Expanded Poly Styrene Core Panel System For Construction of Affordable Housing

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Abstract- *Expanded polystyrene (EPS) is one of the building material capable of enhancing the design and structural integrity of the building. Since its recognition as conventional insulating material in 1950s, EPS has been experiencing swift progress in other new implementations. Currently, EPS is utilized in many building structures owing to its sustainability benefit and improvement in terms of energy efficiency, durability, and indoor environmental quality. The provision of affordable residential houses for the masses in the developing nations has been a mirage over the years and the future does not portend good as the cost of adopting conventional concrete material technologies is escalating while so many environmental issues like climate change are being raised in the recent times. To circumvent this poor housing provision trend, some innovative construction materials and technologies are being introduced to facilitate unique modular designs, reduction of labour, decline in the depletion of exhaustible materials , savings of time and fund.One of such materials is the expanded polystyrene. The introduction of advanced plastic materials and in particular the expanded polystyrene building technologies in the Nigerian construction industry will be a very useful and brilliant initiative that will aid the reduction of cost of construction and facilitate access to affordable houses for the masses.This research aims at studying the applications of this innovative plastic material in the Nigerian building industry with special regard to the performance perception by the clients and the end users.A building estate where expanded polystyrene building technology has been predominantly used in Abuja is considered as a case study. Questionnaires were distributed among clients and residents of the building estate and statistical tools were used to analyse the data collected. Great satisfaction verified among the clients and residents and the high ranking performance confirmed for recyclability, reliability, versatility and moisture resistance of EPS building products all herald a great future for the applications of this advanced building products in the Nigerian building industry. The experimental work is divided into two parts. The first part consist of light weight geopolymer concrete containing sodium based combinations, where two different sodium silicate to sodium hydroxide ratios of 1 and 1.5 are considered and for each ratio the geopolymer concrete specimens are heated at 90oC and 120oC temperatures as well as at ambient temperature. Thus a series of twelve cubes are conducted in the first part. The second part is similar to the first part in every aspect except the alkali activators where potassium silicate and potassium hydroxide are used. For each series, in both parts, 3 cubes of 150 x 150 x 150mm geopolymer concrete specimens are conducted and the average value is shown in the results. In all specimens a constant activators to fly ash ratio of 0.35 is considered. The main performance goals seek to address seismic safety considering wood shortages; energy efficiency in extreme temperatures to reduce both fuel required for heating and indoor air quality hazards; affordability and simplicity of construction in a post-emergency situation or low-income community, as well as ease of expansion for future development; local employment opportunities and small-scale, realistic capital investments; and finally, cultural acceptance through education and adaptation to traditional architecture.*

Keywords- EPS, energy-efficiency, wind, earthquake, affordable, composite, cement, wire, fiber, sustainable.

I. INTRODUCTION

Expanded Polystyrene (EPS) core Panel system is a modern, efficient, safe and economic construction system for the construction of buildings. These panels can be used both as load bearing as well as non-load bearing elements.

EPS core panel is a 3D panel consisting of 3-dimensional welded wire space frame provided with the polystyrene insulation core. Panel is placed in position and shotcrete on both the sides.

The EPS panels consist of a 3-dimensional welded wire space frame utilizing a trussconcept for stress transfer and stiffness as shown in Fig. 1.1.

EPS panel includes welded reinforcing meshes of high-strength wire, diagonal wire and self-extinguishing expanded polystyrene uncoated concrete, manufactured inthe factory and shotcrete is applied to the panel assembled at the construction site, which gives the bearing capacity of the structure.

EPS panel after shotcrete has the following five components (as Fig. 1.1):

1) The outer layer of shotcrete.
2) Welded reinforcing mesh of high wire.
3) The core of expanded polystyrene sheet.
4) Diagonal wire (stainless or galvanized wire).
5) The inner layer of shotcrete.

The welded mesh fabric connected piercing polystyrene with truss of steel wire, welded to the welded fabric at an angle. It gives a rigidity spatial structure, and simultaneously prevents polystyrene core shifting.

