Effect of Particle Size and Geometry on the Performance of Single-layer and Three-layer Particleboard Made from Sunflower Seed Husks

Camelia Cosereanu,* Luminita-Maria Brenci, Octavia Zeleniuc, and Adriana Fotin

The effects of particle size and geometry on the physical (density, water absorption, and thickness swelling), thermal, and mechanical (modulus of elasticity, bending strength, internal bond strength, and screw holding strength) properties of single-layer and three-layer particleboards made from sunflower seed husks were investigated. Panels manufactured from particles with various sizes using a urea-formaldehyde adhesive had densities ranging from 535 to 682 kg/m^3. The adhesive ratio was at a level of 16% for the single-layer mat configuration; for the three-layer structure, levels of 14% for the core and 16% for the faces were used, based on the weight of particles. The best results occurred in single-layer particleboard made from fine particles, which nearly met the general purpose requirements of the EN 312 Standard. Determination of the thermal conductivity coefficient demonstrated good insulation properties of all panels and their potential use for different structural configurations which are not subjected to strong stresses, suitable for interior design.

Keywords: Sunflower; Seed husks; Single-layer; Three-layer; Physical properties; Mechanical properties

Contact information: Transylvania University of Brasov, Faculty of Wood Engineering, Department of Wood Processing and Wood Products Design, 29 Eroilor Blvd, 500036 Brasov, Romania;
** Corresponding author: cboieriu@unitbv.ro*

INTRODUCTION

Agro-residues (AGs) and biomass, such as sunflower stalk, corn stalk, cotton stalk, walnut shell, peanut hull, bagasse fiber, luffa fiber, coconut fiber, kenaf, giant reed, eucalyptus, and grass, have been investigated as possible raw materials for particleboard manufacture, in actual conditions of high demand for wooden materials and decrease in world forest resources (Guler *et al*. 2008; Garay *et al*. 2009; Nemli *et al*. 2009; Ashori and Nourbakhsh 2010; Fiorelli *et al*. 2012). Thus, the application of AGs for sustainable construction materials provides a solution that offers a reduction in natural resource use (Mangesh *et al*. 2013). Particleboards are generally made of wood chips bonded by adhesives, being pressed under heat. Basically, the wood chips can be replaced by any lignocellulosic material, as the chemical composition of that material is similar to that of wood, containing cellulose, hemicellulose, and lignin (Barros Filho *et al*. 2011; Fiorelli *et al*. 2012). The chemical composition of sunflower husks: 21.85% lignin (Carre 2009), or hemicellulose 24%, lignin 23.2%, and cellulose 42.7% (Saura-Caligsto 1983) is similar with that of wood, as found in the literature: 40-50% cellulose, 20-25% lignin, and 25-35% hemicellulose (Hayes 2010). These data show that, from this point of view, the sunflower husks can replace the wood in a particleboard structure.

The percentage of husks in sunflower seeds is in the range of 21.1% to 29.8% (Wan *et al*. 1979; Carre 2009); thus, the manufacturers of sunflower oil are faced with a high stock of residues, taking into consideration also the low husks bulk density, which varies between 150 and 200 kg/m^3 (Carre 2009). Generally, these residues are used for making pellets and briquettes, but the high content of silicon in sunflower husks creates problems, such as wear to the machines making the pellets. At the same time, compared to wood, sunflower husks contain much more nitrogen, which produces strong pollutants (nitrogen oxides) during combustion. A better solution may be the incorporation of husks in structures of boards with improved properties for furniture or building applications.

Some researchers have shown that the presence of sunflower residues (husks or stalks) in particleboard panels decreased the mechanical resistance and dimensional stability. Incorporation of sunflower residues up to 50% led to properties which met the requirements of standards such as CS 236-66 (1968) or EN 312 (2003) (Gertjejansen *et al*. 1972; Guler *et al*. 2006). The same results were obtained by researchers who investigated the properties of particleboards made from other agro-wastes and wood particles. Up to 25% peanut hull mixed with European black pine (Guler *et al*. 2008), a mixture of at least 30% almond shell particles with wood (Pirayesh and Khazaeian 2012), mixtures of up to 30% wheat and corn incorporated with pine (Garay *et al*. 2009), and up to 30% kenaf in combination with rubber wood, have shown good performance in mechanical properties (Abdul Halip *et al*. 2014).

