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Taking into account the inclusions' size in lightweight concrete compressive strength prediction

Robert Le Roy*, Edouard Parant, Claude Boulay

Division Bétons et composites cimentaires, Laboratoire Central des Ponts et Chaussées, 58 Boulevard Lefebvre 75732, Paris, Cedex 15, France

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Abstract

This paper deals with the mix design and mechanical properties of very lightweight concrete (LWC) made of expanded polystyrene spheres (EPS) and very high performance matrix. To avoid the segregation of EPS spheres in the concrete, it is necessary to adjust the matrix threshold by modifying the superplasticizer dosage. Based on experimental data obtained on different EPS concrete, it is shown that the lower the inclusion size, the higher the compressive strength of the hardened concrete. An empirical model is proposed, to take into account these experimental results. Young's modulus was also measured, it was found that its evolution against strength followed usual physical models, like the well-known Hashin's sphere model, and not an empirical one. Finally, a simulation, based on criteria outlined in the paper, shows that quite new concretes can be proposed in a range of strength versus specific gravity not yet achieved.

Keywords: Lightweight concrete; Mixture proportioning; Mechanical properties; Stability; Composite

1. Introduction

Lightweight concretes (LWCs) can be used in various construction fields. It can be used for repairing wood floors of old buildings, carrying walls of low thermal conduction, bridge decks, floating quay, etc. For the first applications, the lightest possible material is used, i.e., usually it has a specific gravity of 0.5, the strength being of less importance. But for some structural applications, a compressive strength higher than 40 MPa is sometimes necessary, which leads the designer to optimise a material with a specific gravity close to 1.8. In such a case, lightweight aggregates, such as expanded glass or clay, take part in the resistance of the composite.

The possibilities offered by new cement-based materials suggest that it is possible to improve the compressive strength versus the specific gravity, or to reach equivalent strength for lower specific gravity. It is proposed to use very lightweight inclusions, like expanded polystyrene (EPS), having a specific gravity of about 0.02 in an ultra high strength matrix having a strength higher than 130 MPa.

However, the mechanical behaviour of such a material is quite different from that of an ordinary LWC. It is known that the stress distribution within a granular cement-based composite depends on the sizes of the inclusions and on the respective modulus of the matrix and of the inclusions. When the aggregate has a modulus higher than that of the matrix, stress concentrations appear in the vicinity of the aggregates. It is said that coarse aggregates channel the stresses in compression. However, the LWC rupture mechanism is quite different from the NWC rupture mechanism, because the inclusion modulus is very low, compared to that of the matrix. To predict the material compressive strength, it could be interesting to develop a model based on a composite approach. The models developed in Refs. [1,2] take into account the relative elasticity modulus of the two phases (matrix and inclusions). However, when dealing with very lightweight aggregate, like EPS, having a negligible modulus, the two-phase models are in their limit of applicability. Another way is to refer to models based on porosity, assuming that the concrete is described as a matrix containing voids (EPS spheres). In these models, the porosity is often taken into account through a power or a logarithmic function [3]. Most of the time, it is also necessary to evaluate the strength of the matrix at zero porosity.

Before developing such a model, it is necessary to assess the rupture mechanisms of these lightweight materials and, as a first step, to quantify the influence of the lightweight inclusion size on compressive strength. Indeed, in literature,

* Corresponding author. Tel.: +33-1-40-43-53-98; fax: +33-1-40-43-54-98.

E-mail address: robert.leroy@lcpc.fr (R. Le Roy).

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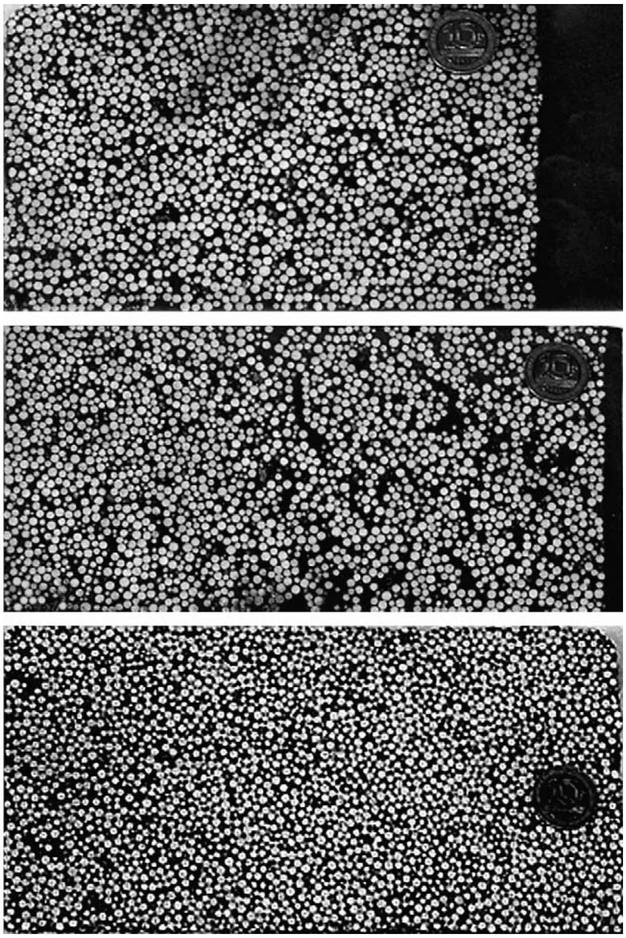