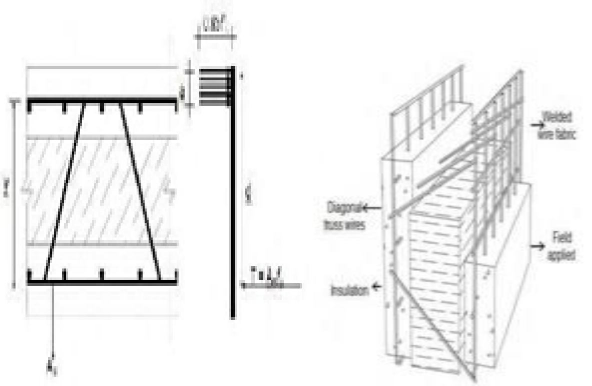

Fig.1 EPS Structure

Figure 2. Reinforcing mesh expanded polystyrene core and diagonal wire.

II. APPLICATION OF EPS IN CONSTRUCTION INDUSTRY

EPS as Aggregate in Lightweight Concrete

Lightweight concrete (LWC) is produced by mixing lightweight aggregates, for example, vermiculite, pumice, clay, or by air- entraining agent in the concrete mix.[14] When EPS is utilized as the aggregates, an LWC that is stronger and lighter than vermiculite concrete is produced. Figure 2 shows the visual comparison between EPS and vermiculite LWCs.[14] Often, more than one type of aggregate is used to produce LWC with better physical and mechanical properties. For example, Demirel[15] added both pumice and EPS aggregates in the concrete mix to construct an insulation block with lower density and thermal conductivity. Waste material such as paper sludge ash is also added as aggregate in conjunction with EPS aggregate to produce sustainable lightweight mortar that adheres to EU standards for masonry, rendering, and plastering mortars.[16]

The compressive strength of EPS concrete is governed by the quantity of EPS, followed by the water to cement ratio.[17]Previousstudies reported that the compressive strength of EPS concrete increases as its density increases.[17,18] Liu and Chen[19] also reported similar finding using ultrasonic testing whereby the EPS particle size affects the mechanical properties, that is, flexural strength of the EPS concrete. Sayadi *et al.*[20] studied the effects of EPS particles on fire resistance, thermal conductivity, and com- pressive strength of foamed concrete. This article concludes that based on the experiment involving foamed concrete and EPS LWC of different densities and volumes, the volume expansion of EPS leads to remarkable reduction in thermal conductivity, fire endurance, and compressive strength of the concrete. Application of LWC allows reduction in structural dead load and cross sec- tional of elements, that is, columns, beams, braces, and plates. In addition, LWC-derived structure is lighter thus lessen the impact of earthquake. Moreover, by using LWC, longer spans, thinner sections, and better cyclic load response can be obtained.[21]

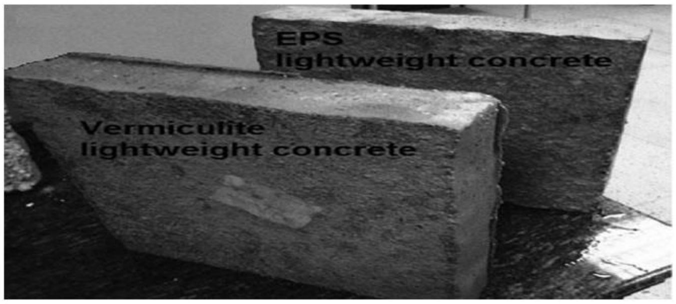

Figure 3. Specimens of vermiculite and EPS LWCs.14

EPS is nonpermeable, hydrophobic, and has closed-cell structure. The hydrophobic characteristic of EPS resulted in low thermal conductivity of polymer-calcined clay complexes.[22] It was introduced in 1973 by Cork to address the issue possessed by conventional lightweight aggregates such as pumice, fly ash, oil palm shell, and waste rubber whose porous structures have resulted in high absorption value and water demand.[23–28] EPS concrete has prospective application in structural elements (e.g., cladding panels, composite flooring systems, and load-bearing concrete blocks), insulated concrete, and protective layer due to its above- average energy absorption.[29] For instance, EPS has cushioning properties that allows it to be utilized as buffer layer on top of debris dam to reduce impact force and lengthen the impact time caused by massive stones during the event of debris flow.[30]

