



# Enhancing oriented strand board performance using wheat straw for eco-friendly construction

Hani Abobakr<sup>a,b,c</sup>, Marya Raji<sup>b,c,\*</sup>, Hamid Essabir<sup>b,d</sup>, Mohammed Ouadi Bensalah<sup>a</sup>, Rachid Bouhfid<sup>b,c</sup>, Abou el kacem Qaiss<sup>b,c,\*</sup>

<sup>a</sup> Laboratory of Mechanics and Materials (LMM), Faculty of Science, Mohammed V-University, in Rabat, Morocco

<sup>b</sup> Composites and Nanocomposites Center, Moroccan Foundation for Advanced Science, Innovation and Research, Rabat Design Center, Rue Mohamed El Jazouli, Madinat El Irfane, Rabat 10100, Morocco

<sup>c</sup> Mohammed VI Polytechnic University, Lot 660 Hay Moulay Rachid, 43150 Ben Guerir, Morocco

<sup>d</sup> Mechanics, Materials, and Composites (MMC), Laboratory of Energy Engineering, Materials, and Systems, National School of Applied Sciences of Agadir, Ibn Zohr University, Agadir 80000, Morocco

## ARTICLE INFO

### Keywords:

Bio-based composites  
Bio-based construction materials  
Oriented strand board OSB  
Wheat straw  
Sound insulation

## ABSTRACT

Wheat straw is an abundant and cheap agricultural by-product. This research aims to produce an outperform-oriented strand board utilizing wheat straw for sustainable construction. The produced rectangular specimens via the compression molding process were tested in terms of mechanical, hygroscopic, morphological, and sound isolation performances. The results compared to the commercial (OSB) EN 300: 2006 standard showed excellent mechanical properties in wheat straw-based panels with a density of  $0.60 \text{ g.cm}^{-3}$ , with a remarkable 44.61% increase in flexural strength and 42.2% improvement in Young's modulus over wood-based OSB. Taking into consideration the hygroscopic properties, wheat straw-based boards showed superior swelling resistance, with WS-OSB-0.45 leading the way with a 23% reduction compared to commercial OSB. Water absorption was inversely related to density, with WS-OSB-0.60 reducing water absorption by 8.9% compared to commercial OSB. The contact angle measurements showed that wheat straw-based panels (WS-OSB-0.60 at  $106^\circ$  and WS-OSB-0.45 at  $100.4^\circ$ ) had more hydrophobic surfaces than commercial OSB ( $88.1^\circ$ ). The wheat straw-based OSB panels, especially WS-OSB-0.45, achieved remarkable sound reduction, with an overall sound reduction value of 35.2 dB, outperforming WS-OSB-0.6 (34.9 dB) and commercial OSB (34 dB). These results demonstrate the viability of using wheat straw residues as an environmentally friendly alternative to wood in the production of panels for building, furniture manufacturing, and equipment packaging applications.

## 1. Introduction

The growing concern for climate change and sustainable development has increased the demand for eco-friendly materials in the construction industry. Wood-based materials like oriented strand boards (OSB) are commonly used in construction because of their durability, strength, and availability. Even so, the manufacture of OSB panel composites depends largely on wood as the main material, which is a limited natural resource, and its excessive use leads to deforestation and ecosystem deterioration, which in turn contributes to climate change [1–3]. On the other hand, wheat straw is an abundant and cheap agricultural by-product. According to USDA Foreign Agricultural Services,

the global wheat production is 781.83 million tons in 2022/2023, and according to the literature, for one ton of wheat grain, there are (1.15–2) tons of wheat straw [4–6]. Therefore, there is a huge quantity of wheat straw leftovers, unfortunately, only 19% is used in farming for bedding, and animal feed, whereas the majority is burned in the field, causing significant environmental threats including carbon monoxide, carbon dioxide, and nitrogen oxide emissions as well as health risks [7–9]. Consequently, the use of agriculture by-products like wheat straw fibers as an alternative resource to produce environmentally friendly building materials, and its use could be a feasible solution to substitute dependence on wood-based products saving the forests which are considered the lungs and cooling system of our planet Earth. In addition, wheat

\* Corresponding authors at: Composites and Nanocomposites Center, Moroccan Foundation for Advanced Science, Innovation and Research, Rabat Design Center, Rue Mohamed El Jazouli, Madinat El Irfane, Rabat 10100, Morocco.

E-mail addresses: [m.raji@mascir.ma](mailto:m.raji@mascir.ma) (M. Raji), [a.qaiss@mascir.ma](mailto:a.qaiss@mascir.ma) (A. Qaiss).

<https://doi.org/10.1016/j.conbuildmat.2024.135135>

Received 7 July 2023; Received in revised form 3 January 2024; Accepted 19 January 2024

Available online 7 February 2024

0950-0618/© 2024 Elsevier Ltd. All rights reserved.

straw has long been widely used as an insulating material for buildings because of its high porosity, light density, and excellent heat insulation properties [10]. The employment of straws for insulating buildings not only addresses the problem of wheat straws as an agricultural by-product but also makes it feasible to build houses with a low environmental impact [11,12].

Agricultural-based composites have demonstrated intriguing thermal and acoustic characteristics. Renovating agricultural byproducts to create a useful product for sound insulation has many benefits in terms of social evaluation, boosting benchmarks for economic applications, and providing a low-cost, environmentally friendly, and far less polluting product, all of which contribute to a country's long-term development [13]. Therefore, using agricultural wheat straws to produce wheat straw-based Oriented Strand Boards for building materials is a way to minimize agricultural leftovers and produce sustainable, eco-friendly, lightweight boards while improving the hygroscopic behavior of OSB panels [14]. Further information regarding Oriented Strand Boards OSB is lightweight and simple to handle and install in comparison to their strengths. OSB is created from chosen wood and polyurethane resin glue. They are often used as structural components, particularly as part of the formwork for reinforced concrete members such as beams, slabs, and columns [15]. In addition, OSB is commonly used for wall and roof sheathing, flooring, packing, and I-joints. Moreover, it is used in furniture, reels, pallets, crates, trailer liners, and recreational vehicle floors, all examples of structural usage [16].

According to the Structural Board Association [17], OSB boards are commonly made up of 3 to 5 layers, and the distribution of longitudinal threads in the outer layers optimizes panel strength and rigidity in the axis of alignment. Furthermore, when wood/straw strands and adhesive are combined, the result is a durable, dimensionally stable panel that can handle deflection, spalling, and warping. It could also withstand tilt and shape deformation when subjected to excessive wind and earthquake conditions [13,18]. Among the mechanical characteristics of OSB made of wheat straw, the elastic modulus in static flexural (MOE) should be addressed, since this is an essential property to performance evaluation in structural designs, as these boards were produced particularly for such applications as an alternative for wood strands OSB and plywood [15]. Previous studies have explored the use of wheat straw in panel production, focusing on various aspects of its mechanical and physical properties. The work of T. Tabarsa et al. focused on the use of a tannin-modified phenol-formaldehyde adhesive to bond wheat straw panels. It showed that these panels had slightly inferior mechanical properties compared to those made with pure phenol-formaldehyde adhesive [19]. B. Xuejiao et al. investigated adhesive selection, bonding mechanisms, and bonding models for wheat straw-based panels. Their results highlighted the significant influence of the adhesive type and amount on the bond strength of these panels [20]. Meanwhile, N. Boquillon et al. [21] investigated the properties of wheat straw-based particleboards bonded with different types of resins, with a particular emphasis on urea-formaldehyde (UF) resins. The results showed sub-optimal properties for UF resin-bonded boards, particularly in terms of internal bond strength and thickness swelling. Another study by Grigoriou et al. investigated the properties of wheat straw particleboards bonded with urea-formaldehyde (UF) resin and one based on epoxidized oil. The results revealed that the particle size of the straw influenced the properties of the panels, with smaller particles resulting in lower thickness swelling and modulus of elasticity [22]. Another study by Y. Zhang et al. investigated the morphology and chemical state of wheat straw particleboards using techniques such as X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM). Their work demonstrated the reliability of these methods in analyzing wheat straw particleboard [23].

In studies other than wheat straw as a natural resource to produce panels, Jorge et al. assessed the utilization of sugar cane bagasse without separating its components as a sustainable product and its mechanical properties of (OSB) [13]. Ali Akrami et al. studied the possibility of using

European poplar and beech species to produce oriented strand boards (OSB) at densities of 0.65 and 0.72 g.cm<sup>-3</sup>. They found that increasing the density of the composite improved the physical and mechanical properties [16]. On the other hand, there is little work on the use of polyurethane with natural fibers, as the study of Lopes et al., [24] for producing oriented strand board natural-based polyurethane matrix composites reinforced with bamboo fiber waste. The advantage of using polyurethane resin among the existing resins is a bio-sourced resin and can show many final characteristics like rigid, flexible, rubbery, and in the form of foams.