Other researchers have investigated the possibility of using 100% agro-wastes in particleboards manufacturing and their impact on the board properties. The effects of panel density and adhesive ratio on some physical and mechanical properties of peanut hull particleboard were investigated (Güler and Buyuksari 2011), and the results showed that only the panels with high density (800 kg/m^3) almost met the requirements of the EN 312 (2003) Standard for general purposes (P1). Attempts to reduce the panels' density to 400 kg/m^3 succeeded and also fulfilled the internal bond requirement (EN 312 - P2) by using only agro-wastes, such as miscanthus, topinambur, and sunflower stalks, for single-mat configurations. The same requirements were unfortunately not met for three-layer particleboard (Balducci *et al*. 2008). Additional promising results of three-layer particleboard made from fast-growing willow and black locust with low densities (600 to 660 kg/m^3) have been obtained (Kowaluk *et al*. 2011).

The quality of the final product and its strength is influenced by the quality, size, geometry, and location of particles in the panel structure. Some researchers found differences in the properties of particleboards, with the best results being obtained for those manufactured with medium sized particles (Lee *et al*. 2006; Pan *et al*. 2007; Garcia-Ortuño *et al*. 2011). Two types of particles are generally prepared: fine and coarse. In mixtures of pine, sawdust, shavings, and chips, the fine particles were in the range of 1 to 3 mm long, 0.5 to 1 mm wide, and 0.1 to 0.3 mm thick. The more coarse particles had a length between 10 to 20 mm, width between 3 and 5 mm, and thickness between 0.3 and 0.5 mm (Garay 2012). In the case of three-layer particleboard, the fine particles (32% to 35%) are used for faces and coarse particles are used for the core layer. The most used adhesive is urea-formaldehyde (UF), the content of which is recommended to be about 8 to 9% for the core and 10 to 12% for the face layers (Buyuksari *et al*. 2010; Güler and Buyuksari 2011; Kowaluk *et al*. 2011; Garay 2012). Sieving, microscopy or mathematical distribution functions are methods described in the literature for determining the particle size distribution (Vitez and Travnicek 2010).

According to the literature (Gertjejansen *et al*. 1972), sunflower seed husks are valorised in particleboard manufacture and have good performance only when they constitute up to 50% of the raw material used. Therefore, particleboards made from 100% sunflower seed husks need to be improved to increase their performance.

The main objective of this research was to obtain particleboards made only from sunflower seed husks, without adding any other lignocellulosic materials, keeping at the same time the board properties at the level of a wood particleboard. Their performance was investigated by testing the density, water absorption (WA), thickness swelling (TS) after 24-h water immersion, thermal properties, bending strength (BS), modulus of elasticity (MOE), internal bond strength perpendicular to the plane of the board (IB), and screw holding strength (HS). These properties were related to board structure, size and geometry of the sunflower husks particles, respectively. Using wastes such as sunflower husks can decrease the consumption of wood, leading to wood savings and forest preservation. Thus, an increase of adhesive ratio up to 16% is economically affordable considering that wood cost (as raw material) was replaced by some low cost wastes.

EXPERIMENTAL

Materials

Particle size analysis

Two categories of the sunflower husks were used in the boards manufacturing. The first category included the uncrushed sunflower husks as coarse particles, and the second one was represented by crushed husks as fine particles. The fine particles were obtained by hammer milling of the coarse particles. The moisture contents were approximately 8.6% and 7.6% for coarse and fine particles, respectively. The coarse (sunflower husks) and fine particles were separately screened using a horizontal screen shaker with sieves of 4, 3, 2, 1, and 0.5 mm to remove undersized particles (dust) and obtain the fractions necessary for the mat formation. Three samples of 25 g each was weighed and screened. The mass fractional shares of different particle sizes within samples of coarse and fine particles are shown in Fig.1.