When EPS is utilized as lightweight aggregate, the beads float and integrated poorly with the cement matrix because of their low density and hydrophobic properties.[20] Hence, the low interfacial bonding strength and poor dispersion between the beads and matrix are solved by using bonding additive, for example, epoxy resin or water-emulsified epoxies. Alternatively, mineral admix- ture such as fly ash or silica fume can also works as bondingadditive.[31] In contrast to normal aggregates, concrete with EPS aggregates has shown to have better resistant against chemical and corrosion due to inert characteristic of EPS.[20]

Based on dynamic cyclic loading carried out by Shi *et al*.,[32] the paper suggests that EPS concrete can be implemented in applica- tion that requires long-term cyclic loading such as protection of buried military structure due to its durability and energy absorb- ing properties. Despite of being lightweight and having good energy-absorbing property, EPS concrete suffers poor workability and low strength as low weight EPS beads are susceptible to seg- regation during casting process as reported by Liu and Chen.[19] In this article, sand-wrapping method was employed by partially substituting the coarse and fine aggregates with EPS beads and using fine silica fume as bonding additive which resulted in improved density and compressive strength of EPS concrete.

In addition, reinforcement of EPS concrete using steel fiber has enhanced the drying shrinkage.[33] In experiment by Pecce *et al*.,[34] corrosion-resistant internal reinforcement such as zinc-coated steel bars are employed onto EPS concrete (see Figure 3) to address the issue of its increased porosity that cause it to prone to penetration. Even though this type of reinforcement increases the bond strength, it causes the EPS concrete to be more brittleas the failure mode changes from pull-out to splitting.

Figure 4. EPS LWC sample reinforced with zinc-coated steel bar.34 (Reproduced from Ref. 34, with permission from Springer Nature.) [Color figure can be viewed at wileyonlinelibrary.com]

Many studies have been conducted on waste EPS-derived con- crete. The EPS is recycled as aggregate for LWC and its proper- ties are examined and compared with other conventional materials in order to promote sustainability development. For instance, Dissanayake *et al*.[35] constructed three single storey houses from three different materials; burnt clay brick, cement sand block, and recycled EPS. Figure 4 shows the house’s wall made with EPS panels. Despite their similar performances in embodied energy, carbon emission, and cost, the paper suggests that recycled EPS is greener alternative for conventional walling material especially in location that has short supply of sand. Her- nández- Zaragoza *et al*.[36] also reported that recycled EPS aggre- gates could replace sandy material to produce less permeable, more flexible, and relatively cheaper lightweight mortar that still comply with Mexico masonry standard.

In addition, EPS waste can be recycled as resin for composite production. Bhutta *et al*.[18] carried out an experiment where EPS waste is recycled into resin for production of polymer mortar panels (PMPs) by mixing the waste in methyl methacrylate (MMA) solution. Based on flexural behavior test, the EPS–MMA- based PMP has better flexibility and high load-bearing capacity than polymer-impregnated mortar panel. EPS waste can also be dissolved into resin using solvents such as toluene and acetone to produce polymer–cement composite that has potential as com- mercial construction material and radioactive waste deactivator.[37]

Also, Kaya and Kar[38] conducted an experiment involving concrete made from different compositions of waste EPS, cement, and tragacanth resin. They conclude that concrete with high ratio of EPS to cement and resin exhibits high porosity and low den-sity, thermal conductivity, compressive, and tensile stress. The formation of artificial pores leads to enhanced insulation proper- ties. Hence, the paper suggests the application of EPS-aggregated and resin-added concrete for a more sustainable approach as wellas reducing building load in construction industry. Bicer and Kar[39] mixed EPS waste with tragacanth resin to produce filling material for gypsum plaster. This plaster has low thermal conductivity and it is applied as inner plaster for building insulationand decoration.

