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RETROFITTING COMPOSITE CEILING BOARDS WITH JATROPHA CURCAS SEEDCAKE MATERIAL

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Abstract: Estimations of properties of composite ceiling boards which employ wood waste particles and jatropha seed cake was studied. Predictive models for the simulation of physical and mechanical properties of the composite products was conducted; and were used to study the characteristics of bulk density (BD), thickness swelling index (TS), modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding strength (IB) of the composite ceiling boards analysed. Equal amounts of jatropha and sawmill dust in the theoretical composite particle/ceiling board resulted in values of properties, bulk density 0.8975 g/cm³, thickness swelling index 9.83%, modulus of rupture 25.05 MPa, modulus of elasticity 2.42 GPa and internal bonding strength 13.86 MPa respectively. Improved mechanical properties and denser composite particle/ceiling board can generally be produced with addition of jatropha to sawmill dust under specified control conditions of fiber-matrix mixture aggregates.

Key words: Ceiling boards, jatropha, sawmill dust, fiber-matrix

1.0. INTRODUCTION

1.1. Threats to naturally existing biomass sources

The conservation of the environment is a growing concern amongst stake holders in the agricultural, manufacturing and industrial sectors especially as regards sustainable use of renewable biomass materials such as wood for production of vast household and office furniture, and structural constructional materials, such as particleboards used for facing, partitioning and ceiling boards’ applications. Constant growth in the world population coupled with urbanisation and industrialisation continues to threaten naturally existing biomass sources for furniture and construction wood materials, and for energy consumption. Presently, there is a high dependence of biomass sources for energy sources and consumption in Nigeria. Osaghae, (2009) as cited in Ojolo and Orisaleye [1], suggests that traditional biomass (wood fuels) accounts for the largest share of the total energy consumption in Nigeria; this is put at 51%, followed by petroleum products 41%, natural gas 5.2%, and electricity 3.1%. In an attempt to address this rising non-sustainable practice which can lead to several environmental degradation, such as deforestation, erosion and flooding, extinction of endangered species of some animals, land sliding, amongst others. There is the need to begin to pay more attention to ways of recycling less important by-products such as jatropha curcas seedcake as suitable resources for manufacturing purposes.

1.2. Jatropha curcas seedcake as a suitable composite material

This study examines the prospect of using jatropha curcas seedcake as a suitable ceiling board composite material. Although, composite materials primarily offers several benefits such as lightweight, heat resistance, mechanical and control characteristics [2], with the objective of making a component which is strong and stiff and of a low density [3]. However, composite engineering can also serve as a means of addressing issues of waste in industrial production processes, thereby enhancing conservation of the environment and sustainability [4]. When adequately explored, jatropha curcas seedcake could be turned into more useful commercial product as wood which is a good renewable resource material due to its valuable industrial applications [5].

1.3. Characteristics of jatropha curcas seed cakes

The jatropha curcas seed cakes are produced by expelling oil from high oil-bearing seeds. Expelled oilseed cake contains 8-12% oil depending on the efficiency of expeller. The seed cake left as a by-product after oil extraction by screw press can contain as much as 500–600 g/kg indigestible shells [6]. This accounts for about 50-60% by weight of the seed. The residue matter or cake can be as much as 75% of the

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1.4 Recycling—means to environmental conservation and sustainability

Growing interest had been made of recent to find means of recycling agricultural waste into profitable uses. Alade et al. [9] suggested that sawdust and related wood by-products from sawmills be converted into value-added products for particle board production rather than disposing off through the traditional method of incineration which has adverse consequences of polluting the environmental with harmful substances such as poly aromatic hydrocarbons (PAHs), nitrogen oxide (NOx) and sulphur oxide (SOx). Idowu et al. [10] had used the fibre from corn cobs, a post-harvest material estimated at over 200 million tons from maize in Nigeria to produce stable particleboards with cement to fibre ratio of 3:1 and 3% additive concentration of calcium chloride (CaCl2), resulting in particleboard of density 1200 kg/m³, modulus of rupture 0.49 MPa and modulus of elasticity 4391 MPa respectively. The enormous amount of wasted corn cobs from post-harvest activities could be utilised as alternative substitute to wood-based biomass so as to achieve environmental conservation and sustainability.