The originality of this work is the use of wheat straw as agricultural waste materials to produce eco-friendly panels with bio-sourced resin as a promising solution to reduce dependence on wood-based materials and contribute to sustainable development. Moreover, there is limited knowledge of the hygroscopic, mechanical, and acoustic properties of wheat straw-based panels at different densities (0.60 g.cm<sup>-3</sup> and 0.45 g.cm<sup>-3</sup>). In this regard, this study aims to produce a lightweight panel at two different densities using wheat straw waste and polyurethane adhesive. In addition, the produced panels were compared with commercially available wood-based OSB in terms of mechanical properties, sound insulation properties, contact angle, and hygroscopic behavior.

## 2. Materials and characterizations

### 2.1. Materials

A bundle of wheat straw (Common wheat: *Triticum aestivum*) utilized in this research was purchased at a local agricultural market in Rabat, and it was harvested in the northern regions of Morocco in 2019. The wheat straw size distribution was determined using ImageJ analysis, and the mean wheat straw size was found to be 5.33 ± 0.23 cm. In addition, the mechanical properties of wheat straw were determined by slicing the stem of wheat straw into strips of the width of 4 mm, and length of 35 mm. Tensile forces were applied to both ends of the wheat straw specimens using a universal testing machine (INSTRON 8821 S) with a 5000 N loading cell sensor and a 3 mm/min crosshead speed. Stress at failure was considered tensile stress, and Young's modulus was determined from the slope of the stress-strain curve. The results were averaged to obtain representative values for the mechanical properties of wheat straw, which are 119.63 ± 5.26 MPa and 10071.61 ± 390.73 MPa for tensile stress and Young's modulus, respectively. On the other hand, the composite's binder was a commercial polyurethane adhesive Vinyprene P2006 (Intercolle, Casablanca, Morocco).

### 2.2. Sample fabrication

This study aims to produce and evaluate the performance of wheat straw-based composites as an alternative to commercial wood-based Oriented Strand Board (OSB). Two wheat straw-based panels were fabricated in the laboratory using polyurethane resin as a binder. The panels were designated as WS-OSB-0.60 (b) and WS-OSB-0.45 (c) (Fig. 1; b; c), with densities of 0.60 g.cm<sup>-3</sup> and 0.45 g.cm<sup>-3</sup>, respectively. These panels will be compared with a commercial wood-based OSB panel, Com-OSB-0.60 (Fig. 1; a), in terms of physical and mechanical properties. To manufacture the wheat straw panels, the wheat straws were randomly cut into short fibers with an average length of 5.33 ± 0.23 cm, as shown in Fig. 1. The nodes and abnormal fibers of the straws were discarded to ensure the uniformity and quality of the panel because their presence in wheat straw can introduce irregularities and inconsistencies in the structure and surface of the panels, potentially affecting their uniform density and mechanical and hygroscopic properties. These nodes are known to contain denser tissue with different mechanical properties compared to the rest of the straw [25]. The wheat straws were then mixed with a modified resin in a mass ratio of 1:4 (resin: wheat straw), as detailed in the Table. 1. The mixing was done manually until the resin completely coated the straws. The mixture was then transferred

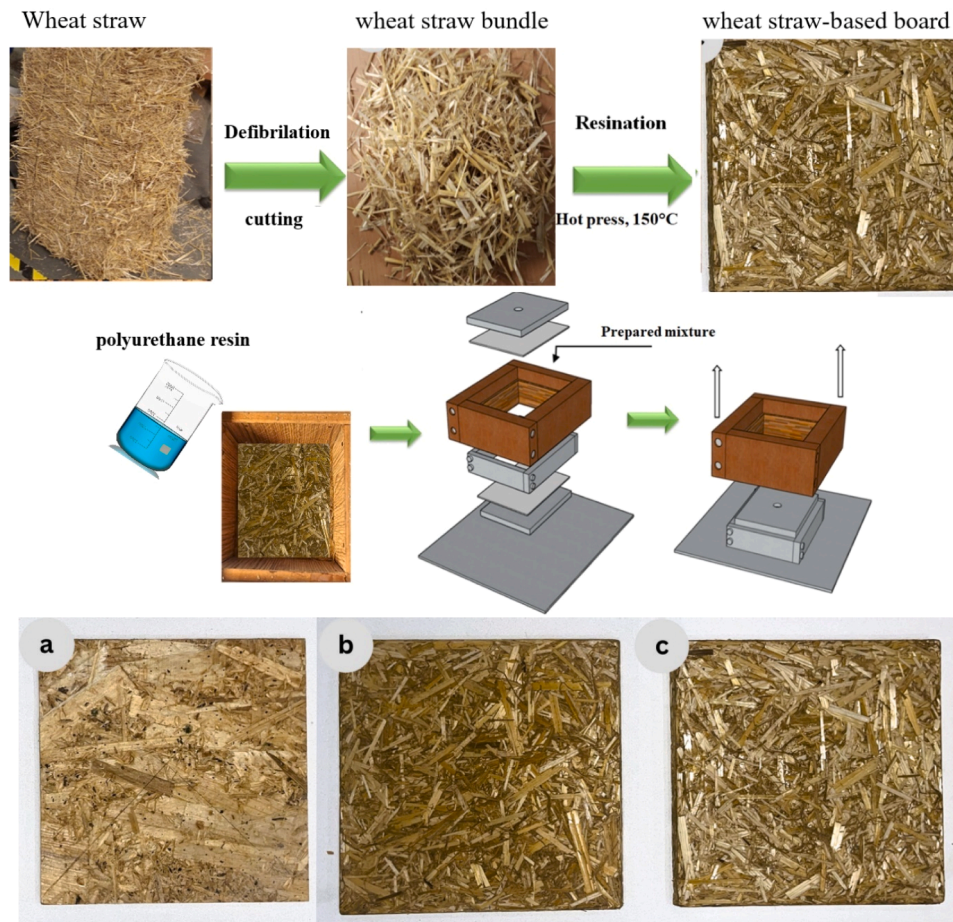


Fig. 1. manufacturing process of wheat straw-based board WS-OSB; (a) Com-OSB-0.60; (b) WS-OSB-0.60; (c) and WS-OSB-0.45.

**Table. 1**  
mix proportions and physical details of manufactured wheat straw boards.

Panel Code	Resin wt. (%)	Straw strands wt. (%)	Board thickness (mm)	Bulk Density (g/cm <sup>3</sup> )	Porosity (%)
Com - OSB	-	-	9.4	0.60	-
WS- OSB1	20	80	8.0	0.60	40.2
WS- OSB2	20	80	10.0	0.45	52.19

to a steel mold with 18 × 18 x H cm<sup>3</sup> dimensions and evenly distributed inside the mold, and the mold was pressed at a temperature of 150 °C using a hot press bench for 10 mins.

### 3. Characterization

#### 3.1. Fourier transforms into infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FT-IR) is a technique used to identify and analyze the chemical structure of a sample by measuring the infrared absorption of the sample. FTIR of wheat straw, polyurethane resin, wheat straw-based OSB panels, and commercial wood-based OSB panels were examined using an ABB Bomem FTLA 2000–102 spectrometer (ATR: SPECAC Golden Gate). The spectra were acquired with a resolution of 4 cm<sup>-1</sup> and an accumulation of 16 scans. To carry out the FTIR analysis of the samples, it is first necessary to prepare the sample by taking small portions of the materials; a thin strip

was taken from the stem of the wheat straw, a thin film of polyurethane resin was prepared, and small pieces of the panels produced were taken for the test. These films or pieces are then placed on the FTIR instrument, and a beam of infrared radiation is passed through them. The molecules in the sample absorb certain frequencies of infrared radiation, which are recorded as a spectrum. The spectrum obtained can be analyzed to identify the different chemical functional groups present in the sample.

#### 3.2. Scanning electron microscopy (SEM)

The morphological analysis is conducted on OSB panels to understand the arrangement of the panels and how it affects the prepared panels' characteristics. The bonding of wheat straw fibers, polyurethane resin, morphology, and the microstructure of various OSB samples was examined using scanning electron microscopy a JEOL JSM 840. All the specimens were immersed in liquid nitrogen to have a clean and accurate section and coated with Au/C to view the samples under various magnifications.

#### 3.3. Bulk density and porosity

The bulk density of prepared composites was determined experimentally by taking the volumetric measurements and mass of each specimen as in Eq. (1) these measurements were taken using a digital caliper and a digital balance. To calculate the porosity presented in the panels, theoretical density was determined by the summation of proportional percentages multiplied by the specific density of the raw material, as in Eq. (2). The difference between theoretical and bulk densities is the porosity of the prepared panel and it can be calculated through Eq. (3).

$$\rho_{\text{bulk}} = \text{Mass of the panel} / \text{Volume of the panel } \text{g}\cdot\text{cm}^{-3} \quad (1)$$

The theoretical density of the specimen:(2)

$$\rho_{\text{theoretical}} = (\rho_{\text{ws}} \cdot W_{\text{ws}} + \rho_{\text{pu}} \cdot W_{\text{pu}})$$

Where:

$\rho_{\text{ws}}$  = Density of wheat straw,  $W_{\text{ws}}$  = weight fraction of wheat straw.

