultural wastes [Lertsutthiwong et al. 2008].

The demand for raw materials in the forest products industry is increasing steadily. There is great interest in finding alternative raw materials for wood-based composite manufacture [Guntekin and Karakus 2008; Guntekin et al. 2008]. A decrease in the availability of raw material resources and the need to protect natural resources have led to increased use of fast growing species and wood wastes in particleboard manufacturing processes. Therefore, it can be said that alternative sources such as industrial wastes and agricultural residues provide significant contributions to the development of the wood composite industry [Bektas et al. 2005]. In this regard, date palm branches [Nemli and Kalaycioglu 2001], coconut shell [Almeida et al. 2002], sunflower stalks [Bektas et al. 2005], mimosa bark [Nemli and Colakoglu 2005], wood waste chips [Wang et al. 2007], hazelnut husk [Copur et al. 2007], eggplant stalks [Guntekin and Karakus 2008], pepper stalks [Guntekin et al. 2008], kenaf core [Okuda and Sato 2008], a mixture of wood and rice husk [Ayrilmis et al. 2012], oil palm trunk [Baskaran et al. 2013], sawmill waste [Alves et al. 2014], different proportions of wood, bamboo and rice husk [Melo et al. 2014], residues from fruit tree branches, evergreen hardwood shrubs and Greek fir wood [Lykidis et al. 2014], sweet sorghum bagasse [Kusumah et al. 2016], agricultural crop residues [Klímek et al. 2016] and soybean waste [Martins et al. 2018] have been trialed for particleboard manufacture.

The goal of the present study was to investigate quality features of particleboards produced from different parts (soundwood, branchwood, and bark) of fast-grown tree of heaven (*Ailanthus altissima* (Mill.) Swingle).

Materials and methods

Ten trees of *Ailanthus altissima* (Mill.) Swingle with an average diameter at breast height of 18 cm were cut for the experiments. Particles from the green soundwood, branches and bark of the trees were used to produce particleboard. The raw material was chipped by a chipper at the harvesting site. A ring-type flaker was used to break the chips down to particle size. The particles were dried in a dryer until they reached the target moisture content (3%) and classified into two sizes for the core and face layers. Based on the oven dry weight of the particles, 10% and 12% urea formaldehyde resin with a solid content of 65% was applied for core and surface particles respectively. Ammonium sulfate (concentration: 25%) was used as a resin hardener during the blending process at a rate of about 1% based on the solid amount of resin. The mats were formed manually and then pressed in an electrically heated press under a pressure of 25 kg/cm^2, at 150°C, for 6 minutes. All of the panels were produced with an average target density of 0.75 g/cm^3. Seven types of panels were made using various mixtures of the three types of residue (table 1). Bark and branchwood were used only in the core layer of the particleboard. A total of 14 panels, two for each group, were made in the laboratory. Table 1 gives percentages of residue types, density and moisture content (MC) of the particleboards.

Table 1. Percentage of residue types, density and moisture content of particleboards

Panel type	Soundwood (%)	Bark (%)	Branchwood (%)	Density (g/cm^3)	MC (%)
A	100	–	–	0.749 (0.027)	9.61 (0.35)
B	90	10	–	0.748 (0.061)	9.63 (0.29)
C	80	20	–	0.748 (0.056)	9.64 (0.41)
D	70	30	–	0.746 (0.029)	9.72 (0.56)
E	90	–	10	0.749 (0.044)	9.62 (0.35)
F	80	–	20	0.748 (0.035)	9.64 (0.45)
G	70	–	30	0.745 (0.049)	9.70 (0.50)

Note: numbers in parentheses represent standard deviations.

The experimental particleboards were stored in a conditioned room at 20°C and 65% relative humidity. A physical property, TS [EN 317:1993], the mechanical properties MOR, MOE [EN 310:1993] and IB [EN 319:1993], and FE [EN 120-1:1993] were determined for the panels. Thirty specimens were used for the physical and mechanical tests, and three specimens were used for the determination of the formaldehyde content.

The anatomical properties of soundwood and branchwood were determined on sawn, 5 cm thick cross-cut disks. The data were derived from 25 and 3 measurements of anatomical and chemical properties, respectively. The determination of the chemical properties and the preparation of the specimens were performed according to TAPPI standards [TAPPI T 11 M-45:1992]. Solubilities in alcohol-benzene, hot and cold water, and dilute alkali (1% NaOH), lignin content and ash content were determined in accordance with the respective TAPPI standards [TAPPI T 204 cm-97:1997; TAPPI T 207 om-88: 1988; TAPPI T 212 om-98:1998; TAPPI T 222 om-02:2002; TAPPI T 211 om--93:1993]. Holocellulose and cellulose contents of the specimens were determined using chlorite and nitric acid methods [Wise and Karz 1962]. The acidity was measured in an extract solution made from 3 g wood flour added to 100 ml water and boiled for 30 min [Prasetya 1989]. The content of condensed tannins was determined according to the method developed by Tisler et al. [1986]. Three specimens were used for determination of the chemical properties.

