Advances and Applications in Mathematical Sciences
Volume 20, Issue 10, August 2021, Pages 2151-2162

PROPERTIES OF EXPANDED POLYSTYRENE (EPS) AND ITS ENVIRONMENTAL EFFECTS

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Abstract

Within the present times, where technology is pacing up dynamically altogether, the necessity of suitable materials for the development industry is rising day by day. More and more buildings are being constructed to cater our needs of producing facilities. Materials required for buildings nowadays must fulfil a wider range of purposes than simply being basic building blocks or binding material. For buildings which require to be at higher temperatures, material used should have higher fire resistance and a high thermal conductivity while the fabric used to build huge suspension bridges must be lightweight. Many such requirements may arise reckoning on the environment and application of construction. Choice of fabric depends highly on these factors and its own properties. First found within the 1950s, EPS could be a fascinating material which serves many if not all of those purposes. Key highlights of its properties are its lightweight alongside the others like fire resistance, chemical activity, high load carrying capacity, high resistance against impact, etc.

Properties of EPS vary with its density, compression and strain rate. On the account of those properties, EPS can be suitably used as backfilling material in embankments, lightweight concrete, Structural Insulated Panels, etc. This paper highlights the manufacturing of EPS, its properties, scope of improvement within the properties that lay effect on major applications within the scope of the topic. Various tests performed on the EPS specimen like water capillary absorption, mercury intrusion porosimetry, open porosity and impedance spectroscopy will be comprehended together with the test of mechanical strength.

2010 Mathematics Subject Classification: 82D60, 74E99
Keywords: EPS, lightweight, properties, compression, construction.
Received February 4, 2021; Accepted April 7, 2021

I. Introduction

An explosive rise in demand within the implementation of expanded polystyrene (EPS) to the development industry has occurred lately. EPS is a lightweight and sturdy foam with high crash strength and strong insulation towards heat. Additionally, it has a robust load-bearing capability at a low weight, air tightness for regulated conditions, enduring, absolute water and vapour-proof capacity, easy to service, quick, and economical design. Extruded Polystyrene has been utilized in many diverse fields like food packaging applications for several years. EPS being pocket-friendly and energy-efficient is used more often as an effective insulation material in building applications, as cushion travel packaging material for shock-sensitive products, etc.

Expanded Polystyrene is an extended white spun plastic material developed through a polymerization process from solid polystyrene beads [3]. EPS foam consistency is influenced by the dimension's distribution of the beads. EPS is impregnated with blowing materials including hexane (C6H12) and pentane (C5H10) following polymerization. Expandable polystyrene is processed to EPS by means of three steps: (1) pre-expansion of EPS beads, (2) conditioning and maturing of beads, and (3) molding and expansion. Polystyrene granulate is pre-foamed over 90°C to form a sufficiently homogeneous cellular framework with tiny closed cells containing air within. This temperature causes the foaming agent to evaporate, thus inflating the bottom thermoplastic material to 20-50 times its original size. The inner gas of the beads' experiences volume expansion during this process, which creates an air-penetrable cellular structure. During the materia's intermediate maturing, this process is meted out in aerated silos. The ageing period is set counting on the beads, air temperature, scale, and density. Enhanced mechanical elasticity and increased expansion capability are achieved by the beads. Steady pre-expanded beads are then moulded and re-exposed to steam to attach the beads together as an important part of the expansion step. The stabilized beads were formed into broad blocks (Block Molding Process) or customized structures (Shape Molding Process) during their final step. Moreover, polystyrene foam is also produced in solid-state. Carbonic acid gas or nitrogen is employed as an expanding agent in extrusion, during the suspension polymerization.

EPS is a rigid and tough, recyclable, closed-cell plastic substance that has been used in a number of applications including impact reduction wrapping, protective helmet, structural crashability, road filling building products, insulated concrete (ICF) frameworks as well as lightweight EPS foamed concrete. EPS foam is waterproof, lightweight and provides outstanding thermal isolation. These properties render it suitable for packaging purposes [8, 11].

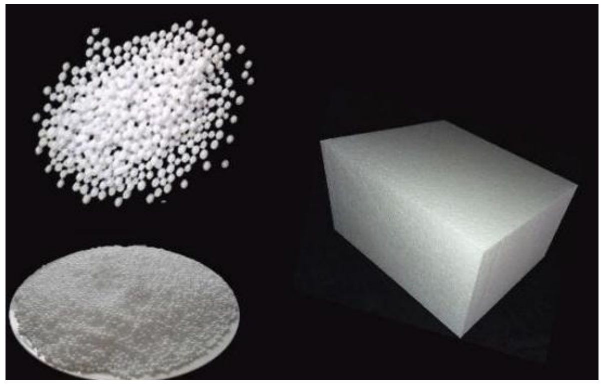

Figure 1. Three significant EPS forms.

