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 flyash 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

In recent years, there has been an explosive growth of interest in the application of expanded polystyrene (EPS) for construction industry. EPS is a well-established insulation material used for various applications as it has a light yet rigid foam with good thermal insulation and high impact resistance. Apart from that, it possesses high load-bearing capacity at low weight, absolute water and vapor barrier, air tightness for controlled environments, long life, low maintenance, fast, and economic construction. The foam in EPS is a lightweight cellular plastic consisting of small spherical-shaped particles containing about 98% air. This micro- cellular closed cell construction provides EPS with its excellent insulating and shock absorbing characteristics.

EPS consists of small polystyrene beads that derived from styrene via polymerization process.1 The foam quality of EPS is affected by the size distribution of the beads. After the polymerization, EPS is infused with blowing agent such as pentane and hexane. The conversion of expandable polystyrene to EPS is carried out in three stages: (1) pre-expansion, (2) intermediate maturing and stabilization, and (3) expansion and final molding. In the first stage, the raw material is heated in pre-expanders with steam at temperature between 80 and 100 ◦C to create a relatively uniform cellular structure with small closed cells that hold air in their interior. According to Doroudiani and Omidian,2 during this process, the beads' internal gas experience volume expansion that generates air-penetrable cellular structure. This process is carried out in aerated silos during the material's intermediate maturing. Based on the air temperature, size, and density of the beads, the aging time is calculated. The beads achieve greater mechanical elasticity and improved expansion capacity. Through the expan- sion process, the stabilized pre-expanded beads are molded and re-exposed to steam in order to bind the beads. Blocks created using this process is further enhanced in terms of dimensional stability prior to separation into required shap

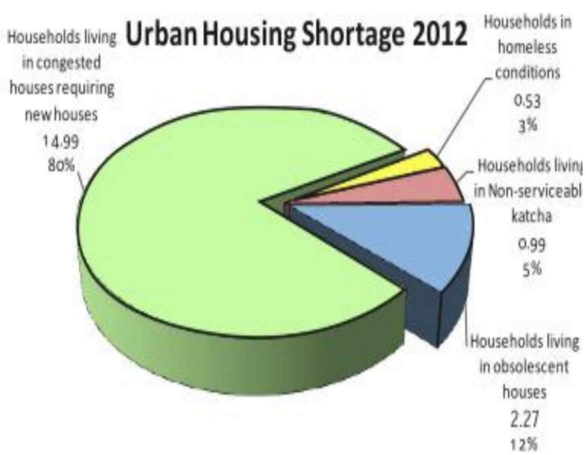

Fig.1 Urban Housing Shortage 2012 (Source- Housing for all)

II. APPLICATION OF EPSIN 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, Demirel15 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] Previous studies 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

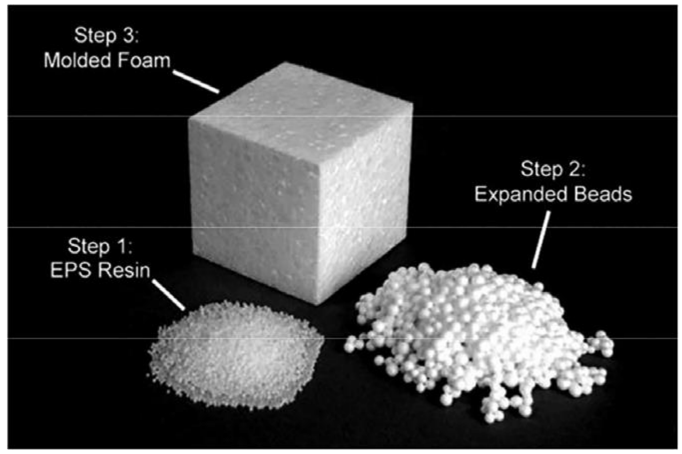

Figure 2. Three important forms of EPS. Beads formed via expansion of resin are molded into desirable shape .

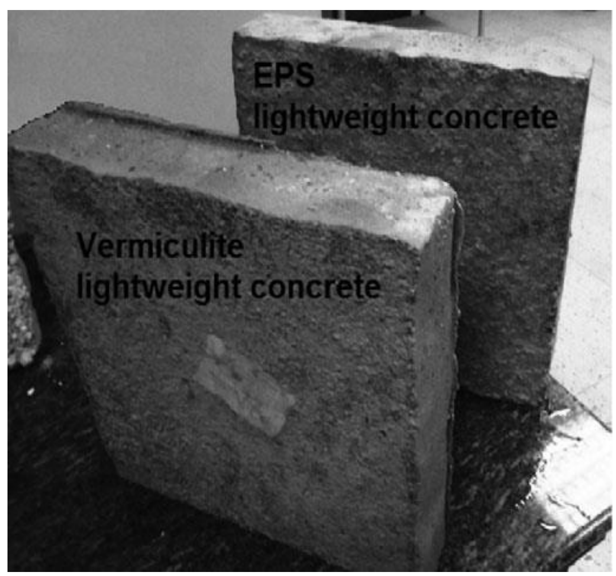

Figure 3. Specimens of vermiculite and EPSLWCs.[14]

