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Development of multi-strength grade green lightweight reactive powder concrete using expanded polystyrene beads

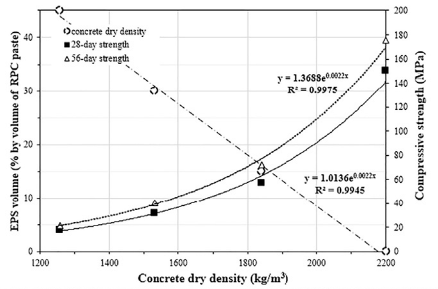
Ali Allahverdi [a,b,*], Seyed Amin Azimi [a], Mehdi Alibabaie [c]

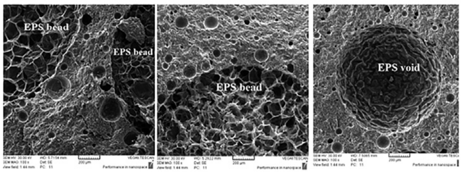
[a] Research Laboratory of Inorganic Chemical Process Technologies, School of Chemical Engineering, Iran University of Science and Technology, Narmak 1684613114, Tehran, Iran
[b] Cement Research Center, Iran University of Science and Technology, Narmak 1684613114, Tehran, Iran
[c] R&D Center of Robin EPC Company, Tehran, Iran

HIGHLIGHTS

- Multi-strength grade lightweight reactive powder concretes are developed.
- Expanded polystyrene beads were used to reduce the concrete density.
- Quartz powder was replaced by GGBFS for environmental and cost effective purposes.
- Different standard water and heat curing conditions were applied.
- Properties of lightweight reactive powder concrete were investigated.

GRAPHICAL ABSTRACT





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ABSTRACT

In this study, a new class of green light weight reactive powder concrete (GLRPC) was developed in different strength-grades by using expanded polystyrene beads. Quartz powder was totally substituted by ground granulated blast furnace slag as an industrial waste material to develop a more cost-effective and environmentally-friendly product. Various mixtures were studied by application of expanded polystyrene beads of the size between 0.5 and 2.3 mm, CEM-II Portland cement, silica fume, GGBFS, polycarboxylate based superplasticizer and water. The effects of different curing regimes including standard water curing and heat curing at 100, 150 and 200 °C on compressive strength, water absorption, and microstructure of GLRPC were investigated. Based on the measurements, density, compressive strength and water absorption values between 1257 to 1840 kg/m^3, 20.8 to 85.6 MPa, 3.47 to 0.22% for GLRPC mixtures were achieved, respectively.

1. Introduction

In the early 1990s, a new class of cement based composite with very high mechanical properties and durability, called reactive powder concrete (RPC) was developed in France [1]. RPC was

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* Corresponding author at: Research Laboratory of Inorganic Chemical Process Technologies, School of Chemical Engineering, Iran University of Science and Technology, Narmak 1684613114, Tehran, Iran.

E-mail address: ali.allahverdi@iust.ac.ir (A. Allahverdi).

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obtained by modifying the microstructure according to the following basic principles [1–5]:

1) Expulsion of coarse aggregate and utilization of fine reactive powder (less than 600 μm) to enhance homogeneity in RPC and to achieve a compact microstructure.
2) Low water-to-binder ratio for reducing capillary porosity and incorporation of superplasticizer to enhance the rheology of the fresh concrete.
3) Addition of secondary cementitious materials such as silica fume (SF) to reduce pore volume by both filling mechanism and pozzolanic reactions consuming $Ca(OH)_2$ to generate additional calcium silicate hydrate (C-S-H).
4) Heat-treatment after setting in order to accelerate pozzolanic reactions and also to crystallize hydration products that enhance microstructural behavior of the RPC matrix.
5) Incorporation of steel fibers to enhance ductility and tensile strength of the material.

Heat curing at temperatures between 50 °C and 250 °C after final setting time results in significant increase in ultimate compressive strength of RPC by improving the microstructure of C-S-H hydrates through increased hydration degree and activated pozzolanic reaction [1,6,7]. The pozzolanic reaction of silica fume strongly depends on temperature. When temperature is increased from 90 °C to 250 °C, the pozzolanic activity of silica fume enhances from 10% to 75% [8]. Furthermore, consumption of crushed quartz in hydration reactions was observed at 200 °C and 250 °C due to significant increase in its pozzolanic activity from 20% to 65% at these temperatures [8].

At about 100 °C, tobermorite is not crystallized, but curing at temperatures between 150 °C and 200 °C causes the formation of coarser and denser tobermorite crystals, whilst xonotlite appears at about 250 °C, which can increase the concrete compressive strength and improve its microstructure [3].

