J. King Saud Univ., Vol. 6, *Eng. Sci.* (1), pp. 41-51 (A.H.1414/1994)

Creep Tests on Small Hollow Cylindrical Mortar Specimens

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(Received 27/1/1991; accepted for publication 29/9/1992)

Abstract. Results of an initial series of four-day creep tests of mortar specimens under constant shear and cycled humidity conditions of 100% to 50% and back, are reported. The tests are conducted in a triaxial torsional testing machine. Tested cylinders are sufficiently small to achieve uniform moisture content in short time, sealed, loaded by torque. Significant differences in creep at different humidity conditions are observed. The results are helpful for the formulation of constitutive relations.

Introduction

When long time stress is not negligible compared to allowable stress, creep is the largest part of deformations of concrete. To calculate deflections reliably, in concrete reactor vessels subjected to a hypothetical nuclear core-distruptive accident, creep must be taken into account. Much experimental research has been carried out to meet these needs, and considerable information has been gathered over the last two decades.

Some experimental information was obtained [1] for the behavior of hardened portland cement paste as a solid cylinder under triaxial loading (without shear) at various hygral conditions, including specimens that are sealed wet, sealed dry and unsealed drying tests. New test data are available under triaxial, shear and high temperature for solid concrete specimens [2]. Limited data are available for torsional loading alone with variable temperature [3] and short time with variable humidity (60%, 100%) [4]. Also some data is available on the very thin (0.7mm) cement paste cylindrical specimens at the slow humidity changes (in 4 or 8 hours) under axial load and torque [5,6]. For cycled humidity tests were performed also in wood specimens under compression [7]. No data exist for deformation under shear stress for hollow mortar cylinder at periodically cycled drying.

In response to this need, a testing program concerned with the shear deformation of cement paste under humidity changes has been done at Northwestern University at USA. Cement specimens are very sensitive to imperfections (air bubbles or cracks), that is why new tests were done on mortar specimens and their results are now reported. The main variable which has been studied in the test program is the variation of relative humidity (RH).

Testing machine

A testing machine which was originally developed for tests of creep of cement paste, mortar and timber was used (Fig. 1). It is described in detail in Bazant *et al.* [1]. This device can be used for triaxial loading but in this initial investigation only one kind of load, torque, has been applied. Torque is applied by weights which were put into the torque arms boxes. The twisting of the specimen was determined from the horizontal displacement of the torque arm and was measured by a pair of LVDT. These measurements were done outside of the chamber (Fig. 1).

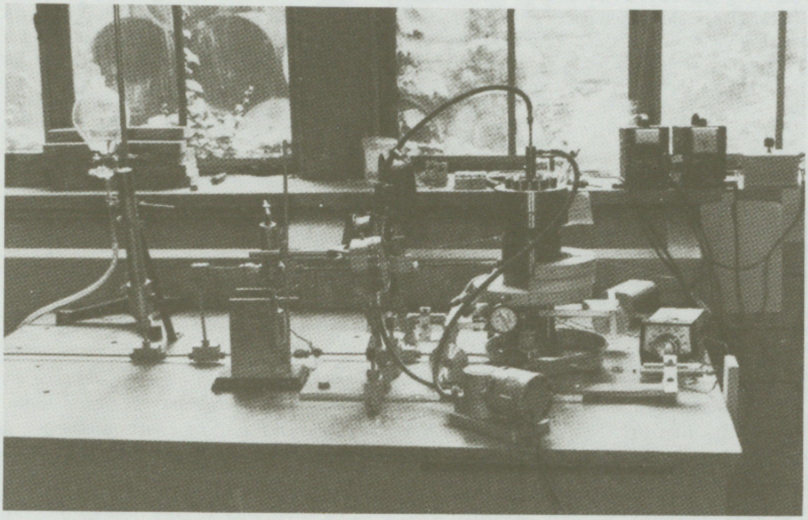

Fig. 1. Testing machine for triaxial loading.