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]

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 intro- duced in 1973 by Cork to address the issue possessed by conven- tional 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 bonding additive.[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 brittle as 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 con- crete 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 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 con- ductivity and it is applied as inner plaster for building insulation and 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

III. METHODOLOGY

To gather various types of work on expanded polystyrene core panel system and there use in housing , various papers and research articles were studied thoroughly and referred. The idea behind doing literature review was to collect data and have understanding on different methods and approaches that can be used, to clear understand the EPS syetem. Literature review was done to have thorough guidelines during the entire project work.

Data Collection

The data regarding Expanded Polystyren material is collected from different research papers. There are many manufacturer of EPS sheet in pune . I visit the Padmashri Steel at Alandi phata, pune, and collect the information regarding practical use of EPS panel in housing and there advantages. Methodology Adopted; As discussed in the scope of the work, the entire work is divided into three parts: Analysis of construction types. Study of EPS panel. Its advantages in construction industry.

1) Common plastics

Plastic materials are made up of a wide range of synthetic or semi-synthetic organic solids that most commonly derived from petrochemicals. They are typically organic polymers of high molecular mass with the addition of other substances (Wikipedia, 2012). The vast majority of these polymers are based on chains of carbon atoms alone or with oxygen, sulphur, or nitrogen. During the plastic production process and based on the properties required, copolymerization among the monomers is necessary for the desired properties to be achieved (Sabu and Visakh, 2011). The fine tuning of the properties of the polymer by repeating unit's molecular structure has allowed plastics to become an indispensable part of the 21^{st} century. Due to relatively low cost, impermeability to water, versatility of use and ease of manufacture, plastics usage has experienced an enormous and expanding range of applications from paper clips to spaceships and ultimately vast presence in the conservative construction industry. Plastics have already displaced many traditional materials such as wood, leather, metal, glass, stone and ceramic in most of their former uses. In the developed nations, about a third of plastic is used in packaging, another third in buildings, while other uses include automobiles with up to 20% plastic parts, furniture and toys. The ratio of replacing conventional materials with plastics is greatly on the increase in the developing nations but still very far less its ratio in the developed nations

2) Polystyrene

This is a synthetic aromatic polymer made from liquid petrochemical monomer styrene. Polystyrene can be rigid or foamed and is one of the most widely used plastics. General purpose polystyrene is naturally transparent, hard and brittle. It is a very inexpensive resin. As a thermoplastic polymer, polystyrene is in a solid state at room temperature but flows if heated above about 100^oC, its glass transition temperature. This temperature dependent behavior is exploited for extrusion, and also for molding and vacuum forming. Chemically, polystyrene is a long chain hydrocarbon $(C_8H_8)_n$ wherein alternating carbon centers are attached to phenyl groups. The material's properties are determined by short-range Van der Waals attractions between polymer chains. Since the molecules are long hydrocarbon chains that consist of thousands of atoms, the total attractive force between the molecules is large. When heated, the chains are able to take on a higher degree of conformation and slide past each other. This intermolecular weakness confers elasticity and flexibility. The ability of the system to be readily deformed above its glass transition temperature allows polystyrene to be readily softened and molded upon heating. Some common forms produced are Sheets, or expanded polystyrene, oriented polystyrene and extruded polystyrene foam. Indebt studies on polystyrene can be found in (Sabu and Visakh, 2011).

3) Expanded Polystyrene

Expanded Polystyrene (EPS) is a thermoplastic material manufactured from styrene monomer, using a polymerization process which produces translucent spherical beads of polystyrene. As a material, EPS is formed by union of so many beads of polystyrene produced during a modelling process with supply of heat as water steam until full formation of the desired properties. For the production of EPS, a low boiling point hydrocarbon, usually pentane gas is added to the material to assist expansion during subsequent processing. EPS is produced in a three stage processes. In the first stage, polystyrene beads are expanded to between 40 and 50 times their original volume by heating to about 100˚C with steam in an enclosed vessel called a pre expander. During this process the beads are stirred continuously until the final density of EPS is determined. From the pre expansion stage, the expanded beads are cooled, dried and then conveyed to storage silos for maturing. During the maturing stage, the expanded beads are stabilized until equilibrium is reached. In the third processing stage, the beads are conveyed into a mold and the softened beads fuse together when correct temperature is reached within the mold. After cooling the mold, the molded product is ejected from the mold at the completion of the cycle.