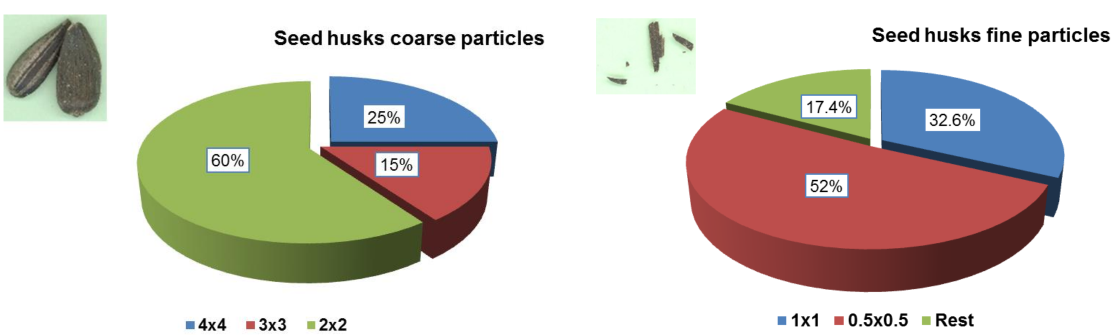

Fig. 1. Average mass fraction share of coarse particles (sunflower husks) and fine particles retained on sieves of 4, 3, 2, 1, and 0.5 mm

The majority of the coarse particles (59 to 61%) passed through the 4.0-mm and 3.0-mm sieves and settled on the 2.0-mm sieve. The coarse particles were from 4.0-mm, 3.0-mm, and 2.0-mm sieves and their dimensions varied between 2.91 and 12.7 mm in length, widths from 2 to 7 mm and thicknesses from 0.2 to 0.5 mm (Fig. 2). The husk thicknesses were measured with calliper and were in the range found also in the literature (Wan *et al.* 1979). The aspect ratio (length to width ratio) varied from 1.07 to 4.9. The measurements were carried out in AutoCAD (Autodesk), version 2007. The particles were first scanned, imported in AutoCAD, then adjusted to 1:1 scale and measured.

Fig. 2. Geometry and size of coarse particles measured in AutoCAD program, in mm

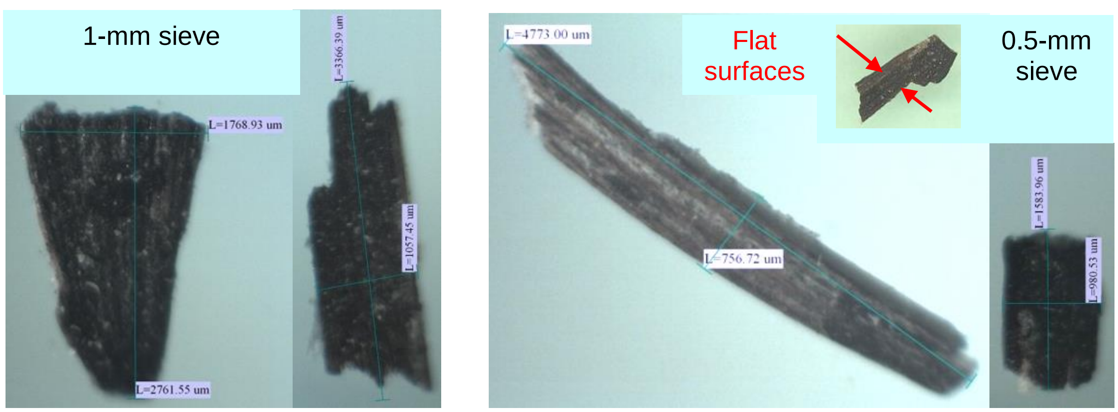

Fig. 3. Geometry and size of fine particles measured in microscopic examination, in microns

For the fines, 51 to 53% of the particles were retained on the 0.5-mm sieve and 31.2% to 33.8% of them on the sieve of 1 mm. These fractions were used as the faces of three-layer particleboard and as a single-layer mat configuration. The fine particle dimensions, from the sieves 1.0-mm and 0.5-mm, were in the range of 0.98 to 4.77 mm for length, 0.7 to 1.7 mm width, and thickness from 0.2 to 0.5 mm. The aspect ratio (length to width ratio) was 1.03 to 6.3 for the fine particles. The fine particles were measured by an Optika microscope (SZM-2; Italy), as can be seen in Fig. 3. The ocular stereomicroscope is equipped with an Optika PRO 3 high resolution digital video camera and Optika vision software package that provides linear in-scale measurements.

