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Thermal Behaviour and Admissible Compressive Strength of Expanded Polystyrene Wall Panelsof Varying Thickness

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Abstract - **Over the years, clay bricks, concrete hollow blocks and other conventional construction materials have been in use and they have stood the test of time. However, in the recent times, modern building materials that conform to the standards of international regulations, meet up with the basic needs of safety, economy, good aesthetics and constructability desired for engineered structures and satisfies the contemporary expectations of sustainability and durability have been introduced to the construction industry in the more advanced nations. In the developing nations such as Nigeria such is not the case as the building industry is faced with shortage of affordable building and the masses have difficulties building houses of their own because of the excessive costs of building materials such as reinforced concrete and sand-crate blocks and the high cost of labor. As a way of finding solution to these housing challenges, this research considers EPS wall panel as a possible substitute to the conventional concrete-sand crate blocks normally used in Nigeria for walls. This research seeks to investigate the thermal behaviour and the compression strength of 3-D wall panel with insulation core of polystyrene and concrete shell. The thickness of the expanded polystyrene and of the concrete shell was varied for this research. The thermal transmittance and reactance of these various wall panels was obtained with the aid of a computer program in Microsoft Excel developed according to ENISO 6946. The results obtained on the admissible axial loads and thermal resistance demonstrate that the application of this innovative construction system is feasible and will be a good substitute for traditional concrete hollow blocks that are predominantly used in Nigeria.**

Keywords - **EPS Wall Panel, Concrete Hollow Blocks, Thermal Resistance, Compressive Strength.**

1. INTRODUCTION

Over the ages, the world has experienced a continuous growth and improvement in every area of human endeavor and the built environment is not left in the process as shelter have remained one of the most vital needs of man.The evolution of the built environment in any nation determines the nature and pace ofnational development and the citizens' quality of life [1]. Construction materials have evolved over the years till the real breakthroughs in the construction industries of the 21st century due to the development of versatile, easy to construct, thermally insulating materials that can be used worldwide to build sustainable homes. A building material that meets the safety standards (including seismic resistance) and the dweller's comfort requirements must also be thermally insulating, light weight and inexpensive [2]. As the world's population increases, the demand for energy and raw materials is growing at a greater pace and has led to the greenhouse gas effect that is responsible to the global climate change[3]. The need for new ecological equilibrium has led to researches into the embracing of materials that are more environmentally friendly and this has brought about greater adoption of plastic based materials in the construction industry. Expanded polystyrene(EPS) represents one of such materials that have found their way into the previously conservative construction industry.Plastics are typically polymers of high molecular mass, and may contain other substances to improve performance and/or reduce production costs. Monomers of plastic are either natural or synthetic organic compounds[4]. With the proven strengths of plastic materials, its use in commercial and residential construction has dramatically increased in the last 30 years due to improved material performance, efficient use of technologies in new applications, and the need for lightweight, durable materials for insulating and construction purposes [5]. Polystyrene is one of the most widely used plastics, the scale being several billion kilograms per year. The polystyrene foam is a thermoplastic material obtained by polymerization of styrene.

2. EPS WALL PANEL

Expanded Polystyrene, or EPS for short, is a lightweight, rigid, plastic foam insulation material produced from solid beads of polystyrene. Expansion is achieved by virtue of small amounts of pentane gas dissolved into the polystyrene base material during production. The gas

