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PRODUCTION OF PARTICLEBOARDS USING POLYSTYRENE AND BAMBOO WASTES

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ABSTRACT
This investigation was able to produce incredibly strong particleboards using bamboo and resinous material obtained from Polystyrene wastes. The particleboards were prepared by mixing the bamboo fibres and Polystyrene based resin (PBR) followed by flat press process at different ratio (v/v). Physical properties were measured, with reference to normal and oven curing methods, according to the ASTM D-1037 standard. Thickness Swelling (TS) of the samples were measured after 2 and 24 hours of immersion in water at 25°C temperature. It was found that the physical properties of particleboards with 20%, 30% and 40% PBR content were all in agreement with low density particleboard classification of American National Standards Institute (ANSI). TS increased as the PBR content decreased in the matrix. Obtained properties convincingly indicate superior bonding ability of the synthesised resinous polystyrene over known industrial adhesives typically used for particleboard production.

Keywords: *bamboo waste Particleboard,, , polystyrene based resin polystyrene waste.*

1. INTRODUCTION

In the last few decades, successful development and improvement of wood based composites panels (with the economic benefit of producing low cost wooden materials) has been a major alternative to solid wood usage [1]. The demand for composite wood products of various genres like particleboard, plywood, hardboard, oriented standard board, medium density fiberboard and veneer board has equally increased significantly throughout the world [2]. In particular, the demand for particleboard has been ever-increasing because of housing infrastructure delivery, interior decoration, manufacturing of furniture, flooring, and work surfaces in offices, educational establishments, laboratories and other industrial needs [3].

Consequently, this enormous demand of particleboard has put the scanty natural forest resources on accelerating pace of disappearance which is raising an alarm on the continuous supply of raw material to the wood based sectors in the future [4]. Hence, the explorations of alternative sources of raw materials for particleboard production technology become crucial. Alternatives to wooden materials like agricultural residues and non-wooden plant fibres may play a major role in meeting the demand of manufacturing the particleboards [5, 6].

Bamboo is a good alternative to wooden material and belongs to group *angiosperms* and order *monocotyledon* [7]. Bamboo is a renewable raw material that is universally accepted for building construction. It plays a fundamental role in industrial and domestic economics in many developing countries. Compared with some commercial wood species, bamboo exhibits equal or better physical and mechanical properties, which offer good potential for processing it into composites (bamboo-based panels) as a wood substitute [8]. The bamboo based industries have developed into a multi-million dollar industry with their variety of products enjoying very high demand domestically as well as internationally [6].

Conventionally, particleboards are produced from chosen particles adhered together with a thermosetting resin. Such resins are mostly formaldehyde based, which are usually synthesised from petrochemical raw materials [9]. The Idea of replacing the fast depleting petrochemical raw material with other environmentally friendly choice is always desired. The originality of this work is the introduction of a synthetic resin formed from the utilization of municipal and industrial polystyrene wastes as substitute for Urea or formaldehyde based resins that are known to emit carcinogenic gases.

The development and properties of bamboo fibre-based composites in the class of medium density fibreboard [1, 10, 11, 12,] have been variously considered in previous studies, with evidence of acceptable physical and mechanical properties. However, most of these

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developments are based on high temperature and pressure processing and the usage of formaldehyde based resin as the binder.

The main objective of this study was to evaluate the technical feasibility of blending particles of bamboo (*G. magna*) with synthetic resins (PBR) in a room temperature process for producing particleboard as well as to assess the properties of the panels developed. The strength and dimensional properties, viz. thickness swelling (TS), water absorption (WA), modulus of rupture (MOR), and modulus of elasticity (MOE) were tested according to the Standard. The effects of curing method and resin content on the board properties are discussed.

