# Development of Particleboard from Waste Styrofoam and Sawdust

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***ABSTRACT:*** The use of Plastic Based Resin (PBR) synthesised from waste Styrofoam as binder in the production of particleboard was the focus of this investigation. This study explored the properties of particleboard produced from sawdust wastes and PBR resin synthesized from waste Styrofoam. Three particleboard panels namely C1, C2 and C3 were prepared with 20%, 30%, and 40%, (v/v), respectively. PBR was synthesised via solvolysis of waste Styrofoam in a chosen solvent, and properly mixed with sawdust by simple mechanical stirring, using hand lay-up process in cold pressing to obtain the desired shapes. ASTM D-1037 standard was used to evaluate the physical and mechanical properties of the manufactured particleboards. Density, moisture content (MC), water absorption (WA), thickness swelling (TS), and mechanical properties i.e. modulus of elasticity (MOE) and modulus of rupture (MOR) of C2 and C3 were better than that of C1 particleboard and met the LD-1 requirement of ANSI A208.1. PBR from Styrofoam waste is confirmed as a good substitute for Urea or formaldehyde based resin presently used industrially. The properties of C2 and C3 synthesised are in tandem with the requirements of the ANSI A208.1 standards.

***KEYWORDS:*** styrofoam waste, plastic-based resin, particleboard, sawdust waste, curing.

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## I. Introduction

Disposal of sawdust has always been a problem of growing concern to the wood industries in Nigeria due to its negative impact on the economy and environment. Enormous quantities of sawdust are produced annually by sawmills. Likewise, in recent years, the Styrofoam, otherwise known as expanded polystyrene (EPS), being produced massively in order to meet the increasing needs and requirement of packaging industry ends up in waste stream in a similar trend (Aminudin *et al,* 2011). Also, the environmental problems associated with the traditional methods of waste disposal such as incineration and landfill are of concern due to the increase in cost of landfill disposal (Idris *et al,* 2012).

An environmentally friendly alternative for the sawmill generated wastes is using them for the manufacture of particulate composites, or particleboards. These particleboards are usually produced from wood particles bound together with synthetic adhesives or other binders, which are pressed under heat until the curing of adhesives is achieved. Various organic and/or inorganic binders have been previously used to ensure bonding between wood particles; examples are Urea-Formaldehyde (UF), Melamine – Urea – Formaldehyde (MUF), Isocyanides, PTP resin (Polymeric material from Triglycerides and Polycarbonic anhydrides), Phenol formaldehyde (PF), etc.

Researchers have studied the particleboard composite production using various types of waste mix to replace the carcinogenic emission of formaldehyde experienced in the production and use of particleboard (Endra *et al.,* 2012). Lapyote (2010) developed a new method of making particleboard with a formaldehyde-free soy-based resin which was hampered by the high viscosity of the resulting resin. Idris *et al* (2012) investigated the suitability of maize cob particles and recycled low density polyethylene (RLDPE) as a raw material for particleboard manufacturing. Their board was produced by varying RLDPE from 30-70wt% at 10wt% interval.

In their study, they concluded that maize cob particles and RLDPE can be used as a substitute in wood-formaldehyde based particleboard for general purpose applications. These results are good and innovative but would not be durable in moist environment due to the condensing nature of the resins used. It will benefit immensely if further studies are explored on other alternatives plastic wastes for the purpose of greener technology and waste abatement.

A large amount of binder is being used in particleboard industry for the production of high-quality products. In the glue-wood composite industry, the cost of binder accounts for up to 32% of manufacturing cost (Lapyote, 2010). Various types of binders have been used in the manufacture of particleboards and they are classified as either satisfying or not satisfying the interior or exterior use requirements primarily on the basis of their response to moisture and/or temperature. The originality of this work, however, is the introduction of a synthetic resin formed from the utilization of our municipal and industrial solid wastes.

This resin could be cheaply synthesised and readily available, from solid waste stream, with low energy demand

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during synthesis. It is being projected as substitute for Urea or formaldehyde based resin whose emitted gasses are carcinogenic. This study investigates a new method of using PBR for making particleboard. This new method involved the formation of a particleboard from mixing PBR and sawdust via simple mechanical stirring and composites fabricated using hand lay-up process in a cold press without hot or mechanical pressing before eventual curing. The research effort ultimately developed a technology for converting recycled sawdust chips and EPS into durable products that are recyclable and otherwise environmentally friendly.

## II. MATERIALS AND METHODS

This research was conducted to study the feasibility of developing composites using PBR as a binder in the production of particleboards. To achieve this, the PBR and the sawdust were mixed in various proportions to produce different target particleboard/panel without any additive and usage of hot press. Three grades of the panels, C1, C2 and C3, were produced based on the percentage of the synthetic resin. The physical and mechanical properties of the developed samples were determined and compared with the conventional and equivalent products.

