ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 9, Issue 4 , April 2022

Assessment of physical and mechanical properties of particleboard from millet husk-recycled expanded polystyrene composite

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ABSTRACT: In this study, physical and mechanical properties of particle boards made from a mixture of millet husks (MH) and resinous materials obtained from polystyrene waste were evaluated and discussed. Particle boards were prepared by mixing polystyrene-based resin (PBR) and millet husks followed by a flat press process at different ratios (v/v). Mix ratios of 2.1:1, 2.3:1, and 2.5:1 of polystyrene-based resin (PBR) by weight of the millet husks were produced. Mechanical (modulus of rupture and modulus of elasticity) and physical properties (density, moisture content, thickness swelling and water absorption) were carried out following ASTM D1037-93 procedures. The results showed that density, moisture content (MC), water absorption (WA), thickness swelling (TS), and mechanical properties such as modulus of elasticity (MOE) and modulus of rupture (MOR) of 2.3:1 and 2.5:1 were better than that of 2:1 particleboard and met the minimum value prescribed by the American National Standards Institute (ANSI A208.1).
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KEYWORDS: millet husks, recycled polystyrene, polystyrene based resin, particleboard, composite materials.

I. INTRODUCTION

Fibreboard includes hardboards, medium density fiber (MDF) boards and particleboard. Particleboard is an engineered panel product in which particles of wood are bonded together to form a panel. Most conventional particleboards are produced from wood-based materials, created by using a synthetic resin adhesive. Particleboards are the most popular materials used in interior and exterior applications, flooring, wall, ceiling, office dividers, bulletin boards, cabinets, furniture, counter and desk tops[1].However, as demand for wood has increased, industrial wood products from natural forests continue to decline. The decline of forest resources in developing countries is due to resource depletion, whereas in developed countries, it is due to the withdrawal of forest areas from industrial production for other uses such as recreation areas. In addition, the increase in population and new areas of application have led significant pressure on standing forest resources due to the higher demand for timber in the forest industry. Therefore, there is a need for alternative resources to replace the raw material wood [2].
The demand for wood composites from waste wood increases as timber resources in natural forests decline. The use of renewable biomass as a raw material in composites production is one approach. The use of renewable biomass may result in several benefits such as environmental and socioeconomic [3]. Today renewable biomass is mostly accepted as waste materials and are mostly ploughed into the soil or burnt in the field. According to the end uses of wood-wastes and their possible reuse products, particleboard has found typical applications in flooring, wall and ceiling panels, office dividers, bulletin boards, furniture, cabinets, counter tops, and desk tops [4]. It seems that the manufacture of particleboard from recycled wood-based wastes is the most common way to reuse such waste materials [5, 6].

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In recent years the utilization of agricultural waste and annual fibers for particleboard or other composite board production is going popularity. Particleboard is known one of the most important products of forest products industry. Throughout the years, the production coast of particleboard has increased while the quality of product was reduced [7]. Agricultural waste materials and annual plants have become alternative raw materials for the production of particleboard or fiber composite materials. The most frequently referred alternative non-wood materials are flax, bagasse, hemp, reed and cereal straws such as rice and wheat straw [1].

Millet husk is an abundant and novel agro-waste from cereal grain (Pennisetum glaucum),with hemicelluloses content of 30-40% of the dry material [8]. Natural fibers have received reasonable attention in the last few decades because of their better properties and environmental issues [9]. There is scarce literature about the use of millet husk as composite material. However, it uses can be encouraged based on the fact that it is readily available, has stable thermal conductivity and it impacts positively on the environment. Millet and other cereal agro-wastes fibers, can invariably act as a vital substitute for wood and natural fiber that pose a threat to environment [7, 10].
Furthermore, one of the significant challenges associated with wood-based particleboard is the use of Formaldehyde resin. Formaldehyde is a volatile, colourless gas with a strong odor commonly used in industrial processes, particularly in manufacturing building materials. Pressed wood products, such as wood-based particleboard and medium density fibreboard, are made using adhesive resins containing urea-formaldehyde [6]. Off-gassing levels are at their highest when the products are new, with emissions tapering off as they age. Exposure to formaldehyde in concentrations greater than 0.1 parts per million (ppm) can cause nasal and throat congestions, burning eyes, or headaches as well as increase the risk of developing cancer [13]. To mitigate and reduce this problem, various approaches had been considered to either completely eliminate it or reduce its quantity in particle board production. Among such proffered solution, the use of expanded polystyrene waste has been exploited by some researchers as a binder. Composite panels are therefore developed when fibers or particles of wood or agro-waste are used as reinforcement and mixed with thermosetting or thermoplastic polymers as binders [14]. In [15], particleboards were fully produced from date palm and expanded polystyrene (EPS) wastes and reported that the bending strength and stress reached acceptable values of 0.78 GPa and 2.84 MPa coupled with good fibre-matrix interface adhesion. The authors [16] investigated the development of boards from coconut shell powder (CSP) filled with EPS wood plastic composite (WPC). They observed increase in mechanical strength and water absorption as the CSP content increased, but elongation decreased on CSP increase.

