Materials and Structures, 1994, **27**, 510–514

Investigation of the basic creep of concrete by acoustic emission

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The physical origins of the basic creep of concrete are still poorly understood even though some researchers have proposed hypotheses concerning the physical mechanisms that govern this delayed behaviour of concrete. A very complete summing up of these hypotheses was produced, in the past, by Neville; he shows that none of them provides a satisfactory explanation of the bulk of basic creep. More recently, Rossi has proposed a new hypothesis, which has been the subject of several articles. This article concerns the use of the acoustic emission technique as a 'tool' to provide information on the pertinence of the physical hypothesis advanced by Rossi.

The counting of the total number of acoustic events together with a frequency analysis of the acoustic emission signals indicate that there is a strong correlation between the basic creep of concrete and the creation of microcracks in the material.

1. INTRODUCTION

The physical origins of the basic creep of concrete are still poorly understood even though some researchers have proposed hypotheses concerning the physical mechanisms that govern this delayed behaviour of concrete. A very complete assessment of these hypotheses was produced some years ago by Neville [1], who showed that none of them provides a truly satisfactory explanation. More recently, Rossi proposed a new hypothesis, which has been the subject of several articles [2–4]. This article concerns the use of acoustic emission as a 'tool' to provide information on the pertinence of the physical hypothesis advanced by Rossi.

2. PHYSICAL MODEL OF BASIC CREEP PROPOSED BY ROSSI

This physical model can be summed up as follows. The application of the instantaneous force in the basic creep test causes the creation of a number of microcracks, distributed throughout the volume of the specimen. This is going to constitute, for the medium (the concrete), a sudden thermodynamic disequilibrium, analogous to a local hygral shock, since the microcracks are effectively voids. The gradients of water molecule concentration, which result from the microcracking, will induce movements of water vapour (Fick's law) from the capillaries to the microcracks, and lead to a drying of these capillaries. This drying, called 'post-cracking', will cause a shrinkage of the same type, in its mechanisms, as drying shrinkage, and so cause the basic creep strain observed experimentally. The proposed physical model is illustrated in Fig. 1.

3. USE OF ACOUSTIC EMISSION IN BASIC CREEP TESTS

The physical model proposed above is based on the assumption that microcracks appear during a basic creep test. To evaluate the accuracy of the model, it is therefore essential to check, first of all, if this microcracking in fact appears during the test. To achieve this, it was decided to use acoustic emission, a nondestructive testing technique perfectly suited to detecting and localizing cracks in concrete [5, 6]. The principle of the use of acoustic emission for the detection of cracks in materials will not be restated in this article, since the literature on this subject is very abundant. Only the test performed and the experimental procedure used will be described.

3.1 Tests performed and experimental procedure

3.1.1 *The creep test*

The creep tests were performed on frames designed at the Laboratoire Central des Ponts et Chaussées (LCPC). The technology of the LCPC creep frame and the test procedure have already been published [7, 8], and therefore will not be presented in this article. The specimens tested were cylindrical, 160 mm in diameter and 1000 mm high, and protected from desiccation throughout the test (the condition for a basic creep test) by a double thickness of self-adhesive aluminium-paper sheet glued to the specimen (method developed by the LCPC [10]). Concurrently with the creep tests, tests of indigenous shrinkage were performed on specimens identical to those for the creep test (the specimens were also protected from desiccation in the same way). The

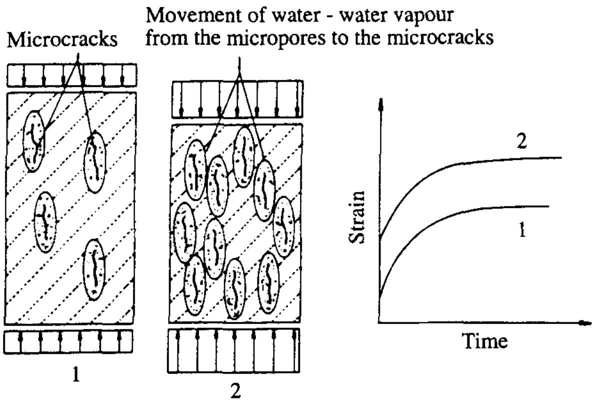

Fig. 1 Basic creep explained on the basis of 'post-cracking' shrinkage.