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expands under the action of heat, applied as steam, to form perfectly closed cells of EPS. EPS building system is based on a group of structural panels of undulated foam polystyrene with a base reinforcement placed against the sides with high resistance steel mesh and each side joined to one another by means of electro-welded steel connectors. The 3D panels consist of an EPS core with a thickness ranging from 40 – 100mm sandwiched between two plane-parallel welded wire mesh sheets (cover meshes) and inclined diagonal wire in between that go through the EPS core and that are welded to the cover mesh. Afterwards approximate 40-60mm thick cement–mortar layer (concrete layer) is applied either manually or mechanically on both side of this structure. As soon as the concrete has hardened, the 3D construction achieves its structural and functional strength. For load-bearing 3D components the minimum thickness of concrete is 50mm [6]. This 3D construction system is an economical alternative to the traditional construction systems and meets all structural and physical requirements relating to building physics. Besides, it reduces the weight of the building by as much as 40% and that brings a lot of savings on the cost of foundations. In spite of its light weight, the unique matrix structure of EPS brings the benefits of exceptional compressive strength and block- rigidity. This means it is ideal for use in many construction and civil engineering applications, particularly as a structural base infill for road, railway and bridge infrastructures. Strength tests performed on EPS which was first placed in the ground almost 30 years ago show that it is still strong today [7]. The thermal properties of concrete were investigated by [8] and were shown to be heavily dependent on the moisture content. Water has 25 times greater thermal conductivity than air, so a small fluctuation in water content can have a large effect on the thermal conductivity. A low density EPS slab demonstrated a thermal conductivity of 0.14 $Wm^{-1}K^{-1}$ with a relative moisture content of 50%. At every stage of its life cycle, from production to recovery or recycling, EPS offers exceptional eco-credentials and is therefore ideally suited to the new generation of eco-friendly building projects. All manufacturing processes comply with current environmental regulation. EPS uses no greenhouse gas producing materials. It is chemically and environmentally non-aggressive and it can be easily recycled into long-life products.

EPS concrete panels have shown have good fire retardant properties, however EPS foam on its own is combustible. The best form of protection against combustion is to fully encapsulate the foam in another fire retardant material. As this is the case in EPS concrete panels, the only time EPS would be exposed to fire would be when a concrete facing disintegrated, in this circumstance the heat would be so intense the EPS would contract due to the heat but would not ignite [9]. In this case there will be adequate warning for the escape of the occupants.

EPS beads can be used in a variety of different applications in the construction industry including as a lightweight aggregate. They can be added to mixes either partially or fully replacing aggregates depending on the strength and properties required. Silica fume is often added to improve fresh properties [10].Light Weight Concrete (LWC) is advantageous in many applications and is becoming increasingly commonly used.Materials that are a mixture of Portland cement and individual EPS beads that have been partly expanded are sometimes referred to as ‘cement-foam composites’ [11]. Some of the earliest research of EPS as an aggregate for concrete can be traced back to [12] investigating EPS aggregate for concrete [13].

EPS is commonly adopted as a permanent formwork just as composite construction materials with a sandwiched core are becoming a more common construction material. [14]states that this is usually to improve the unique properties through the combination of both. A common core used in aerospace applications (which is the focus of Boni and De Almeida’s work) is honeycombed with corrugated or cellular materials. EPS is a cellular material and its application is similar to the aerospace industry where in the majority of forms of sandwich construction, the intermediate layer is the thickest, of lower density and bonded to external facings of a stiffer material. The combination of high stiffness and low weight is beneficial for efficient structures both in the aerospace industry and in the construction industry. Though EPS is not a strong material on its own but its use with other stronger materials makes it a viable structural material. Concrete can be used with EPS to create a strong composite structural system. EPS panels, designed as per projects, are used at the construction sites as walls, partitions and floors and are finished on-site by applying concrete/sand crate with pneumatic devices. Other areas of application of this technology are highway construction, embankments, retaining walls, slope stabilization and basement construction etc. It is in light of these proven strength and properties that this research considers EPS wall panel as a substitute to the convention concrete-sand crate blocks normally used in Nigeria for walls.

Nigeria as a developing nation has for several years been over dependent on conventional concrete and its complementing components for her building needs. Clay bricks, concrete hollow blocks and other conventional construction materials have been in use for centuries, and they have stood the test of time. However, modern times require new materials that conform to the standards of international regulations, meets up with the basic needs of safety, economy, good aesthetics and constructability desired by engineered structures and the popular expectations of the contemporary time such as sustainability and durability. Moreover, most of these conventional materials are rather becoming very expensive and beyond the affordability of the ordinary man. Currently, the Nigeria building industry is faced with shortage of affordable building and the masses have difficulties building houses of their own because of the excessive costs of building materials such as reinforced concrete and sand-crate blocks and the high cost of labor.Elsewhere, plastic materials which are readily available and could be a consistent substitute to these conventional and imported building materials are being adopted for cheap houses. Plastic materials are frequently adopted in construction for the following attributes: fast and easy erection with unskilled laborers, economy, good thermal and sound insulation, easy supply of prefabricated elements produced on an industrial scale (thus, low cost), great versatility of design and form and minimum installation work on site. The conventional building materials such as steel and cement are beginning to cost much, heavy in weights and also utilize large amount of non-renewable natural resources. They contribute adversely to the global climate change. The Nigerian construction industry needs materials that take care of these short comings linkedto the use of conventional materials and EPS material system can be a perfect substitute for conventional materials for mass housing scheme in Nigeria. This is the reasoning that gave rise to this research as a way of contributing to resolving the challenges being faced by the Nigerian building industries.