Against this background this study aims to develop friendly environmentally non-wood particle boards from locally sourced materials using millet husks, while polystyrene waste serves as a binder. This is about reducing the importation rate of synthetic fibers and making locally manufactured building materials available at a lower price.

II. MATERIALS AND METHODS

A. Material Acquisition and Preparation

1) Finger millet husks

The millet husks used in this study were sourced from Uganda. The husks were separated into several grain size classes based on British Standard sieves (BSI, 1990) with 1.25 mm, 0.6 mm mesh and 0.3 mm openings. The husk was then oven dried for 24 hours to reduce the moisture content.

2) Polystyrene based resin

The matrix used is an organic binder obtained by recycling expanded polystyrene (EPS) waste which was obtained from the municipal waste of Nairobi, with a density of 15 kg / m^3, by its dissolution in gasoline. The dissolved EPS is mixed with gasoline for a few minutes to obtain a smooth paste with a mass ratio of 1.4 defined as mass of gasoline / mass of EPS.

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B. Development of Particleboard

The procedure for the development and testing of the particleboard is presented in Figure 2. It entailed manually mixing the millet husks with polystyrene based resin at the ratios presented in Table 1 to obtain a uniform matrix without lumps. The mixture was poured into a steel formwork (700 mm × 150 mm × 40 mm) and was tamped with a stuffing rod to give a uniform mixture. The top of the formwork was covered with another metal plate and was cold compacted with an electronic press. In addition, a heavy weight was applied on it for a period of 24 hours to resist the swelling effect of the particleboard. After the 24-hours, the particleboard was taken out and held at room temperature and left to cure for two weeks.

Table 1:Design mixes used in the production of polystyrene based resin/miller husk particleboards

PBR/MH ratio	Adhesive type	(%)	Materials type	(%)
2.1		67.75		32.25
2.3	Polystyrene based resine	69.69	Finger millet husk	30.31
2.5		71.43		28.57

In the table: PBR is Polystyrene based resine; MH is millet husk

Fig 1:Sample of fabricated Particleboard

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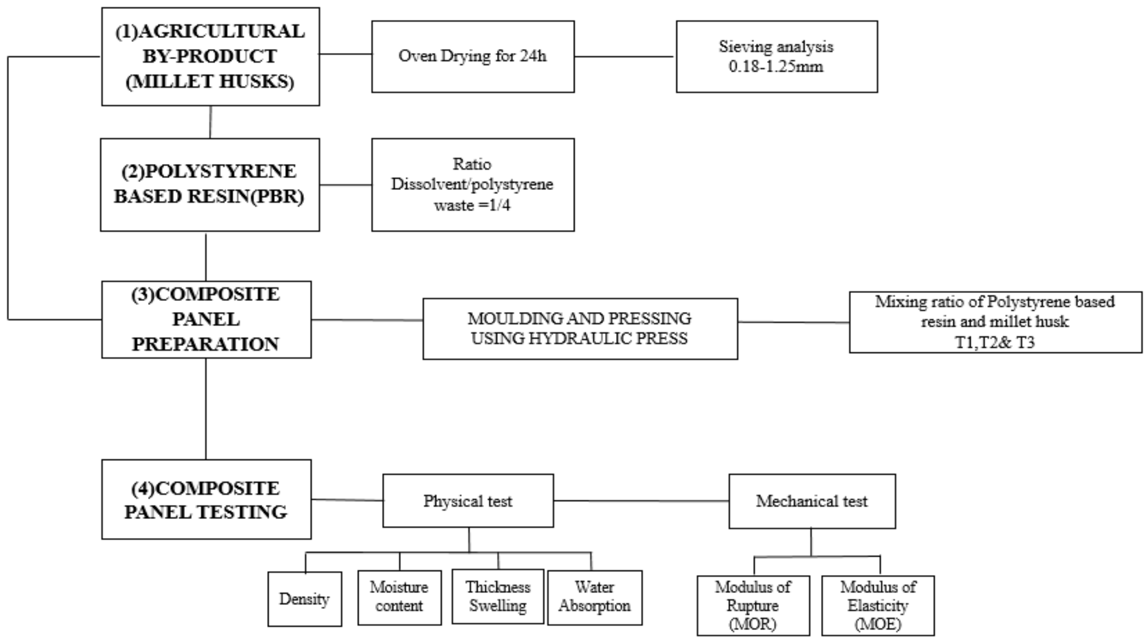