Similarly, Scatolino et al. [11] had adduced that agricultural residues such as, maize cob generated in large quantities in Brazil accumulates to such extent as to cause environmental problems. To ameliorate on the prevailing circumstances Scatolino et al. [11] suggests that an alternative use for maize cob to produce particleboard panels in association with wood particles should be encouraged, which was the spur of their study. They investigated the feasibility of using maize cob for production of particleboard panels in which maize cob percentages of: 0%, 25%, 50%, 75% and 100%, in association with particles of Pinus oocarpa wood. They made panels with 8% of urea formaldehyde and 1% of paraffin (based on dry weight of particles), and compressed the panels with a pressure of 3.92 MPa at a temperature of 160° C, for 8 minutes. Scatolino et al. [11] discovered that increased replacement of pinewood by maize cob residue resulted in increased water absorption and thickness swelling, while the mechanical properties were decreased.

1.5 Potential of allied agricultural products for particle/ceiling boards production

1.5.1 Bamboo

Bamboo mat board (BMB) was the first bamboo-based panel to be produced commercially. It is produced on a commercial scale in China (under the name bamboo mat plywood), India, Thailand and Vietnam. The earliest boards produced were casein-bonded and their principal use was for interiors of aircrafts; only species with long internodes, such as Bambusa textilis, were used. In the 1970s, synthetic resin-bonded BMB was developed in China. Although urea formaldehyde (UF), phenol formaldehyde (PF) and phenol-tannin formaldehyde (PTF) were employed as the bonding resin, UF-bonded BMB is the most common. The physical and mechanical properties of typical UF-bonded common BMB produced in China are given as density 850 kg/m³, internal bond strength 1.57 MPa, modulus of rupture 93.0 MPa, tensile strength 72.6 MPa, and impact tenacity 3.1 J/cm² respectively [12].

Laemlaksakul [13] investigated the feasibility of making single-layer particleboard panels from bamboo waste (Dendrocalamus asper Backer). Bamboo was converted into strips, which were used to make laminated bamboo furniture. The experimental variables were density (600-800 kg/m³) and conditioning temperature (25-55 °C). The experimental panels were tested for their physical and mechanical properties including modulus of elasticity (MOE), modulus of rupture (MOR), internal bonding strength (IB), screw holding strength (SH) and thickness swelling values according to the procedures defined by Japanese Industrial Standard (JIS). Laemlaksakul [13] concluded that a valuable renewable biomass, bamboo waste could be used to manufacture boards.

1.5.2. Cambara, canelinha and cedrinho fibres

Mello da Silva et al. [14], investigated, with the aid of the Brazilian NBR 14810:2002 standard, the physical properties, namely, bulk density and moisture and mechanical properties, namely, flexural strength modulus and internal compliance of particleboards manufactured with bicomponent polyurethane resins derived from castor oil and cambara, canelinha and cedrinho fibres. The factors investigated were: nominal density (0.80 g/cm³), nominal thickness (10mm), moisture content of the particles (5%), percentage of resin (15%), time used in the pressing cycle (10min), hot pressing (100 °C), pressing pressure (5MPa) and length of the particles (3 to 5mm), leading to a full factorial design of 2² type, providing four different experimental conditions. Mello da Silva et al. [14] discovered that the mechanical properties of both materials prepared showed higher values than those stipulated by the standard. And for the physical properties, only the density was found to have exceeded the limits set by the NBR 14810:2002, rating the particleboards produced as high density.

1.5.3. Water melon peels

Idris et al. [15] studied the suitability of using water melon peels as alternatives to wood-based particleboard composites. They produced water melon peels composite boards by compressive moulding using recycled low density polyethylene (RLDPE) as a binder. The RLDPE was varied from 30 to 70% by weight at intervals of 10%. They determined the microstructure, water absorption (WA), thickness...
swelling index (TS), modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding strength (IB), impact strength and wear properties of the boards. Their results showed that high modulus of rupture of 11.45 MPa, MOE of 1678 MPa, IB of 0.58 MPa, rate of 0.31 g was obtained from particleboard produced at 60% RLDEP. Idris et al. [15] concluded that watermelon particles can be used as a substitute to wood-based particleboards for general purpose applications. Aside from being environmentally friendly, using watermelon and RLDEP in production of particleboard was also found to be very cost-effective.

1.5.4. Rice husk

Johnson and Yunus [16] suggested that rice husk particleboard is one of the materials which are being considered for development as a potential substitute for wood and wood-based board products in order to mitigate the growing shortage of wood especially in urban cities, due to the rapid growth of the construction industry as a consequence of increasing population and standard of living. They further alludes the reasons behind the use of rice husk in the construction industry was as a result of its high availability, low bulk density (90-150 kg/m³), toughness, abrasiveness, resistance to weathering and unique composition. Also, the use of rice husk enables the production of much cheaper ceiling boards. The main components of rice husk are silica, cellulose and lignin. The composition of rice husk as a percentage of weight was given as SiO₂: 18.80-22.30%, lignin 9-20%, cellulose 28-38%, protein 1.90-3.0%, fat 0.30-0.80% and other nutrients 9.30-9.50% respectively. Ceiling boards produced from rice husk is done by combining rice husk and sawdust; slurry is produced by heating rice husk with caustic soda. This slurry is then washed with water and beaten into pulp, to which sawdust (filler) and glue is added. The slurry is formed into sheets in the press and sun dried [16].