Following a rapid growth in the industrial waste materials and environmental pollution caused by them and the need to reduce production cost of concrete, some researchers replaced cement or aggregate with supplementary cementitious materials. Yazichi et al. [5] studied the mechanical properties of RPC reinforced with micro fiber and high volume GGBFS replacement at different curing conditions. They showed that production of RPC with cement contents as low as 375 kg/m^3 in comparison to the conventional RPC containing a much higher amount of cement (800–1000 kg/m^3) is possible. In addition, use of GGBFS as an alternative silica source in RPC enables partial replacement of SF content. Zhu et al. [9] showed that SF and cement content of RPC can be partially replaced by recycled powders from construction and demolition waste containing clay bricks and concrete solids. They successfully produced environmentally friendly and low cost RPC. Kushartomo et al. [10] showed that glass powder from waste glass shards material can be used at different proportions instead of quartz powder. In another study, Singh et al. [11] used GBFS instead of fine aggregate in normal concrete. They replaced sand by GBFS at different percentages and investigated the effect on compressive strength of concrete. Their results showed that there exist an optimum replacement level and compressive strength increases to a maximum value with increasing the replacement level and then decreases at higher replacement level. In addition, concrete with high content of GBFS showed higher compressive strength than control sample.

Shaheen and Shrive [12] have produced lightweight RPC with density of 1760 kg/m^3 and high compressive strength by replacing some amount of quartz with carbon fiber and application of heat treatment. Sadrkarimi [13] reduced density of RPC approximately to 1900 kg/m^3 without losing strength by increasing the SF content of the concrete and by high temperature curing. Gokce et al. [14] reported that lightweight RPC of density ranging from 1840 to 2430 kg/m^3 and compressive strength values of 69–175 MPa can be produced by using pumice aggregate, applying pre-setting pressure (between 0 and 50 MPa) and application of heat curing.

Expanded polystyrene is a closed-cell foam that can be used as a lightweight material. Expanded polystyrene beads (EPS) can be added to concrete mix at different volume ratios to achieve different density and strength grade lightweight concretes for different applications [15]. The use of EPS in concrete mix, however, has two important technical disadvantages affecting the concrete quality significantly. These disadvantages include: 1) extreme lightness of the EPS beads that can results in significant segregation in the cement matrix, 2) hydrophobic property of EPS leads to a weak bonding with cement paste [16,17].

This paper aims mainly at investigating the application of commercially available EPS beads or even recycled EPS beads as lightweight aggregate for producing multi-strength grade green lightweight RPC (GLRPC) with a wide range of densities that provide the advantage of reducing the dead load of concrete structures that are exposed to earthquake. This new high strength and lightweight concrete provides new design and building options for tall construction projects and long-span bridges. In addition, for specific structures such as off-shore and oil platform structures, precast concrete columns made of this high strength lightweight concrete can be easily transported to the site by floating on the sea surface. For this purpose, different GLRPC mixtures were prepared by partial replacement of RPC paste volume with EPS beads. The effects of replacement level and curing conditions on compressive strength, density, the amount of water absorption and microstructure of the GLRPC were investigated.

2. Experimental

2.1. Materials

Portland cement CEM-II (PC) of strength grade 42.5 complying with ASTM C150, and manufactured by Tehran Cement Company in Iran, was employed in this study. The undensified SF conforming to ASTM C1240 containing about 90–95% SiO_2 supplied by Iranian ferro-alloys industries was used. Quartz powder and quartz sand were completely replaced by GGBFS as fine aggregate to enhance adhesion of EPS with paste and to improve the distribution uniformity of EPS beads in the RPC matrix. The physical and chemical properties of the materials utilized (PC, SF and GGBFS) are provided in Table 1. The particle size distribution of the materials utilized (PC, SF and GGBFS) are also given in Fig. 1. Polycarboxylate-based superplasticizer (SP) conforming to ASTM C494 was also utilized. Commercially available spherical-shaped EPS beads with properties presented in Table 2 were used as artificial lightweight

Table 1
Physical and chemical properties of Portland cement, silica fume and GGBFS.

Property	Portland cement	Silica fume	GGBFS
Chemical			
CaO	63.26	0.35	36.91
SiO_2	22.50	96.12	36.06
Al_2O_3	4.15	0.82	9.16
Fe_2O_3	3.44	0.59	0.70
MgO	3.25	0.29	10.21
K_2O	0.65	0.40	0.70
SO_3	1.80	0.10	1.15
LOI	0.61	0.63	
Physical			
Density (kg/m^3)	3150	2130	2600
Specific surface area (m^2/kg)	302	18,000	320