Table 1 Compositions of the two concretes tested (per m^3)

Constituent	Concrete 1	Concrete 2
Cement	375	375
Calcareous filler, Picketty, 0/0.8 mm	/	50
Crushed granite sand, 0/0.8 mm	170	/
Dune sand, 0/5 mm	140	/
Crushed granite sand, 0/5 mm	485	/
Silico-calcareous sand, 0/5 mm		722
Crushed granite sand, 5/12.5 mm	340	/
Silico-calcareous gravel, 5/12.5 mm	/	348
Silico-calcareous gravel, 12.5/25 mm	/	700
Crushed granite sand, 12.5/25 mm	700	/
Water	180	180
Superplasticizer	1.5	1.6

Table 2 Mechanical characteristics of the concretes tested

Property	Concrete 1	Concrete 2
f_c at 28 days (MPa)	53	43
E at 28 days (GPa)	32	38

basic creep strain is therefore determined in the usual way by subtracting, from the total strain, the instantaneous elastic strain due to the loading of the specimen and the strain due to the indigenous shrinkage. Two compositions of concrete were tested (Table 1) and their compressive strength f_c and Young's modulus E are presented in Table 2. The age of both concretes at the start of the creep tests was the same: 28 days.

3.1.2 *Acoustic emission*

The acoustic signal is measured using six sensors distributed along the specimen as shown in Fig. 2. These are EPA type S 9204 resonant piezoelectric sensors having a main resonant frequency of 140 kHz. For the two end sensors, the recording system includes: a

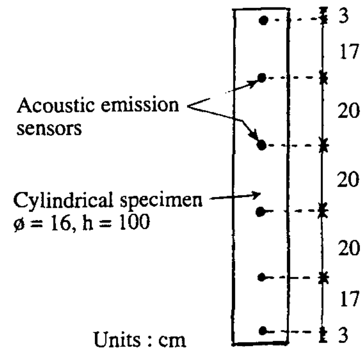

Fig. 2 Arrangement of acoustic emission sensors.

Dunegan type 1801 preamplifier having a linear frequency response from 20 kHz to 2 MHz and a gain of 40 dB; A Dunegan 302 A amplifier having a linear frequency response from 20 kHz to 2 MHz and a gain of 36 dB (there is no low-pass filter); and one channel of a Krentz type 6020 transient signal recorder with a sampling frequency of 2 MHz (size of each sample 4096 points per channel). For the four central sensors, the recording system includes: a Bruel and Kjaer type 2638 preamplifier having a linear frequency response from 10 kHz and 2 MHz and a gain of 46 dB; a Bruel and Kjaer type 2638 preamplifier having a linear frequency response from 50 kHz to 2 MHz and a gain of 30 dB; a low-pass filter with a 500 Hz cutoff frequency (Marconi type 52095.024); and one channel of a Krentz type 6020 transient signal recorder with a sampling frequency of 2 MHz (size of each sample 4096 points per channel).

As soon as a signal is received by one or more sensors, it is therefore amplified and filtered and, if its peak amplitude exceeds 250 mV, the time at which the signal was received, the number of the sensor that received the signal first, and the spectrum of the received signal are recorded. Signals that reach one of the two end sensors first are eliminated immediately to avoid recording noise from the frame helmet/specimen interface, not the interior of the concrete. On the basis of which sensor receives the signal first, it is therefore possible to define four zones of emission in the specimen.

The processing of the data is as follows. After the recording of a signal (time of emission, number of sensor that recorded it first, peak amplitude of the signal), an energy distribution in three frequency bands is produced in accordance with the following principle: for each frequency interval, the area of the curve between the lowest frequency and the highest frequency is calculated and its ratio to the total area is determined. This yields the percentages of the energy in the low, medium, and high frequency bands, which may serve to distinguish signals of different types and therefore of different physical origins. The three frequency intervals chosen are:

Interval 1, low frequencies (LF), 40–100 kHz
Interval 2, medium frequencies (MF), 100–200 kHz,
Interval 3, high frequencies (HF), 220–450 kHz.

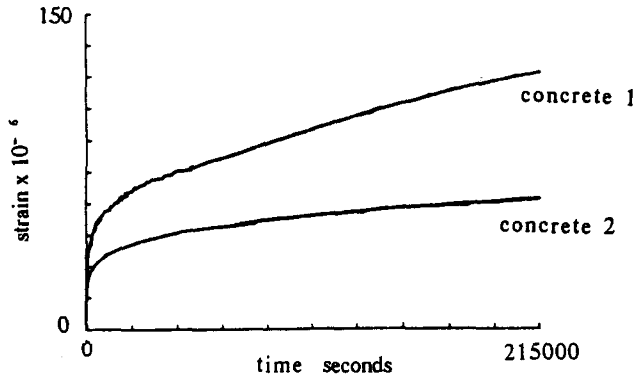

Fig. 3 Basic creep strain versus time for the two concretes.

