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Full Length Research Paper

Roofing Sheets Produced from Cassava Stalks and Corn Cobs: Evaluation of Physical and Mechanical Properties

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Abstract. In this study, roofing sheets were produced from agricultural wastes such as corn cobs and cassava stalks using animal and PVC glue as binders. The sheets were produced using different combinations of the agro- wastes and adhesives. Physical properties of the sheets produced such as percentage water absorption (WA) and thickness swelling (TS) as well as mechanical properties such as modulus of rupture (MOR) and modulus of elasticity (MOE) were evaluated. The roofing sheets produced from a mixture of agro- wastes using a combination of animal and PVC glue gave the best results in terms of the least mean values of WA (2.44%) and TS (0.10%), as well as the highest values of MOR (4.59×10^6 N/m^2) and MOE (793.7×10^6 N/m^2). These results indicate that the sheets produced from a mixture of the agro- wastes using a combination of animal and PVC glue were more dimensionally stable as well as possessing higher mechanical strength. The same set of sheets satisfied the ANSI/A208.1-1999 standard. The results of analysis of variance (ANOVA) carried out showed that the type of agro- waste and adhesive used had a significant influence on the physical and mechanical properties of the sheets ($p < 0.05$).

Key words: Corn cobs, Cassava stalks, Roofing sheets, animal glue, PVC glue

1. INTRODUCTION

Most of the world's population live in the underdeveloped areas where the problems of adequate housing cannot be overemphasized. A large proportion of these people in developing nations live in slums with brick walls, dirty floors, thatch roofs or rusty corrugated roofs (Mathur, 2006). The roof is one of the most important parts of the house as it serves to secure the house and provide shelter for the occupants. Conventional roofing materials include corrugated galvanized iron sheets, aluminum sheets, asbestos sheets, clay tiles etc. Galvanized iron sheets transmit heat from the sun and noise from rain and hail causes an uncomfortable indoor environment. They are also expensive, not generally affordable for low income housing and they perform poorly in coastal regions due to corrosion (Adedeji and Ajayi, 2008). The use of asbestos has been discontinued in most nations of the world due to the danger posed to health (Roy et al., 2013; Stayner et al., 2013). Even though the cost of clay is insignificant, the cost of firing to make tiles is high and this makes it unattractive. In the light of the foregoing, it has become imperative to source local inexpensive raw materials to satisfy this need using available technology (Adedeji and Ajayi, 2008).

The production of building materials from agricultural wastes provides a suitable and sustainable solution to the problem of high cost associated with the import of conventional building materials. These agricultural wastes such as sugar cane, cassava, corn stalks, corn cobs, wood chips, rice husk, and empty oil palm fruit bunch are cheap and abundant in many developing countries, such as the Nigeria, Philippines, Indonesia, Sri Lanka, and India (Amenaghawon et al., 2013). They are mostly underutilized and typically disposed of improperly especially by burning openly thereby creating environmental problems such as increased levels of carbon dioxide (CO_2) which contributes to global warming (Garay et al., 2009). Improper disposal of theses wastes also causes blockage of drains which consequently results in flooding. Accumulation of these wastes results in the release of offensive odour thereby contributing to air pollution and also serves as breeding ground for mosquitoes and flies which spread all sorts of diseases. They also occupy the already limited space available in landfills and remain until biodegradation sets in. The improper disposal of these materials could be avoided by using the wastes as raw materials to obtain value added products (Adedeji, 2011; Adedeji and Ajayi, 2008; Olorunnisola, 2007; Sotannde et al., 2012; Youngquist et al., 1996). One way through which this can be achieved is to incorporate these wastes into bonded roofing sheets production. This will not only reduce waste and its associated environmental problems but will also contribute to economic growth of the country and reduce the dependence on imports. Bonded roofing sheets produced from agricultural wastes are dimensionally stable under varying humidity conditions. They are good construction materials in that they are reliable, resistant to fire, insect attack, and decay. This makes them a very suitable option especially in less developed nations (Papadopoulos, 2008; Sulastiningsih et al., 2000).

This study was therefore carried out to investigate the potential use of cassava stalks and corn cobs for the production of roofing sheets. Also, some physical and mechanical properties of bonded roofing sheets were evaluated. Such production will reduce the pressure on forest resources and provide solutions to the problem of agricultural wastes disposal in Nigeria.

