Experimental Study on Strength Behaviour of Concrete Block with Partial Replacement of "Expanded Polystyrene Beads"

M. Dhivakar Karthick[1]
[1]Assistant Professor, Department of Civil Engg.
Kongunadu College of Engineering & Technology
Thottiyam, Trichy

S. Bhagavath Ramya[2], R. Bharathi[3], R. Mullainathan[4]
[2,3,4] IV Year Students, Department of Civil Engg.
Kongunadu College of Engineering & Technology
Thottiyam, Trichy

***Abstract*— With the increase in demand for construction materials, there is a strong need to utilize alternative materials for sustainable development. The main objective of this investigation is to study the properties, such as compressive strength and tensile strengths of light weight concrete containing Expanded Polystyrene (EPS) beads. Its properties are compared with those of the normal concrete without EPS beads. EPS beads are used as partial replacement to coarse aggregates. The results showed that the amount of polystyrene beads incorporated in concrete influences the properties of hardened concrete. EPS beads are used as partial replacement to coarse aggregates. The results showed that the amount of polystyrene beads incorporated in concrete influences the properties of hardened concrete. At 28 days, it was found that compressive strength of 5%, 10%, 15%, 20%, 25% and 30% EPS incorporated concrete strengths were 91%, 77 %, 71%, 63%, 57%, and 45%,respectively.**

Keywords*— Polystrene beads, concrete block, aggregate replacement, compresive and tensile strength

1. INTRODUCTION

India also is aiming at a high developmental rate compared to other nations in Asia. There is heavy demand for the building materials in the domestic market, which is becoming scarce day by day. In this work, an attempt is made to address the possibility of utilizing Expanded Polystyrene (EPS), a packing material in the form of beads in concrete, which otherwise is posing a threat to waste disposal as well as for waste management. This material is a cause of concern to environmentalists. In this study, it is attempted to partially replace coarse aggregates by means of EPS beads.

Expanded polystyrene (EPS) is a rigid and tough, closed-cell foam. It is usually white and made of pre-expanded polystyrene beads. EPS is used for many applications e.g. trays, plates, bowls and fish boxes. Other uses include molded sheets for building insulation and packing material ("peanuts") for cushioning fragile items inside boxes. Sheets are commonly packaged as rigid panels (size 4 by 8 or 2 by 8 feet in the United States).

Due to its technical properties such as low weight, rigidity, and formability, EPS can be used in a wide range of applications. Sales are likely to rise to more than US$15 billion by 2020.

Thermal conductivity is measured according to EN 12667. Typical values range from 0.032 to 0.038 W/(m·K) depending on the density of the EPS board. The value of 0.038 W/(m·K) was obtained at 15 kg/m^{3}while the value of 0.032 W/(m·K) was obtained at 40 kg/m^3 according to the data sheet of K-710 from StyroChem Finland. Adding fillers (graphites, aluminium, or carbons) has recently allowed the thermal conductivity of EPS to reach around 0.030–0.034 (as low as 0.029) and as such has a grey/black colour which distinguishes it from standard EPS. Several EPS producers have produced a variety of these increased thermal resistance EPS usage for this product in the UK & EU.

Water vapor diffusion resistance (μ) of EPS is around 30–70. ICC-ES (International Code Council Evaluation Service) requires EPS boards used in building construction meet ASTM C578 requirements. One of these requirements is that the oxygen index of EPS as measured by ASTM D2863 be greater than 24 volume %. Typical EPS has an oxygen index of around 18 volume %; thus, a flame retardant is added to styrene or polystyrene during the formation of EPS.

The boards containing a flame retardant when tested in a tunnel using test method UL 723 or ASTM E84 will have a flame spread index of less than 25 and a smoke-developed index of less than 450. ICC-ES requires the use of a 15-minute thermal barrier when EPS boards are used inside of a building.

According to EPS-IA ICF organization, the typical density of EPS used for insulated concrete forms is 1.35 to 1.80 pcf. This is either Type II or Type IX EPS according to ASTM C578. EPS blocks or boards used in building construction are commonly cut using hot wires.

A. Environmental Impact

In general, polystyrene is not accepted in curbside collection recycling programmes, and is not separated and recycled where it is accepted. In Germany, polystyrene is collected, as a consequence of the packaging law (Verpackungsverordnung) that requires manufacturers to take responsibility for recycling or disposing of any packaging material they sell.