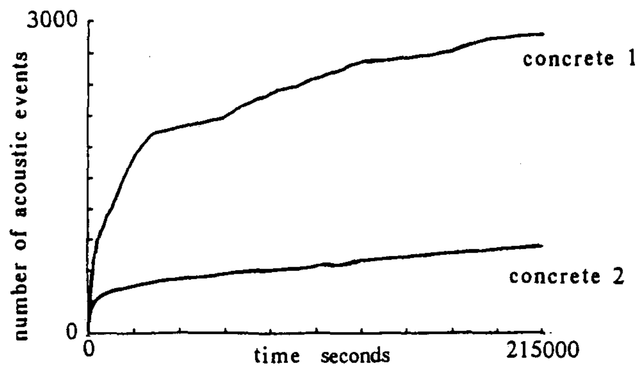

Fig. 4 Total number of acoustic events versus time for the two concretes.

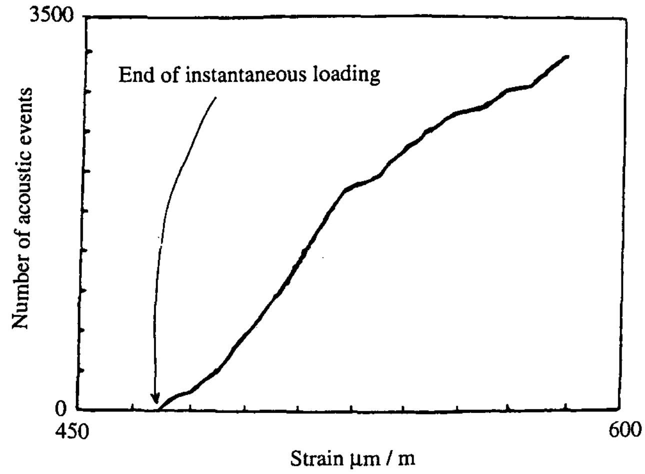

Fig. 5 Curve representing the total number of acoustic events versus the basic creep strain for concrete 1.

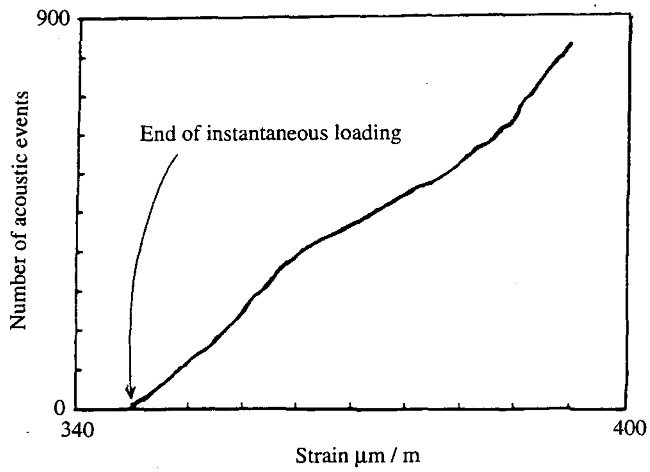

Fig. 6 Curve representing the total number of acoustic events versus the basic creep strain for concrete 2.

3.2 Experimental results

3.2.1 *Basic creep strain curves: comparison of the two concretes*

Fig. 3 compares the basic creep strains found in the two concretes, and shows that the basic creep with time of concrete 1 is much greater than that of concrete 2.

3.2.2 *Total number of acoustic events versus time*

Fig. 4 presents curves showing the total number of acoustic events versus time for both concretes, and indicates that the total number of acoustic events versus time is larger for concrete 1 than for concrete 2. It would therefore seem that there is some correlation between the basic creep strain and the total number of acoustic events.

3.2.3 *Total number of acoustic events versus basic creep strain*

To analyse the type of correlation that may exist between the basic creep strain and the information provided by acoustic emission, curves showing the total number of acoustic events versus the creep strain were plotted for both concretes (Figs 5 and 6), and these suggest that the correlation between the basic creep strain and the total number of acoustic events is extremely strong.

3.2.4 *Frequency analysis of the acoustic emission signal*

It is useful to know that there is a strong correlation between acoustic emission and creep strain, but it is necessary to take the analysis further to obtain information about the physical mechanisms that are at the origin of this acoustic emission. For this, a frequency analysis of the recorded acoustic signal is proposed, based on an assumption and on a methodology.

The assumption is that the acoustic events recorded during the phase of loading of the specimens are due mainly to the creation of microcracks, which is a reasonable assumption given current knowledge. The objective is therefore to check whether, during the remainder of the test, the signal has the same 'acoustic signature' as during this loading phase.