II. Properties of EPS

A. Insulating Properties of EPS against heat and its Fire Conduct

Expanded polystyrene (EPS) is found to be the most commonly used polymer core. This is because it is lightweight, resistant to moisture and also it has a long life. Pertaining to its low thermal conductivity, EPS acts as an excellent insulator for heat flow. Though, it works poorly in resisting fire due to its lower melting point temperature [1]. Studies have concluded that softening of EPS starts when exposed to temperatures ranging from 100^{o}C to 120^{o}C. In the process of flashovers, EPS melted about 160°C and then vaporized, producing poisonous gases at a temperature of 275°C. EPS is an inert, low density hydrocarbon-derived thermoplastic which contains several spherical beads with 2 percent polystyrene and 98 percent air. EPS is a porous structure which enables vast air storage to accelerate fire spread throughout the combustion processes. Fire spread characteristics of both polystyrene foam and organic products are comparable as both are readily flammable [13]. Neat EPS foam is characterized as a highly flammable material due to its very low Limiting Oxygen Index (LOI) which is only 17%.

(1) Methods to Improve Fire Retardant Behaviour of EPS:

- One approach to improve the fire resistance behaviour of EPS may be to apply a small amount (< 1%) of fire-resistant material to the EPS insulation material. The installation of mineral wool on EPS walls as a barrier to inhibit horizontal fire formation.

- Alternate solution is the introduction of flame-retardant additives such as ammonium-polyphosphate (APP), [9] nano zirconia, diammonium phosphate (DAP) and phosphorus-based acid additives into EPS. The fire resistance mechanism emerged from the synergy between phosphorus, silicon and nitrogen resulting in the creation of a defensive layer [1].

- Pre-expanded polystyrene particles have historical influences, such as APP, [9] melamine (MEL), and pentaerythritol (PER), been clearly mixed with important intumescent flame retardants (IFR), to create the flame-retardant EPS foam. However, in addition to IFR, novel additives such as smoking silica and melamine enhanced urea formaldehyde resin have been added to further improve the flame retardance of foam. The adhesion between the flame retardant and the EPS surface can be a key issue to consider in this process. A simple method has therefore been developed to create an additional flame-retardant architecture consisting of APP, PER and TGE in EPS foam layer.

- In recent approach, flame retardants of non-halogen type are used for microencapsulation, which has been proved as a good shielding material from fire due to the variance of flame retardants and their easy to process property [16]. This easy development method from the surface to higher flame retardance produced an important and satisfying attempt to create a flame-retardant EPS without interaction with thermal conductivity and increased fire protection in structures and buildings, thereby reducing the potential secondary fire-induced catastrophe.

A study presented a sample in which thermosetting phenolic resin is used along with hydrated aluminium hydroxide shows better fire tolerance in LOI tests in comparison to other unprocessed samples which shows that the fire activity of fire retarded EPS is substantially different from that of non-fire retarded EPS. Fire-retarded EPS shrinks out of the heat supply when subjected to heat. It won't catch fire from small ignition sources like reefers, electric short-circuits or welding sparks [13].

B. Mechanical Properties of EPS

(1) Density Variations: Density variations have great impacts on mechanical properties of EPS. For instance, yield strength and compressive elastic modulus are directly proportional to the density of EPS. Linear relationship is seen between initial Young's modulus and EPS density in the elastic range. Energy absorption in low density EPS is done via distributed cooperation and via failure of cells in high density EPS with high localized forces at point of impact.

(2) Thickness: Thickness of EPS specimen also affects the shear modulus of elasticity and shear strength.

(3) Loading: During the compressive loading of EPS foam, air entrapped within the cells is also compressed and causes viscous forces which increase with rise in loading rate, and in turn lead to rise in strain rate sensitivity.

(4) Experiments: Research was done by Ferrándiz-Mas and García-Alcocel [6] on EPS mortar's durability. Microstructure of cement mortar was taken into minute consideration and analysis was carried out to test type of EPS and its concentration effects on the strength of mortar.

Some of the methods followed were water capillary absorption, mercury intrusion porosimetry, open porosity and impedance spectroscopy. Results obtained are as follows: It is found that the capillary absorption coefficient is reduced by using EPS. While explaining the microstructure pattern of EPS in mortar, scarcity was observed due to its sponge-like and polymeric behavior. As the insulating properties of EPS rises, compressive strength of EPS also rises as illustrated in Heat cycles and freeze-thaw cycles. By adding air-entraining agents, superplasticizer additives and water retainer the workability of mortar is improved. The maximum uniaxial compressive stress which the material can withstand before fracture is called Compressive strength. Compressive strength of EPS product is tested at compression of 10% and this value is then assigned to EPS product (table I). [7]

Table I. Mechanical Properties by EPS Type [7].