Methods

Single-layer and three-layer particleboard manufacture

Seven types of particleboards in two configurations were manufactured: single-layer particleboards made from 100% fine particles (SLFP), 100% coarse particles (SLCP), 50% coarse with 50% fine particles (1/2SLC-FP), 50% fine with 50% wood particles (1/2SLF-WP), 50% coarse with 50% wood particles (1/2SLC-WP), and 100% wood particles (WP). The second configuration was the three-layer particleboard (TLP) in a ratio 30:70 (fine for faces: coarse for core). Urea-formaldehyde resin with a solid content of 66± 1% was added to the single-mat configuration at a level of 16%, based on the weight of the particles. For the three-layer structure, the ratios were 14% for the core and 16% for the faces. Preliminary tests made in our laboratory showed that lowering the adhesive consumption below 12% led to inadequate results of bonding strength. As a consequence, an amount of maximum 16% urea-formaldehyde adhesive was considered suitable for all tested particleboards. Higher UF adhesive ratios resulted in an increase of bond strength levels, as found in the literature (Ferra *et al.* 2011). Ammonium chloride 1%, based on the weight of dry resin, was added as a hardener. No wax or other hydrophobic substances were used. The adhesive and particle mixture was blended for 3 min to obtain a homogenised mixture. The particleboards were manually formed in dimensions of 620 mm x 620 mm (length x width) and thicknesses from 50 mm to 60 mm (the lowest value for fines and the highest value for the coarse structures) and hot-pressed; after the edge trimming, the panels' final dimensions were 600 mm x 600 mm x 16 mm. The experimental design for the single-layer and three-layer particleboards is shown in Table 1.

Table 1. Experimental Design for Single-layer and Three-layer Particleboards

Board type	Type of particles	Adhesive (UF) resin (%)	Press temperature (°C)	Pressing time (min)	Press pressure (bar)	Final dimensions (mm)
SLFP	fines	16	180	6	30	600x600x16
SLCP	coarses	16	180	6	30	600x600x16
TLP	30% fines (faces) 70% coarses (core)	16 (faces) 14 (core)	180	6	30	600x600x16
1/2SLC-FP	50% fines 50% coarses	16	180	6	30	600x600x16
1/2SLF-WP	50% fines 50% wood particles	16	180	6	30	600x600x16
1/2SLC-WP	50% coarses 50% wood particles	16	180	6	30	600x600x16
WP	100% wood particles	16	180	6	30	600x600x16

After pressing, the particleboards were conditioned at 20 °C and 65% relative humidity for approximately 2 weeks before evaluating the properties. Five replicate panels were made for each board type; two were tested for thermal conductivity using a heat flow meter (HFM 436/6/1 Lambda; Germany) and three were cut to obtain samples for mechanical and physical testing.

Physical and mechanical testing

The physical properties were determined as follows: density (EN 323 1993), water absorption (WA) and thickness swelling (TS) after 24 h of water immersion (EN 317 1993), and thermal conductivity coefficient (λ) (DIN EN 12667 2001 and ISO 8301 1991). Bending strength (BS), modulus of elasticity (MOE) (EN 310 1993), internal bond strength (IB) perpendicular to the plane of the board (EN 319 1993), and screw holding strength (SH) (EN 320 1993) were determined using a universal testing machine (Zwick/Roell Z010, Germany). Testing was performed according to each standard methodology. Density, IB, SH, MOE, and BS were each measured on six specimens. For MOE and BS, the panel length depended on the panel thicknesses. Five panels were tested for WA and TS tests, and two panels tested for the thermal properties. Panels for thermal testing had dimensions of 600 mm x 600 mm x 16 mm, and they were measured at eight points for a difference of temperature (ΔT) of 30 °C between upper and lower plates. The water absorption and thickness swelling tests were performed by submerging the specimens in water at room temperature (20 °C) for 2 h and 24 h, and calculated based on weight and thickness measurements respectively, before and after immersion in water. The results reported were the average of specimens tested, both for mechanical and physical properties.

RESULTS AND DISCUSSION

The panels' characteristics are presented in Table 2. The best results were obtained for SLFP, which had properties that were nearest to the EN 312 (2003) Standard requirements, compare to the other investigated panels.