Test specimens

Development of a production technique for the specimens appeared to be a major task. It was successfully accomplished by using a special teflon mould [5]. The test specimens were made of hydrated mortar. They were hollow cylinders, 14.5 mm, in outside diameter, 60.5 mm in length and 2 mm in thickness (Fig. 2). The reason for

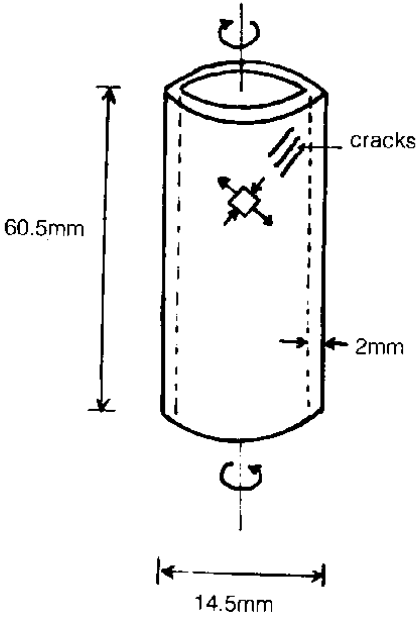

Fig. 2. Test specimen.

choosing hollow specimens was to create a wall of small thickness which permits a rapid moisture exchange in short time, with the result that the material parameters may be obtained directly by experiment.

The small size makes the specimen response to a change in environmental moisture condition much faster. This can be illustrated by the moisture equalization period, understood as the time, t_{95}, in which the center of the cylinder attains 95% of the previous sudden change in surface moisture. According to [1], $t_{95} \approx 1$ year for a 150 mm cylinder and $t_{95} \approx 20$ hours for a 14.5 mm cylinder, in our specimen, it gives $t_{95} \approx 2$ minutes at room temperature.

The specimens were made of ordinary portland cement of ASTM Type I and beach sand passing through sieve No. 40, (dmax = 0.425 mm). The mix ratio of cement:sand:water (by weight) was 1:2:0.6.

Casting of a mortar specimen of water/cement ratio less than 0.6 with 2 mm thickness is impossible. Because the viscosity of mortar was too high, the major difficulties of this test was the entrainment of air bubbles and cracking of specimens before testing. Approximately one in ten specimens developed cracks and one in fourth specimens had some bubbles in them; the bubbles were usually so small that the specimen was still usable.

To eliminate entrapped air bubbles, the paste was mixed in a vacuum and then poured into brass moulds [6]. The specimens were cured in the mould for 1 day at 27°C (80°F) and 98% relative humidity, then unmoulded and cured for 28 days in a water bath at 27°C (80°F) which contained lime to prevent carbonation. The ends of the specimen were grounded in wet condition shortly before the test in order to achieve perfectly flat and orthogonal end surfaces.

Specimen Seal

Specimens were tested with a seal to prevent the escape or ingress of pore water. Seals were used right after specimens were taken out of the water bath.

The seals were made of vinyl chloride (flexible, unfilled) with a wall thickness of 0.76 mm. Torque capacity of the sealing tube were negligible. The internal diameter of the sealing tube equalled the diameter of the test specimen, and the fit was tight. The specimens were then provided with end caps made of stainless steel. These stainless steel pieces were glued to the ends of specimens with a very thin layer of dental carboxylate cement (which bonds well to wet surfaces). The sealing of the tube at the ends was achieved by O-rings tightened by a threaded steel sleeve on the caps.

To provide torque transfer, the steel end caps of the specimens were provided with two radial ribs, each of which was 4.5 mm (0.18 in) wide and 3 mm (0.11 in) deep. These ribs were precisely machined to match the grooves formed in the mould at the specimen ends. The opposite side of each end cap, again, had cruciform ribs which fitted into corresponding grooves on the top of the loading shaft and cap. This provides torque transfer from the loading shaft onto the specimen.