3. METHODOLOGY

This research seeks to investigate the thermal behaviour of 3-D wall structure with insulation core of polystyrene with varying thickness of 50mm to 150mm and varying density of between 10kg/m^3 and 30kg/m^3. The thickness of concrete shell would be varied from between 40mm and 50mm. The thermal transmittance and reactance of these various wall panels would be obtained with the aid of a computer program in Microsoft Excel developed according to EN ISO 6946.

This research design was based on the EVG 3D construction system (EVG 3D, 2007) while Microsoft Excel Spreadsheet package was used for the simulations. The calculation of thermal transmittance and thermal resistance of Expanded Polystyrene was done according [15]. The application of Excel spread sheet package was based on the formulation by the Institute of Construction Technology Warsaw. Approximation method of DIN 1405 as exemplified in the structural engineering handbook [6] was used for the determination of the admissible compression force of different 3D walls in terms of thickness of concrete shells and concrete grades. After going through the extensive body of researches on the use of EPS in different concrete structure applications collated, Microsoft Excel spreadsheet was programmed to calculate the maximum admissible force of EPS wall panels and to determine the thermal resistance and transmittance of EPS of different thickness. To take care of inaccuracies during the execution, eccentricities varying from 20mm to 40mm were introduced. Figure 1shows the Excel sheets used in estimating the admissible axial compressive force and thermal behavior values of Expanded Polystyrene.