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Figure 5. EPS wall panels arranged in staggered joint manner.35 (Reproduced from Ref. 35, with permission from Elsevier.)

[Color figure can be viewed at porosity and low density, thermal conductivity, compressive, and tensile stress. The formation of artificial pores leads to enhanced insulation proper- ties. Hence, the paper suggests the application of EPS-aggregated and resin-added concrete for a more sustainable approach as well as reducing building load in construction industry. Bicer and Kar[39] mixed EPS waste with tragacanth resin to produce filling material for gypsum plaster. This plaster has low thermal conductivity and it is applied as inner plaster for building insulation and decoration.

Properties of EPS

Expanded Polystyrene, often referred to as EPS, is a kind of rigid, closed cell foam plastic. EPS properties have a low thermal conductivity, high compressive strength, is light weight, inert. It can be used as a building material or a design element, and can be molded into many shapes for a number of household uses as well.

Expanded Polystyrene (EPS) is processed from its resin form. The resin contains a pentane gas which is safely released during the expansion process. With the addition of steam, the EPS resin expands up to 40% of its original size. The expanded pellets are then transferred into a block molder.

Density

EPS density can be considered the main index in most of its properties. Compression strength, shear strength, tension strength, flexural strength, stiffness and other mechanical properties depend on the density. The cost of manufacturing an EPS is considered linearly proportional to its density. Non-mechanical properties like insulation coefficients are also density dependent.

Density of EPS shall be 15, 20, 25, 30 or 35 kg/m^3 according to IS 4671: 1984. Table 2.1 shows types of EPS used in USA, which are categorized by ASTM C 578-95.

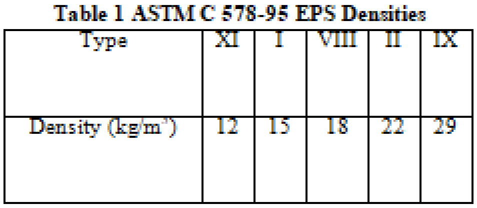

Table 1 ASTM C 578-95 EPS Densities

Type	XI	I	VIII	II	IX
Density (kg/m^3)	12	15	18	22	29

Compressive Strength and Stress-Strain Characteristics

Figure 2.1 shows the uniaxial compression stress-strain curve of EPS for two different densities. The two densities shown are considered the extreme values for most engineering applications done so far. Specimens are 0.05m cubes tested at a displacement rate of 0.005m/min. From the figure the stress-strain curve can be simply divided into two main straight lines connected with a curved portion. The slope of the straight-line portions increase with density. The stress at any strain level increases also with the density. The bead size has no important effect on the compressibility of cut specimens (BASF Corp., 1968)

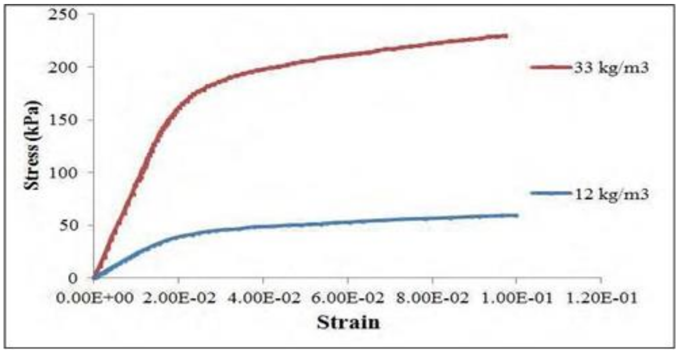

Fig.6 EPS Uniaxial Compression Stress Strain Curves (Negussey andElragi, 2000)

Initial Elastic Modulus

The stress strain curve of EPS has an initial linear portion. The value of the slope of this initial portion is defined as the initial tangent modulus. It is known as Young's Modulus as well as the modulus of elasticity.