Table 2. Physical and Mechanical Properties of Investigated Particleboards

Type	Density (kg/m³)	WA 24 h (%)	TS 24 h (%)	BS (N/mm²)	MOE (N/mm²)	IB (N/mm²)	SH (N/mm)	λ (W/mK)
SLFP	682 (14.5)	55.4 (2.7)	10.2 (1.3)	5.82 (0.26)	1703 (141)	0.24 (0.017)	31.33 (1.50)	0.079 (0.001)
SLCP	587 (15.7)	60.7 (2.3)	11.9 (0.7)	5.33 (0.99)	2030 (125)	0.11 (0.010)	31.47 (1.30)	0.077 (0.006)
TLP	555 (14.83)	53.4 (11.8)	9.2 (0.9)	4.89 (0.50)	1645 (192)	0.18 (0.014)	25.15 (1.42)	0.076 (0.002)
1/2SLC-FP	605 (12.58)	74.5 (13)	14.8 (0.7)	4.15 (0.68)	1718 (159)	0.09 (0.006)	21.93 (1.21)	0.086 (0.001)
1/2SLF-WP	672 (24.8)	46.4 (6.5)	9.9 (1.0)	6.46 (0.49)	1566 (107)	0.18 (0.031)	37.68 (5.00)	0.077 (0.001)
1/2SLC-WP	535 (5.68)	65.2 (2.4)	8.50 (0.5)	4.39 (0.86)	1515 (71)	0.07 (0.004)	17.12 (0.95)	0.079 (0.007)
WP	653 (16.9)	50.6 (7.0)	6.4 (0.9)	10.29 (0.84)	2103 (191)	0.26 (0.023)	41.06 (7.70)	0.075 (0.001)
EN *			14[c]	11.5[a]	1600[b]	0.24[a]		

* Minimum requirements according to EN 312 (2003):
[a] Requirements for particleboards for general uses (P1)
[b] Requirements for furniture manufacturing (P2)
[c] Requirements for moisture resistant particleboards (P3)
Values in parentheses are standard deviations

The results of the most important tested properties of the investigated particleboards are shown in Fig. 4. The density varied within the boards' group, the higher values being noticed for SLFP, 1/2SLF-WP, and WP. The density of the single-layer particleboard decreased with increasing particle size (SLCP compared to SLFP), because of the higher compaction ratio of fine particles compared to the coarse ones. The fine particles are easy to press at high temperature, resulting in higher density panels (Cai *et al.* 2004). The internal bond strength (IB) of SLFP was superior to that of SLCP (0.24 compared to 0.11 N/mm^2) and TLP (0.18 N/mm^2). Corn and rice stubbles mixed with pine wood in various ratios led to similar IB values ranging between 0.11 N/mm^2 to 0.29 N/mm^2 (Garay *et al.* 2009).

