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Size effect and age factor in mechanical properties of BST Light Weight Concrete

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HIGHLIGHTS

- Fracture mechanics is the basic principle in studying the size effect.
- Size effect (scaling factor) and shape effect are not investigated in EPS-LWC.
- Different shape and size of test specimens are used in this study.
- Experimental values of compressive and splitting tensile strength are evaluated.
- Existing models of size effect of LWC conventional concrete are investigated.
- Age factor in compressive and splitting tensile strength of EPS-LWC are proposed.
- Effect of shape and size of test specimens on EPS-LWC properties are modeled.

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ABSTRACT

Replacement of whole or part of normal aggregates with Expanded Polystyrene (EPS) beads in the concrete mix is a reliable method to produce Light Weight Concrete (LWC) with considerable advantages. Due to modification effect on mechanical properties of LWC, it is important to examine whether all the assumed hypotheses about conventional concrete also are applicable for LWC structures. Based on an experimental program, this study investigates the effects of specimen size and shape on the compressive and tensile strength of this type of LWC. In this regard, cylinder specimens with 75 × 150, 100 × 200 and 150 × 300 mm dimensions and cube specimens with 100 and 150 mm dimensions were cast and cured in laboratory conditions. Compressive and tensile strengths were tested after 3, 7, 14, 21, 28, 56 and 91 days. The correlation factor between the compressive strength, tensile strength and the shape and size of specimens is evaluated also.

1. Introduction

The size effect or scaling of failure [16] is a crucial factor to fill the gap between the scales of large structures and of laboratory tests. Effects of the shape and size of element is a crucial parameter in almost all scientific investigations [53]. In engineering applications, the shape and size effect varies from huge elements such as foundations [40] and steel structures [13] to small structure [19] and Nanoparticles [20,6,19].

In concrete structures, the size effect is dealing with the effect of structural dimensions on the nominal strength. The loading scale and similarity of structures dimension are the main parameters in studying the size effect [28].

In recent decades, utilizing the mineral and chemical admixtures in concrete technology has introduced Light- Weight Concrete (LWC) as reliable construction material. Smaller dimension

Abbreviations: BST, Commercial name of EPS-LWC; CYL, Cylinder; CS, Compressive Strength; EPS, Expanded Poly-Styrene; GP, General Purpose; KN, Kilo Newton; LWC, Light-Weight Concrete; MM, millimeter; ML, milliliter; MoE, Modulus of Elasticity; MPa, Mega Pascal; STS, Splitting Tensile Strength; SSD, Saturated Surface-Dry; SL, Shrinkage Limited; g/m^3, gram per cubic meter; kg/m^3, Kilogram per cubic meter; t/m^3, ton per cubic meter; m^2/kg, Squared meter per Kilogram; μm, micrometer; με, micro strain; °C, degree Celsius; $f'_{cmy}(d)$, Compressive strength of cylinder (function of d); $f_{ctmu}(d)$, is the tensile strength of the cylinder with any size as function of the diameter d; f'_c, Compressive strength of the concrete at the age of 28 days; f'_{cmu}, Compressive strength of the concrete at different ages; f_{ct}, Tensile strength of concrete; $f'_{cmy}(d)$, Compressive strength of concrete for cube or cylinder; d, characteristic specimen dimension (diameter of cylinder or cube dimension); d_{max}, maximum size of the coarse aggregate; $l_0 = 2.0d_{max}$, is the characteristic length of test specimen; $\sigma_0 = \alpha \times f'_c$, characteristic strength at failure; σ_N, nominal strength at failure; σ_{cub}, compressive strength for cube; ρ_c, density of concrete (kg/m^3); ρ_0, nominal density of conventional concrete = 2300 kg/m^3 n1= aspect ratio of test specimen; A1, B, B1, X2, X4, α, β, γ, δ, η, λ_0, λ, , empirical coefficients.

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and lighter elements, which both decrease the total weight of the structure and the lateral loads [7,26] are some benefits of using LWC. Also the better thermal insulation; better reinforcing steel-concrete bond, durability performance, tensile strain capacity, and fatigue resistance make it superior to normal weight concrete [26,36]. Generally two types of natural (pumice, diatomite, volcanic cinders, etc) and artificial (perlite, clay, sintered fly ash, expanded shale, etc.) lightweight aggregates are used to supply LWC [50]. Despite limited access to lightweight aggregates such as expanded clay, shale, and slate in some regions, the Expanded Polystyrene (EPS) is commercially available worldwide [47]. EPS is a type of artificial lightweight aggregate with the density of only 10–30 kg/m^3 [50]. It is thermoplastic foam involving of gas phase in a polymer matrix and has high compressibility; therefore it may provide very little restraint to volume changes of the cement paste due to the applied load as well as the changes in the moisture content [42].