The chamber

Immediately after setting up the caps the specimen was dropped in the chamber, which was already hot, and the chamber cap was then closed and tightened. The chamber is described in detail in Bazant *et al.* [1].

Temperature control

The chamber walls were penetrated by bores for six heating elements. The temperature was maintained at a set value by a thermocontroller (Model 49-918 of the Omega Engineering, Inc.), a relay, and two thermocouples. The thermocouples monitored the temperature in the specimen cavity and were located at the mid-height of the cavity and at its bottom.

In all tests, the whole triaxial chamber had been preheated for at least two hours before the test began, in order to prevent thermal expansion of the chamber during the test. The test specimen was then dropped into the hot chamber. It took only about five minutes to set the specimen into the chamber and apply the load. The errors due to this time interval were considered in evaluating the readings.

Test procedure

After setting the specimen in the heated chamber, it was allowed 2 minutes to heat up. Then two 20 gr. initial weights were installed in the boxes which were suspended to the torque arms. Top part of specimen was fixed and bottom part connected with torque arm. After that two 100 gr. weights were installed in the boxes and first, LVDT readings were made. These readings were considered as the zero reading for creep data. Further LVDT readings were made at logarithmic time intervals.

Two test groups were made. Group I was under a constant humidity (100%) and torque. Group II was under the same torque, but with variable humidity. Four specimens were tested so far, as characterized by the conditions listed in Table 1 and by the time histories of loads and variable humidities defined in Fig. 3.

To obtain 100% relative humidity, the interior of the specimen was filled with water. For 50% relative humidity, by exposing only the interior surface of the sealed specimen, and circulating the air through thin tubing and a small glass tube with salt, the volume of air in the system was kept to a minimum. This allowed easy and precise control of humidity with a fast response [6]. All tests were made at 40°C (100°F).

The humidity change that was investigated in this study was from 100% to 50% and back to 100% and to 50%, within a one-day interval. For 50% was achieved by circulating air through tube with salt.

Test Results

The comparison data for creep with a constant environment can be generated by extrapolating the initial creep curve before the change of environment. This extrapolation is possible in the log-time scale because in this scale the creep at constant environment is very smooth, of nearly constant slope, and because the extrapolation segment is very short in the log-scale. The effect of humidity changes is therefore represented by the difference between curves b and c (Fig. 5).

The shear strains due to humidity changes were determined graphically, exploiting the fact that within a one-day interval, the response curves are nearly straight in

Table 1. Characteristics of four types of tests conducted

Specimen no.	Day	T (C°)	H %	Max τ_{xy} MPa
M1, M2	1	40	100	0.619
	2	40	100	0.619
	3	40	100	0.619
	4	40	100	0.619
M3, M4	1	40	100	0.619
	2	40	50	0.619
	3	40	100	0.619
	4	40	50	0.619