In their study, Johnson and Yunus [16] observed that boards with the admixture of rice husk and sawdust have a higher tensile strength (32 N/m²) compared to only rice husk boards (22 N/m²) and are comparable to commercial ceiling boards (23.5 N/m²). Phenol-formaldehyde (PF) resin creates strong and water resistant bonds, but requires the longest pressing time and higher temperatures. The modulus of elasticity (MOE) and modulus of rupture (MOR) of rice husk particleboards with PF as binder are 2.6 GPa and 13 MPa, while in the case of ground rice husk, the modulus drops to 1.6 GPa and 7 MPa [16].

1.5.5. Groundnut shell

Raju et al. [17] investigated the properties of groundnut shell particles reinforced polymer composite (GSPC). They prepared composite samples with different weight percentages of particles in polymer matrix and the physical and mechanical properties were tested. They observed that the sample with 20 wt% of reinforcement had maximum MOR of 40.57 MPa and sample with 60 wt% of reinforcement had maximum MOE of 8.204 GPa. The tensile test shows that sample with 40 wt % had maximum tensile strength and young’s modulus of 28.09 MPa and 8204 MPa respectively. The impact test results show a steady increase in impact strength up to 50 wt % of filler addition. Moisture content of GSPC varied from 1.92 to 4.96% and water absorption was only 1.51-8.82% for 15 days.

1.5.6. Bagasse

A three layer experimental particleboards using a mixture of bagasse and industrial wood particles was investigated by Ghalehno et al. [18]. They produced the boards with ratio of the mixture of bagasse and wood particles, in the surface and middle layers given as 20:80, 30:70 and 40:60, respectively. They selected the press times at two levels of 5 and 7 minutes. Two levels of urea formaldehyde resin were selected for the surface layers, namely: 9 and 11 percent. The Modulus of elasticity (MOE), modulus of rupture (MOR), internal bonding (IB) and thickness swelling (TS) of the panels were determined according to the procedure of DIN 68763 Standard. Their results indicated that all mechanical and physical properties of particleboards improved with an upper percentage of bagasse particles added. They also observed that the treatment with 40% bagasse, 11% resin in the surface layers and with a 7 min press time resulted in an optimum particleboard product.

1.6. Aim and objective of study

Even though many uses had been discovered for Jatropha seed cake (biomass), it has however not been popularly used as composite material for construction products as some other biomass products, especially in the area of particle ceiling boards.

The aim of this study is the theoretical estimations of properties of composite ceiling boards which employs wood waste particles and jatropha seed cake as recycled resource materials to produce potentially economically viable ceiling boards. The objective was the determination and investigation of the physical and mechanical properties of the composite ceiling boards made from wood waste particles and jatropha seed cake, such as bulk density (BD), thickness swelling index (TS), modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding strength (IB) of the composite ceiling boards analysed; and also, the determination of predictive models for the simulation of physical and mechanical properties of the composite products.

2.0. MATERIALS AND METHODS

2.1. Analysis of composites

Usually, composites have strong, stiff fibres in a matrix which is weaker and less stiff. The primary aim of producing composite products is to enhance strength and stiffness while lowering density of the product [3]. The stronger or weaker member of a composite is determined by their characteristic properties. The theoretical techniques in composite materials design and analysis employed in this study was as described by Gay et al., (2003) as cited in Jweeg et al. [19] as follows,
The fibre and matrix mass fraction are defined as,

\[
M'_f = \frac{\text{Mass of fibres}}{\text{Total mass}}
\]

\[
M'_m = \frac{\text{Mass of matrix}}{\text{Total mass}}
\]

Where, \( M'_m = 1 - M'_f \)  

Similarly, for the fibre and matrix volume fraction, we have

\[
V'_f = \frac{\text{Volume of fibres}}{\text{Total volume}}
\]

\[
V'_m = \frac{\text{Volume of matrix}}{\text{Total volume}}
\]

Where, \( V'_m = 1 - V'_f \)  