Mechanical properties of concrete is changing continuously from approximately liquid state to a visco-elastic material within a few hours, which is followed by further development into a hardened material with almost elastic properties. Despite sufficient investigations in conventional concrete, the studies about the mechanical properties and mix proportions of LWC especially with EPS beads are limited in the literature. Concrete structures are designed based on the strength of a standard specimen size. Cube and cylinder specimens are the most commonly used shapes to measure the concrete strength. Table 1 shows the standard shape and size of concrete test specimens used in different countries [51].

The current structural concrete design provisions mainly are referenced to the Compressive Strength (CS) obtained from testing the standard cylinder and cube specimens, cured under standard laboratory controlled conditions. However, when other sizes and shapes of test specimens are used, indications are that the tested concrete strength may be affected. Due to the differences in the shape, height/diameter ratio, and end restraint occurred by the machine platen, cylinder and cube strengths obtained from the same batch of concrete could differ. The actual concrete strength of relatively larger structural members may be significantly lower than that of the standard size [37]. Two main causes of size effect are, a) statistical size effect described by Weibull theory and b) energetic size effect, due to energy release into the fracture front caused by stress distribution [54]. By neglecting the size effect, predicted load capacity values become increasingly less conservative as a member size increases. The failure mechanism in cube specimen affected by the end restraint reduces the uniformity of the test results and increases the effect of coarse aggregate. The ratio of cylinder strength to cube strength varies between 0.8 in normal strength ranges to 1 in strength over 100 MPa [39]. In addition, the effect of specimen size is different in different types of concrete [47]. This concept called the 'size effect', has been investigated and confirmed by various experimental and theoretical studies since the early 1900s [51,23,18,30,29,31,21,33,45].

Along with the effect of shape and size of test specimen, the age of concrete test specimen is another significant factor in accurate determination of the concrete strength. For instance, in LWC containing EPS aggregate, CS and Modulus of Elasticity (MoE) at 7 days is about 75–83% and 85% of those for 28 days, respectively [50,47,42,34].

Table 1
Regional standard shape and size of concrete test specimens.

Region	Cube	Cylinder
USA, South Korea, France, Canada, Australia		150 × 300 mm
UK, Germany, most European,	150 mm	
Norway	150 mm	150 × 300 mm

The main objectives of this study are:

a) Studying the effect of specimen size and shape on the CS and Splitting Tensile Strength (STS) of the EPS-LWC. The Evaluation is based on the fracture mechanism of the specimens;
b) Proposing the relationships to estimating the CS and STS from specimen size in the EPS-LWC;
c) Comparing the predicted compressive strength from cylinder and cube specimens;
d) Developing converting factors between the specimen shapes.

2. Research significance

Expanded Polystyrene (EPS) bead is an ideal artificial lightweight aggregate to produce LWC with considerable performance and structural efficiency. Similar to other types of concrete, the compressive and tensile strength of EPS-LWC are the main concrete properties in design of the concrete structures with any size and shape and must be determined accurately. There is no clear evidence of size effect in EPS-LWC; and for other types of LWC, superiority of one size effect model to the other models is not confirmed in literature. Therefore, validity of several size effect models available in the literature for conventional concrete and the rare models for other types of LWC, to apply in EPS-LWC must be evaluated; and possibly, new models can be developed.

3. Materials

3.1. Natural aggregates

Two types of coarse and fine natural aggregates were used in this study. The crushed latite basalt with the maximum size of 10 mm (Dunmore 10) was used as the coarse aggregate. In this type of LWC, a blend of 50% coarse and 50% fine sand provides the optimum mix, so equal weight proportion of Peppertree-P coarse sand with a maximum size of 5 mm and washed Kurnell Natural River sand fine aggregates were used in the mix. Australian standard, AS-1141 [9] along with the Regional Transportation Authority [41] were applied to sampling and testing of the aggregates.

The properties of Peppertree-P coarse sand and washed Kurnell Natural River sand are presented in Table 2. In addition, the properties of Dunmore coarse aggregate, including the chemical components and physical and mechanical properties are presented in Table 3.

Table 2
Properties of fine and coarse sand types in EPS-LWC.

	Pepper-three P sand	Washed Kurnell river sand
Sieve size	Passing (%)	Passing (%)
4.75 mm	100	
2.36 mm	80	
1.18 mm	55	100
600 μm	37	99
300 μm	23	58
150 μm	11	2
≤75 μm (%)	5	0
Uncompacted bulk density (t/m^3)	1.69	1.33
Compacted bulk density (t/m3)	1.86	1.47
Particle dry density (t/m^3)	2.69	2.52
Particle density (SSD) (t/m^3)	2.71	2.55
Apparent particle density (t/m^3)	2.76	2.59
Water absorption (%)	0.9	1.0
pH value of soil	8.8	
Degradation factor of aggregate	85	
The wash water after using permitted 500 ml	Clear	
Method of determining void content (% voids)	40.7	
Silt content (%)		3
SSD: Saturated surface-dry		