2. MATERIALS AND METHODS

2.1. Material Collection and Pretreatment

The cassava stalks and corn cobs used in this study were obtained from Ifo in Lagos State of Nigeria. Polyvinyl chloride (PVC) and animal glues used as binders were bought from the Mushin area of Lagos State, Nigeria. The cassava stalks were milled and subsequently screened to obtain particles in the size range 2-4 mm using a hammer mill and standard sieves respectively. Three glue solutions were made by separately mixing 40 g each of animal glue, PVC glue and a 1:1 mixture of animal and PVC glue with 30 cm^3 of boiling water. The milled cassava stalks were transferred into hot water at a constant temperature of 85^oC to extract inhibitory sugar compounds such as glucose, hemicelluloses and lignin (Sotannde et al., 2012). This was done in order to ensure proper setting of the sheets. The extracted agro-wastes were separately air dried to attain approximately 12% moisture content before use. The same procedure as outlined in the foregoing was applied to roofing sheets produced from corn cobs and a mixture of cassava stalks and corn cobs.

2.2. Roofing Sheet Formation and Testing

Roofing sheets were made from cassava stalk, corn cobs and a mixture of both. The required amount of agro-waste which was 0.249 kg each was dry-mixed thoroughly with 0.588 kg of the appropriate binder based on ratio 1:2 as shown in Table 1 in a metal container until a uniform lump free matrix was obtained. The furnish was hand formed into a uniform mat inside a wooden box of 0.35 m x 0.35 m that was placed on a steel caul plate and pre-pressed. The steel plate was covered with polythene sheet prior to sheet formation to prevent the sticking of the sheet onto the plate.

Table 1: Experimental conditions for the manufacture of roofing sheets

Production variables	Values
Roofing sheet density	1200 kg/m^3
Mixing ratio of agro-waste to adhesive (binder)	1:2
Roofing sheet thickness	0.006 m
Roofing sheet dimension	0.35m×0.35m×0.006m
Pressing pressure	1.23×10^6 N/m^2

After sheet formation, the wooden plate was removed and another polythene sheet was placed on the mat before placing the metal cauls plate. The mat was then moved to the hydraulic press and pressed under a pressure of 1.23×10^6 N/m^2 for 24 hours. After pressing, the roofing sheets were removed from the cauls and wrapped with polythene sheet and kept in the laboratory environment for 18 days for further curing. The sheets were then stacked for 6 days at a relative humidity of 65 ±2 percent. They were thereafter subjected to physical tests (water absorption (WA) and thickness swelling (TS)) and mechanical tests (modulus of rupture (MOR) and modulus of elasticity (MOE)) in accordance with the procedures stipulated in ASTM D1037 (ASTM, 1995) and DIN 52362 (Normen, 1982) respectively. The sheets produced were labeled in accordance with the materials used as follows: CC: Corn cobs, CS: Cassava stalks, CC-CS: Mixture of corn cobs and cassava stalks. The following nomenclature was used for the binders: AG: Animal glue, PVC: PVC glue, AG-PVC: Mixture of animal and PVC glue.

2.3. Statistical Analysis

The experimental design used in this work was a 3 x 3 factorial experiment in completely randomized design (CRD); the combination of which gives 9 treatments. The factors considered were; material type (cassava stalks, corn cobs and a mixture of cassava stalks and corn cobs) and adhesive type (animal glue, PVC glue and a mixture of animal and PVC glue). Analysis of variance (ANOVA) was used at 5% probability level to test the significance of treatment means.

3. RESULTS AND DISCUSSION

3.1. Effect of production variables on Water absorption (WA) and Thickness (TS) of the sheets

Water absorption (WA) and thickness swelling (TS) tests were carried out on the roofing sheets produced to determine their dimensional stability. The values of percentage water absorption and thickness swelling for roofing sheets produced from corn cobs, cassava stalks and a combination of both using animal glue, PVC glue and a combination of both are shown in Figures 1 and 2. The values of WA obtained from roofing sheets produced from agro-wastes ranged from 8.61 to 57.60 % for animal glue, 5.61 to 47.84 % for PVC glue and 2.44 to 47.4 % for a mixture of animal and PVC glue. Figure 1 shows that the highest WA was obtained for roofing sheet produced from corn cobs with animal glue as binder while the least WA was obtained for roofing sheets produced from a mixture of corn cobs and cassava stalks with a mixture of animal and PVC glue as binder. The high values recorded for WA in glue bonded roofing sheets could be attributed to difficulty in compression and the presence of voids in the sheets which allowed water to permeate in (Lee, 1984; Sotannde et al., 2012). The results presented in Figure 1 shows that the roofing sheets produced from a mixture of corn cobs and cassava stalks with a mixture of animal and PVC glue as binder was more resistant to the permeation of water hence it has the potential to perform better than others in very humid environments or when exposed to water or moisture.