Mechanical Strength (kPA)		Compressive strength	
	10% Compression	10% Nominal Strain	Flexural Strength
EPS 70	70	20	115
EPS 100	100	45	150
EPS 150	150	70	200
EPS 200	200	90	250
EPS 250	250	100	350

Taguchi's approach was used for studying mixed proportion parameters of EPS lightweight aggregate concrete by Yi Xu [14]. As a result of these tests for density, stress-strain variations and compressive strength, it is found that by changing the concentration of EPS in EPS lightweight concrete, its compressive strength is significantly changed. These variations are much more in comparison to the effect of varying water-cement ratio. Effects of changes in cement-sand ratio are even more insignificant.

The properties like performance in traction, compression, and flexion, wear resistance and hydrophobic nature can be enhanced by thermal treatment. To understand the impact of thermal treatment on these properties, both Non-treated EPS and (NTEPS) and treated EPS (TTEPS) are compared. It is found that density of EPS increases ten times by thermal treatment [5]. Strength characteristics of EPS increase with increase in density, while cushioning properties of EPS foam are decided mainly by geometry of molded part and by size of bead, processing conditions and density by smaller extent. The flexural strength of EPS geofoam increases with the increase in density [2].

C. Water and Moisture Absorption

The water absorption capacity of EPS is low, which further shows a remarkable reduction as the density increases. The EPS cellular arrangement is water-resistant, vapour-permeable and has zero capillary properties. Although neither liquid water nor water vapour affects its mechanical properties; however, owing to fine interstitial channels between shaped beads, there is still a higher chance of moisture absorption upon full immersion of EPS.

A low temperature plasma treatment is used as a method to increase EPS surface energy. As a result, the EPS specimen's surface became highly hydrophilic. In order to improve its high temperature tolerance and give it an antibacterial character, SiO2 and TiO2 films may be deposited on the outer surface of EPS beads [15]. In order to lower its adsorption degree to use it as a potential sacrificial agent in chemical enhanced oil recovery, R. Diego et al. [10] used another sort of EPS procedure where they degassed EPS in ethyl acetate and sulfonated it. VEJELIS and VAITKUS have established that the most reliable findings of water absorption by expanded polystyrene are obtained by applying an increased pressure method.

Table II. Moisture Properties of Jablite EPS [7].

Moisture Properties	EPS 70	EPS 100	EPS 150	EPS 200	EPS 250
Water Vapour Intrusion Resistance Factor, μ	20-40	30-70	30-70	40-100	40-100
Vapour Resistivity (MNs/g)	145	200	238	238	238
Water Vapour Permeability, δ mg Pa-1 h-1 m-1	0.015-0.030	0.009-0.020	0.009-0.020	0.006-0.015	0.006-0.015

In addition, the shape of the sample, it's height and its preparation process have a major effect on the absorption of water. Table II indicates the moisture properties of the EPS of various amounts. Because of the water-resistant property of cell walls, the water will only enter into the tiny channels between the fused beads.

D. Chemical Resistance Behaviour of EPS

EPS shows no chemical reaction with water, salt, or alkali solution. The preferences of adhesives, labelling and coatings for EPS material are based upon the insolubility of EPS in certain organic solvents. EPS's chemical tolerance is set by time, temperature and stress applied.

Table III. EPS Resistant Behavior.

Attack Source	Extent of Resistance
Alkali solutions	Resisting
Sodium Hydroxide Solution	Resisting
Soap based	Resisting
Bitumen - air blown	Resisting
Oils based on silicon	Resisting
Sea Water or Salt Water	Resisting
Alcoholic compounds	Resisting
Microbes	Resisting
Vaseline, diesel, parafinn oil	Resistance limited
Organic Solvents	Non-resisting
Acids with high oxidation power	Non-resisting
High Octane no. petrol	Non-resisting
Oleum	Non-resisting
Aliphatic or Straight chain hydrocarbons	Non-resisting

Because of its thin cell walls and wide exposed surface, EPS is at risk of solvent attack that contributes to softening and cracking of itself. In general, by exposing moulded polystyrene thereto at 120-140°F, a material is checked for its compliance with EPS. Its physical properties remain unchanged, considering the ultraviolet radiation leading to superficial yellowing and friability of moulded polystyrene. Table IV outlines the chemical tolerance of EPS with relevance to common reagents and solvents.