$\rho_{\text{gy}}$  = Density of PU,  $V_{\text{pu}}$  = Volume of PU, and  $W_{\text{pu}}$  = weight fraction of PU

$$\text{Estimated porosity}(\%) = \left(1 - \frac{\text{Experimental density}}{\text{Theoretical density}}\right)\% \quad (3)$$

### 3.4. Hygroscopic behavior (swelling and water absorption)

Wheat straw-based OSB composites are porous materials that exhibit hygroscopic behavior like other wood-based panel materials. Their volume changes with the humidity level in the environment, which affects their mechanical and physical properties. To investigate the swelling and water absorption of these composites, six specimens with initial dimensions of 3 cm × 3 cm × H cm were cut from the prepared panels using an electric saw. The specimens were then dried in an electric oven at 80 °C for 48 h until they reached a constant mass. After that, the specimens were submerged in water for 24 h at room temperature (20 °C), and their saturated mass and dimensions were recorded. The same procedure was repeated for different immersion times on a logarithmic scale (1, 2, 4, 8, 16, and 32 days).

The swelling and water absorption were calculated in percentage using Eqs. 4, and 5.

$$\text{Water absorption}(\%) = \frac{M_{\text{sat}} - M_{\text{dry}}}{M_{\text{sat}}}\% \quad (4)$$

$$\text{Swelling}(\%) = \frac{T_1 - T_0}{T_0}\% \quad (5)$$

Where:

$T_0$  is the thickness of the test specimen before immersion in water in mm, and

$T_1$  is the thickness of the test specimen after immersion in water in mm.

### 3.5. Mechanical characterization

The mechanical properties were determined by using a three-point bending test according to EN 310:1993 [26]. Five test samples sawed using an electric wood saw to dimensions of 18 cm × 3 cm × d cm were selected randomly from each prepared panel specimen to ensure reliability following the probability sampling technique. Using a universal testing machine (INSTRON 8821 S), shown in Fig. 2a,b, and c the load is applied in mid-span with a 5000 N loading cell sensor and a crosshead

speed of 3 mm min<sup>-1</sup> until failure. In addition, this testing machine has a sensor that can measure displacement and force up to 0.001 mm and 0.17 N, respectively. The flexural stress ( $\sigma_f$ ), flexural strain ( $\epsilon_f$ ), and modulus of elasticity were calculated from the load-deflection curves obtained from the test using Eqs. 6, 7, and 8, under ASTM D 790 [27].

$$\sigma_f = (3PL / 2bd^2) \quad (6)$$

$$\epsilon_f = 6Dd/L^2 \quad (7)$$

$$\text{Young's modulus, } = M * \frac{L^3}{4bd^3}, M = \frac{(F_1 - F_2)}{(y_2 - y_1)} \quad (8)$$

Where:

$\sigma$  = stress in the outer fibers at the center, MPa,

$\epsilon_f$  = strain in the outer surface in mm/mm,

P = load at a given point on the load-deflection graph, N.

L = support span distance in mm,

b, and d = breadth, and depth of the test piece respectively.

D = maximum deflection at the midspan of the beam in mm,

L = support span in mm, and.

d = depth of beam tested in mm.

m = slope.

(F2 - F1) = Increment in point Force on the line that has a maximum slope in force-deflection curves,

and,

(y<sub>2</sub> - y<sub>1</sub>) = increment of displacement in the mid-span of the beam specimen corresponding to (F2 - F1).

### 3.6. Hardness

One of the methods to evaluate the mechanical properties of natural fibers-based composites is the hardness test. This test measures the resistance of a material to indentation by a rod with a known diameter and depth. In this study, an Instron loading machine was used to apply a force to a 12 mm diameter rod and embed it for 2 mm into different types of composites [28]. The force was then expressed in arbitrary units for commercial wood-based OSB panels. However, it was able to compare the hardness values of wheat straw-based OSB panels produced in the laboratory: (WS-OSB-0.60 and WS-OSB-0.45). The hard test setup can be seen in Fig. 2d.

### 3.7. Sound reduction measurement

Sound reduction is an essential property of materials that can reduce the transmission of sound energy from one room to another. To determine the sound reduction performance of a composite, a laboratory experiment was performed using a developed sound-insulated tube which was fabricated in the laboratory as shown in Fig. 3. The experimental setup consisted of two rooms separated by the composite to be

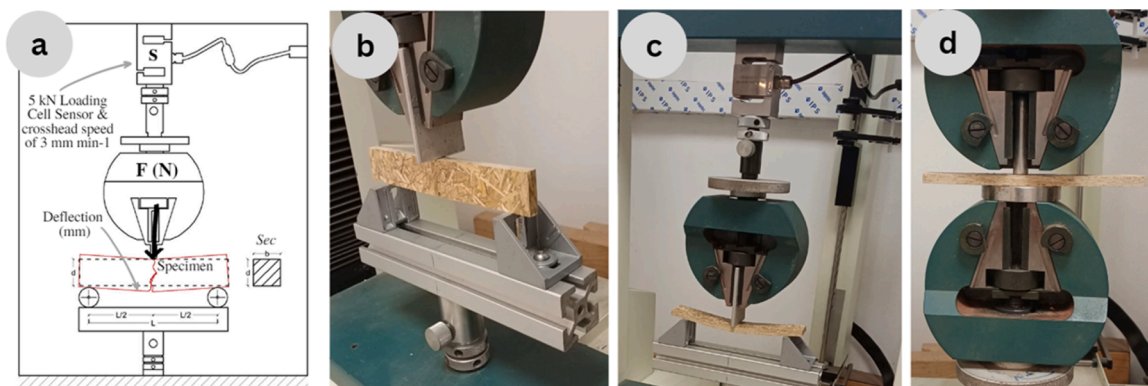


Fig. 2. Mechanical test setup.

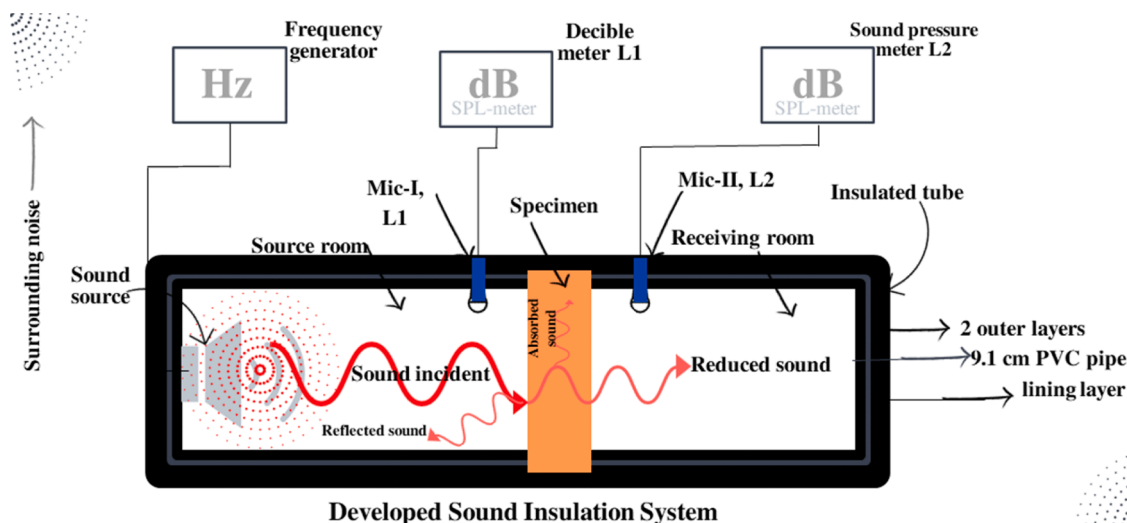


Fig. 3. Homemade sound insulation testing setup.

tested: the source room containing a sound source and a microphone, and the receiver room containing another microphone. The sound generator produced a constant sound pressure level at different frequencies in the range (80 Hz, 3150 Hz), while the microphones measured the sound pressure levels in both spaces at each frequency. The sound reduction was then determined as the difference between the source and receiver sound pressure levels using Eq. 9 [29]. The iNVH Bosch software version 2.1.1 was used to record and analyze the data.

$$\delta L_{\text{red}} = L_1 - L_2 \quad (9)$$

Where,

$\delta L_{\text{red}}$  = Sound reduction / Transmission loss (DB).

$L_1$  = Sound pressure in the source room (dB), and,

$L_2$  denotes Sound pressure in the receiver room.

### 3.8. Contact angle

The water contact angle of the OSB specimens was measured using optical equipment (data physics oca 15 EC) and the sessile drop technique. A water droplet of 9  $\mu\text{L}$  was placed automatically on a fixed sample surface and the contact angle was recorded immediately after the drop touched the surface. Three measurements were performed for each specimen to ensure accuracy and reproducibility.

### 3.9. Statistical analysis

Univariate analysis of variance ANOVA was performed on the mechanical properties in both directions (transverse and depth), including flexural strength, Young's modulus, hardness, and strain energy for the OSB samples ( $n = 3$ ). Tukey Duncan's new multiple-range test was used to detect significant differences between the samples. The results were considered significant when  $P \leq 0.05$ .