### *A. Materials*

The materials required for this work were majorly sourced solid wastes; these include waste sawdust, obtained from a sawmill and Styrofoam from municipal/commercial waste stream. Others are synthesised PBR, rectangular moulds, and the chosen solvent for dissolving the Styrofoam.

#### *i. Sawdust Fibers*

The waste sawdust was obtained from sawmill and dried in oven for 24 hours at 40° C to remove free water present in it. The dried sawdust was graded to obtain the sawdust particles of 25µm in size.

#### *ii. Synthetic PBR*

The synthetic PBR was produced from the dissolution of waste Styrofoam in a chosen solvent. 59g of EPS was dissolved in 100ml of the solvent to obtain 145ml resin weighing 124g empirically. The density of the resultant resin was 855kg/m$^3$ upon re-solidifying at room temperature within 48 hours when left uncovered

#### *iii. Mould preparation*

Aluminium was used for the construction of the moulds for the casting operation to account for the sticky nature of PBR used. The moulds were made having a cross-section 160mm × 150mm with a height of 20mm.

### *B. Particleboard Panel Production*

Three particleboard panels were prepared with 20%, 30%, and 40% of the Styrofoam based resin, namely C1, C2 and C3, using hand lay-up process in cold pressing (Table 1). The sequence of the experimental procedure is given in Figure 1 from waste wood particle sourcing from the sawmill to maturing and finishing of the PBR bounded particleboard produced. Sawdust particles of 25µm were mixed with Styrofoam based resin in a mixer by simple mechanical stirring and the mixture was slowly poured in different moulds. After mixing, the material was placed in a mould and lightly pressed 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 curing of the composites. The produced particleboards were subjected to physico-mechanical tests.

**Table 1: Composition of the PBR Particleboard.**

| Composites | Compositions |
|---|---|
| C1 | 20% PBR + 80% Sawdust Fibres |
| C2 | 30% PBR + 70% Sawdust Fibres |
| C3 | 40% PBR + 60% Sawdust Fibres |

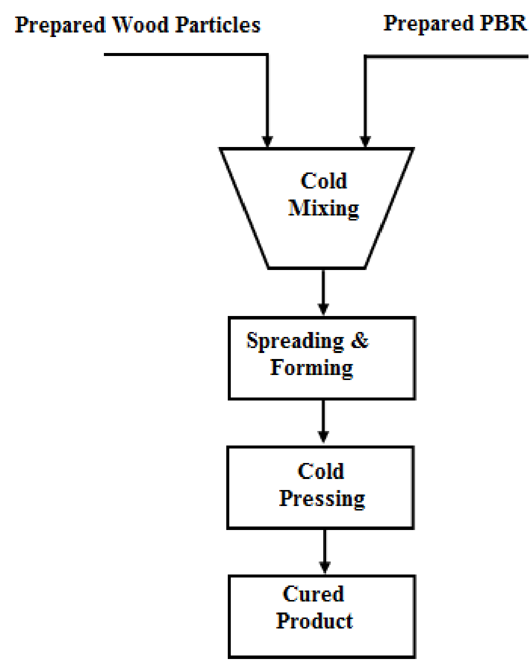


**Figure 1: The sequence of the experimental procedure.**

### *C. Mechanical testing*

The tensile and flexural tests were conducted using a Universal Testing Machine (UTM) at room temperature, according to the ASTM standard method (D1037-99, ASTM, 1999). The loading rate applied to measure the bond strength was controlled at 4 mm/min. Modulus of rupture (MOR) and Modulus of elasticity (MOE) were determined by three-point bending test in the Universal Testing Machine operating with a load cell capacity of 5 kN.

### *D. Water absorption and thickness swelling*

Water absorption and thickness swelling of the three samples of particleboard were determined according to the ASTM standard method (D1037-99, ASTM, 1999). The square samples of 15.4 cm x 15.4 cm were soaked in water at room temperature (20-22° C) for 2 h and 24 h to determine short and long-term water resistance properties, respectively.

The weight and thickness of the sample were measured before and immediately after soaking and used to calculate water absorption and thickness swelling and reported as percentages of the values before soaking.

## III. RESULTS AND DISCUSSION

Experimental results on the mass loss profile and matured mass of the three different composite (Plate 1) are presented in Table 2. Three particleboards C1, C2 and C3 were successfully fabricated as shown in Plate 1. The mass of C1 reduced from 188.6 to 182.2 g in 7 days of curing; the C2 mass reduced from 242.4 to 208.3 g in 10 days of curing while the mass of C3 reduced from 292 to 234 g in 12 days of during.