E. Production of Smoke

The clear colloidal solution within the gas as a combustion and pyrolysis result is defined as smoke [4]. The smoke will be dangerous and poor in oxygen content. Dense black smoke is produced in conjunction with the burning mass when the EPS is burned. because of the low EPS density, the quantity of smoke is reduced. Production of smoke may be suppressed by restricting the power of fabric to ignite and reducing the flame spread and warmth released. In its use as building materials, EPS isn't used exposed, but protected by other materials (sandwiched), so the EPS are shielded from fire. so as to scale back smoke output during fire incidents, the surface region of EPS insulation must be covered by non-combustible material.

III. Environmental Effects of Eps and Its Toxicity

By binding along huge amounts of styrene molecules, polystyrene is produced. Polystyrene may be treated as a solid, film, or foam after the polymerization process. Styrene monomer is a hydrocarbon with C8H8 as molecular formula which gets oxidized fully when burnt to form carbonic acid gas, CO2, and water within the presence of excess element, as seen in the combining equation specified below:

$$C_8\,H_8 + 10O_2 \rightarrow 8CO_2 + 4H_2O$$

Various gases are accustomed to blow it up into foam. The raw materials from which it is manufactured are hydrocarbons (ethylene and benzene) extracted from petroleum and natural gas.

The level of oxygen accessible during the combustion had a direct control on the extent of soot and CO, and CO had formed. The total combustion of one g of polystyrene, in theory, involves more or less 2150cm3 of oxygen. As this tremendous quantity of oxygen is often not usable throughout combustion, polystyrene partly burns to create additional soot and CO, as seen within the equation.

$$C_8H_8 + (10\text{-}0.75\ x)\ O_2 \rightarrow xC + xCO + (8\text{-}2x)\ CO_2 + 4H_2O$$

Styrene use raises the likelihood of cancer, since styrene is one among the carcinogens of humans (National toxicology Program, 2016). In addition, staff members in EPS foam producing facilities are in danger of acquiring diseases like respiratory organ tumours and malignant neoplastic disease. Long-run exposure to vinylbenzene from EPS foam processing typically induces weakness, impairment of the central nervous system, and body defects (US Congress Representatives, 2011).

In reality, the globe experiences plenty more besides the toxic effects on humans. It takes 500 years for EPS foam goods to get decomposed in order that they are recycled in an exceedingly proper manner. Furthermore, water quality is affected because the Advances and Applications in Mathematical Sciences, persisting styrene in landfills leads to the leaching of styrene which further seeps into the groundwater and thus pollutes it. Hazardous gas could also be generated by incinerating EPS foam at a temperature of up to 900°C. This may impact the air quality of the people residing near the incineration facilities, leading to detrimental health consequences and costs [12]. Gypsum, brick, wood or steel are used because the EPS surface insulation materials help to stay fires from spreading to the EPS. The influence of fire-retardant content on EPS toxicity is marginal attributable to the need for just a small addition (0.5-0.1%) of the material. Therefore, relative to natural products, like timber, wool, or cork, EPS emits considerably fewer harmful fumes [13]. Analysis found that starch and cellular-derived composites EPS are more likely to take over traditional EPS in frequent uses, considering its eco-friendly features. EPS doesn't damage the ozone layer to any extent further since it doesn't use CFCs or HCFCs within the manufacturing process. It becomes difficult for fungi and bacteria to grow on the surface of EPS. EPS holds a high calorific value. 1kg of EPS is similar to 1.3 litres of liquid fuel, making it a perfect material for energy recovery.

IV. Conclusion

Expanded Polystyrene (EPS) is a rigid cellular plastic typically white and manufactured from pre-expanded polystyrene beads. High impact resistance and good thermal insulation make it an honest choice in numerous industrial applications. Furthermore, it possesses a light-weight however robust structure and is known for its exceptional qualities like it has a robust load-bearing capability at a low weight, air tightness for regulated conditions, enduring, absolute water and vapour-proof capacity, easy to service, quick, and economical design, which make it more adaptable within the construction industry. This publication aims to provide balanced information based on the manufacturing of EPS, properties concerned with it, how they can be enhanced and their effect on major applications within the scope of the subject. Further, viability of EPS as an insulating material has been discussed and ways to enhance its resistance against flames are discussed which includes a flame suppressive material coated over the surface of EPS to make it safer from fire damages and fulfill the fire safety norms regarding the spread of flame and inflammable properties. Consequently, EPS is an environment friendly polymer which can be recycled completely and effectively. Further scope of research is marked in the field of resistance against organic solvents, health concerns attached with styrene and making EPS flame retardant in cost effective ways.

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