Chapter 4

Development of Sustainable Building Materials from Agro-Industrial Wastes in Nigeria

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Additional information is available at the end of the chapter

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Abstract

One of the continuing challenges posed by unprecedented urbanisation in Nigeria, estimated at about 5% per annum, is the provision of adequate and affordable housing. The shortage in housing, due in part to the ever-rising prices of construction materials, makes it logical to consider alternative building materials. Paradoxically, Nigeria is grappling with the challenges of managing solid waste, many of which could find suitable applications in the production of cement-, concrete- and clay-based walling, roofing and ceiling products as well as pozzolans for partial replacement for ordinary Portland cement. The objective of this chapter is to present information on the development, experimental investigations and practical application of sustainable building materials from agro-industrial wastes in Nigeria. Agroforestry residues such as bagasse and corn cob ashes have been found suitable as pozzolans; cement- and clay-bonded reinforced composite roofing tiles, hollow concrete blocks and stabilised clay bricks have been developed using a variety of lignocelluloses as sources of fibre reinforcement, while biomaterial substitutes for steel reinforcement in concrete have been tested. However, for these products to become widely acceptable, greater awareness has to be created among all stakeholders in the building construction industry, coupled with the development of appropriate building codes.

Keywords: housing, construction materials, agro-industrial wastes, rattan, bamboo

1. Introduction

Housing is one of the three basic needs of mankind, and it is the most important for the physical survival of man after the provision of food. Housing, either in units or in multiple forms, is a significant component of the physical form and structure of a community. In other words, adequate housing contributes to the attainment of physical and moral health of a nation and stimulates social stability and work efficiency. It is also an indicator of a person's standard of living and of his place in the society [1].

One of the continuing challenges posed by unprecedented urbanisation in Nigeria and many other Sub-Saharan African countries is the provision of adequate and *affordable housing*. Affordable housing is a term used to describe dwelling units whose total housing costs are deemed "affordable" to a group of people within a specified income range. Although the term is often applied to rental housing that is within the financial means of those in the lower-income ranges of a geographical area, the concept is applicable to both renters and purchasers in all income ranges. In the United States and Canada, a commonly accepted guideline for housing affordability is a housing cost that does not exceed 30% of a household's gross income. Housing costs considered in this guideline generally include taxes and insurance for owners and usually include utility costs. When the monthly carrying costs of a home exceed 30–35% of household income, then the housing is considered unaffordable for that household [2].

The challenges of urbanisation and the attendant consequences on housing provision are probably more widespread in Nigeria than anywhere else in Sub-Saharan Africa. Approximately 50% of the Nigerian population lives in urban cities with predictions that the urban population will hit the 65% mark by the year 2020. Rapid urban growth has resulted in problems of urban congestion or overcrowding and poor housing, among other challenges. Typical manifestations of this unmet demand include proliferation of slums in the cities with Nigeria having the fourth largest number of slum dwellers in the world (**Figure 1**) and the menace of skyrocketing house rents. Estimates show that Nigeria housing deficit is over 16 million units. An average of 1 million housing units per year is required not only to replenish decaying housing stock but also to meet rising demand [3, 4].