2. EXPERIMENTAL

2.1 Materials Preparation

The bamboo wastes were gathered from construction sites in the premises of University of Ilorin, Ilorin, Nigeria. The bamboo culms were then taken to the mill, where they were sliced to give the needed fibre materials; these slices were further ground to convert them into particles. The bamboo fibre was dried in oven for 24 hours at 40°C to remove free water present in it. The dried bamboo was reduced into finer particles by passing through US mesh standard sieves with mesh size of 40. The polystyrene waste was basically gotten as municipal wastes collection in Ilorin, thoroughly cleaned to remove debris and substance that may stand as impurity cut into small sizes before dissolving its 59 g mass in 100 ml of gasoline to obtain 124g of synthetic PBR in 145ml volume. The density of the resultant PBR was 855kg/m^3. The synthesised PBR from polystyrene waste was used as a binder. The proportion of PBR was varied from 20% to 40% volume basis of graded bamboo particles.

2.2 Particleboard Manufacturing

The dried particles were manually blended with PBR. Three different samples of particleboards were manufactured as indicated in Table 1. The target size of the particleboard was 160mm× 150mm with a thickness of 20mm. After blending, the mats of the particles were formed manually by placing the blend in a mould and lightly press for 10 minutes at room temperature. Oil was used as a releasing agent on mould surface to achieve easy composites removal from the mould after formation. The curing was done in two ways namely; normal curing (NC) and oven curing (OC) at 50°C. The produced particleboards were subjected to physico-mechanical tests after successful curing.

Table 1: Composition of the particleboards

Composites	Compositions (v/v)
CN1, CO1	20% matrix + 80% Bamboo Fibres
CN2, CO2	30% matrix + 70% Bamboo Fibres
CN3, CO3	40% matrix + 60% Bamboo Fibres

2.3 Laboratory Test

All tests were carried out in accordance with ASTM D-1037 standard [16]. At least six specimens were selected for each type of panel for testing the physical and mechanical properties. Modulus of rupture (MOR), modulus of elasticity (MOE), density, water absorption (WA), and thickness swelling (TS) were measured. The MOR and MOE were measured using Universal Testing Machine (UTM: M500-50 AT).To obtain WA and TS, samples were fully immersed in distilled water at 25ºC for 2 and 24 hours respectively.

3. RESULTS AND DISCUSSION

3.1 Mass Loss Profile

Three composite samples; CN1, CN2, and CN3, of 20%, 30% and 40% PBR respectively (Plate 1), were made with initial mass of 218.5g, 240.74 and 280.25 respectively and were left to cure at room temperature. As shown in Table 1, before stabilising, the mass of CN1 reduced from 218.5g to 209.90g in 7 days of curing; CN2 mass reduced from 240.74g to 214.20 in 9 days of curing while the mass of CN3 reduced from 280.25g to 226.80g in 13 days of curing.

Other three composite samples, CO1, CO2 and CO3, of 20%, 30% and 40% PBR respectively (Plate 1), were also subjected to oven curing at a temperature of 50°C for 24hours. After 24 hours of curing in the oven (Table 2), the mass of CO1 reduced from 215g to 206.5g, while the mass of CO2 reduced from 237g to 212.1g, and the mass of CO3 reduced from 282g to 229.5g.

As shown in Table 2, the mass profiles of volatile gases that escaped in the course of curing before a stable mass is attained increased with amount of PBR in the matrix for room temperature curing process. At a higher binder proportion in the matrix, the time taken for curing was longer than with lower binder amount. The observed slow changing mass of the formed composite of normally cured particleboards is connected to the processing method of cold press adopted and the non-precipitation method of preparing the PBR used as binder. This is evident in the release of volatile gases as the composites cure to a stable mass. Conversely, the numbers of days spent in curing for each of the composite class was reduced to 24 hours (1 day) in an oven treatment of the particleboards at 50°C.