The methodology used to compare the acoustic signatures is an approach based on the frequency distribution of the signal. For this purpose, one proceeds as follows: for each signal, the ratios LF/MF, LF/HF, and MF/HF (LF, MF, and HF as already defined) are examined and the signal is classified according to whether

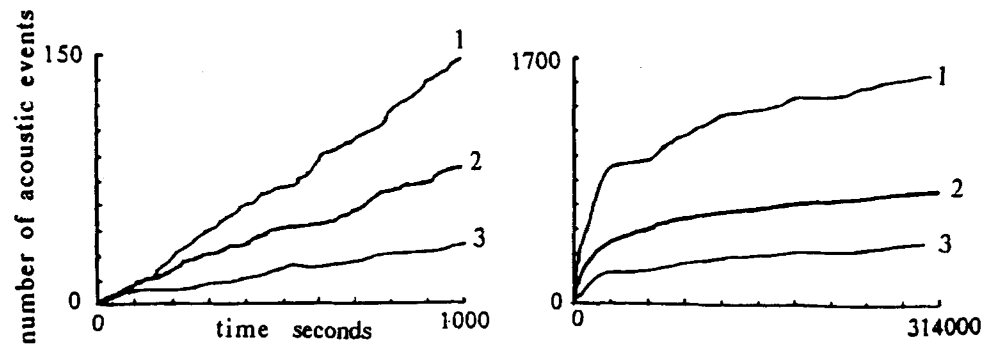

Fig. 7 Increase with time of the total number of acoustic events relative to the ratio LF/MF for concrete 1. Curves: 1 = [1/6, 1/3]; 2 = [0, 1/6]; 3 = [1/3, 2/3].

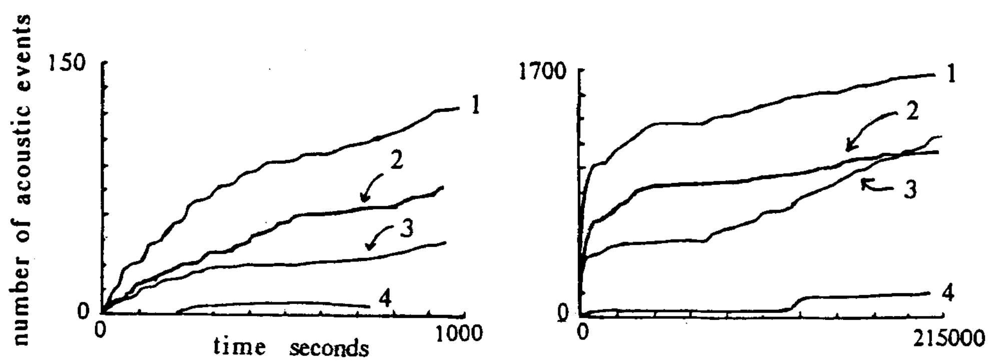

Fig. 8 Increase with time of the total number of acoustic events relative to the ratio LF/MF for concrete 2. Curves: 1 = [1/6, 1/3]; 2 = [0, 1/6]; 3 = [1/3, 2/3]; 4 = [2/3, 4/3].

these ratios belong to the intervals [0, 1/6], [1/6, 1/3]. [1/3, 2/3], [2/3, 4/3], [4/3, 8/3], or ≥8/3. Then, for both concretes, curves giving the increase with time of the total number of acoustic events for which the ratios LF/MF, LF/HF, and MF/HF lie in one of the intervals defined above are plotted, with a distinction made between two time intervals: [0, 1000 s], and >1000 s. Two examples of these curves are given in Figs 7 and 8, and they indicate that the frequency distributions of the acoustic signal remain the same throughout the test, and are identical for both concretes. This finding supports a strong presumption that the acoustic events recorded during the test of basic creep are related to the creation of microcracks and that, in consequence, the basic creep strain is proportional to the total number of microcracks in the specimen.

4. CONCLUSION

An experimental investigation concerning the use of acoustic emission to analyse the physical mechanisms underlying the basic creep of concrete has been carried out. This study seems to indicate that the basic creep strain is proportional to the total number of microcracks created in the material. It therefore strengthens the hypothesis that a physical model of the basic creep of concrete is the creation of microcracks in the material.

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RESUME

Etude du fluage propre du béton par émission acoustique

Les origines physiques du fluage propre du béton sont encore mal comprises bien qu'un certain nombre de chercheurs aient proposé des hypothèses concernant les mécanismes physiques qui régissent ce comportement différé du béton. Plus récemment, Rossi a proposé une nouvelle hypothèse. Elle repose sur la création de microfissures au sein du matériau entraînant des mouvements internes de vapeur d'eau. Le présent article concerne l'utilisation de la technique d'émission acoustique comme 'outil' permettant de fournir des informations sur la pertinence de cette hypothèse physique. L'étude expérimentale montre que la déformation de fluage propre est proportionnelle au nombre cumulé de microfissures créées au sein du matériau. Elle renforce donc l'hypothèse que le fluage propre du béton repose sur la création de microfissures au sein du matériau.