## 4. Results and discussion

### 4.1. Fourier transform-infrared spectroscopy analysis

The chemical composition of the straw materials and polyurethane binder was analyzed by FT-IR analysis to check the structural interaction between each component via the appearance or the disappearance of any chemical structural change in the final panel compositions and to check the chemical structure of the stomata existing on the wheat surface. Fig. 4, shows Fourier transform-infrared spectroscopy obtained from wheat straw and polyurethane resin, a prepared OSB panel based

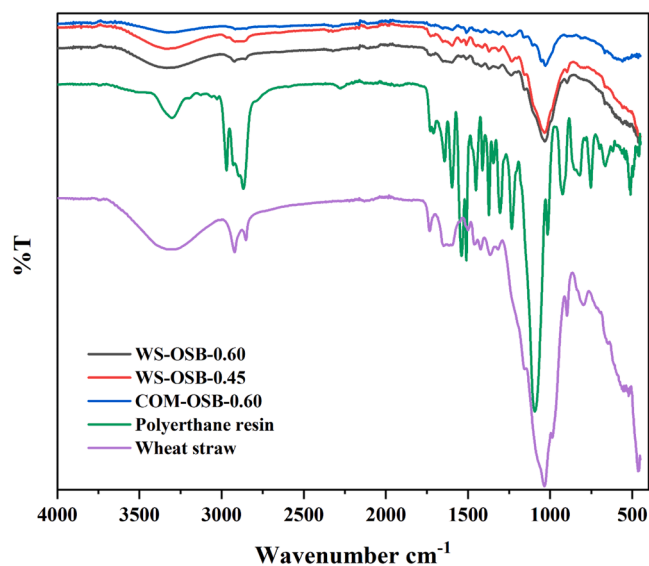


Fig. 4. FT-IR analysis of raw materials and prepared composites.

on wheat straw and wood. FT-IR spectra of wheat straw typically show broad absorption bands in the wavenumber range of 3100  $\text{cm}^{-1}$  to 3500  $\text{cm}^{-1}$  [30]. These bands are due to the stretching of hydrogen-bonded hydroxyl groups of cellulose, hemicellulose, and lignin [31]. The stretch vibration of  $\text{CH}_2$  groups is responsible for the absorption at 2900  $\text{cm}^{-1}$ . The acetyl and uronic ester groups of hemicellulose are represented by the bands at 1735  $\text{cm}^{-1}$  and 1240  $\text{cm}^{-1}$ . The carbonyl group of lignin is represented by the band at 1655  $\text{cm}^{-1}$ . Aromatic backbone vibrations and C-H deformation in lignin are attributed to the bands at 1510  $\text{cm}^{-1}$  and 1425  $\text{cm}^{-1}$ , respectively [32]. C-O-C stretching in cellulose and hemicellulose is associated with the band at 1160  $\text{cm}^{-1}$ . Moreover, the FTIR curve also shows the stretching vibrations of the Si-OH and Si-O-Si groups at 950  $\text{cm}^{-1}$  and 800  $\text{cm}^{-1}$ , respectively [33]. These two bands are related to the silica bumps on wheat straw surface. The Fourier Transform Infrared spectrum of the polyurethane sample had the Transmittance band at 3300  $\text{cm}^{-1}$  corresponding to the NH stretch. The sharp peaks at 2867  $\text{cm}^{-1}$ , and 2970  $\text{cm}^{-1}$  are related to the  $-\text{CH}_2$  stretch, while other modes of  $-\text{CH}_2$  vibrations are indicated by bands at 1454, 1411, 1373, and 1232  $\text{cm}^{-1}$  [34,35]. Furthermore, the absorption band at 1732  $\text{cm}^{-1}$  is linked to the

C=O group in polyurethane [36]. The NH vibrations group is represented by the bands at  $1537\text{ cm}^{-1}$ . The spectrum at  $1716\text{ cm}^{-1}$  is due to hydrogen bonding between N-H and C=O groups in the hard segment and the ester-oxygen groups of the soft segments of the urethane linkage of the urethane bond. The peak at  $1730\text{ cm}^{-1}$  is due to non-hydrogen-bonded carbonyl groups [37]. After combining wheat straw with the PU resin, this band was stretched and appeared at  $3335\text{ cm}^{-1}$ . The band at  $3300\text{ cm}^{-1}$  of the hydroxyl group (-OH) was shifted to  $3325\text{ cm}^{-1}$ , mainly due to hydrogen bonding between -OH of wheat straw with N-H and C-H groups of polyurethane binder resin which indicated the good interaction between wheat straw and PU resin [38]. Good interaction may lead to good mechanical properties.

#### 4.2. Morphological analysis

The morphological analysis is conducted with wheat straw, and prepared wheat straw-based OSB panels to understand the composite's microstructure and how it affects the prepared board's characteristics. Fig. 5(a–e) show the SEM of the wheat straw cellular structure in wheat straw, wheat straw-based OSB panels, and commercial wood-based OSB. The cross-section of the wheat straw in Fig. 5a, reveals several distinct layers and a honeycomb-geometry hollow structure of varying size and shape [14]. The outermost layer called the epidermis, is a thin layer of packed cells that provides the stem with mechanical strength for structural support; the next layer is the parenchyma cells, which are

thin-walled cells that store starch and other nutrients; the vascular bundles; and the innermost layer is called the lumen [39]. In Fig. 5b, it can be noticed that the surface of wheat straw appears smooth and has minor bumps caused by the presence of silica, which is called stomata, through which the plant cells can breathe [39,40]. These bumps give the wheat straw fibers a certain degree of roughness and enable them to form strong interfacial bonding with polyurethane resin by increasing the friction between adjacent layers of wheat straw fibers. The roughness also may enhance the mechanical interlocking and adhesion between the fiber and matrix, and the good interaction between them which improves the stress transfer and load distribution in the composite material [41]. The results of the SEM analysis in Fig. 5c, d, and e, suggest that the density of the wheat straw in the OSB samples influences the structure of the wheat straw fibers. For example, sample WS-0.6 has smaller voids in its cross-section than sample WS-0.45, indicating that it was subjected to higher pressure during production. This resulted in a more densely packed structure and better mechanical performance for the 0.60-density panel. The same figure shows the absence of resin inside the hollow structure, implying a lack of polyurethane resin penetration into the cellular structure. Compared with wood-based OSB, the wheat-straw-based board contains larger cells and has a tubular form in the longitudinal direction, which gives the wheat-straw-based OSB panels superiority over wood-based OSB in thermal and sound insulation. It can be concluded that the cellular structures make wheat straw a sustainable alternative raw material to produce eco-friendly

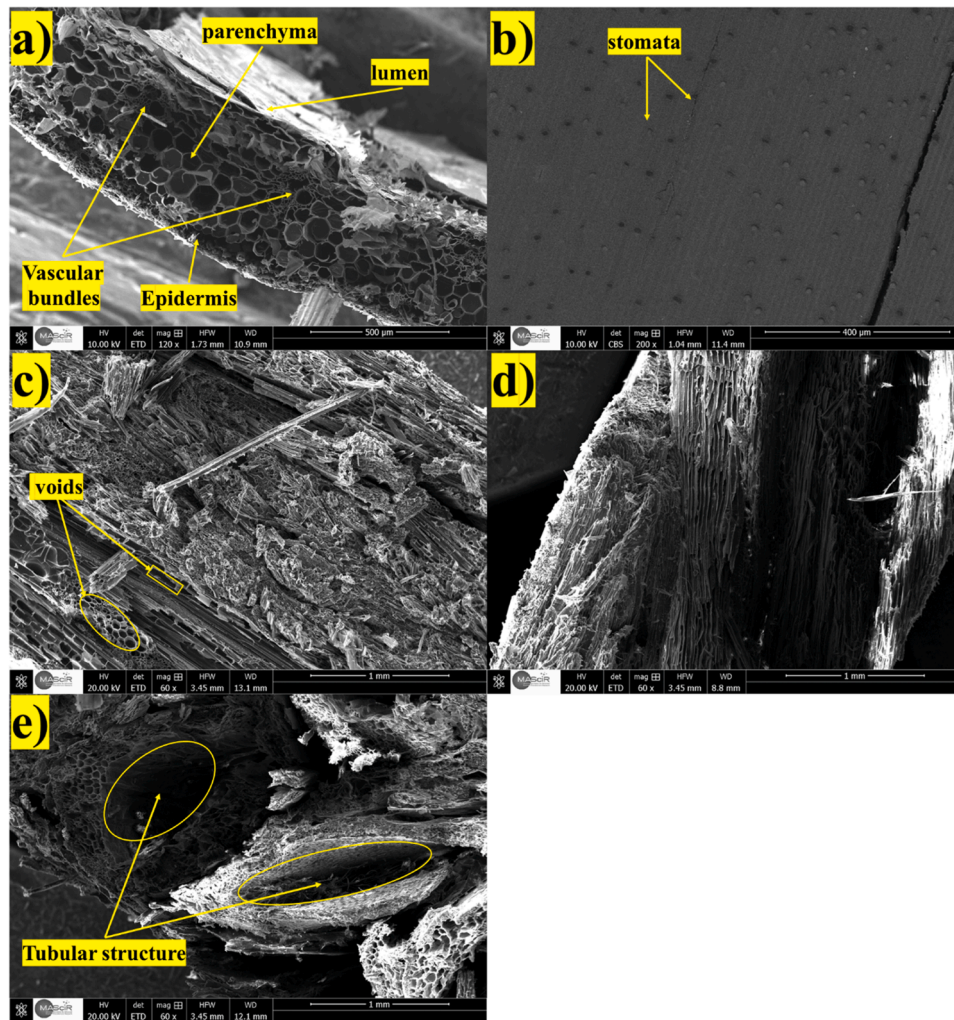


Fig. 5. SEM analysis of a, and b) Cross-section, and the surface of wheat straw, c) wheat straw-based OSB (WS-OSB-0.60), d) commercial wood-based OSB (Com OSB-0.60), and e) wheat straw-based OSB (WS-OSB-0.45).