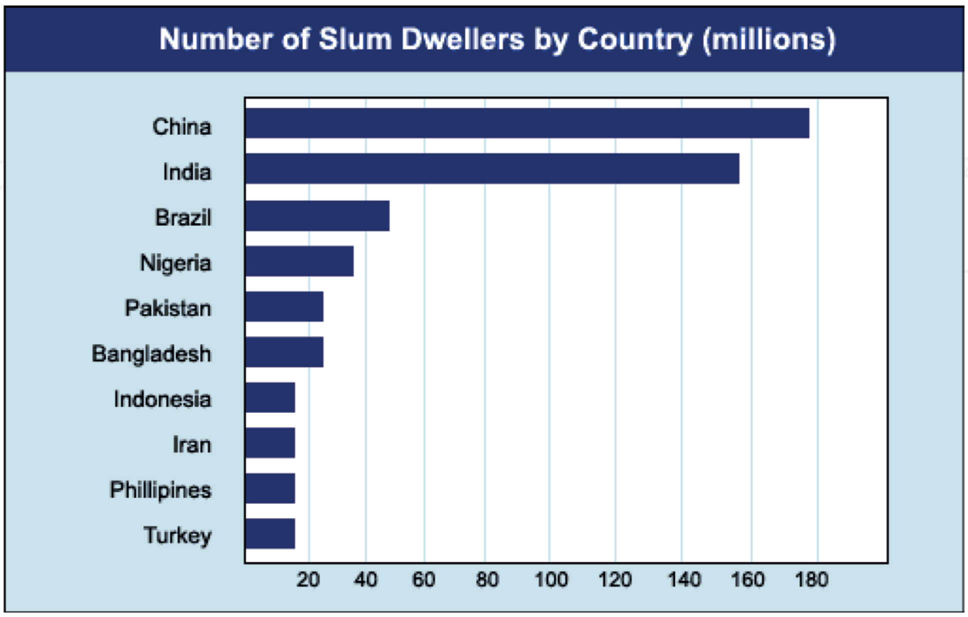

Figure 1. Number of slum dwellers in different countries. Source: [3].

Unfortunately, the twin concepts of *Public housing*, a form of housing tenure in which the property is owned by a central or local government authority, and *Social housing*, an umbrella term referring to rental housing owned and managed by the state, not-for-profit organisations, or a combination of the two, are not popular yet in Nigeria, even though the common goal of both concepts is to provide affordable housing. The consequence is that a vast majority of individuals engage in the construction of personal houses financed through different means including savings and loans, excluding in most cases long-term financing—mortgage financing and mortgage-backed securities—which is still at the rudimentary state of existence in the country at the moment [4].

The housing problem in Nigeria is more serious for the low-income groups whose challenges are complicated by several factors including the ever-increasing cost of construction materials. The aim of this chapter, therefore, is to discuss the potentials of nonconventional building materials derived from agroforestry and municipal wastes in addressing the challenges of affordable housing construction in Nigeria.

2. A brief review of conventional building materials in common use in Nigeria

Rocks and its derivables including stones, granite, gravel, sand and clay and wood, twigs and leaves have been used to construct buildings across Nigeria over the ages. Rock is the longest lasting building material available and is readily available in the country. Wood, a product of trees and sometimes other fibrous plants, is also used for construction purposes when cut or pressed into lumber and timber, such as boards, planks and similar materials. Apart from the aforementioned naturally occurring construction materials, many man-made products are in use including steel used as structural framework for larger buildings such as skyscrapers or as an external surface covering, glass and concrete. The most common form of concrete is Portland cement concrete, which consists of mineral aggregate (generally gravel and sand), Portland cement and water [4].

Concrete hollow blocks (**Figure 2**) and unfired clay bricks (**Figure 3**) are two of the predominant conventional materials for the construction of houses in Nigeria. Concrete hollow blocks manufactured in a factory or on-site made of Portland cement and sand in a ratio of 1:8, and more commonly used in the urban and peri-urban areas, are usually rectangular, often 45 cm

Figure 2. Freshly manufactured concrete hollow blocks.

Figure 3. A typical building constructed using clay bricks.

Figure 4. A typical building under construction using concrete hollow blocks.

wide, 15 cm thick and 30 cm high and yellow/whitish in colour. The hollows tend to run from top to bottom and occupy about two-thirds of the volume of the block [5]. The blocks are usually joined together with mortar in building construction as shown in **Figure 4**.

Clay is relatively cheap, environmental friendly and abundantly available, and there are large deposits of laterite clay in the six geopolitical zones of Nigeria [6]. Hence, clay is widely used for building construction across the country. Unfired clay bricks are particularly prominent in rural housing construction. Such buildings come in different forms such as when the walls are made directly with the mud mixture, when walls are built by stacking air-dried mud bricks, when the walls are made with clay combined with straws to create light clay and when brick walls are made from cement-stabilised bricks, i.e. laterite stabilised with just 5% cement or cement-stabilised interlocking blocks [7].