Conversion from mass fraction to volume fraction and vice versa is possible if the specific densities of fibre and matrix are given as \( \rho_f \) and \( \rho_m \). Thus,

\[
V'_f = \frac{M'_f / \rho_f}{M'_f / \rho_f + M'_m / \rho_m}
\]

\[
M'_f = \frac{V'_f \cdot \rho_f}{V'_f \cdot \rho_f + V'_m \cdot \rho_m}
\]

2.2. Bulk density of matrix and fibre of composite ceiling board and properties of particle boards from different composites

Pan et al. [20] had produced particleboards from 20-40 mesh, with a target bulk density of 0.72 g/cm\(^3\), which corresponded to 0.55 cm thickness square samples of 15.4 cm x 15.4 cm of the finished particleboard, and the press time, temperature and pressure were 8 min, 140 °C and 3 MPa. Pan et al. [20] used polymeric methane diphenyl diisocyanate (PMDI) resin as adhesive for experimental particleboards. Typical average value of density of jatropha briquettes presented by Ghosh et al. [21] as 1.075 g/cm\(^3\) was used for the bulk density of jatropha. Hence, the bulk densities of fibre (jatropha seed cake) and matrix (sawmill dust) adapted for this study are 1.075 g/cm\(^3\) and 0.72 g/cm\(^3\) respectively. The volume of the ceiling board analysed in this study was maintained at same values of those of Pan et al. [20], that is, 0.55 cm x 15.4 cm x 15.4 cm (130.438 cm\(^3\))

The physical and mechanical properties of composite particle boards produced from various constituents were determined in different studies by Ganapathy [12], Idris et al. [15] and Gharehno et al. [18], and presented in Table 1. The properties of the boards given in Table 1 were used to develop general predictive models as a function of the bulk density of the composite products. The determined values of bulk density of the expected composite produced from sawmill dust and jatropha seed cake residue was in turn used together with the general predictive models developed to determine the physical and mechanical properties of ceiling board analysed at different mass and volume ratios respectively.

<table>
<thead>
<tr>
<th>Composite Product</th>
<th>Type of Adhesive</th>
<th>Physical Properties BD (g/cm(^3))</th>
<th>TS (%)</th>
<th>MOR (MPa)</th>
<th>MOE (GPa)</th>
<th>IB (MPa)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bamboo board (Canada)</td>
<td>Phenol formaldehyde (PF) resin</td>
<td>0.75</td>
<td>14.00</td>
<td>17.20</td>
<td>3.100</td>
<td>0.345</td>
<td>[12]</td>
</tr>
<tr>
<td>Water melon peals particleboard</td>
<td>Recycled low density polyethylene</td>
<td>0.75</td>
<td>10.05</td>
<td>12.00</td>
<td>1.650</td>
<td>0.65</td>
<td>[15]</td>
</tr>
<tr>
<td>Bagasse and wood particleboard</td>
<td>Urea formaldehyde (UH) resin</td>
<td>0.70</td>
<td>11.84</td>
<td>16.59</td>
<td>2.384</td>
<td>0.76</td>
<td>[18]</td>
</tr>
</tbody>
</table>

2.3. Determination of internal bonding strength of particleboards

The internal bonding strength of particleboards was estimated by expressions for modulus of rupture (MOR) and internal bonding strength (IB) as described by Laemlaksakul [13] as follows,

\[
MOR = \frac{3P_bL}{2bh^2}
\]

Where, \( P_b \) is the maximum load (N), \( b \) is the width of the specimen (mm), \( h \) is the thickness of the specimen (mm), and \( L \) is the span (mm). In conducting the static bending test, a concentrated bending load was applied at the center by Laemlaksakul [13] with a span of 15 times the thickness of the specimen.

\[
IB = \frac{P_s}{bl}
\]

Where, \( P_s \) is the rupture load, and \( l \) is the length of the specimen. Hence \( IB \) was estimated by assuming \( P_b = P_s \) in equations 9 and 10. Therefore, since \( b = l \) in this study, we have,

\[
IB = \frac{2 \times MOR \times h}{45 \times b}
\]
2.4. Modelling of properties of composite ceiling boards

The physical properties, namely, thickness swelling index (TS) and bulk density (BD), and mechanical properties, namely, modulus of rupture (MOR), modulus of elasticity (MOE), and internal bonding strength (IB), of the composite ceiling boards analysed were modelled so as to simulate the physical and mechanical properties of the composite products as a function of the mass and volume ratios.