One-way analysis of variance (ANOVA) was performed to assess the influence of residue type on the quality features of the manufactured particleboards. In addition, the Newman-Keuls test was used to identify significant differences between average values for the particleboard types.

Results and discussion

Anatomical properties

Table 2 gives the results for anatomical features. The fiber and trachea lengths and the thicknesses of fiber and tracheid cell walls were significantly influenced by residue type. The highest fiber length (1230.49 μm), trachea length (313.57 μm), tracheid cell wall thickness (6.58 μm) and fiber cell wall thickness (4.43 μm) were determined for soundwood, while the lowest fiber length (687.41 μm), trachea length (201.70 μm), tracheid cell wall thickness (2.68 μm) and fiber cell wall thickness (2.86 μm) were determined for branchwood.

Table 2. Anatomical properties of tree of heaven *(Ailanthus altissima* (Mill.) Swingle)

Anatomical properties	Residue types	
	Soundwood	Branchwood
Fiber length (μm)	1230.49 (285.11) a	687.41 (143.02) b
Trachea length (μm)	313.57 (143.02) a	201.70 (44.05) b
Thickness of fiber cell wall (μm)	4.43 (1.27) a	2.86 (0.89) b
Thickness of trachea cell wall (μm)	6.58 (0.96) a	2.68 (0.43) b

Note: numbers in parentheses represent standard deviations.

Chemical properties

The highest levels of cellulose and hemicellulose were determined in the soundwood, followed by branchwood and bark respectively, while the highest lignin content was found in the bark. Table 3 presents the mean values of chemical properties of specimens. The statistical analysis revealed that the chemical features of the specimens were significantly influenced by the residue type. The highest solubility values were obtained for bark, followed by branchwood and soundwood, respectively. The lowest pH values were found in bark. The highest ash content and condensed tannin content were found in bark, followed by branchwood and soundwood respectively.

Table 3. Chemical properties of soundwood, branchwood and bark

Chemical properties	Residue types	
	Bark	Branchwood
pH	5.33 (0.10) a	5.64 (0.13) b
Solubility in dilute alkali (1% NaOH) (%)	48.97 (0.41) a	34.91(0.33) b
Solubility in alcohol-benzene (%)	6.75 (0.31) a	3.81 (0.21) b
Solubility in cold water (%)	12.28 (0.03) (a)	11.15 (0.07) (b)
Solubility in hot water (%)	12.42 (0.10) (a)	11.95 (0.45) (b)
Holocellulose (%)	53.50 (0.30) (a)	64.29 (0.42) (b)
Cellulose (%)	38.89 (0.19) (a)	44.80 (0.09) (b)
Hemicellulose (%)	14.61(0.23) (a)	19.49 (0.25) (b)
Lignin (%)	42.03 (0.06) (a)	34.03 (0.22) (b)
Ash (%)	0.84 (0.02) (a)	0.48 (0.04) (b)
Content of condensed tannin (%)	10.29 (0.36) (a)	7.92 (0.56) (b)
Content of condensed tannin (%) in chips after 2 h water immersion	10.25 (0.39) (a)	7.87 (0.54) (b)
Content of condensed tannin (%) in chips after 24 h water immersion	6.80 (0.48) (a)	3.26 (0.47) (b)

Note: numbers in parentheses represent standard deviations.

Physical and mechanical properties and formaldehyde emission

Table 4 gives the mean values of MOR, MOE, IB, TS and FE. Based on EN 312 [2010], it can be stated that 12.5 N/mm^2 and 13 N/mm^2 are the minimum required MOR values for particleboards for general use and interior fitments (including furniture) respectively. The minimum required value of MOE for interior fitments is 1800 N/mm^2. All of the particleboards except for type D had higher values of MOR and MOE than the general-purpose and furniture manufacturing requirements. The IB values of the specimens ranged from 0.317 to 0.517 N/mm^2. According to EN 312, the minimum required IB values for general use and furniture are 0.28 N/mm^2 and 0.40 N/mm^2 respectively. All panel types produced met the IB requirement for general purposes, while types A, B, C, E and F met the IB requirement for interior fitments. The results also revealed that the panel types did not meet the requirements for TS according to EN 312 [2010] because no wax or other water-repellent agents were used in the panels.

The maximum permissible formaldehyde content for E_1 quality (for indoor applications) is 8 mg CH_2O/100 g dry sample, based on EN 120-1 [1993]. All of the particleboards complied with the requirement for formaldehyde emission.

