Creep behaviour of low strength concrete at elevated temperatures and different moisture conditions

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ABSTRACT

Selected test results concerning the creep of low strength concrete Bk 20 at elevated temperatures up to T = 130°C are presented in the following report, Both drying specimens and those in a vapour saturated environment were investigated at transient temperatures.

The quartzite concrete specimens (cylinders: diam. 150 mm, length 600 mm) were testet after curing periods of 28 and 365 d at load levels of 0 and 27 % of the ultimate strength R^n of a 150 mm cube at ambient temperature.

Besides short informations to the test techniques used this report summarizes the test results of creep behaviour including first observations on moisture transfer in sealed specimens during and after heating up. Finally some generalized conclusions are drawn.

1. INTRODUCTION

From structural and technological reasons for composite structures under elevated temperatures such as the steel cell composite construction method (Thomasch and Friedrich 1976, 1977; Friedrich and Krausche 1985) a low strength concrete is used. For judgement of the creep behaviour of this concrete earlier tests were performed by Wölfel (1980). Experiences from this experiments and analyses of the international situation in the field of creep behaviour testing at elevated temperatures led to the development of an improved test technique (Schwesinger 1984, 1986). Simultaneously a larger test programme comprising several test series were prepared with objectives as follows:

1. Extension of the knowledge derived from earlier investigations for transient temperatures T = 60 and 130°C. From methodical reasons various test parameters (ultimate strength, moisture conditions, loading before heating) were selected to represent boundary conditions which can be expected to occur at service conditions of structural elements exposed to elevated temperatures.
2. Besides testing unsealed specimens investigation of

sealed specimens in a vapour saturated environment (pressure dependent on temperature).

3. Contribution to the formation of a reliable data base as a starting point for both practice-oriented models for prediction of deformation behaviour and standardization tasks to be solved in the future in the field of temperature- and moisture-dependent deformation parameters.

2. TEST EQUIPMENT AND TEST PROGRAMME

Some special characteristics of the used testing techniques can be summarized as follow:

1. Use of a contactless laser-interferometrical length masurement system in conjunction with polarization-optical measuring marks with the aim to avoid measuring errors dependent on temperature. The average uncertainty of measurement of this system is smaller than $6 \cdot 10^{-6}$.
2. Application of elastical metal casings made of stainless steel with a diameter of 160 mm. Outside of this casings electric band heaters were placed. There fore, the metal casing simultaneously serves to distribute and transfer the heat to the specimen. For tests without sealing a similar arrangement is used, but without screwed joints. The maximum permitted vapour pressure is $p_{max} = 0,35$ MPa.
3. Limitation of the measuring length of $l = 300$ mm. As a result of this two steel tubes Ø 30 mm for connection the specimen and the measuring marks are embedded in the concrete. The constructive solution of the tubes was aimed at minimizing the disturbance of the stress distribution in the specimen.

For more details of the testing equipment see Schwesinger (1984) and (1986). For observation of the moisture transfer in sealed and loaded specimens as a function of temperature, pressure dependent on temperature and time the same test equipment was used. In this case in addition a sight glass communicated with the interior of the metal casing was installed.

The test programme of series B shown in Table 1, is similar to that of series A (age of loading 28 d). The main material parameter of the tested quartzite concrete are: max. aggregate size = 22 mm; mix proportion: cement: aggregate: water = 1 : 6,05 : 0,68; fresh concrete density = 2,36 kg/dm³ ultimate cube strength at 20°C, 28 d : 20,0 N/mm², 365 d : 25,5 N/mm². For sealed specimens in preparation of the tests 100 ml (in the case of moisture-transfer-tests 200 ml) water was filled into the space between concrete and metal casing. For all tests at elevated temperatures heating and cooling rates of ca. 5 K/h measured in the center of the specimen were used.

3. TEST RESULTS

For all specimens besides other parameters the total deformations $\varepsilon_{\Sigma}(t, H, T)$ have been measured. As an example this total deformations of two specimens heated up to 130°C a

Table 1: Test programme of the test series B (age at loading 365 d)

Specimen	Curing	Test Conditions		
Nr.	(temperature, rel. humidity)	creep stress N/mm²	temperature °C	sealing (rel. humidity)
01/1			20	
02/1			60	
02/2	1...365 d:	6,75	60	sealed
04/1	under water	= (0,27 R^n)	130	
04/2	(20 ± 2°C)		130	(100 %)
06/1		0	60	
08/1			130	
09/1			20	(65 %)
10/1			60	
10/2	1...7 d:	6,75	60	(65 % 0)
12/1	under water	= (0,27 R^n)	130	
12/2			130	
13/1	8...365 d:		20	unsealed (65 %)
14/1	in air		60	
16/1	(20 ± 2°C,	0	130	(65 % 0)
16/2	65 ± 5 %)		130	

sealed and an unsealed one are shown in Fig. 1. From this results the creep strains were determined in principle as the difference of such deformation functions of both loaded and unloaded specimens at otherwise unchanged conditions. Here, it was assumed that the shrinkage and thermal strains of the loaded specimen correspond to those of an unloaded one.