3. Recent advances in the production of sustainable building materials in Nigeria

One of the challenges associated with the use of concrete hollow blocks in building construction is the relatively high cost of Portland cement. While Nigeria does not produce enough cement domestically to meet demand, imports have been restricted, leading to sharp increases in the price of cement. Also, concrete blocks and unfired clay bricks tend to exhibit brittleness in failure. One way of addressing the challenge of escalating cost of cement is the partial replacement of Portland cement with either with pozzolana or a lime in the production of concrete hollow blocks. The challenge of cost and brittle failure could both be addressed simultaneously by the addition of fibrous materials to delay and control tensile cracking of the matrix [8]. Incidentally, vast quantities of agroforestry, industrial and municipal solid waste are generated which constitute a source of health hazards and environmental pollution in Nigeria. One way of reducing the cost of housing construction is by recycling some of the agroforestry and industrial municipal waste materials either as pozzolanas, fillers or reinforcement materials in innovative cement- and clay-bonded low-cost building materials. Doing so should help in conserving energy and preserving the environment even as the products are expected to exhibit acceptable strength, sound, thermal and durability properties [8]. Examples of such sustainable building materials investigated for diverse applications in Nigeria within the last two decades include the following paragraphs.

3.1. Pozzolans and blended cement

In Nigeria, many agricultural residues are freely available and often treated as waste. Examples include bagasse (waste obtained from sugar cane (*Saccharum officinarum*) processing) and corn (*Zea mays)* cobs. The pozzolanic activities of the ashes of these two residues have been tested and proven [9, 10]. The chemical analysis of bagasse ash is presented in **Table 1**. The combined percentage composition of silica, alumina and ferric oxide exceeds the minimum requirement of 70% for a good pozzolan for the manufacture of blended cement in both bagasse and corn cob ashes. It has been further reported that a corn cob ash (CCA)-blended cement containing not more than 15% of CCA satisfies the NIS 439:2000 and ASTM C 150 requirements for cement. The workability and compressive strength of CCA-blended cement concrete were also investigated [11]. Experimental results showed that CCA-blended cement containing not more than 8% of CCA is suitable for structural concrete works.

Calcium carbide residue is a by-product of oxyacetylene gas welding, a very toxic material whose toxicity can be contained by incorporating it in construction materials [12]. However, it is mostly sent to landfills in Nigeria. It is generally believed that since calcium

Element	Quantity (%)
SiO_2	57.95
Al_2O_3	8.23
Fe_2O_3	3.96
K_2O	2.41
CaO	1.17
Loss in ignition (LOI)	5.00

Table 1. Chemical analysis of bagasse ash.

carbide residue is rich in calcium hydroxide, it behaves like hydrated lime. Hence, calcium carbide residue has also been analysed for potential use as partial replacement for cement in concrete works [13]. A comparison of the results of chemical analysis of the calcium carbide samples tested in Nigeria with those reported by other researchers elsewhere [14, 15] and presented in **Table 2** shows that there were little but insignificant variations in the chemical compositions.

3.2. Natural fibre-reinforced roofing tiles

The major types of roofing materials presently in use in Nigeria include corrugated iron and aluminium sheets, slates and asbestos sheets [16]. While corrugated iron sheets are prone to rusting and can be noisy when it is raining, asbestos roofing sheets are relatively expensive and have been outlawed in many countries due to carcinogenic nature of asbestos fibres. Investigations on the development of alternative roofing materials from wood fibre-cement composites have been going globally on for over 30 years now [17].