Fig 2: Schematic showing procedure used in the development of particleboard.

C. Physical and Mechanical Tests

Tests were carried out on samples of each panel to determine relevant physical and mechanical properties. The tests included moisture content, density, water absorption and thickness swelling all which were conducted according to the ASTM D 1037 specifications [17, 18]. Three (3) samples from each ratio were used to determine moisture content, density, water absorption and swelling in thickness. The moisture content was based on weights before and after direct sun drying. Density calculated as the ratio of mass and volume of the dry sample [17]. Water absorption was determined from the measured weight gain of the panels during the 2 and 24-hour immersion period [17, 19]. Thickness swelling was obtained from the average of the measured change in thickness at four locations on each sample after immersion in water for two and 24 hours.

Mechanical properties evaluated included modulus of elasticity and modulus of rupture. Flexural testing was carried out using a three-point bending test according to ASTM D 1037 [17] to determine the modulus of elasticity (MOE) and modulus of rupture (MOR). Sample sizes used for this test were 550mm x 50 mm x 25 mm. The flexural strength testing was conducted using an Intron 4468 universal testing machine. The testing machine was fitted with a 50 kN load cell at a crosshead speed of 1.45 mm/min. Five (5) samples of each composite were used for this test [20][17].

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III.RESULTS AND DISCUSSION

A. Physical Properties

1) Density and Moisture content

The most important indicator of particleboard performance is density, which primarily affects all other properties and considerations [21]. The densities of the particleboard made from millet husks with polystyrene based resin for different design mixes (i.e., 2.1, 2.3 and 2.5) are shown in Figure 3. It can be observed that, the densities increased from 498.5, 654.26 to 727.3 kg/m^3 with increase in design mixes from 2,1, 2.3 to 2.5, respectively. The increased design mixes imply that the amount of polystyrene based resin increased while that for finger millet husks decreased. According to the ANSI standard (D1037-99, ASTM, 1999), [22] the density of medium density particleboard is between 640 kg/m^3 and 800 kg/m^3. Thus, the densities for design mixes 2.3 and 2.5 correspond to the universal standard for medium density particle board. An earlier report indicated that the smaller woody particles would form a thinner mat and the rate of compaction would be higher, resulting in high density composite materials [23]. It is also evident from the two classes of samples that the higher the polystyrene based resin content, the higher the density. This is a different trend than formaldehyde bonded particleboard. On the other hand, moisture content decreased from 8.9 to 4.4% with increase in design mixes. (Figure 4)