lightweight insulation panels for building construction, reducing the need for wood as a raw material, which could save more forests and combat deforestation problems caused by the consumption of trees. Furthermore, wheat straw is softer and more porous than wood and therefore absorbs more sound energy, as confirmed by the hardness and sound reduction tests.

#### 4.3. Swelling and water absorption

Wheat straw-based OSB composites are porous materials that exhibit hygroscopic behavior like other wood-based panel materials. Their volume changes with ambient humidity, which affects their mechanical and physical properties. The results in Fig. 6a show the thickness swelling (TS) of different composites over time. The highest TS occurred in the first 24 h of all composites, ranging from 16.9% to 20.9%. After 32 days, the TS increased further, from 19.8% to 26.6%. Commercial OSB had the worst performance in terms of TS, while WS-OSB-0.45 had the best performance. WS-OSB-0.60 had intermediate values between commercial OSB-0.60 and WS-OSB-0.45. The lower TS of wheat straw composites can be attributed to the presence of flax on the surface of wheat straw, and higher resin content and density, which improved the adhesion and reduced the porosity of the composites. For example, WS-OSB-0.60 had an average improvement of 9.30% in TS compared to commercial OSB, while WS-OSB-0.45 had an average improvement of 23%. These findings are consistent with previous studies that reported a negative correlation between resin content and TS [42] and a positive correlation between layer density and TS [43]. Water absorption on the other side can be seen in Fig. 6b. The figures reveal that most of the WA occurred in the first four days of all composites and that more than 50% of the WA was reached within 24 h. For instance, commercial OSB and WS-OSB-0.60 absorbed more than 60% of their weight in water, while WS-OSB-0.45 had a maximum WA of over 80% after a day in the water. WA continued to increase gradually until the 16th day when it became more stable until the end of the test period on the 32nd day. WS-OSB-0.6 had an average improvement percentage of 8.9% over commercial OSB of the same density. The results indicate that water absorption has an inverse relationship with the density of the composite, as lower-density composites have more pores in their structure that allow water to penetrate. This finding is consistent with [42], who reported that WA depends on the density of raw materials and that low-density wood with a high void fraction exhibited higher WA values than high-density wood.

#### 4.4. mechanical properties

Generally, the mechanical properties of oriented strand board (OSB) depend on various factors, such as material type, density, resin content, and orientation. In this study, the mechanical properties of OSB panels based on wheat straw and commercial wood-based OSB were compared and measured in two perpendicular directions: crosswise and depth-wise.

According to the flexural modulus results shown in Fig. 7a. It has been found that wheat straw-based (WS-OSB-0.6) with a density of 0.6 g/cm<sup>3</sup> had higher bending strength in both directions than commercial OSB board (Com-OSB-0.60) with the same density by 44.61% ( $p = 0.007$ ) and 26.97% ( $p = 0.015$ ), respectively. This indicates that wheat straw has a higher potential for producing high-quality OSB than wood. It's also observed that increasing the resin content and pressing time improved the mechanical properties of WS-OSB, which is consistent with previous studies [44]. On the other hand, reducing the density in WS-OSB-0.45 to 0.45 g/cm<sup>3</sup> resulted in a significant decrease in bending strength and MOE by 48.51% ( $p = 0.003$ ) and 52.40% ( $p = 0.028$ ), respectively, in crosswise direction and by 35.70% ( $p = 0.001$ ) and 38.5% ( $p = 0.005$ ), respectively, in depth-wise direction. Therefore, it can be summarized that the density is a critical factor for determining the mechanical performance of wheat straw-based OSB WS-OSB, such results are in line with those obtained by [42,45,46].

The results of Young's modulus of the composites are shown in Fig. 7b. It can be observed that all panels tested had a higher Young's modulus in the crosswise direction than in the depth-wise direction. This indicates that the orientation of the strands affects the stiffness of the panels. Among the materials tested, wheat straw-based OSB with 0.60 g/cm<sup>3</sup> density (WS-OSB-0.6) had the highest Young's modulus in the crosswise direction, which was 42.20% ( $p = 0.018$ ) higher than that of commercial wood-based (Com-OSB-0.6) in the depth-wise direction. This could be attributed to the higher resin percentage and longer fiber length of wheat straw, which enhanced the elasticity modulus. However, when the density of wheat straw-based OSB was reduced to 0.45 g/cm<sup>3</sup> (WS-OSB-0.45), a significant drop in Young's modulus was observed, which is almost 52.92% ( $p = 0.028$ ) and 38.48% ( $p = 0.005$ ) compared to Com-OSB-0.6 in the crosswise and depthwise directions respectively. This suggests that density has a major influence on the mechanical properties of OSB panels, as reported by previous studies [42,45,46]. Based on these results, we concluded that WS-OSB-0.6 performed better than Com-OSB-0.6 and met the requirements for OSB/type-2 according to the EN 300 standard [47], while WS-OSB-0.45 only met the requirements for OSB/type-1 except for its lower elastic modulus in the depth-wise direction.

The hardness test is an essential property in evaluating the mechanical behavior of cellulose-based composites. This test measures the resistance of a material to indentation by a rod with a known diameter and depth. The results of the hardness test in a qualitative comparison of prepared composites with commercial OSB are shown in Fig. 7c. The results showed that the hardness of the composites depends on both the density and the type of strands/fibers. For instance, the wheat straw-based OSB (WS-OSB-0.60) composite, which had the same density as commercial wood-based OSB (OSB-0.60), had almost similar hardness values (0.92) ( $p = 0.859$ ) as commercial OSB. This slight difference indicated that wood strands were slightly harder than wheat straw fibers. However, when the density was decreased by 25% in wheat straw-based OSB (WS-OSB-0.45) composite, the hardness was reduced

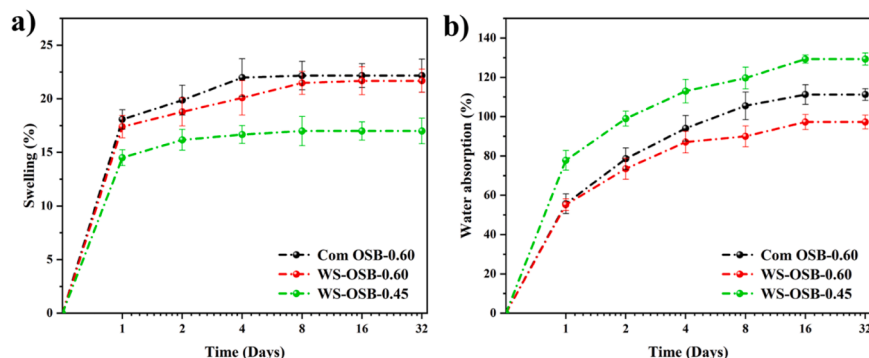


Fig. 6. shows thickness swelling and water absorption behavior.