Most polystyrene products are currently not recycled due to the lack of incentive to invest in the compactors and logistical systems required. Due to the low density of polystyrene foam, it is not economical to collect. However, if the waste material goes through an initial compaction process, the material changes density from typically 30 kg/m^3 to 330 kg/m^3 and becomes a recyclable commodity of high value for producers of recycled plastic pellets. Expanded polystyrene scrap can be easily added to products such as EPS insulation sheets and other EPS materials for construction applications; many manufacturers cannot obtain sufficient scrap because of collection issues. When it is not used to make more EPS, foam scrap can be turned into products such as clothes hangers, park benches, flower pots, toys, rulers, stapler bodies, seedling containers, picture frames, and architectural molding from recycled PS. Currently, around 100 tonnes of EPS are recycled every month in the UK.

Recycled EPS is also used in many metal casting operations. Rastra is made from EPS that is combined with cement to be used as an insulating amendment in the making of concrete foundations and walls. American manufacturers have produced insulating concrete forms made with approximately 80% recycled EPS since 1993.

If polystyrene is properly incinerated at high temperatures (up to 1000 °C) and with plenty of air (14 m^3/kg), the chemicals generated are water, carbon dioxide, and possibly small amounts of residual halogen-compounds from flame-retardants. If only incomplete incineration is done, there will also be leftover carbon soot and a complex mixture of volatile compounds. According to the American Chemistry Council, when polystyrene is incinerated in modern facilities, the final volume is 1% of the starting volume; most of the polystyrene is converted into carbon dioxide, water vapor, and heat. Because of the amount of heat released, it is sometimes used as a power source for steam or electricity generation.

When polystyrene was burned at temperatures of 800–900 °C (the typical range of a modern incinerator), the products of combustion consisted of "a complex mixture of polycyclic aromatic hydrocarbons(PAHs) from alkyl benzenes to benzoperylene. Over 90 different compounds were identified in combustion effluents from polystyrene.

*B. **Safety***

Based on scientific tests over five decades, government safety agencies have determined that polystyrene may be safe for use in foodservice products. For example, polystyrene comes close to meeting the standards of the U.S. Food and Drug Administration and the European Commission/European Food Safety Authority for use in packaging to store and serve food. The Hong Kong Food and Environmental Hygiene Department recently reviewed the safety of serving various foods in polystyrene foodservice products and reached the same conclusion as the U.S. FDA.

From 1999 to 2002, a comprehensive review of the potential health risks associated with exposure to styrene was conducted by a 12-member international expert panel selected by the Harvard Center for Risk Assessment. The scientists had expertise in toxicology, epidemiology, medicine, risk analysis, pharmacokinetics, and exposure assessment.

The Harvard study reported that styrene is naturally present in trace quantities in foods such as strawberries, beef, and spices, and is naturally produced in the processing of foods such as wine and cheese. The study also reviewed all the published data on the quantity of styrene contributing to the diet due to migration of food packaging and disposable food contact articles, and concluded there is cause for limited concern for the general public from exposure to styrene from foods or styrenic materials used in food-contact applications, such as polystyrene packaging and food service containers, especially after microwaving.

Polystyrene is commonly used in containers for food and drinks. The styrene monomer (from which polystyrene is made) is a cancer suspect agent. Styrene is "generally found in such low levels in consumer products that risks aren't substantial". Polystyrene which is used for food contact may not contain more than 1% (0.5% for fatty foods) of styrene by weight.[66] Styrene oligomers in polystyrene containers used for food packaging have been found to migrate into the food. Another Japanese study conducted on wild-type and AhR-null mice found that the styrene trimer, which the authors detected in cooked polystyrene container-packed instant foods, may increase thyroid hormone levels.

Whether polystyrene can be microwaved with food is controversial. Some containers may be safely used in a microwave, but only if labelled as such. Some sources suggest that foods containing carotene (Vitamin A) or cooking oils must be avoided. Because of the pervasive use of polystyrene, these serious health related issues remain topical.