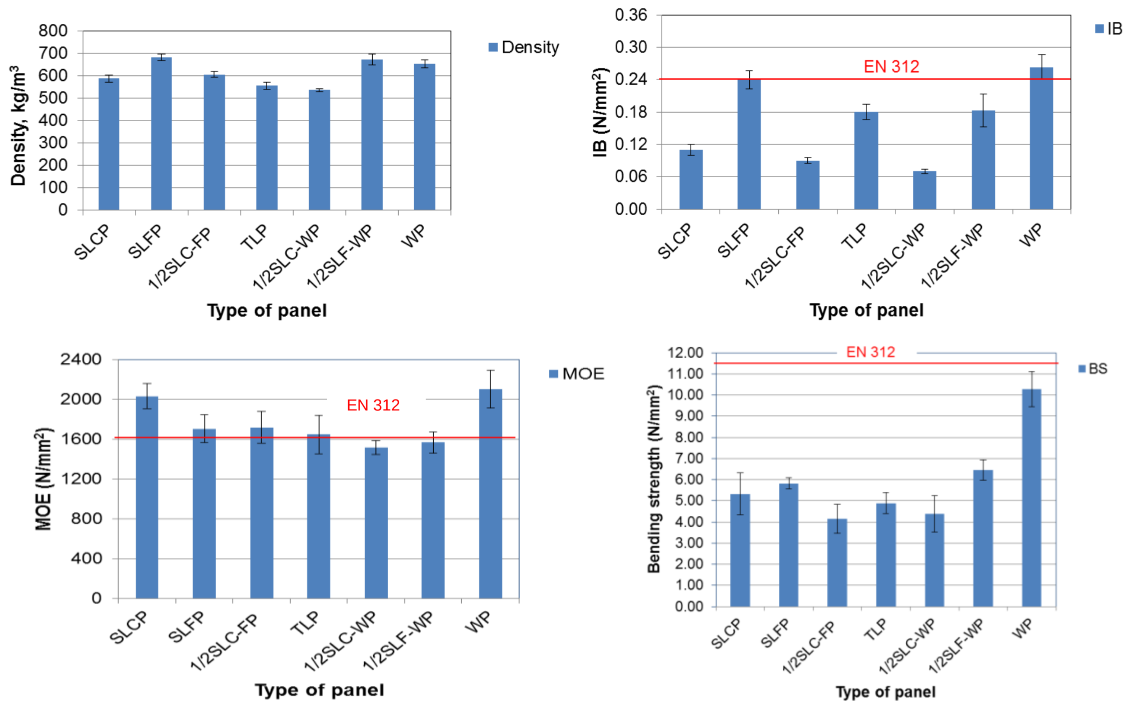

Fig. 4. Density, internal bond strength (IB), MOE and bending strength (BS) for the tested particleboards.

Higher screw holding strengths (SH) were obtained for SLCP, SLFP, and 1/2SLF-WP, as seen in Table 2. It seems that the particles' size and geometry had an important influence on both IB and SH strengths. The fine particles, with their flat surfaces and fusiform appearance, achieved a better bonding contact, so the obtained structure was more compact and homogenous. Coarse particles, with their concave geometry, produced local agglomerations of adhesive with a reduced compactness, lowering the internal bond strength. The highest MOE value was obtained for SLCP, the coarse particles increasing the stiffness of the board (Fig. 4). The values of BS were below the EN 312 (2003) standard limit for all boards. Lower values of WA and TS were obtained for all particleboards. The structures with coarse particles had the highest WA values, explained by the porosity caused by the concavity and variation in shapes of the husks. All the boards with fine particles in the outer layers (TLP, SLFP) had low WA and TS values, because of the higher compactness and low wettability. Similar results were obtained for peanut hulls and pine particleboards (Guler *et al.* 2008; Güler and Büyüksari 2011) and almond shells mixed with wood (Pirayesh *et al.* 2013). Three-layer particleboard (TLP) has similar performance with 1/2SLC-WP board, except IB. Based on the EN Standard (EN 312 2003), SLFP nearly met the minimum requirements for MOE, TS, and IB, but not for BS. Mechanical properties of the tested boards can be compared with those made from grass clipping mixed with wood (Nemli *et al.* 2009). Thermal conductivity coefficients (0.075 to 0.079 W/mK), as shown in Table 2, indicated good thermal insulating properties for all panels. The normal range of insulation materials is between 0.035 W/mK and 0.160 W/mK (Panyakaew and Fotios 2008), agro-wastes boards being included with the following thermal conductivity coefficients: 0.046 W/mK (coconut husks), 0.096 W/mK (bagasse) (Panyakaew and Fotios 2008), 0.0764-0.1254 W/mK (durian peel and coconut coir) (Madurwar *et al.* 2013) and 0.051 W/mK for rice straw (Wei *et al.* 2015).

CONCLUSIONS

1. The size and geometry of particles influenced the performance of studied particleboards. The fusiform shape of fine particles and their homogeneous distribution in the structure improved the performance of single-layer and three-layer particleboards made from sunflower husks. The concave geometry of the coarse particles led to a more porous structure affecting WA and internal bond strength.
2. Better performance was obtained for single-layer particleboards made from fine particles (SLFP) compared to the other panels.
3. Three-layer particleboards had a lower density with negative influence on the bending strength (BS). The boards made from sunflower husks and wood did not exceed the performances of those made only from sunflower husks.
4. The boards are recommended for paneling structures and furniture components which are not subjected to bending stresses.

ACKNOWLEDGMENTS

We hereby acknowledge the structural funds project PRO-DD (POS-CCE, O.2.2.1., ID 123, SMIS 2637, No. 11/2009) for providing the infrastructure used in this work and the Contract No. 7/9.01.2014.

