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H10/1

CREEP OF HIGH STRENGTH CONCRETE AT ELEVATED TEMPERATURES

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Abstract

The creep behaviour of the HTR high strength concrete was studied in the test laboratories of ETH Lausanne, TU Braunschweig and Univ. of Cassel. Unsealed and sealed concrete specimens were tested up to 120° whereby different test procedures and test methods were applied. Important influences on the high temperature creep are the test temperature, the load level during heating up, the process of drying during heating and the type of sealing during the heat exposure. Specimens tested under saturated vapour atmosphere (autoclave tests) indicated the largest creep strains. The creep of drying specimens at 80 or 120°C turned out to be very low after the drying process is completed. Wet specimens sealed with polymer resin and metal foils indicated less creep than those specimens which were tested in an autoclave at high temperatures.

1 Introduction

The following report deals with creep investigations of a special high strength concrete for prestressed concrete reactor vessels (HTR-concrete). As the same type of concrete was tested in different laboratories the report deals also with the influence of different types of creep equipments, test arrangements, test procedures, and on the creep strains at elevated temperatures.

2 Concrete mix design

In connection with the design of the HTR prestressed concrete reactor vessel a special high strength concrete was developed and tested over a broad range of ambient and service conditions. Creep at elevated temperatures was one main point in the concrete research program and three different concrete laboratories were employed for different creep tests at 20 °C, 50 °C, 70 °C, 80 °C and 120 °C.

Two types of coarse aggregate were used for the concrete: crushed basalt (Honnenberg) and quartz gravel (Rhine river gravel). A common Portland cement HOZ

45L (blast furnace slag cement, slow) and EFA-Filller-BM II (electro filter ash) were chosen as binder materials with respect to practical considerations. The complete mix design for the basalt concrete is given in table 2.1. A special sieve size was used as to ensure the pumping of the fresh conrete on the site.

Tab. 2.1: High strength HTR-concrete mix design for basalt concrete

material	dim	basalt concrete
cement	kg/m^3	390
water	ltr/m^3	176
fly ash	kg/m^3	60
sand 0/8	kg/m^3	927
basalt 8/16	kg/m^3	927
plasticizer	% of cement	1.2
retarder	% of cement	0.2

The fresh concrete mix shows the following properties (table 2.2)

Tab. 2.2: Fresh concrete properties of the high strength basalt concrete

density [kg/m^3]	compaction v [1]	spreading a [cm]	air void LP [%]
2534	1.06	45	1.2

The strength properties of the basalt concrete after 7 and 90 days were determind according to table 2.3. Cubes of 20 x 20 cm and cylinders of 15 x 30 cm were being tested. After demoulding reference specimens were stored under water until the date of testing. The Lausanne specimens indicated a 10% higher strength compared to the Cassel specimens.

Tab. 2.3: Concrete properties of the high strength basalt concrete

laboratory	density kg/m^3	$\beta_{w,7}$ N/mm^2	$\beta_{w,90}$ N/mm^2	$\beta_{c,90}$ N/mm^2
Cassel	2528	48	75	64
Lausanne	2510	55	83	75

The modulus of elasticity after 90 days at 20, 70 and 120 C of sealed specimens was determined as follows (table 2.4).

Tab. 2.4: Modulus of elasticity of high strength basalt concrete

laboratory	E_{20}	E_{70}	E_{120}
Cassel	44 000	40 900	37 200
Braunschweig	49 000	38 100*)	36 100*)

*) concrete unsealed

The design stress for the prestressed concrete reactor vessel was fixed at 51 N/mm^2. With respect to the design stresses creep stresses of 15 N/mm^2 and 20 N/mm^2 were employed. As the concrete used was identical in all three cases the creep data derived depend mainly on the creep loads, different test arrangements, type of temperature exposure, test procedure, and test equipment.

3 Test results

The creep strains according to the Cassel creep test I (sealing: metal foil) are shown on fig. 3.1. Each curve represents the average of three creep tests. The scatter inbetween each tests was usually less than 10% which is comparatively small [1]. As no reference values for the creep at 20°C were derived in Cassel the belonging data of reference tests performed in Lausanne are shown on fig. 3.1. These values are comparatively small compared to values of ordinary concrete. A comparison of the test data with data calculated according to the ÖNORM Standard 4250 shows that the expected creep is about 3 times larger than the reported data at 20 °C. The temperature creep values indicate a concrete creep at 70 and 120°C which is roughly ten times higher than that at 20°C. This value exceeds the reported data of high temperature investigations performed in the past by a factor of two [3] and shows that the reference data at 20 °C are not reliable.

Fig. 3.2 shows the creep data of Cassel creep tests II (sealing: autoclave). It is indicated that the autoclave conditions lead to even higher creep strains than the applied foil sealing according to test method I. The difference between 70°C and 120°C data after 420 days comprises roughly 30%. The 120°C data indicate creep strains of 2.4‰ after 420 days in this test. The strain of test I indicated under similar test conditions strains of only 1.6‰. According to our interpretation of these tests we assume that the different type of concrete sealing is the main factor and responsible for the observed behaviour.