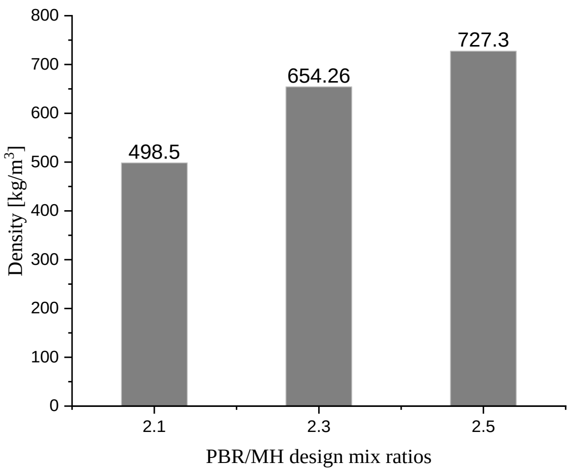

Fig 2:Densities of particleboards with various design mix ratios

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International Journal of Advanced Research in Science, Engineering and Technology
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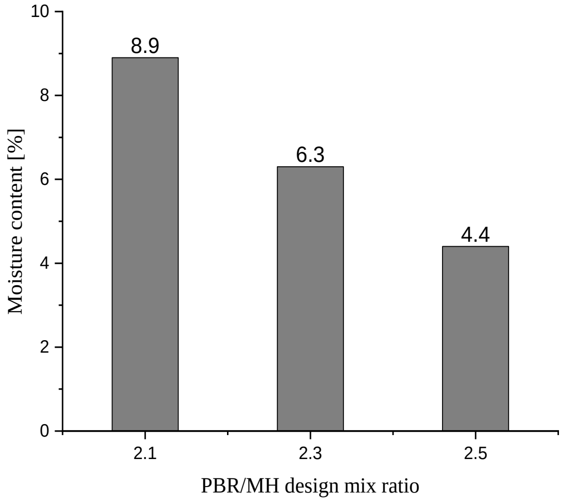

Fig 3:: Relationship between moisture content of particleboards and various design mix ratios.

2) Thickness swelling and water absorption

The response of a particleboard to moisture is a function of its degree of water absorption or its ability to retain moisture. This is a property of the resulting composite rather than its constituents, and as such depends on the composition and processing history of the sample. The results of water absorption and thickness swelling are shown in Figures 5 and 6, respectively. Water absorption decreased with increase in design mix ratios and it was far much higher after 24 hours as compared to 2 hours at ratios ranging from 2.1 to 2.5; water immersion with increase in resin content, there are fewer sites of water as less water was absorbed. On the other hand, composites made with lower resin content ratio had more resident water sites yielding higher water absorption. The water absorption of the composite made with the corresponding highest resin ratio content of 2.5 were 3.3 and 11.4% 2 and 24 hours of water immersion, respectively. The water absorption of the composite made with the lowest resin content 2.1 were 8.3% and 21% after 2 and 24 hours respectively of immersion in water.

Particleboard thickness swelling as a measure of the dimensional stability of the particle board in humid environments and is a function of the composition of the board. The thickness swelling values for the panel with the highest resin ratio were 0.0 and 0.5% after 2 and 24 hours of water immersion, respectively (Figure 7), while the swelling values for the panel with the lowest resin ratio were 3.0 and 5.0% after 2 and 24 hours of water). In general, the panel made of a higher resin content had higher dimensional stability properties.

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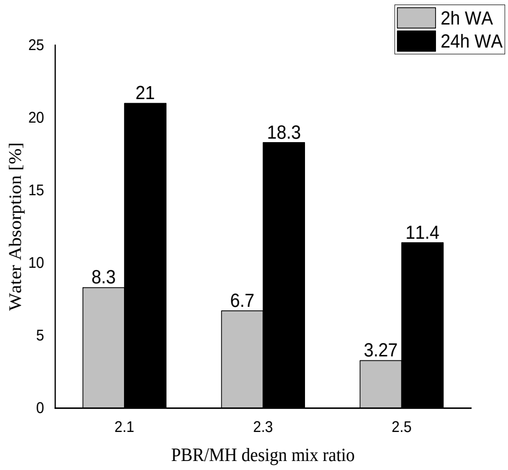

Fig 4:Water absorption for particleboard with various design mix ratios after 2 and 24 hours of water immersion.

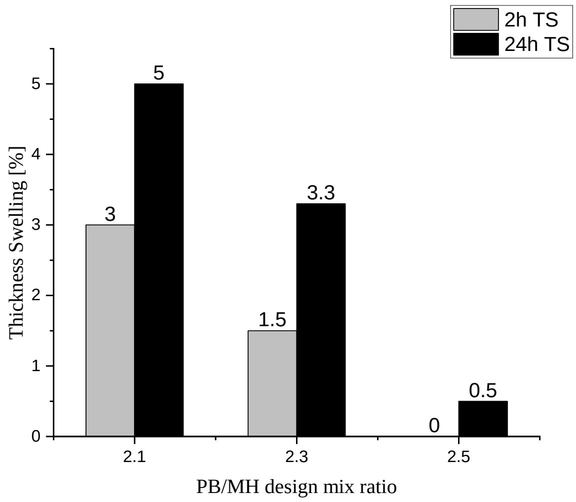

Fig 5:Thickness swelling of particleboards with various mix design ratios after 2 and 24 hours of water immersion.