REFERENCES CITED

Abdul Halip, J., Tahir, P. Md., Choo, A. C. Y., and Ashaari, Z. (2014). "Effect of kenaf parts on the performance of single-layer and three-layer particleboard made from kenaf and rubberwood," *BioResources* 9(1), 1401-1416. DOI: 10.15376/biores.9.1.1401-1416

Ashori, A., and Nourbakhsh, A. (2010). "Bio-based composites from waste agricultural residues," *Waste Management* 30(4), 680-684. DOI: 10.1016/j.wasman.2009.08.003

Balducci, F., Harper, C., Meinlschmidt, P., Dix, B., and Sanasi, A. (2008). "Development of innovative particleboard panels," *Drvna Industrija* 59(3), 131-136.

Barros Filho, R. M., Mendes, L. M., Novack, K. M., Aprelini, L. O., and Botaro, V. R. (2011). "Hybrid chipboard panels based on sugarcane bagasse, urea formaldehyde and melamine formaldehyde resin," *Industrial Crops and Products* 33(2), 369-373. DOI: 10.1016/j.indcrop.2010.11.007

Cai, Z., Wu, Q., Lee, J.N., Hiziroglu, S. (2004). "Influence of board density, mat construction, and chip type on performance of particleboard made from eastern redcedar," *Forest Products Journal* 54(12), 226-232.

Carre, P. (2009). WP2 Report of the SUSTOIL Project, Deliverable D2.1. Review and Evaluation Major and Most Promising Processing Technologies for Oil Seed Pretreatment and Extraction FP7-Energy, http://www.york.ac.uk/res/sustoil/Pages/Deliverable%202-5.pdf, Accessed March 6, 2014.

CS 236-66 (1968). "Commercial Standard. Mat formed Wood particleboard."

DIN EN 12667. (2001). "Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods - Products of high and medium thermal resistance," *British Standards*, London.

EN 310. (1993). "Wood-based panels. Determination of modulus of elasticity in bending and of bending strength," *British Standards*, London.

EN 312. (2003). "Particleboards. Specifications," *British Standards*, London.

EN 317. (1993). "Particleboards and fibreboards. Determination of swelling in thickness after immersion in water," *British Standards*, London.

EN 319. (1993). "Particleboards and fibreboards. Determination of tensile strength perpendicular to the plane of the board," *British Standards*, London.

EN 320. (1993). "Fibreboards. Determination of resistance to axial withdrawal of screws," *British Standards*, London.

EN 323. (1993). "Wood-based panels. Determination of density," *British Standards*, London.

Ferra, J. M. M., Ohlmeyer, M., Mendes, A. M., Costa, M. R. N., Carvalho, L. H., and Magalhães, F. D. (2011). "Evaluation of urea-formaldehyde adhesives performance by recently developed mechanical tests," *International Journal of Adhesion & Adhesives* 31, 127-134. DOI: 10.1016/j.ijadhadh.2010.11.013

Fiorelli, J., Curtolo, D. D., Barrero, N. G., Savastano Jr., H., Pallone, E. M. J. A., and Johnson, R. (2012). "Particulate composite based on coconut fiber and castor oil polyurethane adhesive: An eco-efficient product," *Industrial Crops and Products* 40, 69-75. DOI: 10.1016/j.indcrop.2012.02.033

Garay, R. M., MacDonald, F., Acevedo, M. L., Calderon, B., and Araya, J. E. (2009). "Particleboard made with crop residues mixed with wood from *Pinus radiata*," *BioResources* 4(4), 1396-1408. DOI: 10.15376/biores.4.4.1396-1408

Garay, R. M. (2012). "Lab testing for P3 moisture resistant overlaid particleboards made from wood residues," *BioResources* 7(3), 3093-3103. DOI: 10.15376/biores.7.3.3093-3103

Garcia-Ortuño, T., Andreu-Rodriguez, J., Ferrandez-Garcia, M. T., Ferrandez-Villena, M., and Ferrandez-Garcia, C. E. (2011). "Evaluation of the physical and mechanical properties of particleboard made from giant reed (*Arundo donax* L.)," *BioResources* 6(1), 477-486. DOI: 10.15376/biores.6.1.477-486

Gertjejansen, R. O., Haygreen, J. G., and French, D. W. (1972). "Particleboard from aspen flakes and sunflower hulls," *Technical Bulletin* 290, Forestry Series TU, University of Minnesota, http://digitalcommons.usu.edu/aspen_bib/5418, Accessed March 6, 2014.