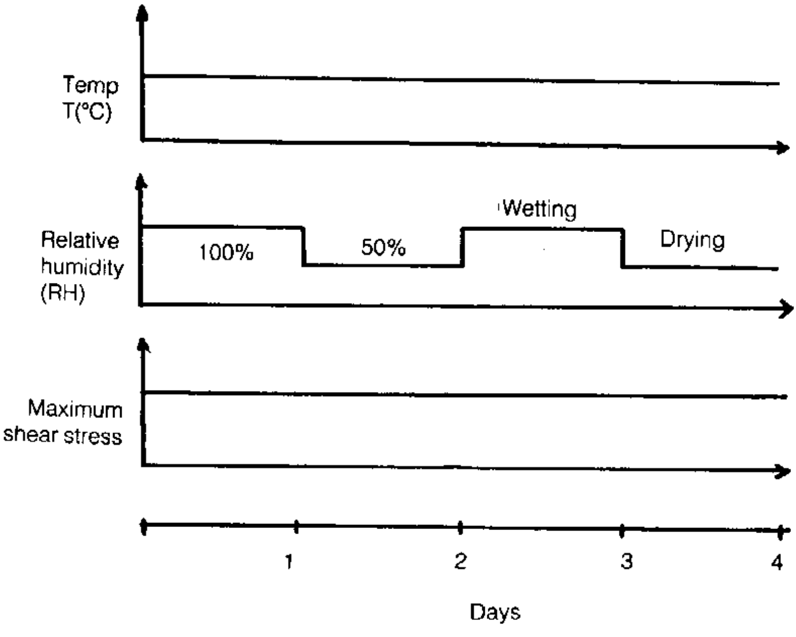

Fig. 3. Histories of environment and loads used in the tests for variable humidity.

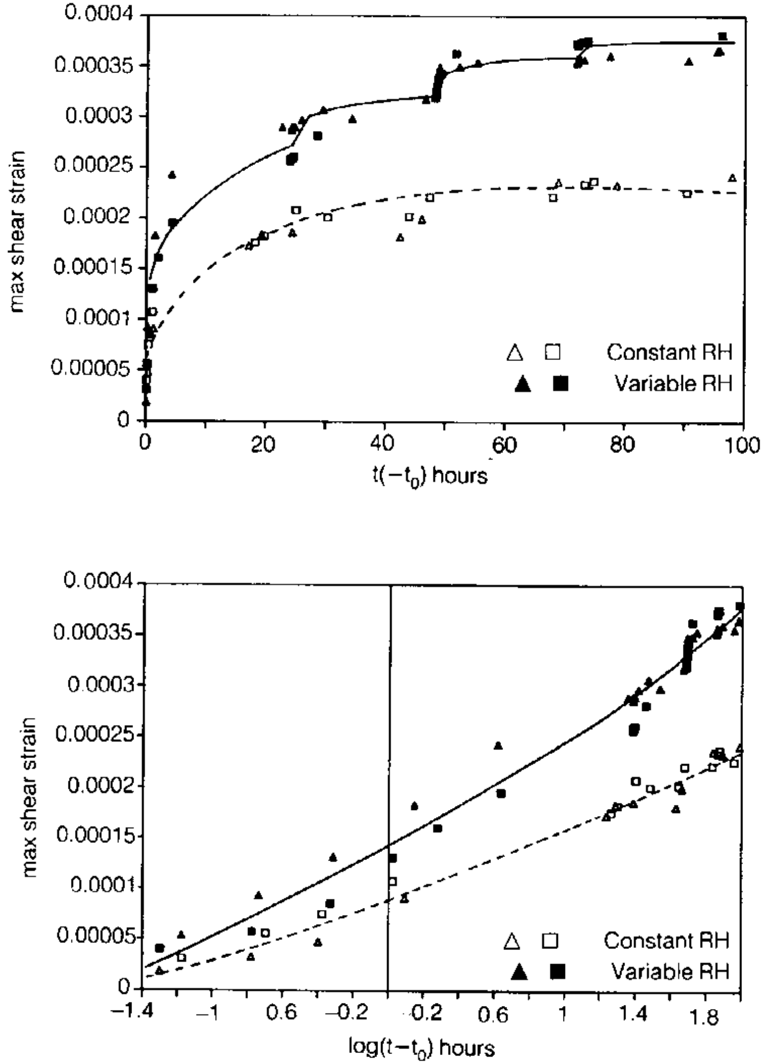

Fig. 4. Measured shear strain for M1,M2 specimens under constant (%100) humidity (△,□) and for M3, M4 specimens under variable humidity (▲,C) in actual time (a) and in logaritmic time (b).