EPS initial modulus is a function of the density as shown from Fig 2.2. For EPS, as shown from the same figure, there is no agreement from the researchers on a constant value for each density. For a 20kg/m^3 density the initial modulus ranges between 5MPa and 7.75MPa, which means a 55% difference. The relation is linear for some researchers (Horvath, 1995b and Miki, H., 1996) while it's nonlinear for others (Duskov, 1997 and Eriksson and Trank, 1991).

Miki 1996a
Horvath 1995

Poisson's Ratio

0 10 20 30 40

Poisson's ratio is an index of the late**D**ra**e**l **n**p**s**re**it**s**y**su**(**r**K**e o**g**f/**m**EP**3)**S on adjacent structural elements, in contact, for a certain applied vertical load on the EPS mass. Value range between 0.05 and 0.5 are found in the literature for EPS as shown in Table 2.2.

Table 2. Poisson's ratio of different types of EPS (Sanders, 1996)

Reference	Yamanaka, et al. (1991)	Negussey and Sun (1996)	GeoTech (1999a)	Duskov et al. (1998)	Ooe, et al. (1996)	Sanders (1996)	Momoi and Kokusyo (1996)
Poisson's Ratio	0.075	0.09 and 0.33	0.05	0.1	0.08	0.05 up to 0.2	0.5

Water Absorption

The water absorption of expanded polystyrene is low. Although water absorption decreases as density increases as shown in Table 2.3. Fusion is the most important factor influencing the moisture resistance of expanded polystyrene. Good fusion reduces the amount of water absorption. For 9–12 years of service, equilibrium values of 8-9 % volume have been found in EPS fills below the ground water table (van Dorp, 1988).

Table 3 % Volume of Water Absorption (German Specifications, after van Dorp, 1988)

Density, kg/m^3	After 7 Days	After 1 Year
15	3.0	5.0
20	2.3	4.0
25	2.2	3.8
30	2.0	3.5
35	1.9	3.3

Durability

No deficiency effects are to be expected from EPS fills for a normal life cycle of 100years [Aabøe, R. (2000)].

Thermal Conductivity

The thermal conductivity at 0°C and 10°C, respectively of the material shall notexceed the values given below according to IS:4671-1984, determined in accordance with the method prescribed in IS : 3346- 1980.

Table 4 Bulk Density and thermal conductivity of EPS

Bulk Density (kg/m^3)	**Thermal conductivity mW/cm °C**	
	0°C	**10°C**
15	0.34	0.37
20	0.32	0.35
25	0.30	0.33
30	0.29	0.32
35	0.28	0.31

III. LOAD CALCULATIONS

Dead load

Dead load has to be calculated based on the unit weight provided in IS 875 Part-1 1987 for each work. Even though total weight of wall highly depends on the type of finish material/ Shot Crete/ other finishes, normally it varies from 0.5 kN/m2 to 2.5 kN/m2.

Weight of the floor normally varies from 2 kN/m^2 to 3 kN/m^2.

Load for Roof normally varies from 0.4 kN/m^2 to 0.75 kN/m^2 for GI Sheet and 2.4kN/m^2 to 3 kN/m^2 for
R.C.C Slab.

These are indicative values.

l uniform load l Span length.

Live load

Live load for different occupancies may be taken from Table 1 of IS 875 Part-2: 1987. Live load for dwelling units is considered 2.0 kN/m^2 except corridors and balconies. Extra load of 0.5 kN/m^2 shall be considered for service and false sealing.

Wind load

Wind loads apply on face of elevations of the buildings. The face loads are transferred from the cladding outer leaf by the wall ties to the stud sections, which span vertically between horizontal floor diaphragms. The floor diaphragm spans horizontally between each of cross walls, which can be internal load bearing, or external walls.

Wind load analysis

Wind load analysis conduct as per IS875-Part3. The 90-degree case acts on the side elevation and 0° wind load case acts on the front or back elevation. Each elevation will be analyzed separately and the highest calculated load will be applied throughout the entire structure. Therefore, this technique is deemed to be conservative.