The curing profile for each of the particleboard is presented in Figure 2. The profile suggested the trend of mass of volatile gases that escaped in the course of curing before a stable mass is attained. At a higher binder proportion, the period taken for maturation were confirmed longer than at lower binder amount. The changing mass of the formed particleboard until maturation is traceable to the processing method of cold press adopted and the non-precipitation method of preparing the PBR used as binder (Zheng *et al*, 2007). This can be traced to the release of volatile gases as the composites cure naturally to a stable mass. This mass loss profile is unique to this production process.

Likewise, in the trend of mass loss before maturation, it is evident from the arrays of the composites in Plate 1 that the property of the particleboard is a function of the percentage composition of the components. This implies that the properties of the particle board depend on the resin-sawdust ratio. Consequently, variation in the percentage composition alters the properties of the particleboard.

**Plate 1: Photographs of PBR Bounded Particleboards fabricated: C1, C2 and C3.**

**Table 2: Mass Loss Profile.**

| Composites | Mass at the formed stage (g) | Mass at the cured stage (g) | Total Mass Loss before curing (g) | Time before Curing (days) |
|---|---|---|---|---|
| C1 | 188.6 | 182.4 | 6.2 | 7 |
| C2 | 242.4 | 208.3 | 34.1 | 10 |
| C3 | 292 | 234 | 58 | 12 |

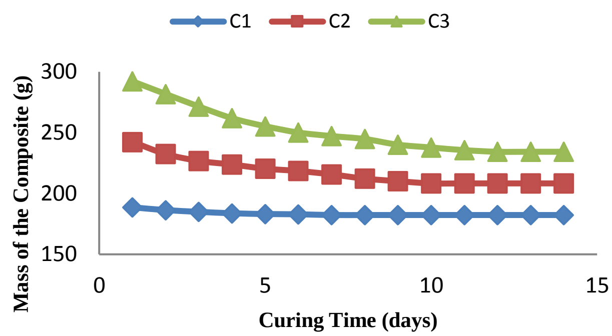


**Figure 2: Curing Profile of C1, C2 and C3.**

### *A. Moisture absorption and thickness swelling*

The response of a particleboard to humidity is a function of the degree of its water absorptivity or ability to retain moisture. It is a property of the resultant composite rather than its constituents, and as such, it depends on the composition and processing history of the sample. Results of the moisture absorption and thickness swelling are presented in Figures 3 and 4 respectively. It was found that the water absorption decreased with increasing resin content in the composites – a trend that is true for both 2h and 24h water immersion tests. However, after 24h water immersion, the water absorption by the composites was almost doubled as given in Figure 3. With the increase in resin content, there are less water-resident sites thus less water was absorbed. On the other hand, the composites made with lower resin content had more water-resident sites and thus had higher water absorption. The water absorption of the highest resin panels was only 4.6% and 10.46% after 2 h and 24 h water immersion respectively, while the water absorption of the lowest resin panels was only 25.15% and 33.96% after 2 h and 24 h water immersion respectively.

The graphical illustration of the results of the thickness swelling of the particleboards showed that the degree of thickness swelling; a measure of the dimensional stability of particleboards in humid environment is a function of the composition. Thickness swelling of the panel increased with the water absorption and thus had similar trend to the water absorption regarding the impacts of wood to resin ratio (Table 3.2). The thickness swelling values for highest resin panel was only 1.08 % and 2.15 % after 2 and 24 h water immersion respectively while the thickness swelling values for lowest panel was only 5.63% and 7.83% after 2 and 24 h water immersion respectively. In general, the panel made of higher resin content (C2 and C3) had stronger dimensional stability properties.

The results on WA and TS when compared with previous works indicate overall excellent performance and conform to national and international standards in good stead. The superiority of our study over previous work is in the minimal thickness swell experienced as compared to water absorption that is general in all sawdust containing composites. The resin content has made it more water resistant and can be considered more chemically stable in moist environment.

The superiority of the PBR used in this work over prior practice is evident when compared with other works on the same subject whose resin/binder were synthesised via condensation method. This is not unexpected because, principally condensation polymers are susceptible to degradation due to effect of water, and multiple exposures such as moisture and heat can result in accelerated deterioration