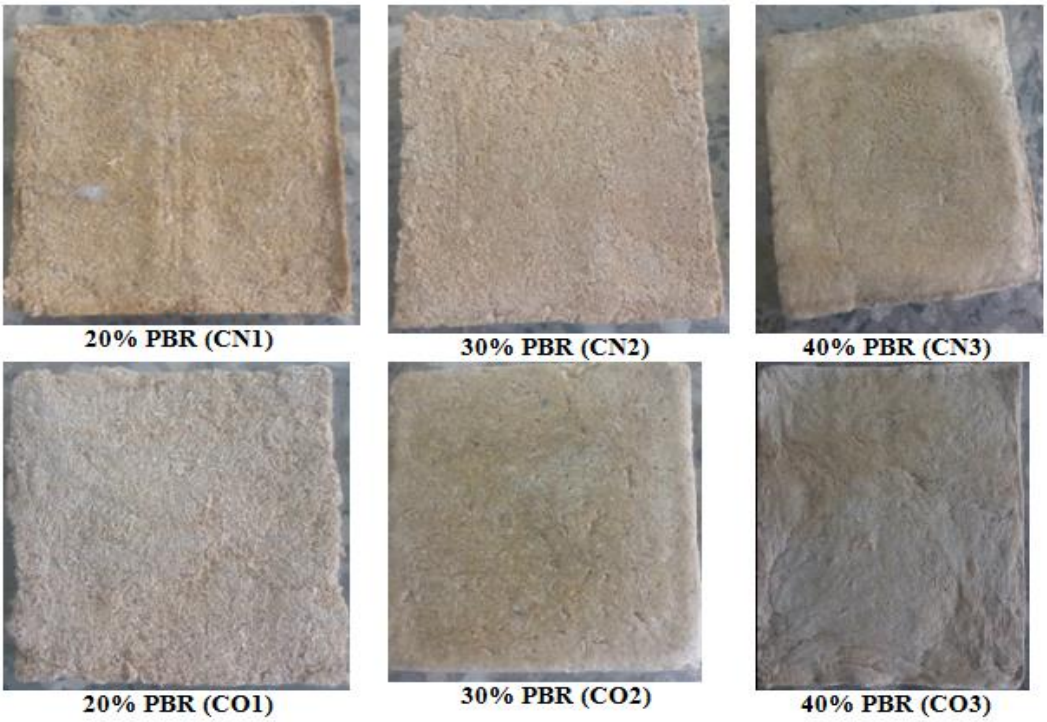

Plate 1: Particleboards from Normal and Oven Curing Methods

Table 2: Mass Loss Profiles of Normal and Over Cured Particleboards

Composites	Mass at the formed stage (g)	Mass at the cured stage (g)	Total Mass Loss before curing (g)	Curing Time (days)
CN1	218.50	209.90	8.6	7
CN2	240.74	214.20	26.5	9
CN3	280.25	226.80	53.5	13
CO1	215	206.5	8.5	1
CO2	237	212.1	24.9	1
CO3	282	229.5	52.5	1

3.2 Density

The most important gauge of particleboards' performance is density, which mostly affects all other properties and considerations [13, 14, 15]. The density of all the particleboards made from bamboo waste at 20%, 30% and 40% PBR content for normal (NC) and oven (OC) curing are shown in Figure 1. At 20% PBR the densities were 562.5 and 542.7 for room temperature and oven cured respectively; at 30% PBR content, the densities were 612 and 605.7 respectively, while at 40%, they were obtained as 636.65 and 618.8 respectively.

According to ANSI (D1037-99, ASTM, 1999) standard, [16] the density of low density particleboard is in the range 610-640 kg/m^3. Hence, the densities of all the particleboards produced are corresponding to the universal standard for low or light density particleboard. An earlier report indicated that the smaller woody particles would make a thinner mat and the compaction ratio would be higher resulting in high density composite materials [2]; in this investigation however, the results showed that particleboard from room temperature curing are denser than their counterparts in oven curing. This indicated the fact that the bonding strength of PBR is affected by the curing temperature. It is also evident from both classes of samples, that the higher the PBR content the higher the density. This is a trend that is different from those of particleboards bonded by formaldehyde.