A major source of fibre for cement-bonded roofing tile production is rattan, a specialised group of scaly fruited, spiny, climbing palms with flexible stem generally found near water courses in no less than 20 African countries including Nigeria. The stem popularly referred to as 'cane' is generally considered an 'open-access' resource that is readily harvested from wild forests largely for furniture and handicraft production. However, in many rural areas, the cane is split to make ropes used to tie bamboo and stick frame of houses before the frame is plastered with mud [18, 19]. To its advantage, rattan is much easier to harvest, requires simpler tools and is much easier to transport and grows much faster than most tropical wood [19]. The bonding of whole rattan canes, fibres and splits with ordinary Portland cement has been reported [20] as well as the development of methodologies for rattan fibre, particle and

Element	Sources of calcium carbide residue		
	Nigeria [9]	Bahrain [13]	Thailand [14]
	Quantity (%)		
SiO_2	2.69	<0.10	3.4
Al_2O_3	1.78	<1.22	2.6
Fe_2O_3	0.17	0.02	0.3
K_2O	0.10		0.0
CaO	61.41	65.05	51.9
MgO	0.80	0.97	0.5
Na_2O	0.0	Not indicated	0.0
SO_3	Not indicated	0.64	0.2
Loss in ignition (LOI)	32.51	27.92	41.7

Table 2. Chemical analyses of calcium carbide residues of various origins.

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strand application in cement-bonded composite manufacture [21–23]. Also, the production of relatively strong and dimensionally stable cement-bonded roofing tiles reinforced with rattan fibres in which cement was partially replaced with carbide waste has been reported [24, 25], and samples are shown in **Figure 5**.

Banana (*Musa acuminata*) fibre has also been investigated as a reinforcement material in cement-bonded composite roofing tile production in Nigeria [26]. The researchers studied the effects of partial replacement of cement with calcium carbide residue and the addition of calcium chloride ($CaCl_2$) on the properties of banana fibre-reinforced roofing tiles. The fibre content was fixed at 3%, while lime replacement levels by mass of cement were 0 (control), 10, 20 and 30%. Two percent of Iron II oxide was added for colouring, while $CaCl_2$ was added at 0 (control) and 3% levels. The density of the roofing tiles ranged between 1.63 and 2.0 g/cm^3. Calcium carbide residue and $Cacl_2$ reduced the density of the composites. There was also a decrease in impact strength as the calcium carbide residue content increased.

Other fibrous materials already investigated and found suitable for cement-bonded composite roofing tile production in Nigeria include bamboo (*Bambusa vulgaris*), coconut husk (*Cocos nucifera*), sugar cane bagasse (*Saccharum officinarum*), raffia palm (*Raphia africana*) and luffa (*Luffa cylindrica*) [27–31]. Samples of bamboo and coconut husk roofing tiles are shown in **Figures 6** and **7a,b**.

In a departure from the use of ordinary Portland cement alone as the binder, the production of clay-cement-sawdust composite roofing tiles using sawdust derived from teak (*Tectona grandis*) and wood ash as a partial replacement for cement was investigated [32]. The basic properties of the lateritic clay material used are presented in **Table 3**, while the properties of the tiles produced are presented in **Table 4**. Partial replacement of ordinary Portland cement with about 10% of wood ash was found very acceptable in producing composite roofing tiles with relatively good bending strength, while partial replacement of cement with between 20 and 30% of wood ash reduced the thermal conductivity of the composite roofing tiles to acceptable levels.

Figure 5. A prototype roof fabricated from rattan-cement composite tiles. Source: [16].

Figure 6. Fibre-reinforced composite roofing tiles installed on a gable-roofed building in Ibadan, Nigeria. Source: [23].

