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Suitability of sorghum stalk fibers for production of particleboard

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ABSTRACT

The aim of this study was to investigate the suitability of sorghum (*Sorghum bicolor*) stalk (SS) as a promising raw material for particleboard manufacturing. The SS particles and industrial hardwood particles in various proportions were used as the raw materials for the surface and core layers of the three-layer particleboards. Commercial urea formaldehyde (UF) adhesive was used as a binder. Morphological and chemical characteristics of the SS were evaluated. Effects of five variable parameters on the physical (thickness swelling (TS), water absorption (WA)), and mechanical (modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB)) properties of the particleboards were determined. Other parameters such as type of resin (UF), hardener content (1%), type of hardener (NH_4Cl), press closing time (5 mm/s), board density (0.70 g/cm^3), and press pressure (30 kg/m^2) were held constant. Fractional factorial was used to find the optimum condition for the studied variable parameters. The morphological results showed that SS had comparable fiber length with softwoods and fiber width and wall thickness values greater than the hardwood of common forest species. They had higher hot-water solubility values, lignin and ash contents than those of the other woody materials. The experimental results showed that increasing of SS particles usage in the surface layer significantly affects the board properties. Containing 50 wt% SS particles in the surface, the MOE and MOR values exceed the minimum requirements of the European norms (EN) standards, for general purposes. All of the particleboards produced from SS had IB higher than the EN standard requirement. The presence of SS in the particleboards resulted in higher WA and TS values. All the mechanical properties of the boards decreased when the press temperature was increased from 160 to 180 °C. Finally, it can be stated that SS has enough potential as a supplement fibrous material, in combination with industrial hardwood particles, for particleboard manufacturing and indoor applications.

1. Introduction

Recently, increasing environmental awareness, growing global waste problem, depletion of fossil fuels, and the increasingly higher price of crude oil have together created a groundswell of interest in renewable resources (Dos Santos, Battistelle, Bezerra, & Varum, 2014). In addition, deforestation and over-harvesting have created environmental issues, while increasing demand for forest resources in various applications has led to the shortages of wood supply in the most developing countries like Iran (Azizi, Tabarsa, & Ashori, 2011). Thus, there is a need to look for innovative ways of using non-traditional forest resources such as non-woods, agro residues and wood wastes, to substitute wood raw material for wood-based industries (Abdul Khalil, Issam, Ahmad Shakri, Suriani, & Awang, 2007). Agro residues and wood wastes are potentially usable in different ways. According to the end uses, agro residues could be sorted, processed and provided as raw materials for manufacture of pulp, fiberboard and particleboard (Ashori, 2006). Manufacturing of value added panel products may be the most efficient use of such waste materials.

Particleboard has become one of the most popular wood-based composite materials for decorating materials because of its low density, good thermal insulation, sound absorption, and wonderful machining properties. The primary lignocellulosic material used in the particleboard industry is wood (Yang, Fei, Wu, Peng, & Yu, 2014). However, the manufacture of particleboard is the most common way to reuse waste materials (Akgul & Camlibel, 2008). Research has been carried out on a wide variety of non-wood plant fibers and agro residues from many different regions of the world: wheat–cereal straws (Cheng, Sun, & Karr, 2004; Sain & Panthapulakkal, 2006), rice straw (Zhang & Hu, 2014), tobacco (Ntalos & Grigoriou, 2002), bagasse (Widyorini, Xu, Umemura, &

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Table 1
Various blending formulations and their mass ratios of the boards produced.

Board type	Particle size (mesh)	SS content (wt%)	Press time (min)	Press temp. (°C)	UF content (wt%)
L1	20	10	6	160	8
L2	20	10	6	180	12
L3	20	10	10	160	8
L4	20	10	10	180	12
L5	20	50	6	160	8
L6	20	50	6	180	12
L7	20	50	10	160	8
L8	20	50	10	180	12
H1	40	10	6	160	8
H2	40	10	6	180	12
H3	40	10	10	160	8
H4	40	10	10	180	12
H5	40	50	6	160	8
H6	40	50	6	180	12
H7	40	50	10	160	8
H8	40	50	10	180	12

Kawai, 2005), rapeseed straw (Mazhari Mousavi, Hosseini, Resalati, Mahdavi, & Rasooly Garmaroody, 2013), sunflower stalks (Nemli, 2003), kenaf (Kalaycıoglu & Nemli, 2006), bamboo (Sudin & Swamy, 2006), oil palm (Abdul Khalil et al., 2007) and cotton carpel (Alma, Kalaycıoğlub, Bektas, & Tutus, 2005).