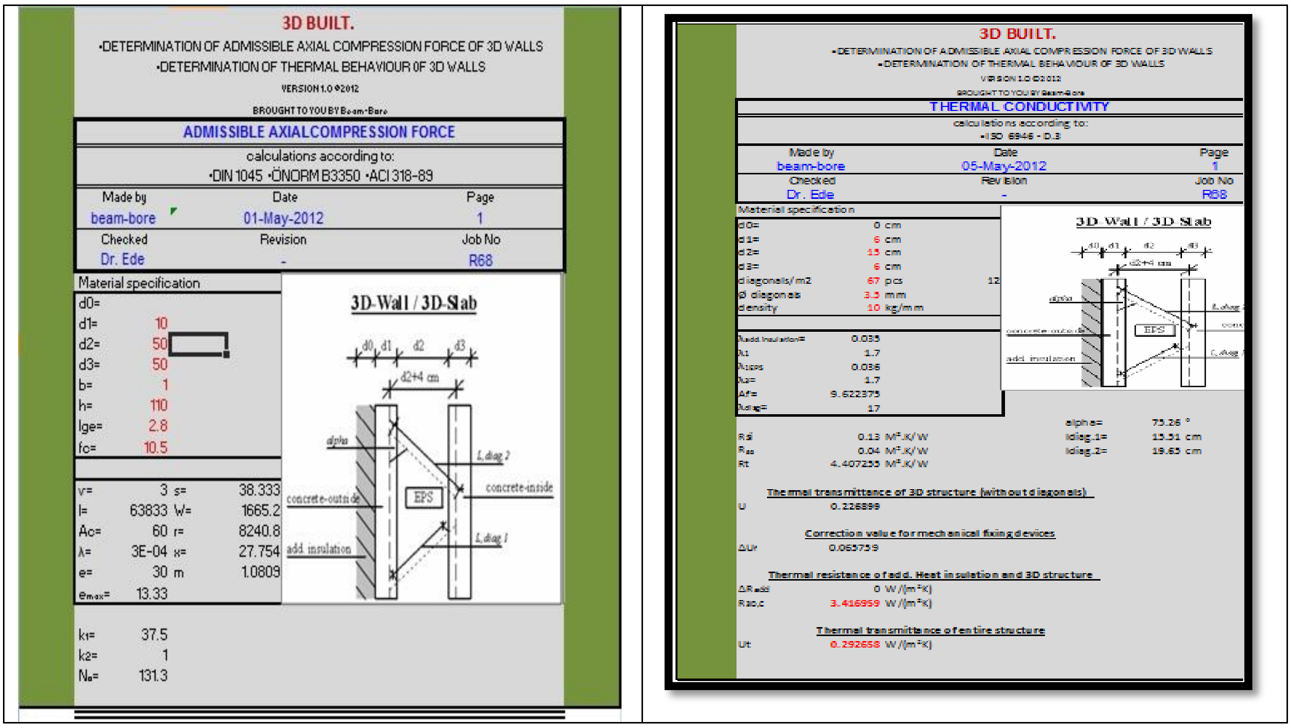

Figure 1: Excel sheets used in estimating the admissible axial compressive force and thermal behavior values of Expanded Polystyrene.

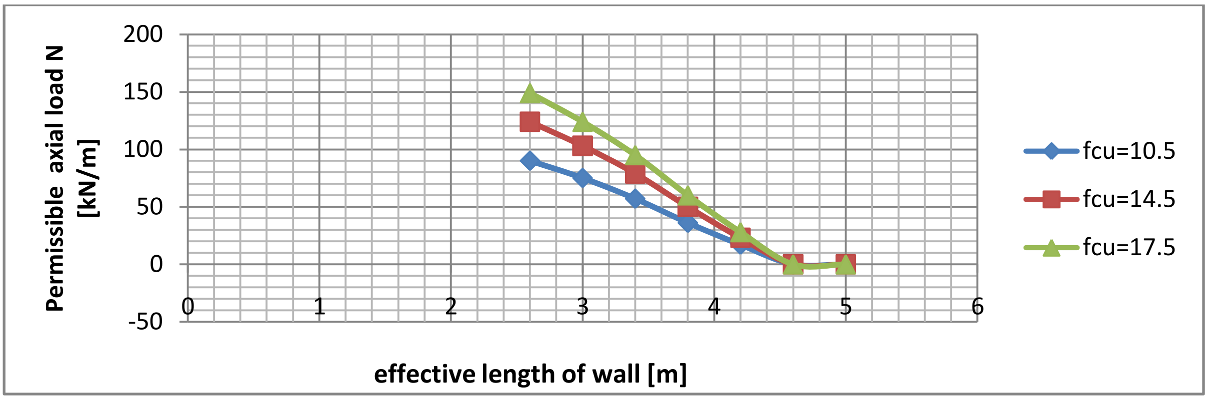

Figure 2: shows the relationship between permissible axial load and the effective length of wall for 40mm concrete shell + 50 mm EPS + 40 mm concrete shell at varying concrete grade.

4. RESULTS AND DISCUSSIONS

Admissible axial loads

Admissible axial loads (kN/m) of 3D-walls with eccentricity e=30mm, varying concrete strengths (f_{cu}= 10.5; 14.5 and 17.5 N/mm^2) and varying wall thicknesses in mm of the ratio (40:50:40; 50:50:50; 40:100:40; 50:100:50) for cement shell-EPS-cement shell wall system were determined. Figures 2 to 5 shows the admissible axial loads for different ratios of varying concrete strengths and varying lengths of the walls.

Admissible axial loads [kN/m] of 3D-walls built according to DIN for vaying values of eccentricity (from 20 to 50mm), f_{cu}=10.5N/mm^2 and thickness of EPS of 50 and 100 mm respectively were also considered and shown in figure 6. This was done to ascertain the influence of changing thickness of the EPS on the compressive strength of the EPS walls.