The data of fig. 3.1 and 3.2 indicate that the main part of creep strains occurs within the first 20 days after heating. During this time the specimens in the autoclaves creep two times faster than the sealed concrete. Thereafter a dramatic reduction of creep rate was observed. The creep strains of the 120°C tests from 20 to 420 days are in the range of 0.75‰ (test I) and 0.84‰ (test II), i. e. both test methods indicate comparable values in this time range.

Fig. 3.3 shows the observed creep data of the drying concrete of the Lausanne creep tests. It should be noted that in this case the specimens were already loaded during heating and that the creep load was 15 N/mm ^{2}. Unfortunately there are no data on the transient creep strains during heating in the report [2], i. e. transient creep was not determinded. It should be noted that also in this case creep occurs mainly during the first 20 days. Thereafter a moderate creep rate was observed. Surprisingly the creep strains of 80 and 120°C tests do not differ very much i. e. they are of comparable order whereby the difference of similar tests at 50 and 120°C is comparatively high. This is possibly due to test difficulties concerning the strain measurements at 80 °C.

The Lausanne test with sealed specimens indicated at 50°C creep strains which are similar to the strains of unsealed specimens. The measurements at 80°C showed a large scatter at the beginning of the temperature increase and are assumed to be less reliable. In the Lausanne report [2] it is concluded that drying creep and creep of sealed specimens under the investigated conditions might be the same.

From the creep investigations of Lausanne and Cassel one basic conclusion has been drawn: Concrete tested within a vapour pressure tight autoclave which is partly filled with water indicate considerable higher creep strains than foil sealed concrete or drying concrete.

The observation of creep recovery of concrete at 20°C after a temperature and creep exposure for 570 days (see fig. 3.4) indicated a large potential for recovery of sealed concrete. During the Cassel creep tests II the creep recovery was determined after cooling down under load (20 N/mm^2) at a rate of 5 K per day. At 20°C the specimens were unloaded and creep recovery was observed for 42 days. It was surprising to note a creep recovery of about 1‰. The recovery of 70°C specimens was comparatively higher than those of the 120°C specimens. We suppose that there is a considerable influence of the autoclave conditions on the creep recovery at elevated temperatures.

4 Conclusions

The tests results support the hypothesis that the high temperature creep potential is a unique property of concrete which may be activated in a comparatively short period of time or can be consumed within a long period of loading depending on the moisture transfer and temperature state of the concrete i. e. the thermodynamic equilibrium in the concrete plays an important role in this connection. The test results strongly support findings of Schwesinger et al. published in 1987 (see [4], especially page 212-217). Conditions within an autoclave (vapour saturated atmosphere) do not comply with the internal equilibrium of a completely sealed and wet concrete specimen at elevated temperatures. The results indicate a reduction of creep rates in the letter case after load application.

From the tests it is obvious that the main creep and shrinkage effects occur immediately after heating, and shortly after load application within the first 20 days after heating and load application. If the tested concrete is in a quasi-equilibrium with the ambient temperature and moisture state a test period of one year is sufficient as to determine the main parts (about 80%) of creep strains. If concrete specimens dry during temperature exposure the creep strains depend mainly on the rate of drying. After drying is completed only small creep strains occur especially at temperatures above 100°C.

It is proposed to divide temperature creep strains into two separate parts: Part 1 should comprise the irreversible transient creep strains and part 2 should account for steady state creep strains which are partly reversible.. This is important for those casees where the the specimens are being loaded during heating up.

5 Literature

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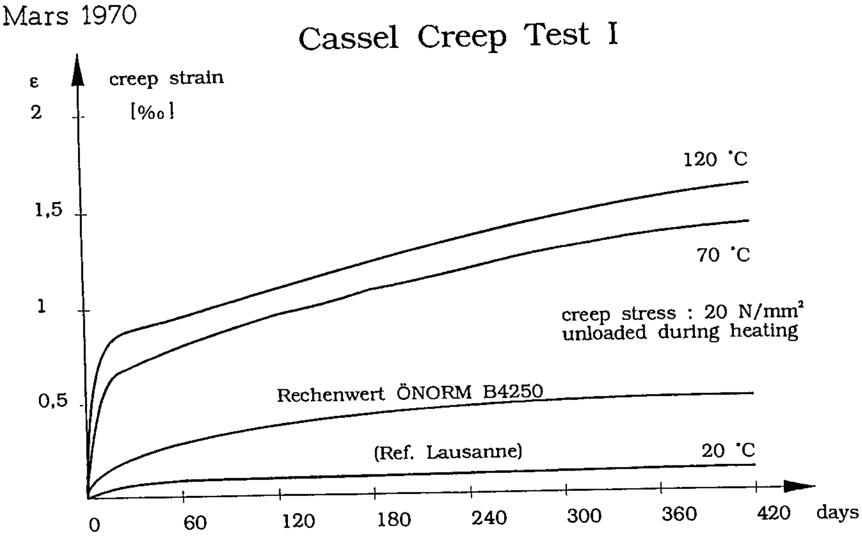