The main goal of the current study is to confirm the feasibility of applying sorghum stalks as alternative raw material for particleboard industry, which, to our knowledge, has not been thoroughly investigated before. The objectives of study are; (a) to investigate the chemical and fiber morphology of sorghum stalks, (b) to prepare 3-layer particleboards made from mixture of sorghum stalk (SS) and industrial hardwood particles, bonded with urea–formaldehyde resin and, (c) to study the effect of some variable parameters on the physical and mechanical properties of particleboard samples. This reuse would provide a solution to the wood shortage, especially in countries with insufficient forest resources.

2. Methods

2.1. Materials

Two different types of fibrous materials were used in this study: sorghum (*Sorghum bicolor*) stalks and the mixture of industrial hardwood. The sorghum stalks were collected from an experimental field in the Gorgan-Kordkoy road in Iran, directly after crop harvest. The industrial hardwoods were obtained from forests in the northern part of Iran. Leaves, branches and piths were removed and then sorghum stalks were gently scrubbed in tab water. After air-drying, the stalks and industrial hardwoods were separately chipped using a laboratory-scale Drum-Chipper. The chips were then reduced into smaller pieces using a laboratory-scale Ring-Flaker. Particles were oven-dried at 80 °C for 10 h to a moisture content of less than 4% and then stored in plastic bags for future use.

Urea–formaldehyde (UF) adhesive with a solid content of 67%, density of 1.265 g/cm^3, viscosity of 61 cp, gelation time of 45 s, and pH of 7.5 was applied. As a hardener, ammonium chloride (NH_4Cl) solution (solid content: 20%) was added to the adhesive.

2.2. Chemical compositions

The chemical compositions of sorghum stalks were determined following the standards outlined in the TAPPI test methods and the other published procedures where indicated. Alpha-cellulose was determined following the procedure of T 203 cm-99. Acid-insoluble (Klason) lignin content was determined by hydrolyzing the carbohydrates with 72% sulfuric acid as per T 222 om-02. The procedure for the hot-water solubility was determined by T 207 cm-99. To determine ash content, the procedure outlined in T 211 om-93 was followed.

2.3. Fiber morphology determination

The samples for fiber measurements were obtained from the middle sections of the stalks. As per the modified Franklin method (Sheshmani, Ashori, & Farhani, 2012), pieces of samples were placed in test tubes containing an equal amount of glacial acetic acid and 35% hydrogen peroxide. For this study, one hundred (100) undamaged/unbroken fibers were measured in terms of their length (L), fiber width (d), lumen diameter (l) and cell wall thickness (w), directly from the magnified image.

2.4. Lab production of boards

Three-layer particleboards were produced using sorghum stalk for face layers and industrial hardwood particles for core layer. The whole experimental plan is shown in Table 1, where the blending formulations are summarized. As seen, five variable parameters are: particle size (20, 30 and 40 mesh), sorghum stalk content (10, 30 and 50%), UF content (8, 10 and 12%), pressing time (6, 8 and 10 min), and press temperature (160, 170 and 180 °C). Other parameters such as hardener content (1 wt%), press closing rate (5 mm/s), press pressure (35 kg/cm^2), board thickness (10 mm), and target density (0.70 g/cm^3) were held constant.

Dried particles for the face and core layers were separately blended with UF adhesive in a rotating drum-type mixer fitted with a pneumatic spray gun. The resinated particles were placed in a molding box with dimensions of 30 cm × 30 cm and manually formed. The press cycle consisted of two phases. First, in order to reduce the mat height and to densify it, the randomly oriented mats were cold pressed at a load of approximately 30 kg/m^2 for 4 min. In the second phase, the boards were pressed using a hydraulic hot press (OTT, Germany). Stop bars were used in the press to allow the same board thickness to be achieved for all the test runs. No wax or any other hydrophobic substance was applied for manufacturing of the boards.

2.5. Testing methods

After hot pressing, boards were stacked for 24 h in order to be completely cured and then trimmed and cut into various test specimens. All specimens were conditioned at a temperature of 25 ± 2 °C, and 65 ± 5% relative humidity in a conditioning chamber for at least