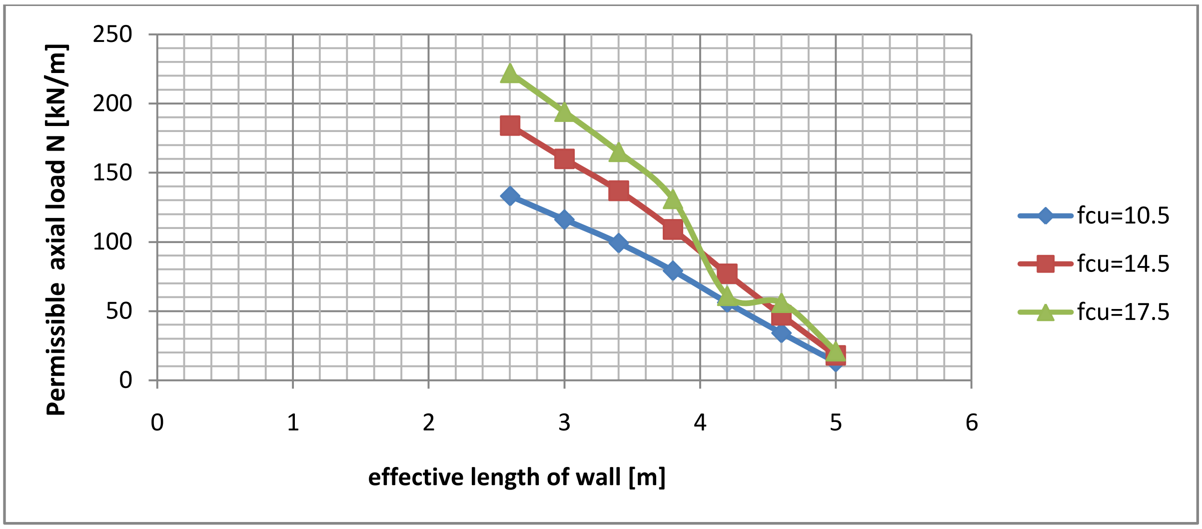

Figure 3: shows the relationship between permissible axial load and the effective length of wall for 50mm concrete shell + 50 mm EPS + 50 mm concrete shell at varying concrete grade.

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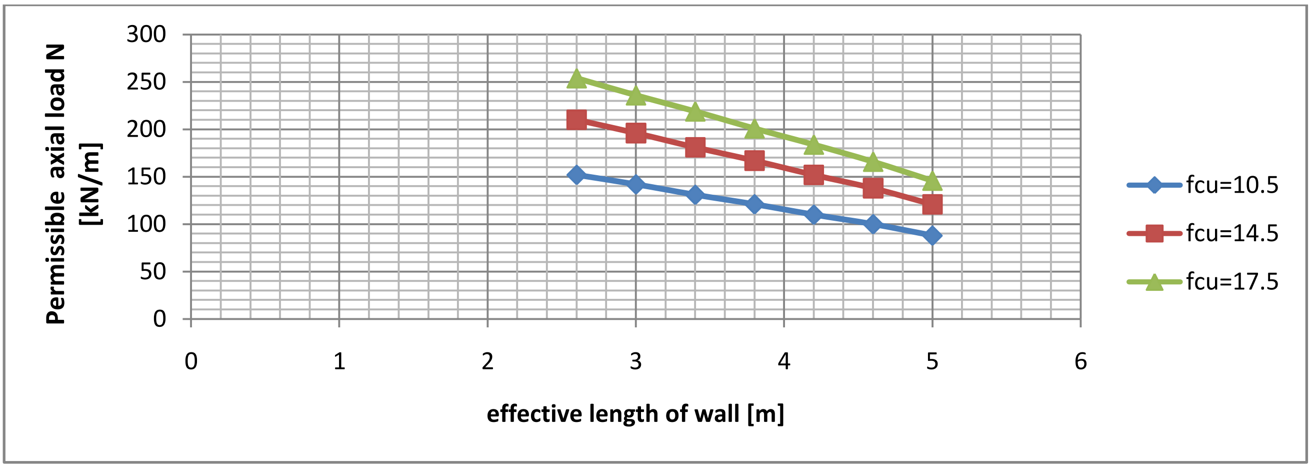

Figure 4: shows the relationship between permissible axial load and the effective length of wall for 40mm concrete shell + 100 mm EPS + 40 mm concrete shell at varying concrete grade.