Fig. 1. Segregation evolution according to the sphere packing density observed on sections of 11 × 22 (cm) cylinders. From bottom to top, sphere packing density of 0.7, 0.4 and 0.3 (sphere diameter = 3 mm).

the fact that the compressive strength increases when the pore size or EPS sphere size decreases is well known [3,4].

The aim of this study is to propose a support for the mix design of a new type of LWC and to evaluate some main features of its other mechanical properties. To this end, the influence of the aggregate-packing density and of the EPS sphere size on the resistance and modulus of LWCs is studied. The bases of a model suitable to lightweight EPS concretes are proposed. Experimental results used in this paper come from Ref. [5].

1.1. Materials and mix design principles

The two-phase material is an ultra high strength mortar and expanded polystyrene spheres (EPS). The basic matrix is of the same type as that used for very high strength concretes (VHSC) [6]. It is made with CEM I 52.5 cement, class A silicafume (according to NF P 18 502), a rounded quartz sand having a maximum diameter of 400 μm, and a polycarboxylate-based superplasticizer. The lightweight inclusions are EPS of three different diameters: 1, 3 and 6 mm, each of one being used separately. It is possible to find in the market polystyrene spheres coated with a layer of polymers used to inhibit the material hydrophobia, to lower the electrostatic effects, and, to possibly create air voids in the mixture. To control the proportion of air voids in the concrete, and due to the fact that the paste had a good consistency that contributed to maintain the mixture homogeneity, no coated white spheres were used.

Two forces interact in the balance of a polystyrene sphere embedded in a viscoplastic fluid: Archimed's force and the resulting shear stress developed in the matrix especially at the matrix–inclusion interface. To maintain the concrete homogeneous, it is necessary that the matrix develops a threshold balancing the upward driving force. However, the presence of the other spheres influences this balance (Fig. 1). In the presence of a low sphere dosage, i.e., when the specific gravity of the LWC is high, the spheres are free to move, whereas for low specific gravity (≈ 0.6), the high sphere concentration is favorable to maintain the homogeneity.

In practice, it is possible to obtain homogeneous mixtures by adjusting the superplasticizer dosage. Indeed, a variation of superplasticizer dosage affects the matrix slump flow, which is itself directly linked to the shear resistance (Fig. 2). This can be shown by a dimensional analysis and in experiments on materials in which size of heterogeneity is

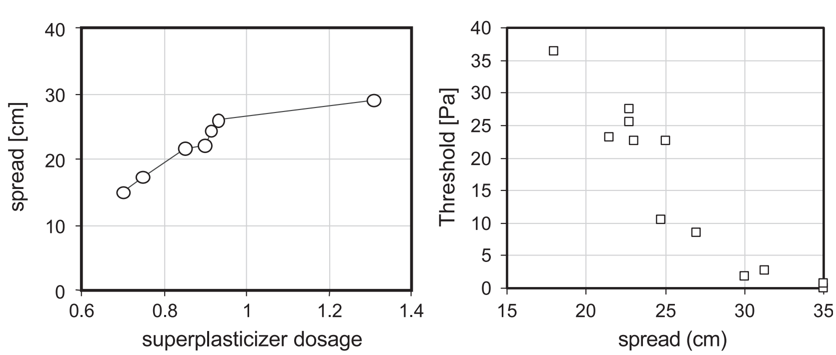

Fig. 2. Slump flow evolution (dim. B × b × h = 100 × 70 × 50 mm) according to superplasticizer dosage and correlation between paste threshold and spread. The threshold was measured by extrapolation on the y axis of the decreasing curve obtained on coaxial viscosimeter (Haake VT550).