The specific creep strains of the test series A und B in a generalized form can be seen in Fig. 2. Because of relative small differences a separate representation of the results of both series A and B was renounced. As a result of different curing conditions (see Table 1) a mean difference of water content between sealed and unsealed specimens of ca. 1 kg was measured at beginning of series B tests. This difference can be considered as one reason for the similar behaviour in the transient part of the creep functions of sealed and unsealed concrete. Additional in Fig. 3 the relative creep strains $c_T/c_{20^\circ C}$ are given as a function of time.

The moisture transfer behaviour between concrete and environment inside of the sealing case during and after heating up to 60°C and 130°C is shown in Fig. 4. The curing and test conditions of the investigated specimens corresponded to that of the specimens 02/1 and 04/1 of the test programme (Table 1).

From the presented test results the following interpretations can be deduced:

1. The transient creep strains of sealed and unsealed specimens at temperatures $T \geq 60^\circ C$ are significantly higher than supposed so far. They reach in both cases nearly the same extent (different curing conditions, of course, must be taken into account). At the creep stress used these creep strains are approximately compensated by thermal strains realized simultaneounsly. In principle these observations correspond with results reported by Khouri et al. (1985).

2. After reaching the steady state temperature (30...50 h after the start of the heating period) the creep rate of unsealed specimens is intensively slowed down as a result of the water loss occuring during this time. From this reason it can be concluded that simultaneously a steady state moisture on a very low level was reached. In contrast to this state an obvious state of moisture equilibrium cannot be stated for sealed specimens at the same time. This indicates connections between the observed further increase of creep of sealed specimens as a function of time and processes of moisture transportation.

3. The relative creep strains $c_T/c_{20^\circ C}$ of sealed and unsealed specimens attain a maximum in the range of t = 30... 50 h after start of heating. For large periods of time values of $c_T/c_{20^\circ C} \sim 1$ can be expected in unsealed specimens because of a lower increasing of c_T and simultaneously continual rising of $c_{20^\circ C}$. In the case of sealed concrete in a vapour saturated environment a quantitatively changed behaviour was observed. Here values of $c_T/c_{20^\circ C} \sim 5$ should assumed to be real.

4. The functions of creep coefficients $\varphi(t)$ of sealed specimens calculated by ε_{el} (t = 0) are considerably greater than results known up to now. For t = 365 d and $T > 100^\circ C$ values in the range of $\varphi = 10$ can be expected. In comparison to them in unsealed specimens for t = 365 d approximately $\varphi = 5$ can be taken into account with the tendency of further decreasing for larger periods.

5. A more or less significant moisture exchange takes place as shown in Fig. 4 also in sealed specimens during a creep test. In specimen K 05/079 the process of water loss was started at the end of the heating period ($T = 130^\circ C$) under a temperature dependent vapour pressure inside the casing of p = 0,35 MPa. Remarkable is the peak at $t \sim 400$ h due to a decrease of pressure p = 0,12 MPa. During the cooling process a considerable part of water was absorbed again. Whereas the water loss of this specimen at the end of the test amounted to $V \sim 500$ ml, the gross weight (specimen and metal casing) was unchanged.

6. Whereas the observed creep behaviour at ambient temperature coincides well enough with known prediction algorithms, the attainable degree of coincidence at temperatures $T \geq 60^\circ C$ cannot be satisfactory. For a comparison of the observed creep strains with results of varions prediction models see Schwesinger et al. (1987)

4. CONCLUSIONS

From the discussion of the presented test results a number of questions arises, e. g.:

1. Does the creep stress (o,27 R^n, approximately 34 % of the ultimate cylinder strength) used in the tests lie within the proportionality limit of creep stress and creep strain? From some experience a decreasing of this limit at elevated temperatures compared with ambient temperatures can be assumed.
2. Is it suitable to calculate the creep coefficient φ also at elevated temperatures with ε_{el}(t = o)? Because of changing (also decreasing) the modulus of elasticity as a function of temperature and time it would be more sensible to introduce an experimentaly determined function ε_{el} (t,T,H). The thermal strain coefficient should also be available as a function of time, temperature and moisture.
3. What effect have the processes of moisture transfer in sealed specimens on the creep behaviour? Do these changes of moisture content appear also under conditions of full-scale structures exposed to elevated temperatures?