Table 4. Summary of experimental results for the panel types

Panel type	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS* (%)	TS** (%)	FE (mg CH_2O)
A	15.49 (2.85) a	2278.99 (194.86) a	0.517 (0.054) a	13.65 (1.19) a	24.96 (0.56) a	7.28 (0.12) a
B	15.27 (2.58) a	2222.76 (192.63) a	0.497 (0.072) a	13.34 (1.21) a	24.55 (0.45) a	7.17 (0.13) a
C	13.70 (2.79) b	2112.64 (180.16) b	0.407 (0.060) b	11.76 (0.92) b	23.18 (0.51)b	6.84 (0.17) b
D	12.12 (2.95) c	1999.38 (211.96) c	0.317 (0.064) c	10.13 (1.51) c	21.01 (0.35)c	6.50 (0.09) c
E	15.38 (2.08) a	2267.92 (195.99) a	0.491 (0.052) a	13.39 (1.04) a	25.18 (0.58)a	7.22 (0.20) a
F	15.07 (2.88) a	2215.02 (200.03) a	0.482 (0.077) a	13.15 (0.95) a	25.24 (0.49)a	7.15 (0.13) a
G	13.52 (3.02) b	2106.39 (174.25) b	0.377 (0.065) b	12.04 (1.18) b	26.88 (0.31)b	6.92 (0.09) b

Note: numbers in parentheses represent standard deviations.
* after 2 h immersion, ** after 24 h immersion.

The addition of bark to more than 10% and branchwood to more than 20% reduced the strength values of the particleboard. The highest strength values were obtained for particleboards manufactured from 100% soundwood. The panels containing 30% bark had the lowest mechanical strength properties. The negative impact of branchwood and bark residues on the strength values of the particleboard is possibly because of the reaction wood in the branchwood, having reduced fiber and trachea length and fiber and trachea cell wall thickness, and the higher contents of extractives (solubility values) and ash content and lower cellulose content of branchwood and bark (table 3) compared with the soundwood. Greater cell length, thicker cell walls and higher cellulose content cause a tighter and more compact structure and increase the strength values [Baharoglu et al. 2013]. High solubility values mean that the wood has a high quantity of extractives. The presence of extractives adversely affects adhesive bonding and adhesion. Extractives fly during hot pressing. They create air bubbles and cause pre-curing of the urea formaldehyde. As a result, this reduces the internal bonding between wood particles [Ayrilmis et al. 2009; Ayrilmis et al. 2017]. Similarly, Martins et al. [2018] reported that a high content of extractives impairs resin curing in the board. This results in poor bonding between the particles and resin.

The FE and TS values of the specimens were not affected significantly by the addition of bark (10%) and branchwood (10% and 20%). However, increasing bark and branchwood content (20% and 30% respectively) significantly improved the thickness swelling (2 h immersion) and formaldehyde content at the 95% confidence level. Chemical analysis showed that branchwood and bark had higher extractives than soundwood (table 3). The extractives contribute positively to the waterproofing of the particleboard [Maloney 1993]. This positive contribution to water resistance has been confirmed in other studies [Nemli and Colakoglu 2005; Nemli et al. 2008; Buyuksari et al. 2010; Nasser 2012; Muhcu et al. 2015]. On the other hand, lignin has a hydrophobic structure [Kang et al. 2019]. The bark and branchwood had higher contents of lignin than the soundwood (table 3). Another factor is hemicellulose content. Hemicellulose absorbs a greater amount of water than cellulose [Sari et al. 2012]. The soundwood had a higher content of hemicellulose than the bark and branchwood, as is shown in table 3. However, use of 30% branchwood increased the TS after 24 h immersion. This may be related to the movement of tannin from branchwood after 24 h water immersion and the presence of reaction wood in the branchwood. As table 3 shows, branchwood and soundwood had similar condensed tannin content after 24 h immersion. The reason for the lower formaldehyde emission of the panels made from bark and branchwood is the content of extractives (tannin, phenolic compounds, etc.) in the structure of this type of residue. These fix the formaldehyde, as formaldehyde scavengers. A higher tannin content is associated with a higher level of polyphenolic extractive content. The reason for the lower formaldehyde content of the particleboard made from bark and branchwood may be a reaction between the formaldehyde and polyphenolic extractives. Nemli and Colakoglu [2005] reported similar results in their studies on the effect of bark use on some quality properties of particleboard. Ayrilmis et al. [2009] found that the addition of pine cone flour to medium-density fiberboard decreased formaldehyde emission. In another study, Buyuksari et al. [2010] reported a decrease in the formaldehyde emission of particleboard produced from waste stone pine cones.

Conclusion

In this study, various parts of tree of heaven were used to make particleboard panels. While the addition of bark and branchwood improved the TS and FE values, it led to a worsening of the mechanical properties. The results indicate that this species may be utilized to produce particleboard. In addition, it is recommended that the content of added bark and branchwood in the particleboards should not exceed 10% and 20% respectively, to ensure their desired characteristics. The residue types and chemical and anatomical composition of residues were the basic parameters affecting the quality characteristics of the manufactured particleboards. Extractives and condensed tannin positively affected the thickness swelling and formaldehyde emission. Greater cell length and cell wall thickness, and a higher content of cellulose, provided better strength properties. The strength properties were also shown to be dependent on ash content – a high ash content was associated with lower strength properties.

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