After many years of trials and errors of advanced plastic materials in general and the EPS material systems in particular, their applications are becoming common place in the construction industry all over the world. Advanced plastic materials are used in many aspects of building work including large structures such as road constructions, bridges, railway lines, embankments, retaining walls, slope stabilization, basement construction, public buildings or even small family residences. One of the areas that advanced plastics have found wide applications is in the improvement of concrete materials. Concrete technology is growing and many advances and innovations have been made to cope with challenges of many construction aspects. Many productions of lightweight concrete had been designed and among them are by the use of lightweight aggregates and artificial aggregates such as EPS beads, fly ash and slag (Ismail *et al*, 2003; Bonacina et al., 2003; EUMES, 2002; Babu and Babu, 2002; Concrete Homes, 2012; Cook, 1973; Cen and Liu, 2004). EPS beads can be added to mixes either partially or fully replacing aggregates subject to the desired strength and properties. Light Weight Concrete is advantageous in many applications and is becoming increasingly used often in the form of cement-foam composites. EPS is commonly adopted as a permanent formwork just as composite construction materials with a sandwiched core are becoming a more common construction material. (Boni and De Almeida, 2008) 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 to produce sandwich construction material of thicker lower density intermediate layer bonded to external facings of a stiffer material. The high stiffness/low weight efficient structures is beneficial both in the aerospace industry and in the construction industry. The lightweight EPS is combined with other stronger materials to make it a viable structural material. Concrete is then used with EPS to create a strong composite structural system.

Design Concepts

The EPS Core Panel System may be designed using the appropriate design software. The buildings constructed in EPS Core System shall be studied and designed as reinforced concrete structure since the parameters required for their design are the same as needed for traditional reinforced concrete. In the calculation model, the building shall be designed as a structure composed of load bearing walls with a box- like structure. The basis of design is given at Annex III. The system is intended for use where Architectural drawings are available and satisfy the various requirements. The Architect and Engineer designer team of the concerned developer (client) is GI Wire in coil from (Raw Material) EPS Granules (Raw Material) Wire Straightening Machines (Straightens and cuts the coiled wire to required length) Pre Expander Machine (Expands the EPS Granules to be ready for block moulding) EPS Scrap Recycling Machine (Crushes, deducts and mixes fresh and recycled materials) Mesh Welding Machine (Makes weld meshes from straightened wires) Block Moulding Machine (Makes Blocks from expanded EPS Granules by further heating and fusion EPS Cutting Machine (Gives the required shape by slicing the EPS Blocks) Panel Assembling Machine (Makes Panels from wire mesh and EPS Panels) 12 responsible for the drawings and overall building design to comply with the various regulatory requirements applicable to the area. iii) The Engineer of JSPL shall liaise with the engineer of the developer and provide the necessary loading information for the design of the foundation. The system shall be designed to provide the required performance against the loads to be taken into account in accordance with IS 875 (Parts 1-5):1987 and the data given by manufacturer for various panels. It shall also provide the required bearing resistance for earthquake and wind forces as per IS 875 (Part 3):1987 and IS 1893 (Part 1):2002, wherever applicable. Foundation shall be specifically designed in accordance with provision given in IS 1904:1986. The design concept is same as that of the conventional building design. The safe bearing capacity and soil properties (soil investigation report)) shall be provided from the site after soil investigations. Foundation shall be designed based on the soil investigation report. Both single and double panels should have starter bars from either foundation or ground floor slab. All foundations should be designed by experienced engineer with appropriate reference. The design assumptions, detailed calculations, references to necessary and detailed design drawings shall be made available on demand, if required. The structural design calculations should clearly demonstrate structural integrity and stability including connection details. Design calculations should have proper sketches annotated in English. In addition, any other requirement regarding safety against earthquake need to be ensured by the designer as per prevailing codal requirements Vacuum Insulated Panel. Vacuum insulated panel (VIP) is an evacuated open porous material inserted within multilayer enve- lope. VIP consists of inner core, barrier envelope, and desiccant as shown in Figure 9.67 The envelope protects the panel against external stress. VIP is categorized based on the type of material used as envelope; either thick metal sheet or metallized polymer film. EPS foam is used as core to maintain the vacuum condition as well as to provide support for the envelope. The desiccant is placed in the core as adsorbent in order to avoid infiltration by external gas or water vapor. Therefore, VIP is an alternative to conventional building insulation material. It creates vacuum inside the core which is effective in inhibiting the heat transfer Additionally, the thermal conductivity of VIP can be reduced by decreasing the pore of open cell foam such as EPS.