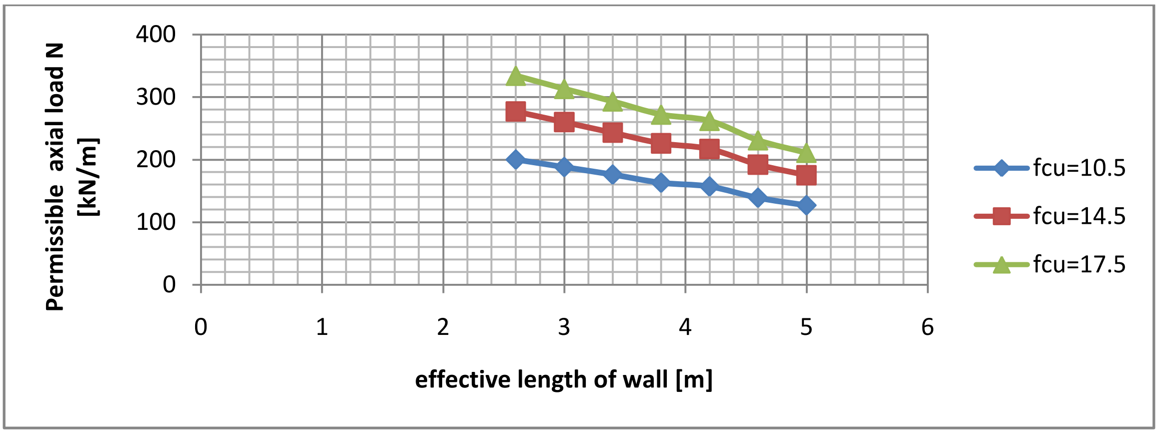

Figure 5: shows the relationship between permissible axial load and the effective length of wall for 50mm concrete shell + 100 mm EPS + 50 mm concrete shell at varying concrete grade.

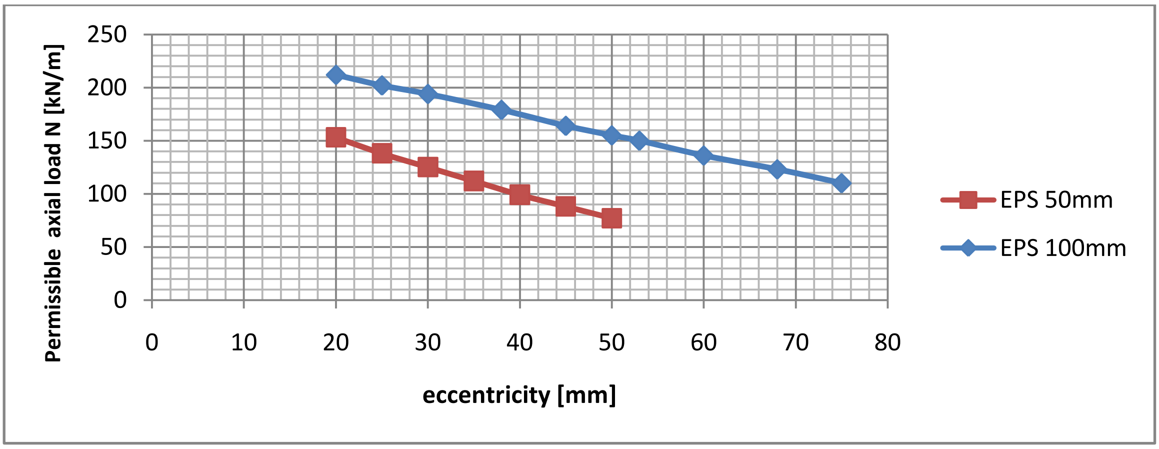

Figure 6: shows the relationship between the permissible axial load and eccentricity for 50mm and 100mm thicknesses of EPS core.

Thermal Transmittance and Thermal Resistance of EPS 3D wall

The thermal transmittance and thermal resistance for various densities of Expanded Polystyrene ranging from $10kg/m^3$ to 30kg/m3 and various thickness of the 3D wall ranging from 150mm to 250mm was obtained using Excel spreadsheet package according to EN ISO 6946. Themal conductivity values of various density groups according to the work of [16] form basis of the result shown below in figure 7. For EPS thickness of 50 and 100mm, there was no significant difference in their thermal resistance while the thicknesses of 120 mm and 150mm

showed significant increase in the thermal resistance. The thermal behaviour of concrete hollow blocks commonly used in Nigeria for walls was obtained using methods specified in the EN ISO 6946. This research work considered concrete hollow blocks building system because it is commonly used in Nigeria and is the primary competitor of EPS wall panel. The thermal transmittance of EPS wall panel and of the concrete hollow blocks is shown in figure 8. From this result, it can be clearly seen that hollow blocks transmit far more the EPS wall panel.