2. LITERATURE REVIEW

[1] Properties of Hardened Concrete Containing Treated Expanded Polystyrene Beads, in the first part of the study, the effects of the water to cement ratio on the properties of poly-styrene aggregate concrete having a nominal density of 1300 kg/m3 were studied. The cement content was kept at 400 kg/m3 for the mixes (mixes 1-4). The water to cement ratio by weight was varied between 0.35 and 0"60. In the second part of the study, silica fume was used as an addition or replacement material to cement. The silica fume content in the mixes (mixes 5 and 6) was kept at 10% of cement weight. The water to cement plus silica fume ratio was kept at 0.40 and the beads content was targeted to 40% by volume.

[2] Lightweight Concrete Incorporating Waste Expanded Polystyrene Reuse and recycling of wastes materials is considered the best environmental alternative for solving the problem of disposal. One of such waste materials is Expanded Polystyrene (EPS). Polystyrene is a thermoplastic substance and has the potential use in concrete to produce lightweight concrete by replacing normal aggregate in concrete.

The Idawati ismail [1] project reports the results of an experimental investigation into the properties of hardened concrete bricks containing expanded polystyrene beads. The beads are used as part of sand replacement in the mixes. It was found that polystyrene concrete is very prone to segregation and has low compressive strength. The properties of the bricks are mainly influenced by the content of polystyrene beads in the mix. The results indicate that polystyrene concrete mix with certain portion of the beads may provide as a suitable alternative material in the construction industry.

[3] Experimental study of the influence of EPS particle size on the mechanical properties of EPS lightweight concrete, EPS concrete is a mixture consisting of cement, sand and poly-styrene aggregate. The research on EPS concrete can be traced back to 1973, when Cook investigated EPS as the aggregate of concrete. In recent years, considerable research has examined EPS concrete, including experimental and theoretical research. It has been demonstrated that the mechanical properties of EPS concrete can be significantly improved with the additional of silica fume, fly ash, or

ISSN: 2278-0181
ICITMSEE - 2018 Conference Proceedings

bonding additives to the concrete matrix. Several researchers developed numerical models to analyse and predict the properties of EPS concretes. All of these studies have promoted the applications of EPS concrete in construction indus-try. Currently, EPS light concrete is used in various structures, such as cladding panels, curtain walls, composite flooring systems, load-bearing concrete blocks, sub-base materials for use in pavement, floating marine structures, and protective layers of structures used for impact resistance, due to its good energy-absorbing characteristics.

[4] Engineering properties of lightweight concrete containing crushed expanded polystyrene waste, The 28-day axial compressive strength of most of the EPS concrete specimens in the paper were determined to reach 12 MPa, which meets the requirement of concrete structure. Compared with the designed densities n, the true densities of the EPS concrete are higher. These results indicate that the true volume fraction of EPS is lower than the designed volume fraction, which is consistent with the results. The higher densities are mainly due to the EPS aggregates being compressed by hydrostatic pressure during the mixing process, which results in the higher density.

[5] Partial Replacement Of Coarse Aggregates By Expanded Polystyrene Beads In Concrete, Increase in the developmental activities world over, the demand for construction materials is increasing exponentially. This trend will have certainly greater impact on the economic system of any country. India also is aiming at a high developmental rate compared to other nations in Asia. There is heavy demand for the building materials in the domestic market, which is becoming scarce day by day. At this point researchers and engineers who have the foresight to keep the developmental activities abreast and curtail the cost factor should look out for other alternative building materials. There are many advantages to be gained from the use of lightweight concrete. These include lighter loads during construction, reduced self-weight in structures, and increased thermal resistance.

[6] Effect of cement and EPS beads ratio on compressive strength and density of lightweight concrete, Expanded polystyrene waste from the packaging industry, in crushed and graded form, can be used as aggregate in concrete mixtures. The polystyrene granules, when coated with an inert hydrophilic chemical, can be added to normal weight concrete mixtures to produce lightweight concrete. Depending upon the amount of expanded polystyrene (density of about 60 kg/m3) aggregate used, lightweight concrete with a wide range of densities from 1000 to 2000 kg/m3 can be obtained for structural and non-structural applications. The coating to the polystyrene aggregate particles is needed to achieve proper dispersion of the granules in the concrete matrix without any segregation. The expanded polystyrene aggregate is a thermoplastic form consisting of gas phase in apolymer matrix. It possesses the property of high compressibility, and can be expected to provide very little restraint to volume changes of the cement paste reducing from due to the applied load as well as the changes in the moisture content.