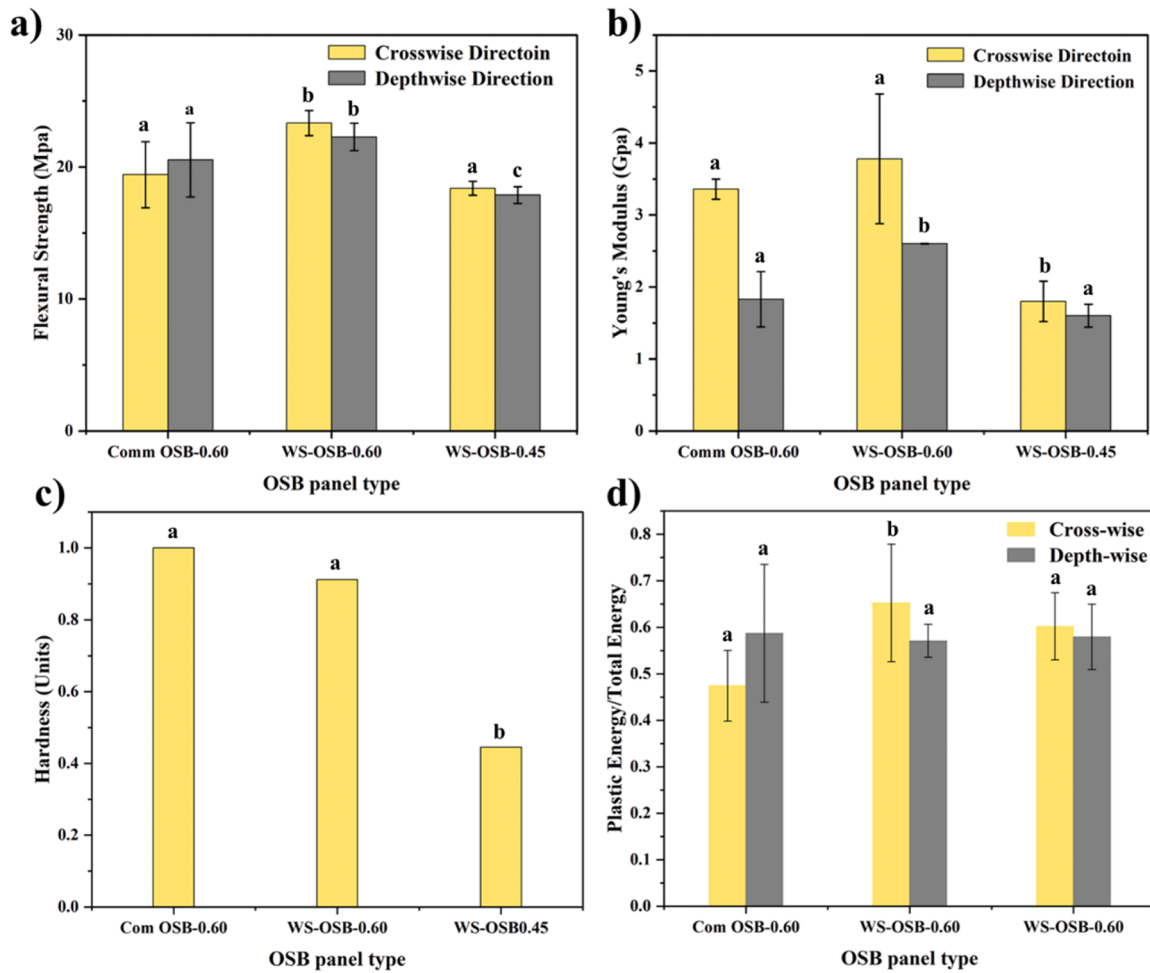


Fig. 7. Mechanical properties.

significantly to 0.45, i.e., 50% ( $p = 0.006$ ) of that of commercial OSB. This suggested that density had a greater influence on hardness than fiber type or orientation.

The strain energy results are shown in Fig. 7d. In terms of ductility, the wheat straw-based OSB composites behaved slightly better than commercial OSB. This is perhaps because the wheat straw fibers are long, thin, and flexible; these physical properties enhance the ductility of the wheat straw composites. In addition, the resin quantity in wheat straw panels might be greater than that in commercial OSB.

#### 4.5. Noise reduction

In this study, the approach to noise reduction was based on analyzing the mathematical difference between the sound pressure levels in two distinct rooms [29,48,49]. Fig. 8a illustrates the sound reduction in the third-octave band. It is worth noting that each board exhibited varying degrees of sound insulation across different frequency ranges, indicating frequency-dependent sound reduction characteristics. Additionally, the sound insulation performance was found to be less effective at lower frequencies compared to higher frequencies and this is because low-frequency noise has a longer wavelength that can pass through voids of the materials whereas high-frequency have shorter wavelengths

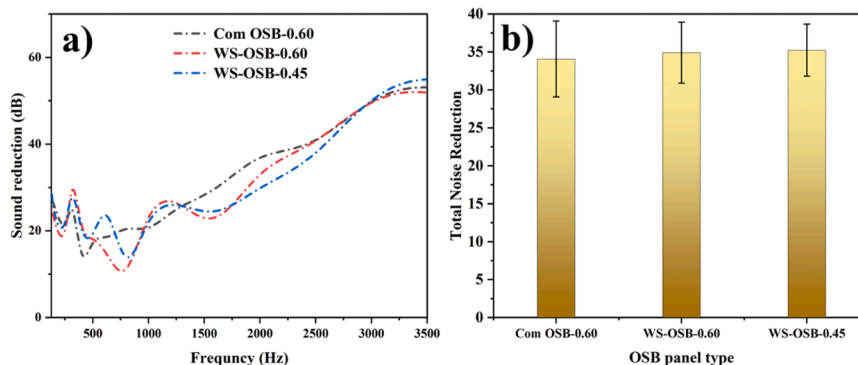


Fig. 8. Sound insulation.

that are blocked by material or absorbed porosity easily [50]. Notably, the wheat straw boards (WS-OSB-06 and WS-OSB-0.45) exhibited superior sound reduction behavior in the low-frequency range of 80–500 Hz when compared to the commercial OSB-0.6. As the frequency exceeded 500 Hz, the sound reduction began to increase, reaching its maximum value of 55 dB at a frequency of 3.15 kHz the same effect has been noticed by N. Flores Medina et al. [51].

The total noise reduction, which represents the average of all sound reduction values across different frequencies, is presented in Fig. 8b. It is evident from the data that the wheat-based OSB panels, specifically WS-OSB-045, achieved a total noise reduction value of 35.2 dB, while WS-OSB-060 attained a value of 34.9 dB. In contrast, the commercial OSB exhibited the lowest average sound reduction value of 34 dB. This discrepancy in performance can be attributed to the sound-absorbing properties of wheat straw panels, which absorb more sound energy compared to wood. The softer nature of wheat straws and the higher porosity of wheat straw panels are likely contributing factors. These characteristics enable the wheat straw boards to effectively mitigate sound transmission. Based on these findings, it can be concluded that the sound reduction capabilities of wheat straw boards make them highly appealing to produce OSB panels used in applications such as wall sheathing, flooring, and roofing in residential construction. Incorporating wheat straw-based OSB panels can significantly enhance sound insulation within homes, contributing to a more comfortable and peaceful living environment.

#### 4.6. Contact angle

The contact angle is a crucial parameter to evaluate the surface properties of a composite and provides insight into determining if the surface is hydrophobic (water-repellent) or hydrophilic (water-absorbing) [52]. Based on the results shown in Fig. 9, the wheat straw-based OSB panels (WS-01 and WS-02) showed a higher contact angle compared to the commercial wood-based OSB panels, indicating a more hydrophobic surface. WS-OSB-0.60 had the highest contact angle of  $106^\circ$ , while WS-OSB-0.45 had a slightly lower contact angle of  $100.4^\circ$ . The OSB panel had a lower contact angle of  $88.1^\circ$ , indicating a more hydrophilic surface. The difference in contact angle values can be attributed to the difference in surface chemistry between the wheat straw-based and wood-based OSB panels. Wheat straw-based panels are likely to have a rigorous surface due to the presence of silica nanoparticles on the wheat straw surfaces as SEM images show, these bumps give the wheat straw fibers a certain degree of roughness that favors rolling when water drips on the surface [33]. In general, a rough surface and a low-energy compound form a superhydrophobic surface, but in the case of wheat straw, the main reason for the hydrophobicity is the rough surface.

Furthermore, this could be due to the higher content of polyurethane resin in the wheat straw-based panels, which is known to be a hydrophobic material. The contact angle also decreases slightly with

decreasing density, which could be attributed to the higher porosity and roughness of the lower-density panels, which increase the surface area and create more sites for water adhesion. In contrast, wood-based OSB panels are likely to have a higher proportion of cellulose, which is more hydrophilic. These results suggest that the wheat straw-based panels have better water resistance than the wood-based panels, which could be an advantage for their application in humid environments. This is consistent with previous studies on untreated commercial wood-based OSB [53].

