FRACTURE OF CONCRETE UNDER BIAXIAL HIGH TEMPERATURE TESTS

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Abstract

A new concrete test equipment has been developed. It allows the performance of fracture tests and the determination of the stress-strain behaviour of concrete subjected to biaxial stresses at high temperatures up to 1000 ^{o}C.

The test set-up consists of a rigid steel construction with four hydraulic jacks. The concrete specimens are loaded in a manner whereby stresses or strains may be controlled. The maximum forces comprise 1000 kN in each direction. The forces are transmitted by water-cooled pressure pistons. A nearly unrestrained load application to the specimens is achieved by so-called "loading brushes". Loads are measured by load cells and deformations by a special deformation measuring device. The specimens are heated by an electrical furnace.

The test results indicate an increase of the ultimate biaxial high temperature strength compared to the uniaxial strength. The increase of the biaxial strength is comparatively great at high temperatures. The occurrence of fracture up to 300^{o}C is suddenly and explosive. At higher temperatures the failure mechanisms are moderate.

Keywords: concrete, fracture, strength, biaxial, high temperature, test equipment

1. Introduction

Up to now properties of concrete concerning fracture, strength and deformation behaviour at high temperatures were investigated under uniaxial conditions. Constitutive equations, which are derived from data of this type, cannot simply be applied to complex concrete structures like pressure vessels or even slabs and other flat concrete elements which have multiaxial stress states. For this reason a test facility was designed and constructed, which allows a study of the fracture and stress-strain behaviour of concrete subjectet to biaxial stresses and high temperatures. A brief outline of the construction and test results are given in this report.

2. Test set-up

Fig. 1 shows a sketch of the whole test set-up. The loading system consists of a closed, rigid steel frame. The concrete specimens, plates of 200 x 200 x 50 mm^3, are loaded by four servohydraulic jacks. Each hydraulic cylinder may be employed as a stress or strain rate controlled loading system with a maximum load of 1000 kN. For the biaxial tests the control units of each hydraulic cylinder are interconnected and equalized

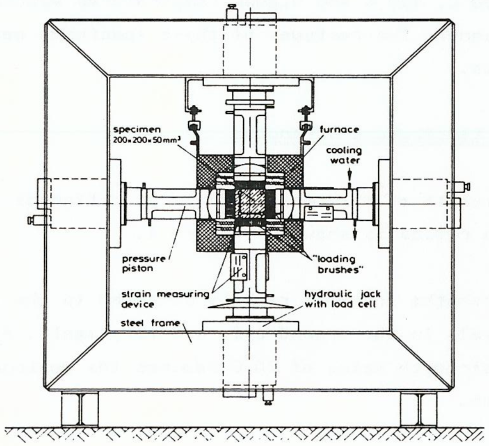

Fig. 1. Test set-up

to maintain the specimens stable in space during the tests. The forces are transmitted by water-cooled pressure pistons. Three of the loading devices are spherically supported. The loads are measured by load cells, which are installed in the water-cooled regions of the pistons.

The deformations are measured directly on the surface of the specimens. At room temperature pasted strain gauges are used. For the strain measurements at higher temperatures a special deformation measuring device with SiO_2-rods and inductive displacement transducers was developed. With it the strains in the three axes are measured.
The specimens are heated by a controlled electrical furnace, which consists of two halves. Seperate adjustable heating circuits render a homogeneous distribution of temperature in the specimens.

Special problems in biaxial tests arise from the load application to the specimens especially at high temperatures. Generally a nearly unrestrained load application is required. The test set-up must allow for a defined and homogeneous state of stress in the specimens. To minimize the restraint resulting from the friction between loading platens and specimens so-called "loading-brushes" (fig. 2) were constructed. Each load application steel platen is divided into 190 parallel rods having a distance of about

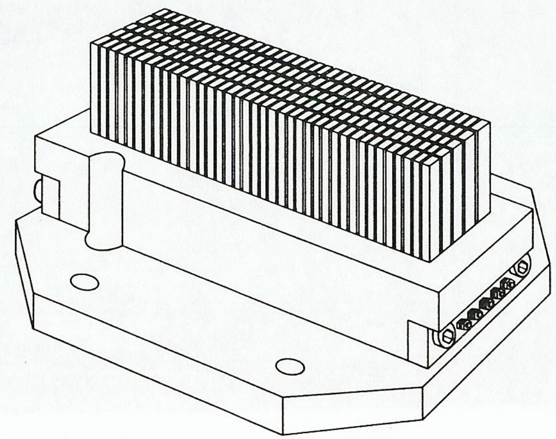

Fig. 2. "Loading brush"

0,1 mm from each other. These rods follow the deformations of the loaded specimens surfaces and so reduce the transverse strain inhibition to a minimum.
By comparing the uniaxial and biaxial strengths determined with brushes and with rigid steel platens the reduction of the strain inhibition by using loading brushes was proved. When the brushes were used the strengths were lower than the strengths determined with rigid platens.

3. Fracture and crack patterns of specimens

In the uniaxial tests cracks developed uniformly through the specimens in the load direction (fig. 3a). With the biaxial tests, additionally surfaces of fracture parallel to the nonloaded specimen surfaces were observed. The specimens failed by the spalling of plain, nearly circular sheets from the nonloaded surfaces. This result strongly supports the assumption of a biaxial state of stress in the specimen. These crack patterns were observed at room temperature and in an equal manner at high temperatures, too (see fig. 3b).

Fig. 3a. Specimen, tested at 20°C, $\sigma_1 : \sigma_2 = 1:0$

Fig. 3b. Specimen, tested at 700°C, $\sigma_1 : \sigma_2 = 1:1$

The fractures occur with a detonating noise without warning, when the specimens were tested at room temperature and at 300°C, especially when tested biaxially. This coincides with the highest strengths of the specimens. At 150°C, 450°C and higher temperatures specimens fractured in a moderate manner. The residues of these specimens generally crumbled into small pieces.

4. Biaxial high temperature strengths

The ultimate strength of a normal concrete at different temperatures and different stress ratios is shown on figure 4.

The ultimate strengths increase rapidly compared to the uniaxial strength even if load levels in the second axis are very small. At a stress ratio of 1 : 1,9 the strength value of 20°C reaches the maximum of 134% of the uniaxial strength.

The relative increase of the biaxial ultimate strength is more marked at higher temperatures.

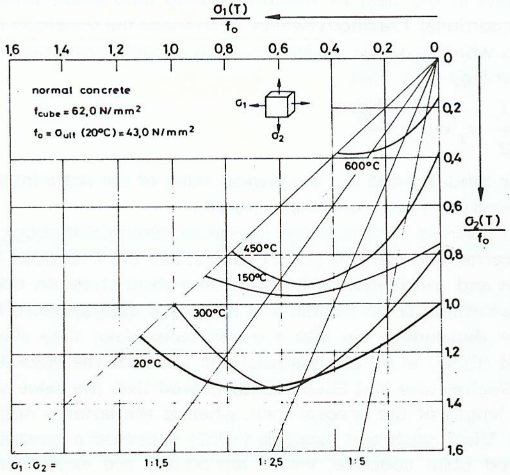

Fig. 4. Biaxial ultimate strength envelopes

5. Conclusions

The biaxial strength tests have shown that even very small load levels in the second axis alter the mechanical properties of concrete significantly. Therefore the biaxial high temperature behaviour of concrete needs further investigations as the comparison with the well known uniaxial test data indicates considerable differences especially in the high temperature region.