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Effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete

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Abstract

The aim of this study is to investigate the effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete. The present study covers the use of expanded polystyrene (EPS) and un-expanded polystyrene (UEPS) beads as lightweight aggregate in concretes that contain fly ash as a supplementary cementitious material. Lightweight concrete with wide range of concrete densities (1000–1900 kg/m^3) were studied mainly for compressive strength, split tensile strength, moisture migration and absorption. The results indicate that for comparable aggregate size and concrete density, concrete with UEPS aggregate exhibited 70% higher compressive strength than EPS aggregate. EPS aggregate concrete with small EPS aggregates showed higher compressive strength and the increase in compressive strength was more pronounced in low density concrete when compared with high density concrete. The UEPS aggregate concrete exhibited brittle failure similar to normal weight concrete (NWC), whereas, gradual failure was observed in EPS concrete. Moreover, the moisture migration and absorption results indicate that the EPS concrete containing bigger size and higher volumes of EPS aggregate show higher moisture migration and absorption.

Keywords: Expanded polystyrene; Fly ash; Compressive strength; Splitting tensile strength; Moisture migration; Water absorption

1. Introduction

The uses of lightweight concrete has been increasing especially in the construction of high rise buildings, off-shore structures and long span bridges due to the advantage of its low density, which results in a significant benefit in terms of load bearing elements of smaller cross section and a corresponding reduction in the size of the foundation [1]. The lightweight concrete can be produced by introducing: 1. gassing agents such as aluminum powder or foaming agents, 2. lightweight mineral aggregate such as perlite, vermiculite, pumice, expanded shale, slate, clay, etc., 3. plastic granules as aggregate e.g. polystyrene or other polymer materials [2]. The low density lightweight concretes made with first two methods absorb high amounts of water (20–50% weight of dry concrete), which increase the weight of floating structure [3,4]. The weight of the structure is an important factor particularly in the design of floating marine structures. Lightweight concrete made with non-absorbent, artificial ultra-lightweight (density of less than 300 kg/m^3) EPS aggregate can be used to produce a lightweight concrete that floats on water [2,5].

Polystyrene concrete is made from a mixture of cement, sand and polystyrene aggregate (EPS or UEPS aggregates). Polystyrene is a thermoplastic polymeric material initially in the solid form (UEPS) and it can be expanded by the use of steam and expansive agents [6]. EPS aggregates are commercially available worldwide, unlike the other artificial lightweight aggregates (expanded clay, shale, slate, sintered pfa, etc.), where most of the production plants are concentrated in Russia and Europe [5]. EPS aggregate has a closed cell structure consisting essentially of 98% air [1]. By incorporating the polystyrene aggregate at different

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volumes in the concrete, mortar or in the cement paste, a wide range of concrete densities can be produced.

Polystyrene aggregate can be used to produce low density concretes required for building applications [6] and it can be used for other specialised applications like the sub-base material for pavement and railway track bed, as construction material for floating marine structures, sea beds and sea fences, as an energy absorbing material for the protection of buried military structures and as fenders in offshore oil platforms [5,7–10]. Moreover, for equal concrete densities, EPS aggregate concrete have exhibited 70–270% higher compressive strength than vermiculite or perlite aggregate concrete [11] and these were found to be fire-resistant and hence used as a good thermal insulation material in building construction [2,11].

In recent years, the construction industry has been widely using fly ash with cement and this reflected in various changes in the standards worldwide. Moreover, it is known that the use of fly ash in NWC has shown excellent mechanical properties and long-term durability [12–14]. However, the information on the use of fly ash as supplementary cementitious material in lightweight polystyrene concrete is still meager.

This is the fourth in a series of reports on the comprehensive results of an investigation on the behaviour of lightweight concretes containing polystyrene aggregates and mineral admixtures. The first paper reported the strength and durability of EPS concrete containing silica fume [15], the second on the durability and corrosion performance [16] and the third on the strength behaviour of EPS concrete containing 50% fly ash [17]. The main objective of this work is to study the effect of polystyrene aggregate size on strength and moisture migration characteristics of polystyrene concrete containing fly ash.

2. Experimental investigation

2.1. Materials and mix proportions

Ordinary Portland cement (OPC) conforming to both IS:12269 and ASTM Type I, Class F fly ash and silica fume were used as cementitious materials in the concrete mixes. The chemical characteristics of cement, fly ash and silica fume are given in Table 1. Sand finer than 2.36 mm, and with a fineness modulus of 2.8, was used. Normal coarse aggregate (crushed blue granite) passing through 8 mm sieve was used in concrete of higher density. Commercially available spherical shaped polystyrene aggregates of different sizes labeled as P, Q and U, were used. Types P and U have same aggregate grading, however, the Type P is EPS aggregate and the Type U is UEPS aggregate. The properties and grading details of polystyrene aggregates are given in Table 2. All the polystyrene concretes were initially designed as per the recommendations of ACI-211.2 [18] and were modified by considering the efficiency of fly ash, similar to the mixes designed for previous studies [15–17,19]. The detailed mix proportions are given in Table 3. The production and curing of concrete adopted has been described earlier [15–17].

Table 1
Chemical composition of the cement, fly ash and silica fume

Chemical composition	OPC	Fly ash	Silica fume
Silica (SiO_2)	21.78	58.29	74.07
Alumina (Al_2O_3)	6.56	31.74	2.22
Ferric oxide (Fe_2O_3)	4.13	5.86	1.57
Calcium oxide (CaO)	60.12	1.97	2.95
Magnesium oxide (MgO)	2.08	0.14	1.27
Sodium oxide (Na_2O)	0.36	0.76	2.89
Potassium oxide (K_2O)	0.42	0.76	6.51
Sulphuric anhydride (SO_3)	2.16	0.15	0.95
Loss on ignition (LOI)	2.39	0.31	7.67

Table 2
Characteristics of polystyrene aggregates

Sieve size (mm)	Grading of polystyrene aggregate – cumulative passing (%)[a]		
	Type P	Type Q	Type U
8	100	100	100
6.3	100	100	100
4.75	100	0	100
2.36	100	0	100
1.18	0	0	0
Bulk density (kg/m^3)	23.6	9	66.5
Specific gravity	0.029	0.014	1.02

[a] Types P and Q are EPS; Type U is UEPS.

2.2. Test program

The flow values of the fresh concrete were measured according to ASTM C 124-1973. Compressive strength tests were carried out on 100 mm cubes at the age of 1, 3, 7, 28 and 90 days on a testing machine of 2000 kN capacity at a loading rate of 2.5 kN/s. The splitting tensile strength test was conducted on cylinders of 100 mm in diameter and 200 mm in height, at 28 days as per ASTM C 496-89. Each of the results reported for the compressive strength and splitting tensile strength were average results of two specimens. However, if the variation between the two values is more than 10%, an additional specimen was tested to find this average.

The moisture migration test was carried out on different polystyrene concrete in order to characterize the rate of moisture migration of water into the pores in concrete. After 28 days of curing, two 100 mm cube specimens were properly cleaned with nylon brush and washed thoroughly with flowing water. These specimens were dried in a similar manner to the specimens prepared earlier for absorption study [15,16]. The schematic diagram of the moisture migration test setup used is shown in Fig. 1. All the dried specimens in this test were placed on cotton cloth, which rests on perforated steel plate. The test was carried out up to the point at which the difference between two