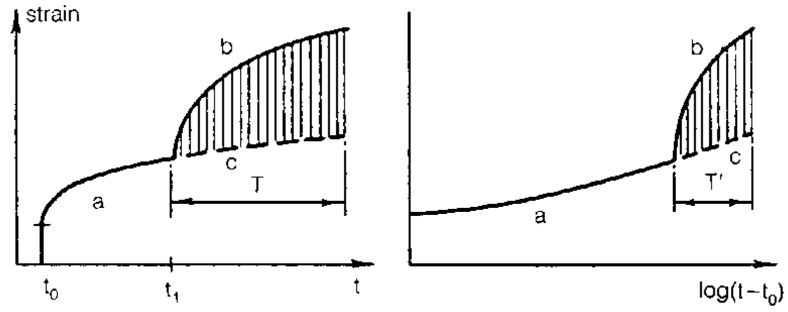

Fig. 5. Extrapolation in log-time scale used to determine additional creep due to environmental changes.

the logarithmic scale (Fig. 5). Thus a graphical extrapolation in the semi-log plot was quite reliable, and the effect of the change of environment could be determined as the difference of the measured response plotted in the long-time scale. In this manner, one could avoid for the present types of tests the need for testing companion load-free specimens subjected to the same environmental history, in order to determine the difference between the two tests. The avoidance of comparison specimens improves the test results because this difference exhibits a large statistical scatter as the properties of a companion specimen are never the same, due to the random nature of the material [2,7].

The amount of creep at any given time after loading was very closely proportional to the stress level, which confirms the suggested theories to predict creep when the stress level does not reach the so called plastic limit, which produces microcracking. This limit has been suggested to be higher than 40% of the short time strength in case of creep axial compression. In our case, maximum shear stress level was kept in all cases equal and smaller than 45% of the shear strength. The reason for this difference is that the strength in torsion is controlled by the tensile strength of concrete and fracture occurs with little plastic deformation [4].

Conclusions

Up to now it was believed that creep rate increases rather than decreases due to drying. However this increase, often termed the Pickett effect, is now known to be due to the rate of humidity change, combined with effect of distributed cracking [8-10].

Analysis of the results in Fig. 4 leads to the following observations:

1. Immediately on exposure to water (100% RH) the specimens which were under shear stress at 50% RH exhibited an increase in creep (Fig. 4a).

2. The rate of creep immediately after the water treatment is larger than that for similar untreated specimens in Fig. 4. It appears the ultimate creep of specimens subjected to cycles of change in hygrometric conditions would be larger than the ultimate creep of similar specimens kept under constant (100% RH) humidity. Similar behavior could be seen for constant 50% RH due to drying.

3. Shortly after the treatment was over, there was a recovery in deformations, i.e. the rate of creep was negative. Only after considerable time (about 10 hours) does the rate of creep became again positive. However, the net effect of each treatment appears to be an increase (positive) in deformation (Fig. 4a).

4. For a sufficiently long time (fourth day) for constant humidity, or last cycle for variable humidity, the slope of the creep curve in the actual time scale begins to diminish (Fig. 4a).

Results show also cracking effects [11]. It is important to repeat same test program on the triaxial and torsional case which will show only the effect of induced creep (no cracking). After that it will be possible to find out the effect of cracking on the creep deformations.

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تجارب الإمطاط لأسطوانات أسمنتية صغيرة داخلها فراغ

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(استُلم في ٢٧/١/١٩٩١م؛ قُبل للنشر في ٢٩/٩/١٩٩٢م)

ملخص البحث. يقدم البحث النتائج الأولية لاختبارات الزحف على مدى أربعة أيام لعيّنات من المونة الأسمنتية تحت تأثير قوة قص ثابتة ورطوبة نسبية تتردد بين ١٠٠٪ و٥٠٪ وقد أجريت التجارب باستخدام آلة اللّيّ ذات المحاور الثلاثة. كما اختيرت العيّنات الأسطوانية الصغيرة للحصول على رطوبة متجانسة في فترة قصيرة، وتم فحصها وهي مغلفة بتعريضها إلى عزم اللّيّ.

إن نتائج الاختبار تشير إلى وجود فروقات كبيرة في الزحف عند الحالات المختلفة للرطوبة مما سيساعد على عمل نماذج جديدة للزحف.