Overturning (global stability) and holding down analysis is conducted for the widest cases. Comprehensive explanation of the global stability analysis follows.

Design wind pressure (N/m^2) Pz = 0.6 x V_z^{2} (IS875-1987 Part-3; Clause: 5.4)

Design wind speed (m/s) Vz = Vb x K1 x K2 x K3 (IS875-1987 Part-3; Clause: 5.3)Basic wind speed (m/s) Vb can be taken from IS 875(Part 3)-1987; (Fig 1)

Risk coefficient factor (K1) can be considered from IS 875(part 3)-1987; Table: 1Clause: 5.3.1)

Terrain, height and Structure factor (K2) IS 875(part 3)-1987; Table 2; Clause: 5.3.2)Topographic factor (K3) (IS 875(part 3)-1987; Clause 5.3.3.1)

Seismic load

Seismic loads apply on the each floor and roof level of the buildings. The horizontal loads are transferred from the floor Panel to the walls tying or supporting the floors and roof.

By inspection, the seismic loads are critical for overall stability.

Total Design lateral Force or Seismic Base Shear V (KN) = Ah × Wtotal (Asper IS1893-2002 ; Clause: 7.5.3)

Design Horizontal Seismic Coefficient Ah= (Z×I×Sa/2×Rg) (As per IS1893-2002 Clause: 6.4.2)

Zone Factor (Z) (As per Table2 IS1893-2002 (Clause: 6.4.2) Seismic Zone (As per Seismic Zone map IS1893-2002) Seismic Intensity (As per Table2 IS1893- 2002 (Clause: 6.4.2)

Importance Factor (I) (As per Table6 IS1893-2002 Clause: 6.4.2) Response Reduction Factor (R) (As per Table7 IS1893-2002 Clause: 6.4.2)

Average response acceleration coefficient factor (Sa/g) (As per IS1893-2002 Clause:6.4.5).

Total weight of building (W, total) (kN) (As per IS1893-2002 ; Clause 7.3)

Serviceability requirements

Serviceability performance concerns the limits on deflections due to loading and the control of vibrations, due to regular activities. Appropriate limits are specified, depending on the application.

Deflection

The deflection under serviceability loads of a building or its members should not impair the strength or efficiency of the structure or its components or cause damage to the finishing. The recommended deflection limits for certain structural members shall be as per IS 456:2000 and IS 1893:2002.

Deflection criteria

Static criteria

a. The maximum deflection for a single panel subject to dead and imposed loads is limited to the smaller of span/350, or 15 mm.

b. The maximum deflection for a single Panel subject only to imposed load is limited to span/450.

Dynamic criteria

a. The natural frequency of the floor should be limited to 8Hz for the uniformly distributed load case of dead plus 0.3 KN/m^2, which represents the nominal load on lightly loaded floor. This is achieved by limiting the deflection of a single Panelto 5mm for this loading condition.

b. For the floor subjected to imposed loads in excess of 1.5 KN/m^2, the governing criterion is most likely to be (a) (Span/350 or a maximum of 15mm).

Deflection of uniformly distributed simply supported beam can calculate by 0

$$\mathit{Deflection} = \frac{5Wl^4}{384EI}$$

E is the modules of Elasticity 205000 N/mm^2.I is the moment of inertia mm

IV. CONCLUSIONS

EPS is a well-established insulation material that is used for various applications such as LWC, decorative molding, backfilling, and as a core in panel application for buildings. EPS is used for applications over a range of both combustible and noncombustible materials. EPS is a light yet rigid foam with good thermal insulation, impact resistance, load-bearing capacity at low weight, absolute water and vapor barrier, air tightness for con- trolled environments, long life, low maintenance, fast, and eco- nomic construction. This article establishes the feasibility and benefit of EPS as insulator that satisfies all insulation requirements in building design process, including fire safety. Flame retardant grade EPS is imperative in order to oblige with the fire safety regulation and addressing the flammability and flame spread on the surface of EPS product. Consequently, EPS is implemented in building design in collaboration with other material capable of resisting fire.

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