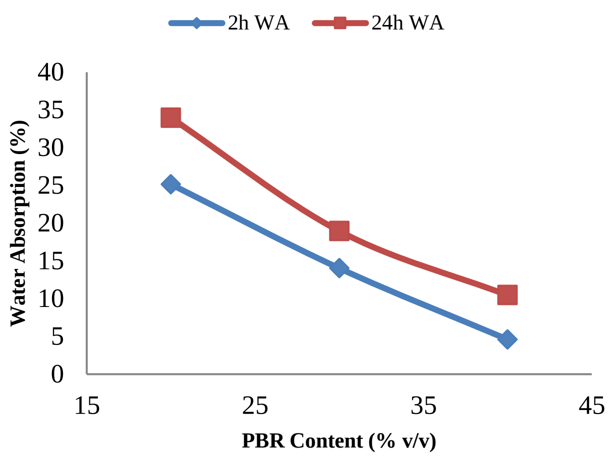


**Figure 3: Water Absorption of C1, C2, and C3 after 2h and 24h.**

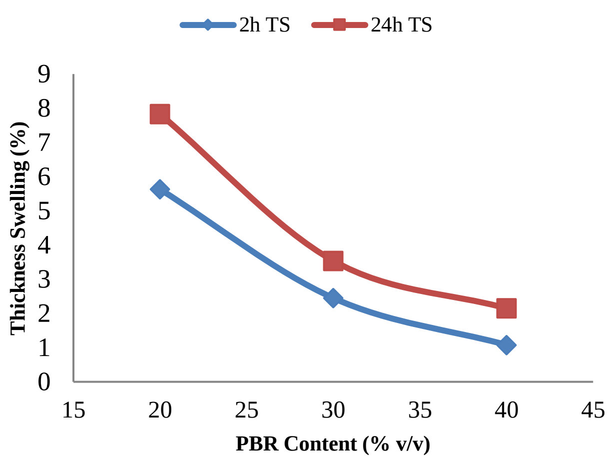


**Figure 4: Thickness Swelling of C1, C2, and C3 after 2h and 24h.**

*B. Mechanical properties*

The modulus of elasticity and modulus of rupture tests were carried out to investigate the mechanical and physical properties of the particleboard at different PBR content were presented in Table 3.

**Table 3: Mechanical and Physical Properties of C1, C2 and C3.**

| PBR Content (%) | Flexural Strength (MPa) | Tensile Strength (MPa) | MOE (MPa) | MOR (MPa) | Density ($kg/m^3$) |
|---|---|---|---|---|---|
| (C1) 20 | 2.05 | 0.93 | 206.11 | 095.63 | 380.00 |
| (C2) 30 | 4.06 | 2.30 | 577.02 | 222.45 | 433.33 |
| (C3) 40 | 5.33 | 3.10 | 675.48 | 380.81 | 487.50 |

Particleboard with 40 % PBR content gave the highest modulus of elasticity with 675.48 MPa, followed by 30% and 20% PBR with 577.02 MPa and 206.11 Mpa respectively (Table 3). Consequently, the modulus of elasticity (MOE) for 20 % PBR particleboard showed the lowest MOE. MOE is the stiffness of an object; particleboard tends to be brittle when the value of MOE is extremely high. In this case, the MOE for C2 and C3 panels are in tandem with LD-1 of ANSI 208.

Similar to the result obtained for MOE, the value of MOR was influenced by the content of PBR. The result showed that particleboard with 40% PBR gave the highest value of MOR with 380.81 MPa while 20% PBR had the lowest MOR with only 95.63 MPa. Modulus of rupture is a measure of the ability of a sample to resist a transverse (bending) force perpendicular to its longitudinal axis. Therefore, it was obvious that the particleboard with 40% PBR can withstand more force than the other samples before it breaks.

The trend of influence of the resin proportion in the composites is evident and similar on all physical and mechanical properties presented in Table 3. Board C3 had the highest physical and mechanical properties The MOE reveals the ability of the boards to withstand stress, while the MOR reveals the bending strength of the boards. In this experiment, the particleboard with 30% of PBR and above fulfilled the minimum requirement of MOE and MOR for general purpose boards for use in dry conditions by ANSI A208. Moreover, the properties compete favourably with those in the publications by Kwon and Geimer (1998), Zheng *et al.* (2007).

Also, from the results of the tensile and Flexural strength, as shown in Table 3, it was observed that the mechanical behaviour of the particleboard samples is actually in line with the earlier stated position; that the ultimate stress, resulting from large and irreversible deformation, is a composite rather than its constituent properties and strongly influenced by processing history of the sample. The C2 and C3 particleboards generally, exhibited better tensile strength than the C1 particleboards, which can be attributed to the strong binding force and compaction strength at the resin – sawdust interface for PBR content of 30% and above.

## IV. CONCLUSION

The synthesised resin from waste styrofoam had strong binding characteristics that could serve some industrial purposes when applied in the production of the particleboards at percentage 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. PBR particleboards have more ability to resist water penetration than the Urea formaldehyde particleboards. Hence, PBR particleboards have more dimensional stability than the Urea formaldehyde particleboards of comparable density. As a result, PBR particleboards have better application in moist or humid environment than UF particleboard. PBR imparted better mechanical properties to the particleboards. As a result, the PBR particleboard is able to exhibit better resistance to deformation than the Urea formaldehyde particleboards. Therefore, the PBR particleboards would be more durable, tough and have more ability to resist abrasion.

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