[7] Compressive behavior of an idealized EPS lightweight concrete: size effects and failure mode The demand for lightweight concrete in many applications of modern construction is increasing, owing to the advantage that lower density results in a significant benefit in terms of creating much more elegant and economical structures. Lightweight aggregates are broadly classified into two types: natural (pumice, diatomite, volcanic cinders, etc.) and artificial (perlite, clay, sintered fly ash, expanded shale, etc.). Expanded polystyrene (EPS) beads of very smooth and rounded shape are a type of artificial ultra-lightweight aggregate (density of less than 30 kg/m3). They can be incorporated in mortar or cement paste to produce low density concretes required for building applications like cladding panels and load-bearing concrete blocks.

3. METHODOLOGY

Literature
↓
Material testing
↓
Mix design
↓
Quantity estimation
↓
Specimen casting
↓
Curing and testing
↓
Result analysis
↓
Conclusion

4. MATERIAL TEST DATA

A. Materials and mix proportions

The materials used in this study were ordinary Portland cement conforming to BS12: 1991, river sand with a fineness modulus of 2.85, crushed granite with a maximum size of 10 mm, available spherical EPS beads. The M20 grade of concrete mix was used in this study.

B. Properties of EPS

Property	**Average value**
Density	13kg/m3
Compressive strength	0.09MPa
Flexural strength	0.21MPa
Water absorption	4%by volume

C. Mixing

Concrete was mixed in a planetary mixer. A technique similar to ‘sand-wrapping’ was applied on the EPS beads. EPS beads were wetted initially with 30% of the mixing water and then the remaining materials are added. Mixing was continued until a uniform and flowing mixture was obtained. The fresh concrete was then poured into prepared molds of required dimensions in layers and compacted by compacting rod.

D. ***Casting and Curing***

A number of test specimens, having the dimensions of length-304.8mm,breadth-152.4mm,depth-203.2mm for compressive and tensile strengths tests, The specimens were demoulded after 24 hrs and stored in water. The blocks were kept in water for 28 days.

5. MATERIAL TESTING

A. Tests on EPS based concretes

Workability

The slump test is the most well-known and widely used test method to characterize the workability of fresh concrete.

B. Compressive Strength

Strength of concrete is the most important, although other characteristics may also be critical and cannot be neglected. Strength is an important indicator of quality because strength is directly related to the structure of hardened cement paste. Even though strength is not a direct measure of durability or dimensional stability, it has a strong relationship with the water to cement ratio of the concrete, which in turn influences durability, dimensional stability and other properties of concrete.

(1) The compressive strength of the EPS concrete is proportional to the strength of the matrix.

(2) The compressive strength of the EPS concrete tends to the value of the matrix strength as the volume fraction of EPS tends to zero.

(3) The compressive strength of the EPS concrete tends to zero as the volume fraction of EPS reaches the maximum packing density.

C. Split Tensile Strength

Tensile strength governs the cracking behavior and affects other properties such as stiffness, damping action, and the durability of concrete. It is also important regarding the behavior of concrete under shear loads. Tensile strength can be determined by either direct tensile tests or by indirect tensile tests such as flexural or split cylinder tests in accordance with

National standards. Similar to the compressive strength, the splitting tensile strength of the EPS concrete also decreased with increasing EPS Volume fraction. The decrease of the tensile strength is primarily due to the decrease of the valid stress area with the increase of the volume fraction of EPS, while the packing density has little effect on the tensile strength. During the testing of the splitting tensile strength, the EPS concrete did not exhibit the same splitting behavior as that observed in normal concretes. The failure observed was more gradual, and the specimens did not separate into two pieces, which reflected the toughness of the EPS concrete. The variation of the tension/compression ratio with EPS volume fraction.

6. RESULTS AND DISCUSSIONS

In this section, results of the various tests conducted on both control and Polystyrene concrete mixes, both in their fresh and in hardened states are discussed. In fresh state, their workability, and in hardened state, their mechanical properties (compressive and split tension) at 7-days and 28-days of curing are discussed and are evaluated.