Multivariate functions, that is, functions having two or more independent variables are usually given by tabular data. Multivariate approximation is necessary for interpolation, differentiation, and integration. Caution must be exercised to ensure that the number of data points must be equal to the number of coefficients [22]. Since six data points have been used in this study, hence six coefficients suffice. The generic model equation for modelling of the composite product as a function of the mass and volume ratios can be expressed as,

\[ Y = \beta_0 + \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_5 Z_5 \]  

Equation 12 may be re-written specifically in terms of the mass and volume ratio as follows,

\[ Y = \beta_0 + \beta_1 M_f' + \beta_2 M_m' + \beta_3 V_f' + \beta_4 V_m' + \beta_5 M_f'M_m' \]  

Furthermore, statistical analysis using advanced regression techniques was used to develop functional models of the physical and mechanical properties of the theoretical composite particle/ceiling board with respect to the mass and volume ratios of the fibre (jatropha) and matrix (sawmill dust) members of the board. In other words, board properties represented by the function given in by equation 14 were solved from generated data and relation given in equation 13.

\[ Y = f(M_f', M_m', V_f', V_m') \]  

3.0. RESULTS AND DISCUSSIONS

General models developed from data of previous studies as presented in Table 1 which relates properties of particleboards to bulk density \( \rho \) are given for thickness swelling index (TS), modulus of rupture (MOR) and modulus of elasticity (MOE) as stated in equations 15-17 respectively. The internal bonding strength was estimated using the expression derived in equation 11 as previously explained.

\[ TS = 3.7 \rho + 9.25, \quad se = \pm 2.793\% \]  

\[ MOR = -39.8 \rho + 44.45, \quad se = \pm 3.677 \text{ MPa} \]  

\[ MOE = -0.18 \rho + 2.51, \quad se = \pm 1.025 \text{ GPa} \]  

The thickness swelling index (TS), bulk density (BD), modulus of rupture (MOR), modulus of elasticity (MOE), and internal bonding strength (IB), of the composite ceiling boards composed of jatropha and sawmill dust, modelled as a function of the mass and volume ratios of the fibre (jatropha), that is, \( Y = f(M_f', V_f') \) are stated in equations 18-22 accordingly.

\[ TS = 0.437 V_f' + 9.613 \]  

\[ \rho = 0.355 V_f' + 9.613 \]  

\[ MOR = 0.202 M_f'^2 + 0.251 M_f' - 0.685 V_f' + 25.221 \]  

\[ MOE = 9.1 \times 10^{-4} M_f'^2 + 1.14 \times 10^{-3} M_f' - 3.09 \times 10^{-3} V_f' + 2.42 \]  

\[ IB = -22.43 M_f' + 25.073 \]  

The model equations 18-22 was used to simulate the properties of the theoretical composite particle/ceiling boards and their characteristics are shown in Figures 1-4 respectively. The thickness swelling index (TS), bulk density (BD) internal bonding strength (IB) (Figures 1-3) all increased with increasing values of fibre (jatropha) in the composite product; while the modulus of rupture (MOR) and modulus of elasticity (MOE) (Figures 3 and 4) both experiences deceases with increases in quantity of jatropha. However, the modulus of rupture (MOR) was almost constant.

Figure 1. Thickness swelling index with respect to volume ratio of fibre (jatropha)

Figure 2. Bulk density variation with respect to volume ratio of fibre (jatropha)
For equal amounts of jatropha and sawmill dust in the theoretical composite particle/ceiling board, the properties are obtained as bulk density (BD) 0.8975 g/cm³, thickness swelling index (TS) 9.83%, modulus of rupture (MOR) 25.05 MPa, modulus of elasticity (MOE) 2.42 GPa and internal bonding strength (IB) 13.86 MPa respectively. When compared with previous studies indicated in Table 1, that is bulk density (BD) 0.70-0.75 g/cm³, thickness swelling index (TS) 10.05-14%, modulus of rupture (MOR) 12.00-17.20 MPa, modulus of elasticity (MOE) 1.650-3.100 GPa and internal bonding strength (IB) 0.345-0.760, results shows that addition of jatropha in composite particle board resulted in a denser product due to higher value of bulk density of jatropha seed cake. The modulus of rupture was improved while comparable modulus of elasticity was obtained. The internal bonding strength was significantly higher than that obtained from previous studies, although, this may not be the case in reality.

4.0. CONCLUSION

A denser composite particle/ceiling board can generally be produced with improved mechanical properties with the addition of jatropha to sawmill dust under specified control conditions of fiber-matrix mixture aggregates. Other undisclosed benefits may be discovered when composite particle/ceiling board are experimentally produced and investigated. The possibility of replacing wood biomass for particleboard and related products would go a long way in achieving a greener and sustainable environment, and value addition on naturally occurring agricultural resources and in areas yet to be explored.

5.0. REFERENCES


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