Güler, C., and Büyüksari, Ü. (2011). "Effect of production parameters on the physical and mechanical properties of particleboards made from peanut (*Arachis hypogaea* L.) hull," *BioResources* 6(4), 5027-5036. DOI: 10.15376/biores.6.4.5027-5036

Guler, C., Bektas, I., and Kalaycioglu, H. (2006). "The experimental particleboard manufacture from sunflower stalks (*Helianthus annuus* L.) and Calabrian pine (*Pinus brutia* Ten.)," *Forest Products Journal* 56(4), 56-60.

Guler, C., Kopur, Y., and Tascioglu, C. (2008). "The manufacture of particleboards using mixture of peanut hull (*Arachis hypogaea* L.) and European black pine (*Pinus nigra* Arnold) wood chips," *Bioresource Technology* 99(8), 2893-2897. DOI: 10.1016/j.biortech.2007.06.013

Hayes, D. (2010). "Chemistry and properties of woods-Carbolea," *DAFF RSF Project Database*, University of Limerick, www.carbolea.ul.ie/wood.php, Accessed November 14, 2014.

ISO 8301 (1991). "Thermal insulation - Determination of steady-state thermal resistance and related properties - Heat flow meter apparatus," *International Organization for Standardization*, Geneva, Switzerland.

Kowaluk, G., Fuczek, D., Beer, P., and Grzeskiewicz, M. (2011). "Influence of the raw materials and production parameters on chosen standard properties for furniture panels of biocomposites from fibrous chips," *BioResources* 6(3), 3004-3018. DOI: 10.15376/biores.6.3.3004-3018

Lee, S., Shupe, T. F., and Hse, C. Y. (2006). "Mechanical and physical properties of agro-based fibreboard," *Holz als Roh- und Werkstoff* 64(1), 74-79. DOI: 10.1007/s00107-005-0062-z

Madurwar, V. M., Ralegaonkar, R. V., and Mandavgane, S. A. (2013). "Application of agro-waste for sustainable construction materials: A review," *Construction and Building Materials* 38, 872-878. DOI: 10.1016/j.conbuildmat.2012.09.011

Nemli, G., Demirel, S., Gümüşkaya, E., Aslan, M., and Acar, C. (2009). "Feasibility of incorporating waste grass clipping (*Lolium perenne* L.) in particleboard composites," *Waste Management* 29(3), 1129-1131. DOI: 10.1016/j.wasman.2008.07.011

Pan, Z., Zheng, Y., Zhang, R., and Jenkins, B. M. (2007). "Physical properties of thin particleboard made from saline eucalyptus," *Industrial Crops and Products* 26(2), 185-194. DOI: 10.1016/j.indcrop.2007.03.006

Panyakaew, S., and Fotios, S. (2008). "Agricultural waste materials as thermal insulation for dwellings in Thailand: Preliminary results," PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, Dublin.

Pirayesh, H., and Khazaeian, A. (2012). "Using almond (*Prunus amygdalus* L.) shell as a bio-waste resource in wood-based composite," *Composites: Part B: Engineering* 43(3), 1475-1479. DOI: 10.1016/j.compositesb.2011.06.008

Pirayesh, H., Khanjanzadeh, H., and Salari, A. (2013). "Effect of using walnut/almond shells on the physical, mechanical properties and formaldehyde emission of particleboard," *Composites Part B: Engineering* 45(1), 858-863. DOI: 10.1016/j.compositesb.2012.05.008

Vitêz, T., and Travniĉek, P. (2010). "Particle size distribution of sawdust and wood shavings mixtures," *Research in Agricultural Engineering* 56(4), 154-158.

Wan, P. J., Baker, G. W., Clark, S. P., and Mattock, S. W. (1979). "Characteristics of sunflower seed and meal," *Cereal Chemistry* 56(4), 352-355.

Wei, K., Lv, C., Chen, M., Zhou, X., Dai, Z., Shen, D. (2015). "Development and performance evaluation of a new thermal insulation material from rice straw using high frequency hot-pressing," *Energy and Buildings* 87, 116-122. DOI: 10.1016/j.enbuild.2014.11.026

Article submitted: June 6, 2014; Peer review completed: October 15, 2014; Revised version accepted: December 12, 2014; Published: December 18, 2014.