C. ***Fresh concrete mixes***

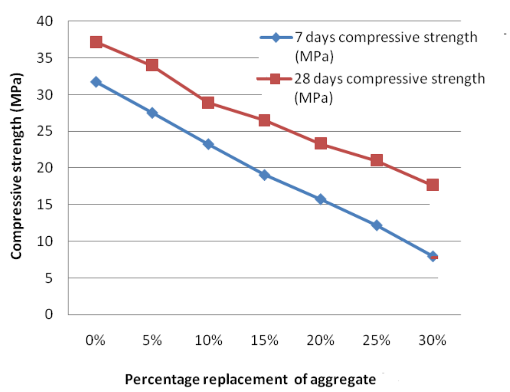
In general, it was observed that workability of a concrete mix increased on addition of polystyrene. Workability of the mixes was observed to increase with increase in percentage replacement of coarse aggregate with polystyrene (as a partial replacement of aggregate) i.e., higher the polystyrene replacement, higher was the workability. Bleeding was observed with the increase in water/cement ratio. Compactions of the specimen were done with vibrating machine, high degree of vibration resulted in segregation of polystyrene beads from the rest and bleeding occurred.

EPS based concrete mixes, in general, decrease with an increase in polystyrene beads content. This can be attributed to,

a. Increase in polystyrene volume, increases the voids as compared to the control mix.

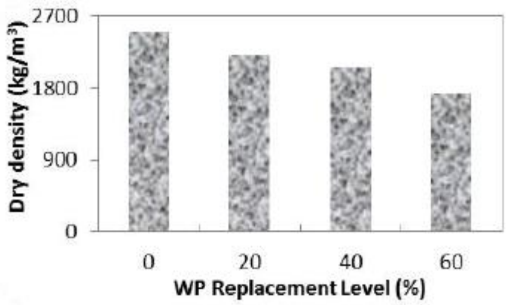
b. Smooth surface of the polystyrene; hence the polystyrene beads tend to bond loosely with the cement paste. It is seen that the polystyrene particles could be easily plucked and removed from the rupture surfaces of the cubes after compression tests. Due to this poor bond characteristic, failure takes place through the cement paste- polystyrene interface at much lower stress levels.

Low specific gravity of the polystyrene due to which there is a reduction in overall density of the concrete. Density affects the compressive strength. The results of split tensile tests are presented in Fig.3. It is clear from the bar chart that, the higher the amount of polystyrene beads in concrete mixture, the lower the tensile strength. Mix with 15% EPS has a relative strength of 80% and that with 30% EPS has a relative strength of 70%.



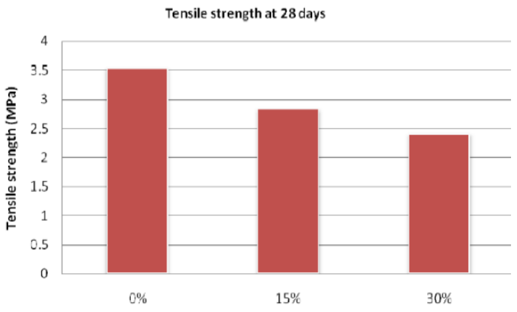
B. ***Water Absorption***

The total water absorption of concrete containing different amounts of WP is presented in Fig. 7. At the 28-day age, the total water absorption of concretes is between 4.65-6.06%. The concrete with a higher volume of WP shows higher water absorption. The possibility for higher absorption may be due to the shrinkage of polystyrene particles and increasing porosity in concrete.This can be confirmed from the higher water absorption of low density concretes which have higher volumes of WP. In the investigation conducted by [22], the total water absorption of concrete containing polystyrene was between 6.7-28.8%. In contrast, water absorption for the concretes in the present study made with 20-40% WP is between 4.97-5.27%.



C. Splitting tensile strength

Similar to the compressive strength, the splitting tensile strength of the EPS concrete also decreased with increasing EPS volume fraction, as shown in Fig. The decrease of the tensile strength is primarily due to the decrease of the valid stress area with the increase of the volume fraction of EPS, while the packing density has little effect on the tensile strength. During the testing of the splitting tensile strength, the EPS concrete did not exhibit the same splitting behaviour as that observed in normal concretes. The failure observed was more gradual, and the specimens did not separate into two pieces, which reflected the toughness of the EPS concrete.. The tension–compression ratio is observed to initially increase with the increase in the volume fraction followed by a decrease.