Table 2 shows the result of analysis of variance (ANOVA) of the effect of production variables on water absorption. The results show that the effect of adhesive type and the two factor interaction between adhesive type and agro-waste on the WA of the roofing sheets were not significantly different at the 5% probability level observed. On the other hand, the effect of different agro-wastes on WA was significantly different at the same probability level. This shows that different agro-wastes reacted to the moisture exposure test carried out on the produced roofing sheets.

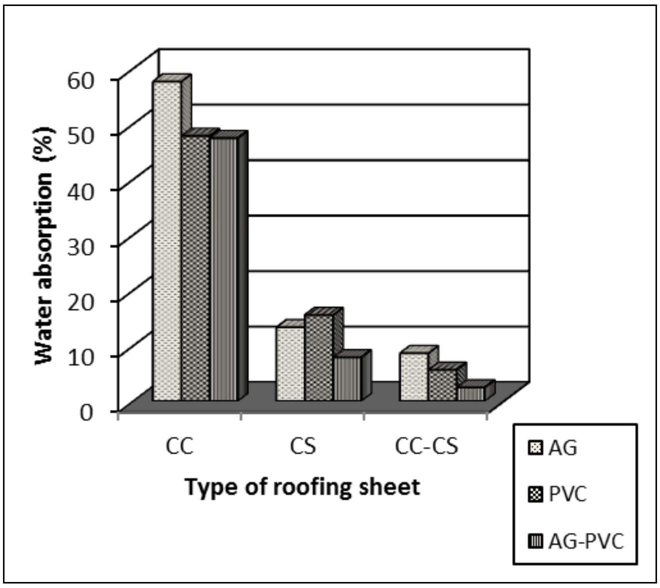

Fig. 1: Percentage water absorption of roofing sheets produced under different conditions

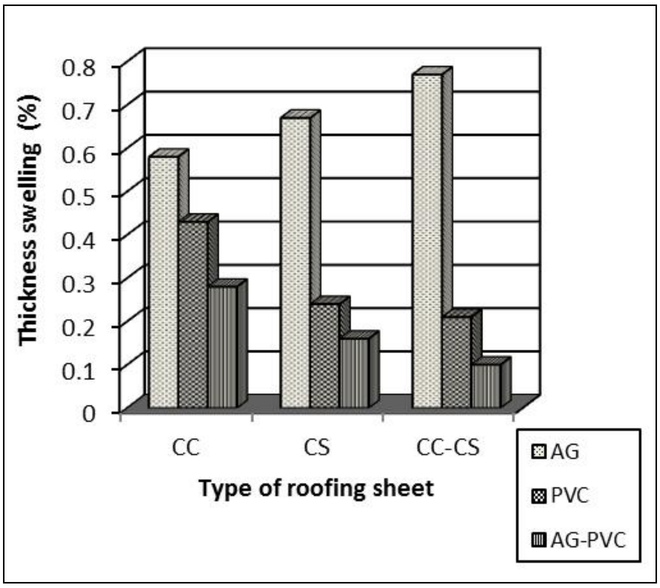

Fig. 2: Thickness swelling of roofing sheets produced under different conditions

Table 2: Analysis of variance of the effect of production variables on water absorption

Source	Df	Type III Sum of squares	Mean square	F	Sig
Adhesive	2	235.7	117.9	2.696	0.089^{ns}
Agro-waste	2	10824.1	5412.1	123.781	0.001*
Adhesive× Agro-waste	4	111.8	27.9	0.639	0.64 ^{ns}
Error	18	787.1	43.7		
Total	26	11958.7			

* = Significant, ns = Not significant

The values of TS obtained from roofing sheets produced from agro-wastes ranged from 8.61 to 57.60 % for animal glue, 5.61 to 47.84 % for PVC glue and 2.44 to 47.4 % for a mixture of animal and PVC glue as shown in Figure 2. The trend of TS was similar to that observed for WA of roofing sheets produced with