Fig.3.1: Creep strains of high strength sealed basalt concrete, age : 90 days cylinder : d = 15 cm, l = 30 cm, sealing: polymer and metal foil

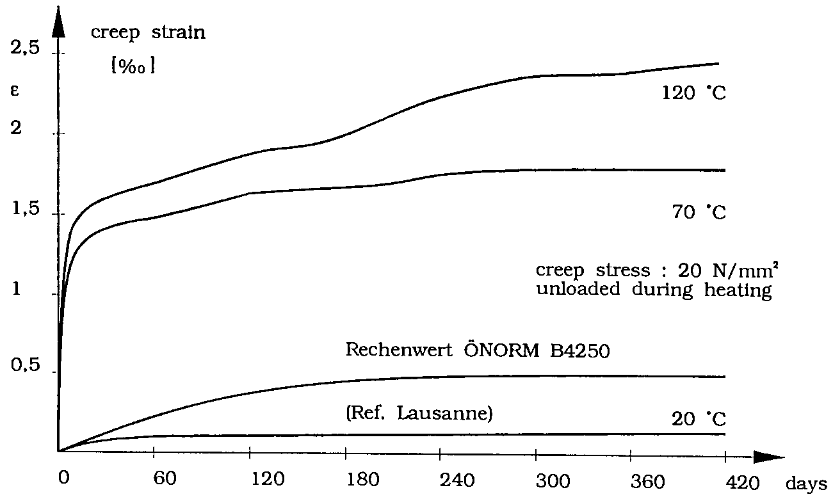

Fig.3.2: Creep strains of high strength sealed basalt concrete, age : 90 days cylinder : d = 8 cm, l = 24 cm, sealing : autoclave (saturated air)

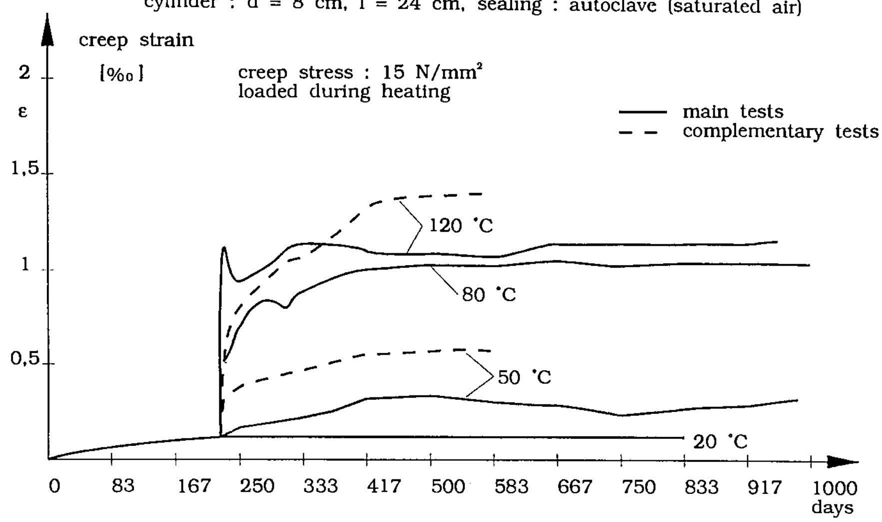

Fig.3.3: Creep strains of high strength drying basalt concrete; age : 3.5 years or 90 day (compl. tests); cylinder : d_i/d_a =7,5/27,5 cm, l = 50 cm

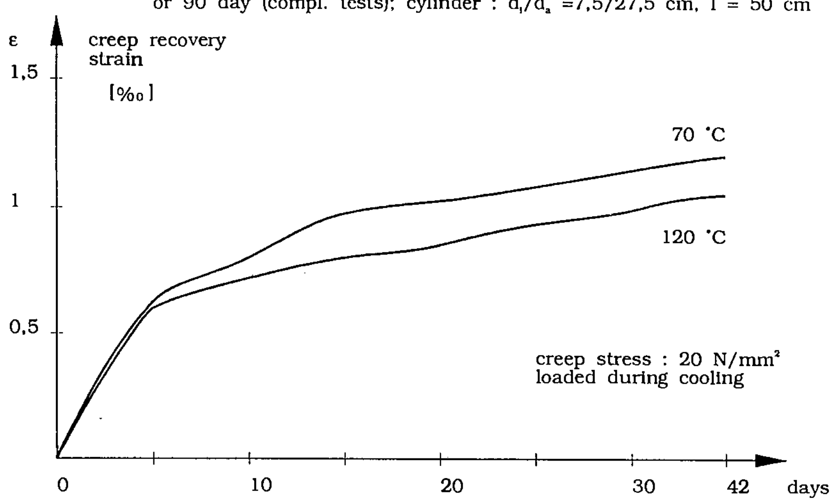

Fig.3.4: Creep recovery of high strength sealed basalt concrete at 20 °C (after cooling)