Backfilling Construction of embankment using heavy filling material resulted in several problems such as bearing failure and slope instability. Commonly, EPS geofoam is used as backfilling to reduce the weight of embankment especially when it is erected on top of soft soil.[68]

EPS geofoam is also used as backfilling material for bridge abut- ment and road widening.[69] As lightweight fill, EPS is suitable for construction of ground embankment with low-bearing capability. Furthermore, it reduces the lateral forces on the back of bridge abutment’s structure. In a case study conducted in Thanet Way, England, EPS lightweight blocks were used to eliminate the lateral loading on bridge abutment and stabilized the weak foundation formed on chalk ground. The lightweight property of EPS block allows it to be carried and positioned easily without requiring any lifting equipment thus reducing transportation cost. The blocks were arranged in staggered conformation and steel bars were embedded to further strengthen the structure. Figure 10 shows the construction of Grimsøyvegen Bridge that utilizes EPS as the bridge abutment.

EPS is lightweight, waterproof and has good cushioning ability as well as ease of application. In Norway, usage of EPS geofoam as backfilling has prevented the gradual sinking of bridge deck by reducing the load applied to the weak foundation.71 More- over, the road constructed using lightweight fill costs less than using traditional backfilling despite their comparable perfor- mances.72 Beju and Mandal73 found that the EPS geofoam with higher density has higher compressive strength and modulus values but lower absorption capacity compared to the lower density geofoam.

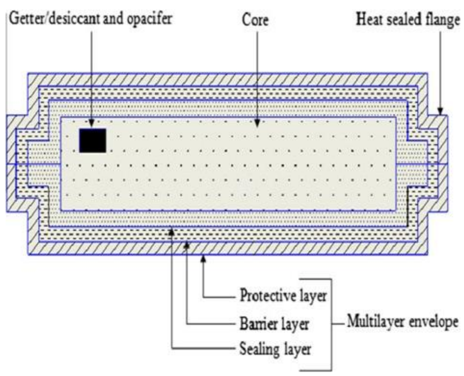

Figure 6. Schematic of a VIP.[67] (Reproduced from Ref. 67, with permission from Elsevier.) [Color figure can be viewed at wileyonlinelibrary.com]

According to Yucel *et al*.,[80] studies were conducted on thermal insulation properties of EPS as construction and insulating mate- rials. Thermal conductivity test provides information that deter- mines the performance and suitable application for the insulating material. As construction equipment, insulation material has to comply with parameters such as temperature, humidity, and over- all assembly condition. The laboratory test results are vital factor in characterization of structure and selection of total insulation-building assembly. The framework of the insulating material is evaluated based on its class, thermal conductivity, density, and mechanical properties. Using the plate method with thermal conductivity detection between 0.036 and 0.046 W mK^{-1}, the EPSs with densities between 10 and 30 kg m^{-3} were tested for its construction-grade insulating performance. The results conclude that the insulating performance of EPS is influenced by material composition in cell, that is, homogenous, porous, or multilayer. Production of Smoke. Smoke is described as visible suspension of solid or liquid particles in the gas as product of combustion and pyrolysis.[81] Production of smoke can be suppressed by restricting the ability of material to ignite and reducing the flame spread and heat released.[82]

IV. RESULTS AND DISCUSSION

Table1. Mechanical Properties by EPS Type[92] (Adapted from Ref. 92)

Mechanicalstrength(kPa)	EPS 70	EPS1 00	EPS1 50	EPS2 00	EPS2 50
Compressivestrength@10%compression	70	100	150	200	250
Compressivestrength@10%nominalstrain	20	45	70	90	100
Bendingstrength	115	150	200	250	350

Chemical Resistance. Chemical resistance of EPS is affected by the reaction time, temperature, and applied stress. It has iden- tical resistance to general polystyrene. EPS is sensitive toward solvent attack which leads to softening and cracking of itself due to its thin cell walls and large exposed surface. Table IV summarizes the chemical resistance of EPS with respect to the common reagents and solvents.

EPS does not react with water, salt, or alkali solution. The insolubility of EPS in most organic solvent influences the selection of adhesive, label, and coating of EPS product. In general, substance is tested for its compatibility with EPS by exposing molded polystyrene to it at 120–140 Despite the ultraviolet radiation resulted in superficial yellowing and fria- bility on molded polystyrene, its physical properties remain unaltered.

Water and Moisture Absorption. EPS has very poor water absorption which decreases as density increases as shown in Table II. EPS with 9–12 years of usage period has 8–9% of its volume filled under groundwater table.[93] The cellular structure of EPS is water resistant, vapor permeable, and possesses zero capil- larity though neither liquid water nor water vapor influences its mechanical properties. However, absorption of moisture is still possible upon complete immersion of EPS due to fine interstitial channels between molded beads

Table2. Percentage (%) Volume of Water Absorption[93] Adapted from Ref. 93

Density(kgm^{-3})	After7days	After1year
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

V. CONCLUSIONS

EPS is a well-established insulation material that is used for var- ious 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 noncombus- tible 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 require- ments 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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