PVC and a mixture of animal and PVC glue as binder. However, a different trend was observed for the TS of roofing sheets produced with animal glue as binder. The TS is affected by the presence of void spaces in the roofing sheets in the same way as WA as these spaces enhance the absorption of water by the sheets. Lee (1984) reported that the presence of large number of voids within these kind of composite materials results in internal swelling. The roofing sheet made from a mixture of the agro-wastes with a combination of animal and PVC glue as binder had the smallest value of TS. This result coupled with that obtained for WA of roofing sheets made from a mixture of the agro-wastes with a combination of animal and PVC glue indicate more dimensionally stability of the sheets. This might probably be as a result of the increase in the hydrophobicity of the composite material formed from a combination of the two agricultural wastes. Erakhrumen et al. (2008) reported that the physical properties of bonded particle boards can be affected by the lignocellulosic material they are made from. Bektas et al. (2004) reported that these properties can be improved by the utilisation of hydrophobic materials in the composite. For general purpose panels/boards, the American National Standard ANSI/A208.1-1999 specifies maximum TS of 8%. The results presented in Figure 2 show that all the roofing sheets produced met the requirements specified by the American National Standard Institute ANSI/A208.1-1999 for general use panels (ANSI, 1999).

The results of analysis of variance (ANOVA) of the effect of production variables on thickness swelling as shown in Table 3 indicate that the effect of agro-waste type and the two factor interaction between adhesive type and agro-waste on the TS of the roofing sheets were not significantly different at the 5% probability level. However, the effect of different adhesives on TS was significantly different at the same probability level.

Table 3: Analysis of variance of the effect of production variables on thickness swelling

Source	Df	Type III Sum of squares	Mean square	F	Sig
Adhesive	2	1.193	0.596	16.805	<0.0001*
Agro-waste	2	0.032	0.016	0.450	0.645 ns
Adhesive× Agro-waste	4	0.166	0.042	1.171	0.357 ns
Error	18	0.639	0.035		
Total	26	2.029			

* = Significant, ns = Not significant

3.2. Effect of production variables on Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of the sheets

The mean values of modulus of rupture of the different roofing sheet tested are presented in Figure 3. Roofing sheets produced from a mixture of agro-wastes with a combination of animal and PVC glue as binder had the highest value of MOR (4.59×10^6 N/m^2) while the least MOR (0.41×10^6 N/m^2) was obtained for roofing sheets produced from corn cobs with PVC glue as binder. The high values of MOR obtained could be as a result of the random distribution of the particles in the sheets as explained by Sotannde et al. (2012). The American National Standard ANSI/A208.1-1999 specifies a minimum MOR of 3×10^6 N/m^2. The results obtained show that the roofing sheets produced from a mixture of agro-wastes with a combination of animal and PVC glue as binder met the requirements specified by the American National Standard Institute ANSI/A208.1-1999 for general use panels (ANSI 1999). Roofing sheets produced from cassava stalks and animal glue as well as sheets produced from a mixture of agro-wastes and animal glue also met the standard set by ANSI (1999).

The results of analysis of variance (ANOVA) of the effect of production variables on MOR as shown in Table 4 indicate that the effect of agro-waste type and the adhesive type on the MOR of the roofing sheets were significant at the 5% probability level. However, the effect of the interaction between the adhesive type and agro-waste type on the MOR was not significant at the same probability level.

The modulus of elasticity (MOE) of the different roofing sheets is presented in Figure 4. The results show that the MOE followed the same trend as that of the MOR as shown in Figure 4. Roofing sheets produced from a mixture of agro-wastes with a combination of animal and PVC glue as binder had the highest mean value of MOE (793.7×106 N/m2) while the least MOE (193.6×106 N/m2) was obtained for roofing sheets produced from corn cobs with PVC glue as binder. This might probably be as a result of the combined mechanical strengths offered by combining both materials. For general purpose panels/boards, the American National Standard ANSI/A208.1-1999 specifies a minimum MOE of 550×106 N/m2. The results presented in Figure 4 show that the roofing sheets produced from a mixture of agro-wastes with a combination of animal and PVC glue as binder met the requirements specified by the

American National Standard Institute ANSI/A208.1-1999 for general use panels (ANSI 1999). Roofing sheets produced separately from corn cobs and a mixture of animal and PVC glues, cassava stalks and animal glue, cassava stalks and a mixture of animal and PVC glue, also met the standard recommended by ANSI (1999).