B. **Mechanical properties**

The modulus of rupture and modulus of elasticity test were performed to study the mechanical and physical properties of particle boards at different polystyrene-based resin and millet husk design mix (Figures 8 and 9). Particleboards with a ratio of 2.5 had the highest modulus of elasticity of 1203.3 MPa, and this was followed by the ratio of 2.3 and 2.1 at 842.1 and 355.7 MPa, respectively (Figure 8). Modulus of elasticity is the stiffness of an object; particleboard tends to be brittle when the modulus of elasticity is extremely high. In this case, the modulus of elasticity values for mix ratios of 2.3 and 2.5 are in tandem with the standard of ANSI 208.1.

The values of modulus of rapture were influenced by the various mix design ratios. The result show that particleboards with the design mix ratio 2.5 had the highest modulus of rapture of 8.72 N/mm^2, this was followed by the ratio of 2.3 and 2.1 at 5.81 and 2.6 N/mm^2, respectively Modulus of rupture is a measure of the ability of a sample to resist a transverse

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(bending) force perpendicular to its longitudinal axis. Therefore, it was evident that the particleboard with the ratio 2.5 can withstand more force than the other samples before breaking. The tendency of the influence of the proportion of resin in composites is evident and similar on all the physical and mechanical properties was evident in Figures 7 and 8.
The panel with ratio 2.5 had the highest physical and mechanical properties. Modulus of elasticity indicates the ability of panels to resist stress, while modulus of rapture indicates the flexural strength of planks. In this study, particleboards with mix design ratios of 2.3 and 2.5 met the minimum modulus of elasticity and modulus of rapture requirements for general purpose boards for use in dry conditions by ANSI A208.1-1999.

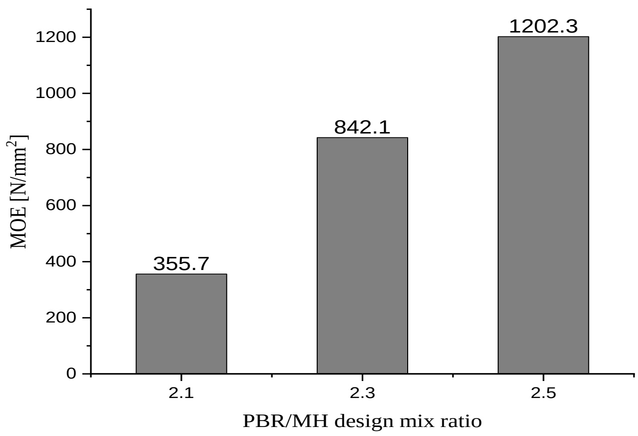

Fig 6:Modulus of elasticity for particleboards with various design mix ratios

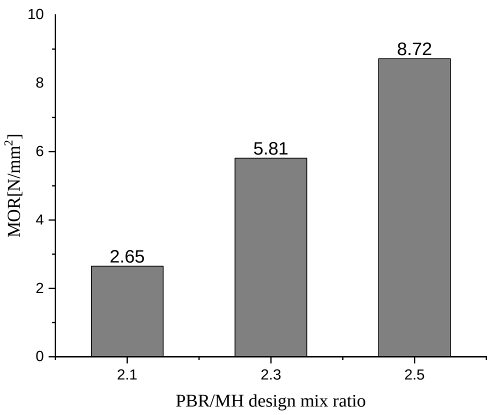

Fig 7:Modulus of rupture of particleboard with different mix design ratios

IV. CONCLUSION

From the results of the tests carried out, the following conclusions can be drawn:

i. The densities of 654.3 and 702.7 kg/m^3 corresponding to design mixes (polystyrene-based resin to finger millet husks) of 2.3 and 2.5 suggest that the boards obtained in this study are of medium density, according to the ANSI standard (D1037-99, ASTM, 1999).

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ii. The percentage of water absorption and thickness swelling and moisture content decreased with increasing the weight of the resin. Particleboard produced a design mixes ratio (polystyrene resin / millet husks) of 2.1 have higher percentage of water absorption, thickness swelling and moisture content, while that of the ratio 2.5 have lower percentage of water absorption, thickness swelling and moisture content.

iii. Particleboard produced using a 2.5: 1 design blend (millet husk polystyrene resin) has a higher modulus of rupture and modulus of elasticity 8.72 and 1202,3N /mm^2 respectively while that of the ratio 2: 1 has lower modulus of rupture and modulus of elasticity with an average values of 2.65 and 355.7 N / mm2, respectively.

iv. Further study of other performance characteristics such as internal bonding, compressive strength capability, additive impregnation and durability parameters are recommended.

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