5. Conclusion

This paper has presented researches into the thermal behavior and the admissible compressive strength of EPS wall panels at varying wall thickness. The results of this research have shown the basis for improving EPS and concrete application for wall panels. The formulae implemented in the Excel spread sheet for design of these panels can be used for estimating the thermal behavior of this material through numerical modeling.

The result of the thermal transmittance of EPS wall panel which was compared to that of concrete hollow blocks commonly adopted in Nigeria shows that the EPS wall panel will be far more beneficial than the concrete hollow blocks in terms of thermal resistance of the walls. The decrease of thermal transmittance of EPS panel is provided by increase in number of EPS grains in unit volume which results in less void volume between grains and also increase in number of pores in the EPS grains.For the compression strengths, admissible axial loads values of EPS wall panels with different internal and external layer thickness were obtained. Influence of eccentricity on the admissible axial load was also obtained. Results from these numerical modeling have shown a composite relationship between the concrete layers and the EPS core hereby resulting in high ultimate load bearing capacity of these EPS panels when compared to the concrete hollow block system.

Based on these results, it can be rightly said that the admissible axial loads and thermal resistance as presented in this paper demonstrate that the application of this innovative construction system is feasible and it is therefore recommended as a substitute for traditional concrete hollow blocks that are predominantly used in Nigeria. The development of this lightweight concrete panel with EPS foam cores and a steel mesh frame will brings great innovation to the Nigerian construction industry of the 21st century.

This work could serve as a useful tool for further investigation, and by contributing to the available research regarding this material, it is hoped it will encourage more widespread use of EPS wall panel in the construction industry in Nigeria. These results will help to strengthen the acceptability of this novel building system even as future researches should go a long way to develop simplified methods for predicting the ultimate load of the wall panels for different values of load eccentricity. More works need to be done to integrate EPS and concrete- EPS-concrete sandwich panels into design codes.

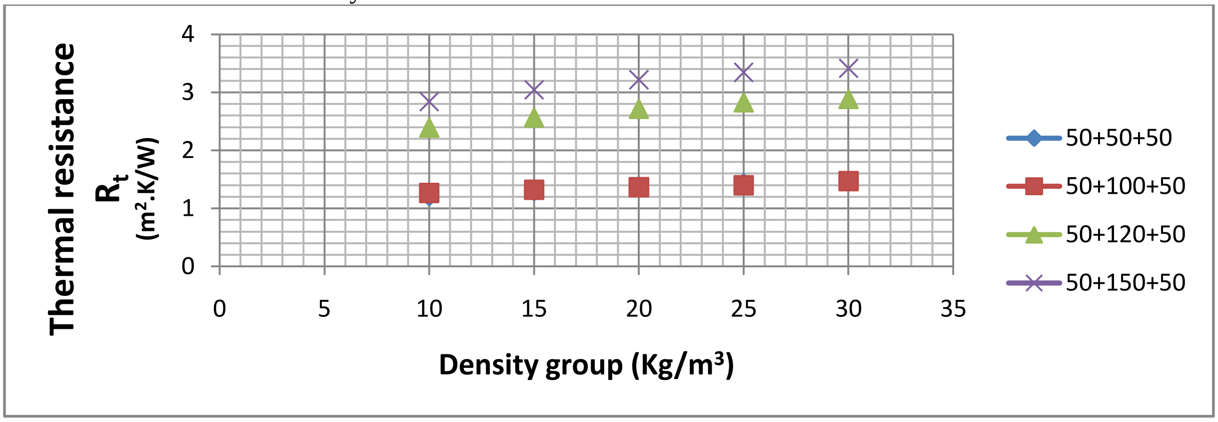

Figure 7: shows the relationship between the various density groups and thermal resistance of varying EPS wall thickness.