Table 4: Analysis of variance of the effect of production variables on MOR

Source	Df	Type III Sum of squares	Mean square	F	Sig
Adhesive	2	24.802	12.401	65.138	<0.0001*
Agro-waste	2	17.409	8.704	45.721	<0.0001*
Adhesive× Agro-waste	4	1.270	0.318	1.668	0.20 ns
Error	18	3.427	0.190		
Total	26	46.908			

* = Significant, ns = Not significant

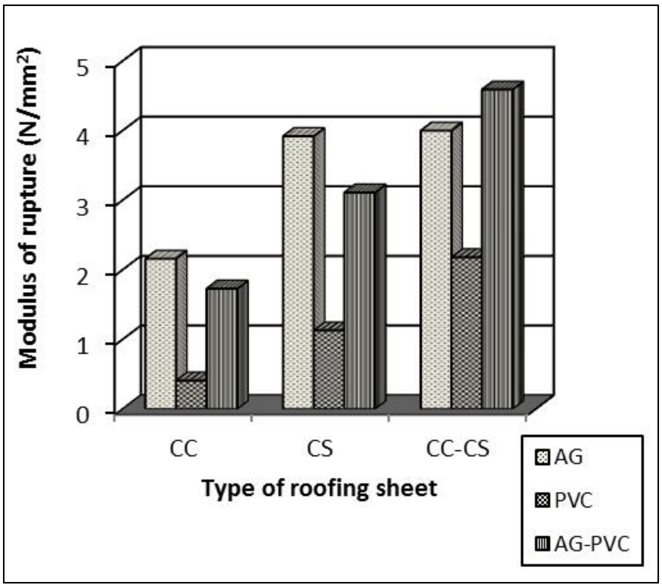

Fig. 3: Modulus of rupture of roofing sheets produced under different conditions

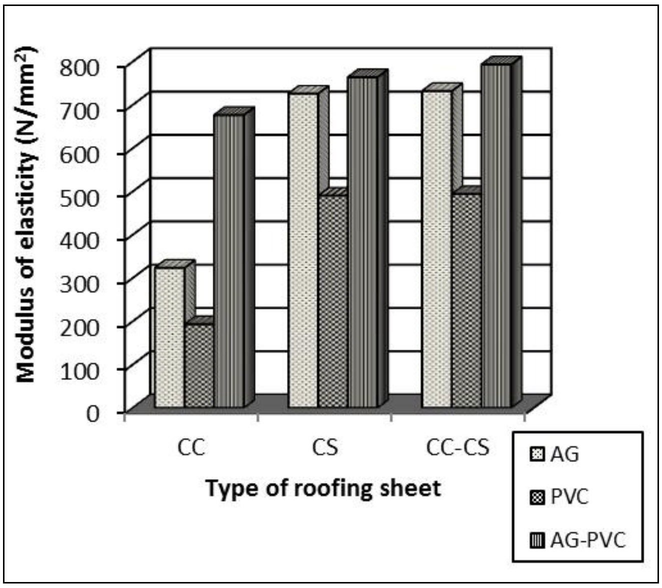

Fig. 4: Modulus of elasticity of roofing sheets produced under different conditions

The results of analysis of variance (ANOVA) of the effect of production variables on MOE as shown in Table 5 indicate that the effect of all factors on the MOE of the roofing sheets were significant at the 5% probability level. This shows that all the factors had a significant influence on the MOE of the sheets.

Table 5: Analysis of variance of the effect of production variables on MOE

Source	**Df**	**Type III Sum of squares**	**Mean square**	**F**	**Sig**
Adhesive	2	534676.892	267338.446	182.901	<0.0001*
Agro-waste	2	448653.247	224326.624	153.474	<0.0001*
Adhesive× Agro-waste	4	131559.713	32889.928	22.502	<0.0001*
Error	18	26309.787	1461.655		
Total	26	1141199.639			

* = Significant

4. CONCLUSION

The present study investigated the potential use of cassava stalks and corn cobs for the production of roofing sheets using animal and PVC glues as binder. Roofing sheets can be produced from agricultural wastes such as cassava stalks and corn cobs using animal and PVC glues as binder.

The sheets produced from a mixture of corn cobs and cassava stalks using a combination of animal and PVC glues as binder are more dimensionally stable as evident in their small values of water absorption and thickness swelling compared to the other samples. They have higher mechanical strengths as evident in the higher values of MOR and MOE compared to the other samples and satisfy the ANSI/A208.1-1999 standard.

Conclusively, the type of adhesive used significantly influence the TS, MOR and MOE except the WA. The type of agro-waste used significantly influenced the WA, MOR and MOE but not the TS.

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