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ON THE EQUATION OF STATE OF CEMENTITIOUS COMPOSITES - AN EXPERIMENTAL STUDY

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Abstract

The behavior of cementitious materials under severe loading is of particular interest, for research on ballistic impact, penetration and near distance explosions, where very high pressures are developed. Therefore it is important to investigate the behavior of such materials in the exceptionally high hydrostatic pressures range. One of the key characteristics of this behavior is the equation of state (EOS) that is the relationship between hydrostatic pressure and density (or bulk strain). However it has not been adequately investigated, and therefore the mechanisms of cementitious materials deformation and damage that are developed within that range of high pressures is at least partly obscure and far from being clearly understood. This is partly because the controlled application of extreme pressures requires special equipment and expensive experimental setups and testing is associated with a wide variety of technical problems. This paper aims at presentation of the development of an experimental setup to perform confined compression tests of mortar and concrete specimens at high pressures up to 1GPa. It presents the experimental study of different cement paste and mortar specimens and their comparison with previous results, obtained under high pressures up to 300 MPa. This allows the investigations of size effect for unsaturated samples, as well as the effect of the sand volumetric content on the loading branch of the equation of state.

The experimental study shows a good repeatability for the cement paste specimens and for mortar specimens with fine sand. It also shows that decrease of water/cement ratio in the cement paste mix as well as increase of the sand volumetric contain in mortar results in monotonic increase of the secant bulk modulus of the loading branch of EOS. The comparison of the mean loading branch of the experimental EOS for unsaturated specimens having 30 mm diameter (70 mm height) and 70 mm diameter (150 mm height) clearly indicates that there is practically no size effect for all tested mixture compositions. While for the cement paste there is no difference up to 270 MPa (highest pressure level in the test in the small apparatus), the addition of sand yields an increase of the difference, which, anyway, remains small.

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Keywords: uniaxial confined compression test, equation of state, cement paste, mortar, high pressure, size effect

1. Introduction

The behavior of cementitious materials under severe loading is of particular interest, for research on ballistic impact, penetration and near distance explosions, where very high pressures are developed. Therefore it is important to investigate the behavior of such materials in the exceptionally high hydrostatic pressures range. One of the key characteristics of this behavior is the equation of state (EOS) that is the relationship between hydrostatic pressure and density (or bulk strain).

However, this problem has not yet been adequately investigated, and therefore the mechanisms of bulk deformation and damage that are developed within that range of high pressures are far from being clearly understood. This is partly because the application of controlled extreme pressures requires special equipment and expensive experimental setups and the testing process is associated with a wide variety of technical problems.

There exist two major techniques to obtain the EOS: dynamic and static. The static tests may be performed on large specimens containing coarse aggregates. Several studies are reported in the literature on either triaxial pressure loading [1-3] or using a uniaxial confined testing technique [4-5]. The triaxial loading tests are commonly performed by high-capacity tailor made hydraulic triaxial press machine [6-8]. Specimens that are loaded by pressurized fluid are jacketed with a rubber membrane [2]. These tests allow pressures up to ~ 600 MPa for relatively large concrete specimens. The uniaxial confined tests are more affordable and provide quality results at this high-pressure range. Utilization of uniaxial strain tests to such pressure levels under confinement conditions may apply very high pressures and develop relatively large deformations of the specimen.

In an earlier study, the authors have developed the first generation of a multi-scale mix based model for unsaturated cementitious materials [9] and have validated the proposed model for small specimens (30 mm diameter) made of cement paste and mortar in confined tests with high pressures up to 300 MPa [5] (hereafter – “small device”).

This paper aims at presentation of the development of an experimental setup to perform confined compression tests of mortar and concrete specimens at high pressures up to 1GPa (hereafter – “large device”). It presents the experimental study of different cement paste (small device) and mortar (both small and large devices) specimens, including investigations of size effect for unsaturated samples, as well as the effect of the sand volumetric content on the loading branch of the equation of state.

2. Materials and setup

2.1. Mix proportions

Mortar mixes with water to cement (w/c) ratio of 0.50 and various content of natural quartz sea sand were tested. The cement used in this research was a Portland cement of CEM I 52.2 N type. The chemical composition of the cement can is given in Table 1.

Table 1. Chemical composition of Portland cement

Oxide	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	TiO_2	K_2O	Na_2O	P_2O_5	Mn_2O_3	SO_3
% by weight	63.03	18.53	5.60	3.43	1.37	0.38	0.45	0.14	0.53	0.04	2.53

Natural quartz sea sand that is passing a sieve size of 1.18 mm was used as fine aggregate in the mortars.