## 5. Conclusion

This comparative study investigated the feasibility of using wheat straw fibers as an alternative source for wood in oriented strand board (OSB) production. Wheat straw is an abundant and cheap agricultural by-product. This research aims to produce an outperform-oriented strand board utilizing wheat straw for sustainable construction. The produced rectangular specimens via the compression molding process were tested in terms of mechanical, hygroscopic, morphological, and sound isolation performances. The results showed that wheat straw OSB boards had better swelling resistance, with an average of 9.3% for WS-OSB-0.60 and 23% for WS-OSB-0.45, and an average water absorption resistance of 8.9% for WS-OSB-0.60 over commercial wood-based OSB. In addition, the contact angles of wheat straw boards were greater than  $90^\circ$ , which indicates hydrophobic surfaces, unlike commercial OSB panels, which had a contact angle of  $88.1^\circ$ , indicating hydrophilic surfaces. Moreover, wheat straw-based OSB exhibited higher mechanical strength in both directions. In the case of flexural strength, the enhancement was by 44.61% in the crosswise direction. Whereas the modulus of elasticity of WS-OSB-0.60 was improved by 12.53% and 42.20% over commercial OSB-0.60 in the crosswise and depth-wise directions, respectively. Density was found to be a critical factor with a significant effect on flexural strength and Young's modulus. Comparison with EN 300 standards confirmed that WS-OSB-0.60 met the requirements for OSB/type 2, while WS-OSB-0.45 met those for OSB/type 1. For hardness, WS-OSB-0.60 behaved almost the same as commercial OSB-0.60 by 92%. The hardness test emphasized the role of density in determining hardness, with slight differences observed between wood-based and wheat straw-based OSB. Notably, the strain energy results revealed the favorable ductility of wheat straw-based OSB, attributed to the unique physical properties of wheat straw fibers and potentially higher resin content. The acoustic characteristics of wheat straw OSB were also evaluated and found to be superior to commercial OSB, especially the lightweight WS-OSB-0.45, which has achieved a maximum sound reduction value of 35.2 dB. The paper concluded that wheat straw fibers can be used as a viable alternative to wood in OSB production without compromising the board's performance while reducing the cost of raw materials and the environmental impact of wood consumption.

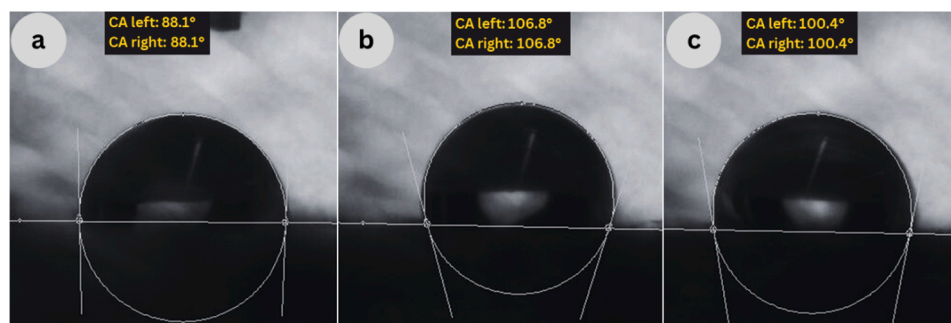


Fig. 9. Contact angle measurements of a) Wood-based OSB (Com-OSB-0.60); b) Wheat straw-based OSB (WS-OSB-0.60); and c) Wheat straw based OSB (WS-OSB-0.45).

## CRediT authorship contribution statement

**Bensalah Mohammed Ouadi:** Validation, Resources. **Bouhfid Rachid:** Visualization, Methodology. **Qaiss Abou el Kacem:** Project administration, Funding acquisition. **Abobakr Hani Abobakr Hussein:** Writing – original draft, Data curation. **Marya Raji:** Visualization, Validation, Supervision. **Essabir Hamid:** Formal analysis, Conceptualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data Availability

No data was used for the research described in the article.

## Acknowledgements

This work was supported by MAScIR; Moroccan Foundation for Advanced Science, Innovation and Research.

## Dedication

This paper is dedicated to the soul of the deceased Adam Bouhfid, whose name is preserved in the memory of each mascierian, and profit the occasion to pray that May Allah grants him the highest rank in Jannat and courage, strength, and patience to his family.

## References

- Oriented structural boards from split wheat straw: Effects of straw length, panel density, and resin content:: BioResources, (n.d.). (<https://bioresources.cnr.ncsu.edu/resources/oriented-structural-boards-from-split-wheat-straw-effects-of-straw-length-panel-density-and-resin-content/>) (accessed July 5, 2023).
- A. Lunguleasa, A.E. Dumitrascu, C. Spirchez, V.D. Ciobanu, Influence of the strand characteristics on the properties of oriented strand boards obtained from resinous and broad-leaved fast-growing species, *Appl. Sci.* 11 (2021) 1–14, <https://doi.org/10.3390/app11041784>.
- Violeta Jakimovska Popovska, Borche Iliev. CHARACTERISTICS COMMERCIAL ORIENTED STRAND BOARDS (OSB), *International Journal - Wood, design & Technology* 8 (2020) 8–15.
- Production of wheat worldwide 2022/2023 | Statista, (n.d.). (<https://www.statista.com/statistics/267268/production-of-wheat-worldwide-since-1990/>) (accessed May 7, 2023).
- Y.K. Kalkhajeh, Z. He, X. Yang, Y. Lu, J. Zhou, H. Gao, C. Ma, Co-application of nitrogen and straw-decomposing microbial inoculant enhanced wheat straw decomposition and rice yield in a paddy soil, *J. Agric. Food Res* 4 (2021) 100134, <https://doi.org/10.1016/j.jafr.2021.100134>.
- J. Ren, P. Yu, X. Xu, Straw Utilization in China—Status and Recommendations, 1762 11, *Sustainability* 2019 Vol. 11 (2019) 1762, <https://doi.org/10.3390/SU11061762>.
- Y. Zhang, A.E. Ghaly, B. Li, Physical properties of wheat straw varieties cultivated under different climatic and soil conditions in three continents, *Am. J. Eng. Appl. Sci.* 5 (2012) 98–106, <https://doi.org/10.3844/ajeassp.2012.98.106>.
- R. Ahmadi, B. Soury, M. Ebrahimi, Evaluation of wheat straw to insulate fired clay hollow bricks as a construction material, *J. Clean. Prod.* 254 (2020) 120043, <https://doi.org/10.1016/j.jclepro.2020.120043>.
- D. Jiang, S. Lv, D. Jiang, H. Xu, H. Kang, X. Song, S. He, Effect of modification methods on water absorption and strength of wheat straw fiber and its cement-based composites, *J. Build. Eng.* 71 (2023) 106466, <https://doi.org/10.1016/j.jobe.2023.106466>.
- M. Ali, A. Alabdulkarem, A. Nuhait, K. Al-Salem, G. Iannace, R. Almuzaiqer, A. Al-turki, F. Al-Ajlan, Y. Al-Mosabi, A. Al-Sulaimi, Thermal and acoustic characteristics of novel thermal insulating materials made of Eucalyptus globulus leaves and wheat straw fibers, *J. Build. Eng.* 32 (2020) 101452, <https://doi.org/10.1016/j.jobe.2020.101452>.
- M. Ali, A. Alabdulkarem, A. Nuhait, K. Al-Salem, G. Iannace, R. Almuzaiqer, Characteristics of agro waste fibers as new thermal insulation and sound absorbing materials: hybrid of date palm tree leaves and wheat straw fibers, *J. Nat. Fibers* 19 (2022) 6576–6594, <https://doi.org/10.1080/15440478.2021.1929647>.
- S.H. Ghaffar, Straw fibre-based construction materials, *Advanced High Strength Natural Fibre Composites in Construction* (2017) 257–283. <https://doi.org/10.1016/B978-0-08-100411-1.00011-X>.
- A. Jorge, P. Silva, F. Antonio, R. Lahr, A.L. Christoforo, Properties of Sugar Cane Bagasse to Use in OSB, *International Journal of Materials Engineering* 2 (2012) 50–56, <https://doi.org/10.5923/j.ijme.20120204.04>.
- S.H. Ghaffar, Wheat straw biorefinery for agricultural waste valorisation, *Green Mater.* 8 (2019) 60–67, <https://doi.org/10.1680/JGRMA.19.00048>.
- S.B. Osb, A.M. De Souza, L.D. Varanda, A.L. Christoforo, M. Fátima, S. Fernanda, S. Poletto, T.H. Panzera, F. Antonio, R. Lahr, Modul. Elast. Static Bend. Oriented 4 (2014) 56–62, <https://doi.org/10.5923/j.cmaterials.20140402.03>.
- A. Akrami, M.C. Barbu, A. Fruehwald, Characterization of properties of oriented strand boards from beech and poplar, *Eur. J. Wood Wood Prod.* 72 (2014) 393–398, <https://doi.org/10.1007/s00107-014-0793-9>.
- Structural Board Association. Oriented strand board and waferboard. Technical bulletin. Available from, (2011).
- S. Augusto, A.L. Christoforo, S. Luiz, M. Ribeiro, L.D. Varanda, F. Antonio, R. Lahr, Particleboard manufactured with bicomponent polyurethane resin base on castor oil 2 (2012) 115–118, <https://doi.org/10.5923/j.cmaterials.20120206.01>.
- T. Tabarsa, S. Jahanshahi, A. Ashori, Mechanical and physical properties of wheat straw boards bonded with a tannin modified phenol–formaldehyde adhesive, *Compos B Eng.* 42 (2011) 176–180, <https://doi.org/10.1016/J.COMPOSITESB.2010.09.012>.
- D. Jawad Mohamed, N. Jawad Hadi, Z. Kareem Alobad, Study on adhesive mechanism and sizing process of wheat straw board in interior decoration, *IOP Conf. Ser. Earth Environ. Sci.* 237 (2019) 052070, <https://doi.org/10.1088/1755-1315/237/5/052070>.
- N. Boquillon, G. Elbez, U. Schönfeld, Properties of wheat straw particleboards bonded with different types of resin, *J. Wood Sci.* 50 (2004) 230–235, <https://doi.org/10.1007/S10086-003-0551-9/METRICS>.
- A.H. Grigoriou, Straw-wood composites bonded with various adhesive systems, *Wood Sci. Technol.* 34 (2000) 355–365, <https://doi.org/10.1007/s002260000055>.
- Y. Zhang, J. Gu, H. Tan, M. Di, L. Zhu, X. Weng, Straw based particleboard bonded with composite adhesives, *Bioresources* 6 (2011) 464–476, <https://doi.org/10.15376/BIORES.6.1.464-476>.
- M.D.M. Lopes, M.D.S. Pádua, J.P.R.G. De Carvalho, N.T. Simonassi, F.P.D. Lopez, H.A. Colorado, C.M.F. Vieira, Natural based polyurethane matrix composites reinforced with bamboo fiber waste for use as oriented strand board, *J. Mater. Res. Technol.* 12 (2021), <https://doi.org/10.1016/j.jmrt.2021.04.023>.
- Y. Ding, Z. Pang, K. Lan, Y. Yao, G. Panzarasa, L. Xu, M. Lo Ricco, D.R. Rammer, J. Y. Zhu, M. Hu, X. Pan, T. Li, I. Burgert, L. Hu, Emerging engineered wood for building applications, *Chem. Rev.* 123 (2023) 1843–1888, [https://doi.org/10.1021/ACS.CHEMREV.2C00450/ASSET/IMAGES/MEDIUM/CR2C00450\\_0023.GIF](https://doi.org/10.1021/ACS.CHEMREV.2C00450/ASSET/IMAGES/MEDIUM/CR2C00450_0023.GIF).
- B.S. En, Wood-based panels — Determination of modulus of elasticity in bending and of bending strength, (1993).
- ASTM INTERNATIONAL, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. D790, Annual Book of ASTM Standards (2002) 1–12. <https://doi.org/10.1520/D0790-10>.
- Z. Cai, C.A. Senalik, R.J. Ross, Chapter 12: Mechanical properties of wood-based composite materials. In: *Wood handbook - wood as an engineering material*, USDA - General Technical Report (2021) 15.
- S.T. Djambova, N.B. Ivanova, S.G. Pleshkova-bekiarska, Comparative Measurements of Sound Insulation of Materials Placed in Small Size Acoustic Chamber, (2022) 22–25.
- M. Raji, A.E.K. Qaiss, R. Bouhfid, Effects of bleaching and functionalization of kaolinite on the mechanical and thermal properties of polyamide 6 nanocomposites, *RSC Adv.* 10 (2020) 4916–4926, <https://doi.org/10.1039/c9ra10579d>.
- J. Li, X. Zeng, T. Ren, E. van der Heide, The preparation of graphene oxide and its derivatives and their application in bio-tribological systems, *Lubricants* 2 (2014) 137–161, <https://doi.org/10.3390/lubricants2030137>.
- M. Raji, H. Essabir, R. Bouhfid, A. El Kacem Qaiss, Impact of chemical treatment and the manufacturing process on mechanical, thermal, and rheological properties of natural fibers-based composites, *Handb. Compos. Renew. Mater.* 1–8 (2017) 225–252, <https://doi.org/10.1002/9781119441632.ch71>.
- H. Gu, G. Li, P. Li, H. Liu, T.T. Chadyagondo, N. Li, J. Xiong, Superhydrophobic and breathable SiO<sub>2</sub>/polyurethane porous membrane for durable water repellent application and oil-water separation, *Appl. Surf. Sci.* 512 (2020), <https://doi.org/10.1016/j.apsusc.2019.144837>.
- M. Raji, H. Essabir, M. ElAachy, R. Bouhfid, A.E.K. Qaiss, Morphology control of poly(lactic) acid/polypropylene blend composite by using silanized cellulose fibers extracted from coir fibers, *Cellulose* 29 (2022) 6759–6782, <https://doi.org/10.1007/s10570-022-04675-7>.
- H. Abdelaoui, M. Raji, H. Essabir, R. Bouhfid, A.E.K. Qaiss, Effect of hybridization and long-term aging on mechanical and rheological properties epoxy laminate composites: case of jute/coir fibres and jute/doum fibres, *Waste Biomass Valoriz.* (2021), <https://doi.org/10.1007/s12649-021-01616-6>.
- A. Halloub, M. Raji, H. Essabir, H. Chakchak, B. boussem, M. ouadi Bensalah, R. Bouhfid, A. el kacem Qaiss, Intelligent food packaging film containing lignin and cellulose nanocrystals for shelf life extension of food, *Carbohydr Polym.* 296 (2022), <https://doi.org/10.1016/j.carbpol.2022.119972>.
- M. Sain, S. Panthapulakkal, Bioprocess preparation of wheat straw fibers and their characterization 23 (2006) 1–8, <https://doi.org/10.1016/j.indcrop.2005.01.006>.
- S. Zhao, Z. Wang, W. Zhang, J. Li, S. Zhang, A. Huang, Dopamine-mediated pre-crosslinked cellulose/polyurethane block elastomer for the preparation of robust biocomposites, *ACS Omega* 3 (2018), <https://doi.org/10.1021/acsomega.8b01694>.

