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Hugoniot properties for concrete determined by full-scale detonation experiments and flyer-plate-impact tests

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Abstract

Two different and independent shock compression experiments have been performed in order to determine equation of state (EoS, Hugoniot) properties of concrete. The techniques used in the present study are full-scale detonation experiments where pressures were obtained in the affected concrete body with carbon resistor gauges, and, flyer-plate-impact tests where subsequent velocity histories were monitored by a VISAR (velocity interferometer system for any reflector) and the related pressures and densities evaluated by means of the conservation equations. The different specimens have been produced with concrete out of the same charge. The experiments were performed in different laboratory locations but at the same time. Pressure–density data are reported from both methods up to 16 GPa. The investigation has been carried out in order to assess the validity of two different methods with respect to EoS-data. To the knowledge of the authors, this has not been done before.

Keywords: Hugoniot properties for concrete; Equation of state; Full-scale detonation experiments; Flyer-plate-impact tests

1. Introduction

High dynamic loadings like explosions have the capability to release a large amount of energy within microseconds. In such circumstances, the concrete material undergoes high pressures in the gigapascal range including thermodynamic influences. These short term loadings cause shock waves which propagate in the affected solid body. Material models must represent these complicated phenomena. If they are available and implemented into numerical tools, numerical simulations might partly substitute time consuming and expensive experiments.

Ruppert, Gebbeken, Greulich and Pietzsch developed a model for plain and steel fibre reinforced concrete (RGGP-model) [1–3], which is specified for hydrocode simulations, where the constitutive equations of the material properties consider strain-rate dependence, and where the three-invariant yield surface or the damage

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formulation are modularly composed. This leads to a model formulation in an elasto-plastic continuum damage theory considering the constitutive equations in the framework of macromechanics.

Adopting the classical theory of thermodynamics, the Cauchy-stress tensor was additively disparted into a hydrostatic pressure component and a deviatoric stress component. In doing so, the material dependent constitutive equations are split in an equation of state, e.g. a pressure–density–energy relation, and a plastic yield condition including isotropic hardening due to strain-rate effects and isotropic softening due to macroscopic damage (degradation of stiffness and strength).

In this context, the focus of interest is here laid on the experimental determination of equation of state properties for concrete. This means a great challenge to the experimental methods to provide data of shock induced Hugoniot states. There is still a lack of experimental data for equation of state properties for concrete, which is needed for our material models.

The main testing methods are contact detonation experiments and flyer-plate-impact tests. Up to now, the data of some experiments has been collected, but only for either of the methods. The different methods have not yet been checked against each other. Therefore, we inspired our partners, the WTD 52[1] and the EMI[2], to conduct coordinated experiments in order to get comparative results. Thus, contact detonation experiments at the WTD 52 and flyer-plate-impact tests at the EMI have been performed at the same time on different types of concrete specimens produced out of the same charge of concrete mixture. This procedure enables a direct comparison of the two techniques. Moreover, one method can probably complement the other. Such a study has, to the knowledge of the authors, not done before.

2. Material description—concrete mixture

In order to produce identical specimens a company was instructed to manufacture all elements out of the same charge of concrete mixture. For the full-scale tests at the WTD 52 four slabs of $100 \times 100 \times 30$ cm were casted and for the EMI a cylinder of the length of 25 cm and diameter of 5.8 cm from which 1.2 cm thick disks have been cut by a diamond saw. In addition, nine test cubes (according to the German code DIN 1048) have been produced to determine the concrete strength after 28 days. The concrete mixture had the following properties:

- maximum grain size 8 mm,
- cement PZ 35F,
- content of cement 450 kg/m^3,
- content of aggregates 1730 kg/m^3,
- water–cement ratio 0.45,
- uniaxial compression strength at the day of experiments 51.2 MPa (average of six tests).

Unfortunately, the grain size distribution line of the concrete is not available. The density of 2.35 g/cm^3 has been determined with cylinders drilled out of one slab. Further descriptions concerning the concrete mixture and specimen testing are included in the report by Landmann [4].

3. Equation of state—Hugoniot properties

Material formulations on the level of macromechanics can be developed using the classical theory of thermodynamics. For this, the material independent relations are given by the balance equations which start from a global or integral proposition in a control volume of a material body in space. Hence, the local or

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