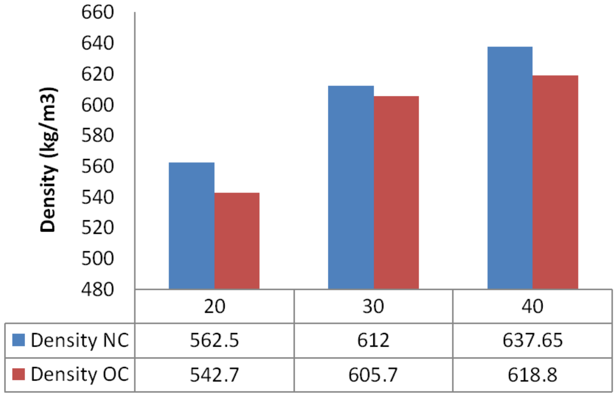

Figure 1: Relationship between Density and PBR content for Particle Boards.

3.3 Thickness Swelling

The thickness swelling values for the particleboard of highest (40%) PBR content was 0% for both 2 hour and 24 hour water immersion at room temperature curing and 2.15% at 50^{o}C oven curing for both 2 hour and 24 hour immersion. For the particleboard with lowest PBR content, the thickness swelling increased from 6.25% at 2 hour immersion to 7.75% in 24 hour water immersion for normal curing and in the oven cured panels, the thickness swelling is 9.09% for both 2 hour and 24 hour immersion in water for the particleboard of 20% resin content. In general, the particleboards made of higher resin content had stronger dimensional stability properties.

The maximum thickness swelling tolerable after 24 hours of water immersion expected of a low density particleboard according to [16] is 15%. The thickness swelling values of particleboards produced from each class and treatment were all below 15% as shown in Table 3.

The resultant composites from the usage of PBR resin as binder are excellent water repellent. This is due to a non precipitation approach of synthesising them. As a consequence, the boards require no additional treatments such as the coating of particleboard surfaces with any laminates or high press temperature treatment before they become stable products.

The density and water absorption capacity have more effect on thickness swelling and linear expansion of particleboard i.e. the higher density board absorbs less water than a lower density board. An earlier report had posited that the higher holocelluose content of bamboo is mainly responsible for the low water thickness swelling of particleboard [8]. So, the excellently low thickness swelling properties in this work is traceable to PBR chemistry and the natural bamboo characteristics.

Table 3: Thickness swell of bamboo based Particleboards

	After 2 hours (%)	After 24 hours (%)
CN1	6.25	7.75
CN2	4. 45	4.45
CN3	0	0
CO1	9.09	9.09
CO2	6.25	6.25
CO3	2.15	2.15

3.4 Mechanical Properties

In this investigation, the modulus of elasticity and modulus of rupture tests were carried out to study the mechanical and physical properties of the particleboard at different PBR content as shown in Figures 2 and 3. Modulus of rupture (MOR) is a measure of the ability of a sample to resist a transverse (bending) force perpendicular to its longitudinal axis. Table 4, also shows the modulus of rupture (MOR) of composites with different resin content to bamboo fibre content. The result showed that composite with 30% PBR content at room temperature curing gave the highest value of MOR with 9.42 MPa. It is established that composite with 30% PBR content can withstand more force than the other samples before failure and therefore represents the optimum mix ratio of the blend.

According to ANSI A208.1 standards, the maximum MOR expected of low density particleboard is 3 MPa, it is however noted in this study that the MOR values obtained for all the particleboards, based on the percentages of PBR investigated and the mode of curing employed, were much higher than the expected MOR benchmark. This phenomenon must be due to high bonding strength of PBR resin investigated.