These and other questions can be answered only by further experiments. Important conditions and aims for the experimental work in this field should be among others:

1. Improvement of the comparability of test results by reduction of influences from the testing process. Development and use of uniform recommendations for testing at elevated temperatures.
2. Contribution to the increase of the still relatively small statistical data base.
3. Carrying out of further investigations of the microstructure behaviour as a function of time, temperature and moisture for a better understanding of results from macrostructure tests.

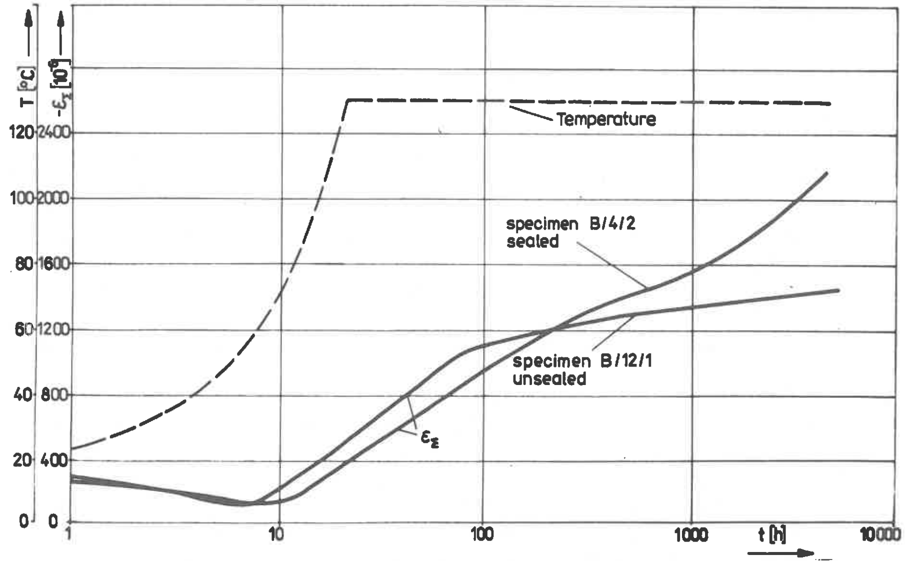

Figure 1. Total deformations $\varepsilon_{\Sigma n}$ of a sealed and an unsealed specimen at T = 130°C, loaded with 0,27 R^n before heating up.

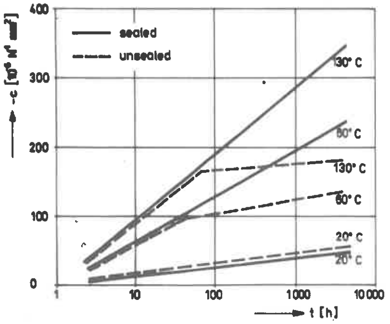

Figure 2. Specific transient creep strains of sealed and unsealed specimens

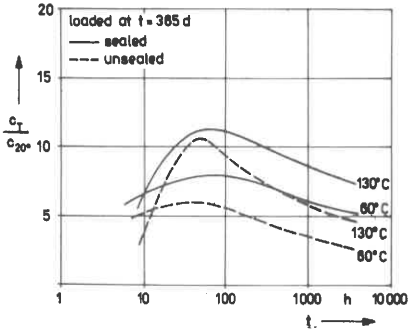

Figure 3. Comparison of relative transient creep strains $c_T/c_{20^\circ C}$ of sealed and unsealed concrete

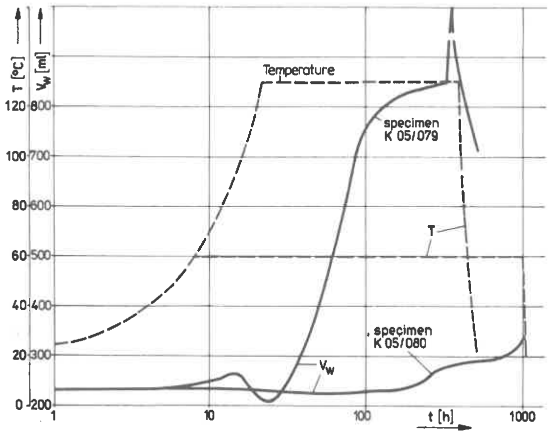

Figure 4. Moisture exchange v_W of sealed specimen under action of the temperature dependent vapour pressure inside of the casing.

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