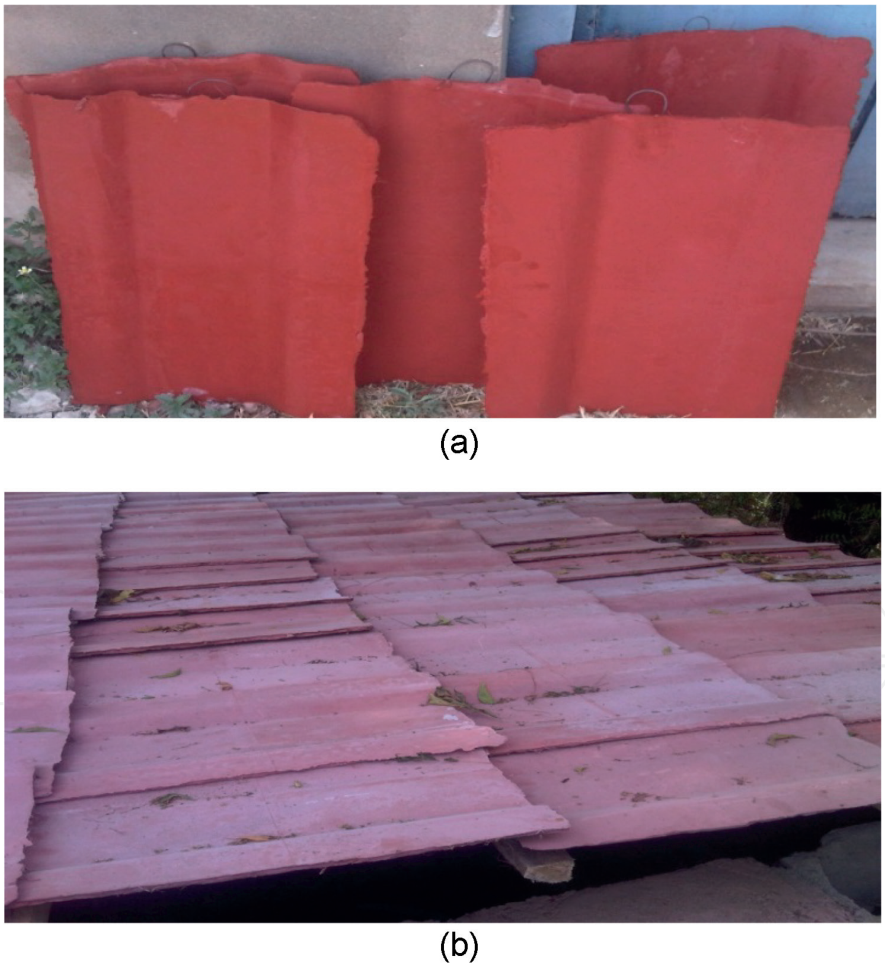

Figure 7. (a) Samples of cured coconut husk fibre-reinforced roofing tiles, (b) coconut husk fibre-reinforced roofing tiles installed on a flat roof building. Source: [30].

Properties	Quantity
Natural moisture content (%)	3.18
Liquid limit (%)	71.5
Plastic limit (%)	59.63
Plasticity index (%)	11.87
Percentage passing BS.NO.200 sieve	233.5
Specific gravity	2.78
AASHTO classification	A-7-6
USCS classification	CH
Maximum dry density, MDD (M/m^3)	1.45
Optimum moisture content, OMC (%)	25.25
pH value	6.7
Colour	Reddish brown

Table 3. Basic properties of the laterite used for composite tile production.

Sample composition	Mean density (Kg/m^3)	Mean impact energy (J)	Mean thermal conductivity (W/m.k)	Mean 24-h water absorption (%)
Clay + cement + sawdust (2:3:1) (control)	850	0.95	1.44	32.2
Clay + 90% cement + 10% wood ash + sawdust	960	1.14	1.26	23.8
Clay + 90% cement + 20% wood ash + sawdust	940	0.68	1.18	38.3
Clay + 90% cement + 30% wood ash + sawdust	980	0.64	1.18	43.2

Table 4. Selected properties of laterite-cement composite roofing tiles.

3.3. Cement-bonded composite ceiling boards

Cement-bonded particleboard is a generic term for a panel product manufactured from lignocelluloses primarily in the form of discrete pieces or particles, combined with cement and compacted. Some of the admirable properties of cement-bonded particleboards include relatively high strength-to-weight ratio and durability; high resistance to moisture uptake, nailability and ease of sawing; excellent insulation against noise and heat; and high resistance against fire, insect and fungus attack. The panels do not emit gases or leak harmful chemicals [33]. One of the common nonstructural uses of cement-bonded particleboard in housing construction is for ceiling, i.e. as an overhead interior surface that bounds the upper limit of a

Figure 8. Made-in-Nigeria ceiling board-making machine. Source: [16].