Also from Figures 2 and 3, the room temperature cured composite with 30 % PBR gave the highest modulus of elasticity (MOE) value of 1537.94 MPa followed by 40% oven cured with 954.32 MPa. The modulus of elasticity (MOE) for 20% resin content composite showed the lowest MOE with value of 568.11 MPa. A similar trend is observed with the 50^{o}C oven cured product. Modulus of elasticity (MOE) is the tendency of an object to deform along an axis when opposing forces are applied along that axis; it is said to be an important determinant of a product's application. In this case, the MOE are all above the specified benchmark of 550 MPa, with values of room temperature cured samples notably higher than that of 50^{o}C cured ones.

In this investigation, the entire three composite samples fulfilled the minimum requirement of MOE and MOR for general purpose boards for use in dry conditions by American Standard [16] and it is equally confirmed from the trend of the relationship between MOR, MOE and PBR content in Figures 2 and 3 that the optimal PBR content that gives highest amounts of MOR and MOE is 30% PBR. Moreover, the properties compare favourably with those in the publications by [17, 18].

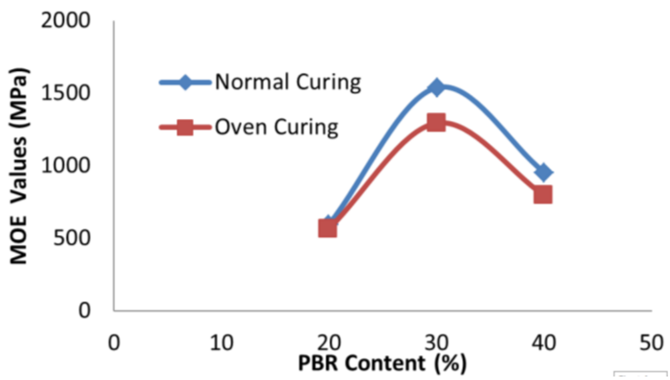

Figure 2: Effects of PBR Content on MOE Values

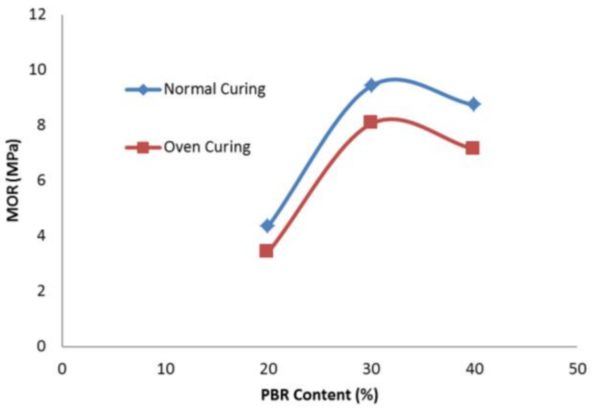

Figure 3: Effect of PBR Content on MOR Values

4. CONCLUSIONS

A new environmentally friendly technology for turning bamboo wastes into quality value-added composite products, using non-conventional resin from polystyrene wastes as binder, has been developed. The implementation of this new technology, entirely at room temperature process without recourse to hot-press unit operation, will result in waste materials being efficiently utilized as a sustainable resource for the industrial manufacture of particleboards thus reducing the amounts of wastes and eliminating the pollution occasioned by the burning of such residues. Superior bonding ability of the synthesised resinous Polystyrene over conventional industrial adhesives typically used for particleboard production resulted in lightweight material of superior mechanical strength.

The synthesised resin from waste polystyrene had strong binding characteristics that could serve some industrial purposes when applied in the production of the particleboards at PBR concentration above 20%. The property of the particleboard is a function of the percentage composition of the components. This implies that the properties of the particleboard depend on the resin-filler ratio. Consequently, variation in the percentage composition alters the properties of the particleboard proportionately.

4.1 Authors' contributions

This work was carried out in collaboration between all authors. Authors SAA and AGA designed the study. Authors AGA and AA performed the experimental study, and authors AGA and AA wrote the first draft of the manuscript. Authors SAA, AGA and AA managed the literature searches, and authors SAA and AGA managed the analysis of data and Authors AGA wrote the final manuscript. All authors read and approved the final manuscript.

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