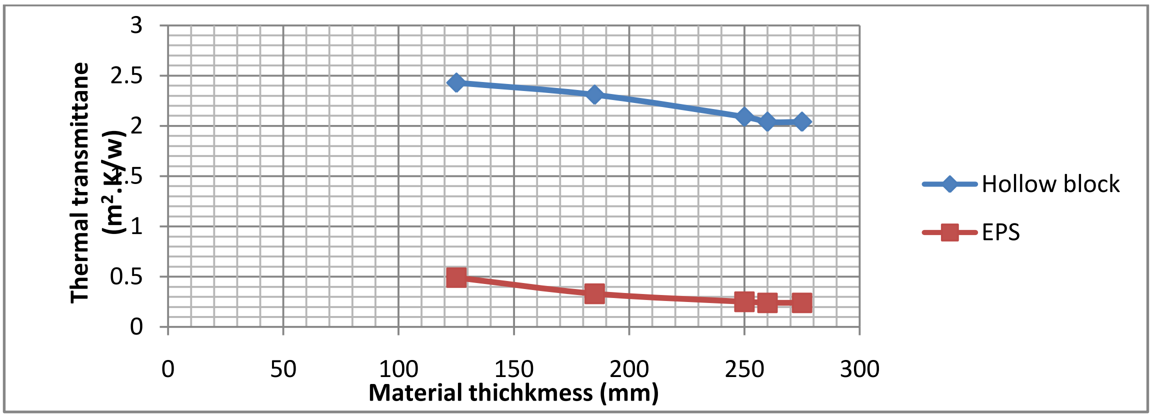

Figure 8: shows the comparison between the thermal transmittance value for Hollow blocks and EPS at varying material thickness.

REFERENCE

[1] Ede, A. N;Measures to Reduce the High Incidence of Structural Failures in Nigeria, Journal of Sustainable Development in Africa, Volume 13, No.1, 2011.

[2] Lee, A. J., Kelly, H., Jagoda, R., Rosenfeld, A., Stubee, E., Colaco, J., Gadgil, A., Akbari, H., Norford, L., Burik, H. Affordable, safe housing based on expanded polystyrene (EPS) foam and a cementitious coating. *J Mater Sci*41:6908–6916 Springer Science, 2006.

[3] Ede, A.N. and Oshiga, K; "Mitigation strategies for the effects of climate change on road infrastructure in Lagos", International journal of Science Commerce and Humanities, Vol. 2 No.1, pp. 173-184, 2014.

[4] Wikipedia; Expanded Polysterene concrete, Retrieved may 20, 2012, from wikipedia website: http:/www.wikipedia.com.

[5] Parker A.J, PE, BeitelJ.J , Modern materials:Flamability requirements for plastic materials April 2006 p. 10-12.

[6] EVG 3D;*Constructuion system-Structural Engineering Handbook.* Canda: evg press, 2007.

[7] British Plastic Federation (BPF), Expanded Polysterene Retrieved may 13, 2012, from EPS group website: http://www.bpfepsgroup.com, 2009.

[8] Bonacina, C., Campanale, M., Moro, L; Analytical and Experimental Investigations on the Heat Transfer Properties of Light Concrete. *International Journal of Thermophysics*, Vol. 24, No. 5, 2003.

[9] European Manufacturers of EPS (EUMES);Behaviour of EPS in case of fire. *Information Paper*, EUMES, 2002.

[10] Babu, K. G., Babu, D. S; Behaviour of lightweight expanded polystyrene concrete containing silica fume. *Cement and Concrete Research*, 33 755 – 762, 2002.

[11] Concrete Homes;Technology Brief: Plastic Foams for Concrete Homes http://www.toolbase.org/PDF/DesignGuides/Concrete_Homes_Brief_PlasticFoams.pdf. (accessed 4 April 2012), 2009.

[12] Cook, D. J; Expanded polystyrene beads as lightweight aggregate for concrete, *Precast Concrete*, 4:691–3, 1973.

[13] Chen, B., Liu, J; Properties of lightweight expanded polystyrene concrete reinforced with steel fiber. *Cement and Concrete Research*,34, 1259 – 1263, 2004.

[14] Boni, T. L., De Almeida, S. F. M; Laterally supported sandwich panels subjected to large deflections — Part 1: Test apparatus design and experimental results. *Thin-Walled Structures*, 46, 413–422, 2008.

[15] ISO;*EN ISO 6946 - Building components and building elements, Thermal resistance and thermal transmittance – Calculation method*, Geneva, ISO, 2007.

[16] Yucel, K. T., Basyigit C. C; Thermal insulation properties of expanded polystyrene as Construction and insulating materials. *Expanded polystyrene research*, 1 – 13, 2007.

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