Figure 9. Made-in-Nigeria wood-cement composite ceiling boards after installation. Source: [16].

room, a finished surface concealing the underside of the roof structure. Ceiling boards serve the purposes of thermal insulation, noise reduction/absorption and fire protection.

Ceiling boards have been manufactured from a number of lignocellulosic fibres and wastes in Nigeria including sawdust, waste paper, rattan cane, coconut husk, maize husk, elephant grass (*Pennisetum purpureum*), pawpaw (*Carica papaya*) pseudostem, okra (*Abelmoschus esculentus* L. Moench) and *Cissus populnea*, among others. In many of these investigations, ordinary Portland cement was partially replaced either with rice husk ash (RHA) or calcium carbide residue [34–39]. The development of a low-cost motorised ceiling board-making machine (**Figure 8**) has also been reported [16]. Samples of selected made-in-Nigeria ceiling boards are shown in **Figures 9** and **10**, while a comparison of the basic properties of some of the ceiling boards with asbestos cement ceiling board is presented in **Table 5**.

3.4. Sawdust-reinforced concrete hollow blocks and clay bricks

As earlier noted, concrete hollow blocks and clay bricks remain popular construction materials in Nigeria for walls of single-storey buildings in urban and rural areas, respectively.

Figure 10. Made-in-Nigeria wastepaper-cement composite ceiling boards. Source: [16].

Board properties	Asbestos cement	Sawdust cement	Maize stalk cement	Coconut husk cement	Rattan cement
Density (kg/m^3)	1200	1200	1200	990–1200	1360
Modulus of rupture (N/mm^2)	7.7	2.0–4.0[a] 8.7–11.2[b]	3.1–5.4	4.3–7.4	7.0
Modulus of elasticity (N/mm^2)	3142	1250–3000[a] 3000–4000[b]	6409	4253	3350
Water absorption at 24 h (%)	13.8–17.8	18.0[a] 28.0[b]	25.7	22.1	2.5
Thickness swelling at 24 h (%)	0.21–0.29	0.16[a] 0.43[b]	0.88	0.6	0.5
Sound absorption ratio (%)	35.0	35.0[c]	35.0[c]	35.0–40.3[c]	
Thermal conductivity (W/Km)	0.38	0.38[c]	0.38[c]	0.30–0.38[c]	

[a]100% sawdust cement panel
[b]Three-layered boards incorporating flakes
[c]Theoretical computed value

Table 5. A comparison between asbestos cement and cement-bonded composite ceiling boards manufactured with selected agroforestry materials.

Though the strength of a concrete hollow block is less than that of fired clay bricks, it is considerably cheaper. In a bid to further reduce the cost of concrete hollow blocks, the possibility of incorporating Nigerian-grown teak (*Tectona grandis*) sawdust and partial replacement of cement with calcium carbide residue and poultry egg shell powder in the mix for the production of low-cost concrete hollow blocks was investigated [30]. Representative samples of 100 × 100 × 100 mm sawdust-reinforced concrete hollow blocks were produced using different percentages of sawdust (20, 25, 30%) and carbide calcium carbide residue (30, 25, 20%) in the mix. These were cured for 28 days, after which 24-h water absorption and thickness swelling as well as compressive strength were determined. The water absorption (6.1–10.3%)

and thickness swelling (1.2–1.9%) were quite acceptable. The maximum compressive strength obtained in the mix containing 20% sawdust and 30% of carbide waste fell within the measured strength values (0.5–1 N/mm^2) of commercially available concrete hollow blocks in Nigeria. The preliminary cost analysis indicated the possibility of a 20% reduction in the production of concrete hollow blocks with the incorporation of sawdust and calcium carbide residue in the production mix.