- [39] I.C.H. Se, R.D.I.W. Centre, M. Processing, U.K. The, Preparation and properties of polypropylene composites reinforced with wheat and flax straw fibres Part I Fibre characterization, *J. Mater. Sci.* 2 (1997) 443–449. (<https://link.springer.com/content/pdf/10.1023/A:1018521920738.pdf>).
- [40] R. Liu, H. Yu, Y. Huang, Structure and morphology of cellulose in wheat straw, *Cellulose* 12 (2005) 25–34, <https://doi.org/10.1007/s10570-004-0955-8>.
- [41] M. Yasin, A. Waheed Bhutto, A.A. Bazmi, S. Karim, Efficient Utilization of Rice-wheat Straw to Produce Value-added Composite Products, *Int. J. Chem. Environ. Eng.* 1 (2010).
- [42] O. Zeleniuc, A.E. Dumitrascu, V.D. Ciobanu, Properties evaluation by thickness and type of oriented strand boards manufactured in continuous press line, *Bioresources* 15 (2020) 5829–5842, <https://doi.org/10.15376/biores.15.3.5829-5842>.
- [43] P.M. W.X. Winistorfer, Layer water absorption of medium density fiberboard and oriented strandboard, *Prod. J.* 46 (1996) 69–72.
- [44] H.K.G.ökhan Gündüz, Fatih Yapıcı, Ayhan Özçifçi, The effects of adhesive ratio and pressure time on some properties of oriented strand board, *Bioresources* 6 (2011) 2118–2124, <https://doi.org/10.15376/biores.6.2.2118-2124>.
- [45] S. Chen, C. Du, R. Wellwood, Effect of panel density on major properties of oriented strandboard, *Wood Fiber Sci.* 42 (2010) 177–184.
- [46] A. Lunguleasa, A.E. Dumitrascu, V.D. Ciobanu, Comparative studies on two types of OSB boards obtained from mixed resinous and fast-growing hard wood, *Appl. Sci.* 10 (2020) 1–15, <https://doi.org/10.3390/APP10196634>.
- [47] BS-EN-300 | Oriented strand boards (OSB). Definitions, classification and specifications | Document Center, Inc., (n.d.). (<https://www.document-center.com/standards/show/BS-EN-300>) (accessed June 8, 2023).
- [48] O. Green, R. Gislum, R.N. Jørgensen, C.G. Sørensen, Forage density effect on sound insulation properties, *Grass Forage Sci.* (2010) 362–366, <https://doi.org/10.1111/j.1365-2494.2010.00747.x>.
- [49] V. Wittstock, M. Schmelzer, C. Kling, On the use of scaled models in building acoustics, (n.d.) 6909–6914.
- [50] J. Zhao, X.M. Wang, J.M. Chang, Y. Yao, Q. Cui, Sound insulation property of wood-waste tire rubber composite, *Compos Sci. Technol.* 70 (2010) 2033–2038, <https://doi.org/10.1016/j.compscitech.2010.03.015>.
- [51] N. Flores Medina, D. Flores-Medina, F. Hernández-Olivares, Influence of fibers partially coated with rubber from tire recycling as aggregate on the acoustical properties of rubberized concrete, *Constr. Build. Mater.* 129 (2016) 25–36, <https://doi.org/10.1016/j.conbuildmat.2016.11.007>.
- [52] N. Bouhfid, M. Raji, M. ouadi Bensalah, A. el Kacem Qaiss, Functionalized graphene and thermoset matrices-based nanocomposites. Mechanical and Thermal Properties, Elsevier Inc., 2018, <https://doi.org/10.1016/B978-0-12-814548-7.00003-9>.
- [53] P. Cetera, F. Negro, C. Cremonini, L. Todaro, R. Zanuttini, Physico-mechanical properties of thermally treated poplar OSB, *Forests* 9 (2018), <https://doi.org/10.3390/f9060345>.