7. CONCLUSIONS

EPS concretes of density of approximately 1100 kg/m^3 and the 28-day axial compressive strengths of approximately 12 MPa are successfully developed, which achieve the integration of structure and function.

(1) The relationship between the compressive strength and the volume fraction of the EPS concrete nearly follows an exponential decay, which is related to the particle size of the EPS and its composition.

(2) The EPS particle size affects the flexural strength, primarily affecting the reduction of the effective cross-section flexural height.

(4) The failure modes of EPS concrete is related to the EPS volume fraction: the higher the content, the better the plastic deformation.

The replacement by using EPS has shown a positive application as alternate material inbuilding nonstructural members, and it also serves as a solution for EPS disposal.

REFERENCE

[1] ACI Committee 213 R-0.3. Guide for structural lightweight aggregate concrete. American Concrete Institute, Farmington Hills, MI, 2003.
[2] Narayanan N, Ramamurthy K. Structure and properties of aerated concrete: a review. Cem Concr Compos 2000;22:321–9.
[3] Wee Tionghua, Babu Daneti Saradhi, Tamilselvan T, Lim Hweesin. Air-void system of foamed concrete and its effect on mechanical properties. ACI Mater J 2006;106:45–52.
[4] Jones MR, McCarthy A. Preliminary views on the potential of foamed concrete as a structure material. Mag Concr Res 2005;57:21–31.
[5] Babu DS, Babu KG, Wee TH. Effect of polystyrene aggregate size on the strength and moisture migration characteristics of lightweight concrete. Cem Concr Compos 2006;28:520–7.
[6] Ganesh Babu K, Saradhi Babu D. Behaviour of lightweight expanded polystyrene concrete containing silica fume. Cem Concr Res 2003;33:755–62.
[7] Saradhi Babu D, Ganesh Babu K, Wee TH. Properties of lightweight expanded polystyrene aggregate concretes containing fly ash. Cem Concr Res 2005; 35:1218–23.
[8] Cook DJ. Expanded polystyrene beads as lightweight aggregate for concrete.Precast Concr 1973;4:691–3.
[9] Chen B, Liu J. Properties of lightweight expanded polystyrene concrete reinforced with steel fiber. Cem Concr Res 2004;34:1259–63.
[10] Chen B, Liu J. Mechanical properties of polymer-modified concretes containing expanded polystyrene beads. Constr Build Mater 2005;21:7–11.
[11] Bouvard D, Chaix JM, Dendievel R, et al. Characterization and simulation of microstructure and properties of EPS lightweight concrete. Cem Concr Res 2007;37:1666–73.
[12] Miled K, Sab K, le Roy R. Particle size effect on EPS lightweight concrete compressive strength: experimental investigation and modeling. Mech Mater 2007;39:222–40.
[13] Miled K, le Roy R, Sab K, Boulay C. Compressive behavior of an idealized EPS lightweight concrete: size effects and failure mode. Mech Mater 2004; 36:1031–46.
[14] Dekelbab MW. Particle packing using computational and experimental simulation. Michigan: Wayne State University; 2002.
[15] le Roy R, Parant E, Boulay C. Taking into account the inclusions' size in lightweight concrete compressive strength prediction. Cem Concr Res 2005; 35:770–5.
[16] Chen B, Fang CQ. Mechanical properties of EPS lightweight concrete. Constr Mater 2005;1:7–11.
[17] Kan Abdulkadir, Demirboga Ramazan. A novel material for lightweight concrete production. Cem Concr Compos 2009;28:225–9.
[18] Ramamurthy K, Kunhanandan Nambiar EK, Indu Siva Ranjani G. A classification of studies on properties of foam concrete. Cem Concr Compos 2000;31:388–96.
[19] Sengul Ozkan, Azizi Senem, Karaosmanoglu Filiz, Tasdemir Mehmet Ali. Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete. Energy Build 2011;43:671–6.
[20] Mounanga P, Gbongbon W, Poullain P, Turcry P. Proportioning and characterization of lightweight concrete mixtures made with rigid polyurethane foam wastes. Cem Concr Compos 2008;30:806–14.
[21] Shehata Ibrahim AEM, Shehata Lidia CD, Mattos Tales S. Stress–strain curve for the design of high-strength concrete elements. Mater Struct 2000;33:411–8.