In another investigation, the possibilities of using sawdust of *Cordia millenii* timber species, calcium carbide residue and poultry eggshell powder for the production of stabilised laterite clay bricks were explored [40]. It is well known that poultry egg contains about 95% calcium carbonate and hence can be used as a supplement for lime. The index properties of the laterite were first determined. A set of 100 mm × 100 mm × 100 mm bricks (**Figure 11**) was then produced using laterite stabilised with 50% of sawdust and 10% ordinary Portland cement (w/w). Based on the combined results of the liquid limit and the particle size analysis, the clay was classified as A-7-6 and CH in accordance with AASHTO and the Unified Soil Classification System, respectively. Its specific gravity of 2.8 fell within the range of 2.6 and 3.4 reported for lateritic soils, while its pH of 6.7 showed that it was slightly acidic. In some of the samples, ordinary Portland cement was partially replaced (w/w) with calcium carbide residue (50%) and eggshell powder (30%). The density, compressive strength and 24-h water absorption of the bricks were determined after 28 days of air drying under a shade and shown in **Table 6**. Both the calcium carbide residue and egg shell powder significantly lowered the density and compressive strength ($p \leq 0.05$). Incorporation of the poultry egg shell powder led to an increase in water absorption of the bricks. Only bricks produced from a mixture of laterite, sawdust and cement met the minimum compressive strength requirement of 1.65 N/mm^2 specified by the Nigerian Building and Road Research Institute for building construction.

3.5. Natural fibre-reinforced floor and wall tiles

Tiles are hard-wearing thin, flat slabs or blocks typically made from porcelain, fired clay or ceramic with a hard glaze or other materials such as glass, metal, cork and stone. They

Figure 11. Samples of nonconventional clay bricks. Source: [33].

Brick composition	Density (Kg/m^3)	Compressive strength (N/mm^2)	24-h water absorption (%)
Sawdust + cement + laterite (control)	950	1.73	54.9
Sawdust + cement + calcium carbide residue + laterite	940	1.59	59.2
Sawdust + cement + egg shell + laterite	930	1.53	51.9
Sawdust + calcium carbide residue + laterite	860	1.39	62.1
Sawdust + egg shell + laterite	830	1.13	63.5

Table 6. Selected properties of the modified clay bricks.

are usually used to form wall and floor coverings and can range from simple square tiles to complex mosaics. Modern concrete tiles are made from the mixture of Portland cement and quarry sand as an aggregate. The major advantage of fibre reinforcement of concrete tiles is to impart additional energy-absorbing capability and to transform a brittle material into a pseudo-ductile material [41]. One of the sources of natural fibres found throughout West Africa and readily available in Nigeria is *Cissus populnea* (Guill. and Perr.) shown in **Figure 12**, a strong woody climbing shrub, typically 8–10 m long and 7.5 cm in diameter. Although greater attention has been paid to the binding properties of *Cissus populnea* [42], less attention has been paid to the fibrous leftover once the gum is extracted, a potential material for fibre-reinforced cementitious composite production.

A manually operated machine for the manufacture of *Cissus* fibre-reinforced cement-bonded composite floor tiles (**Figure 13**) was developed and used to produce 200 (length) × 100 (width) × 10.5 mm (thickness) tiles of different colours—white, red, yellow, blue, green, black and grey (**Figure 14**) [41]. The average mass per unit area was 25.5 kg/m^2. The impact energy absorption capacity of the composite tiles (2943 Nmm) was relatively lower than that of a typical ceramic tile (3746 Nmm). However, the fibre-reinforced tiles had much lower water absorption of 7% than 12% for a typical ceramic tile at after 24 h of soaking in cold water, while both types of tiles had the same thickness swelling of 3%.

Figure 12. *Cissus populnea* shrubs.

Figure 13. Side view of the tile-making machine. Source: [41].

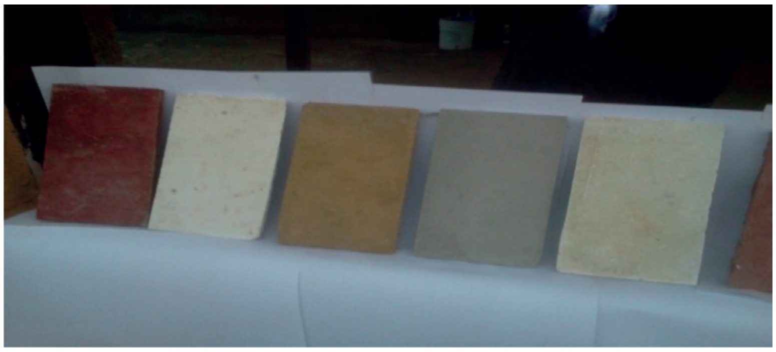

Figure 14. Samples of cement-bonded *Cissus populnea* fibre-reinforced floor tiles produced. Source: [41].

3.6. Concrete beam reinforcement

Portland cement concrete is relatively strong in compression but weak in tension. The weakness in tension is typically overcome by the use of the conventional rod (steel bar) reinforcement. However, the permeability of concrete allows the entry of other aggressive elements which leads to carbonation and chloride ion attack resulting in corrosion problems, hence the search for alternative reinforcing materials.

The bond strength of the canes of selected rattan species in concrete was investigated [43]. It was reported that the strength could be up to roughly 30% of that of mild steel with concrete. The use of whole canes, fibres and splits of rattan canes as reinforcement materials in concrete slabs was also investigated [20]. It was noted that rattan canes remained stable in strength and dimensions after 36 months of embedment in concrete and that canes could be used as reinforcement in lightly loaded structures. In another study, the suitability of bamboo (*Bambusa vulgaris*) as an alternative reinforcement material in concrete slabs was also investigated and confirmed [44], as well as the suitability of bamboo and rattan cane as reinforcement in concrete struts [45]. It was reported that the average compressive strength of the bamboo- and rattan-reinforced struts was about 78 and 64% of the equivalent steel reinforcement, indicating that both materials could be used as replacements for steel in struts of low load-bearing structures.

Figure 15. (a) Rattan cane reinforcement, (b) lintel beam casting in progress, (c) the cured concrete lintel beam after 28 days. Source: [23].

The potential use of oil palm (*Elaeis guineensis*) stem as reinforcement in concrete was also confirmed [46] as well as the suitability of rattan cane in reinforced concrete lintel beam fabrication in rural building construction in Nigeria [30]. The concrete lintel beam dimensions were 0.23 m × 0.254 m × 1.37 m, while the mean diameter of the rattan cane stems was 30 mm. They were soaked in water for 24 h to ensure flexibility, manually straightened and cut into 4 long (1300 mm) and 12 short (187 mm) pieces. The short pieces were tied to the long ones as stirrup with binding wires, sun-dried for 2 days to about 15% moisture content and then placed in the formwork for casting three 0.23 m × 0.254 m × 1.37 m concrete lintel beams (**Figures 15a,b**). The cement content of the concrete was partially replaced with 20% RHA to reduce the alkalinity. After 28 days post-casting operation, the formwork was removed, and it was observed that the lintel was straight with no sign of deformation (**Figure 15c**). Hence, it was successfully demonstrated that rattan canes with diameters ranging from 26 to 31.5 mm could be used as alternative to steel in lintel construction with up to 54% reduction in production cost.

4. Conclusion

Article 25 of the Universal Declaration of Human Rights states that "Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing …". In confronting the daunting challenges of inadequate housing in Nigeria, research efforts in recent years have been geared towards using locally available materials in developing sustainable wall construction, roofing, flooring and ceiling products, as well as concrete slab and strut reinforcement products in residential building construction. Some efforts have also been geared towards developing appropriate facilities for the small-scale manufacturing of fibre-reinforced roofing, flooring and ceiling tiles. However, for these products to become widely acceptable as building components, greater awareness has to be created among all stakeholders in the building construction industry, coupled with the development of appropriate design codes.

Conflict of interest

There is no conflict of interest.

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