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EXPERIMENTAL METHODS AND DEVICES
METHODES EXPERIMENTALES ET APPAREILLAGE

A dilatometer for measuring autogenous deformation in hardening Portland cement paste

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Different techniques for measuring autogenous deformation in cement paste are discussed, and a newly developed dilatometer designed specially for measuring this deformation is described. A particular characteristic of the dilatometer is the encapsulation of the cement paste in corrugated moulds. This restricts moisture loss and ensures that the hardening cement paste suffers insignificant restraint. In addition, the encapsulation permits measurements to commence shortly after casting.

1. INTRODUCTION

Cement paste may shrink or expand during hardening even when it is completely sealed and at a constant temperature. This bulk deformation, autogenous deformation, may be a result of several physical and chemical phenomena in the hardening cement paste, for example self-desiccation [1]. For many years the practical consequences of autogenous deformation have been ignored, but this phenomenon seems to constitute a serious problem in the manufacture of high performance concretes. Several authors state that high performance concrete may crack as a consequence of restrained autogenous deformation [2–4].

In order to investigate this problem a reliable technique is required for the measurement of autogenous deformation. However, examination of the literature shows that autogenous deformation is a rather difficult quantity to measure.

2. TECHNIQUES FOR MEASURING AUTOGENOUS DEFORMATION

Measurement of autogenous deformation has been carried out in two fundamentally different ways: measurement of volumetric deformation and measurement of linear deformation.

Volumetric measurement of autogenous deformation is frequently performed by placing the fresh cement paste in a tight rubber balloon immersed in water. The change in volume of the cement paste is measured by the amount of water displaced by the immersed sample, for example, by measuring the change in weight of the immersed sample (buoyancy).

Linear measurement of autogenous deformation is frequently performed by placing the cement paste in a rigid tube with low friction. The change in length of the cement paste is recorded by a displacement transducer at the end of the specimen.

Both methods of measurement have advantages and disadvantages. One advantage of the volumetric method is the possibility of commencing the measurements immediately after casting. In contrast, the lack of a steady contact between the rubber balloon and the cement paste is a considerable disadvantage of the volumetric method. Bleeding water or entrapped air at the surface of the cement paste may obstruct this contact significantly. During the hydration process the bleeding water or entrapped air will be sucked back into the cement paste as a consequence of internal volume reduction caused by chemical reactions. Since the volume of the rubber balloon is the combined volume of the cement paste and the volume of the bleeding water or entrapped air, the internal volume reduction also may be measured erroneously as an outer deformation. Since the internal volume reduction is considerably larger than the autogenous deformation this may lead to a substantial error.

In addition, Buil [5] mentions that the pressure caused by a tight rubber balloon could damage the weak

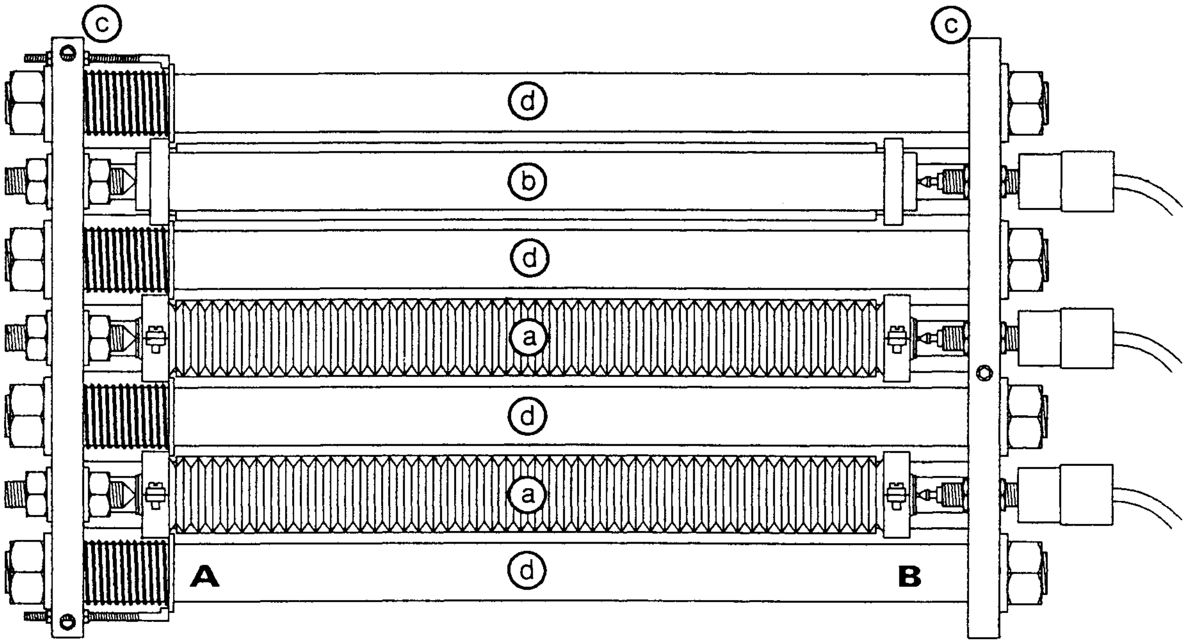

Fig. 1 Dilatometer frame with two test specimens a and an invar reference specimen b. The lengths of the specimens are approximately 300 mm.

structure during setting. Furthermore, volumetric measurements of autogenous deformation are normally associated with large scatter of the data.

Based on the above observations we agree with Buil [5] and Baron and Buil [6] that the volumetric method seems less suitable for measuring autogenous deformation.

One advantage of the linear method is the firm anchorage of the measuring point to the cement paste. This reduces the above mentioned problems greatly. At the same time this is a disadvantage of the linear method since the measurements cannot be started before the cement paste has set. The linear method has an additional problem: the risk of restraining the cement paste. In the very first hours after setting, the cement paste is too weak to overcome the friction against a rigid tube. However, this problem can be reduced by lubricating the tube.

This paper describes a newly developed technique for measuring autogenous deformation which combines the advantages of linear and volumetric measurements.

3. THE DILATOMETER FOR MEASURING AUTOGENOUS DEFORMATION

The dilatometer consists of a measuring frame and special moulds for encapsulation of the cement paste. During the tests the dilatometer is submerged in a thermostatically controlled glycol bath. The proposed measuring technique permits: (i) commencement of the measurements shortly after casting (1 h after water addition in the present case); (ii) insignificant restraint of the hardening cement paste; (iii) accurate control of the temperature of the dilatometer and of the hardening cement paste; and (iv) efficient sealing of the cement paste. The dilatometer is shown in Fig. 1.

3.1 Construction

The dilatometer frame consists of two steel plates c joined rigidly by four solid ϕ22 mm invar rods d. This construction ensures a high degree of mechanical stability and reduces the temperature deformation of the frame; invar has a very low thermal expansion coefficient, approximately 1×10^{-6} K^{-1}.

Each of the specimens investigated is longitudinally supported by two parallel rods, which are attached to the steel plates. As shown in Fig. 1, the specimens are gripped by coil springs at one end (A). The coil springs locate the specimens against adjustable pins. The remainder of each specimen can slide freely on the supporting rods, and changes in length may be measured at the opposite end (B). Fig. 2 shows the details.

3.2 Transducers

The changes in length of the specimens are recorded by three TRANS-TEK 350-000 displacement transducers. The tip of each transducer is spring-loaded in order to follow the length changes of the specimens automatically. The tip force is approximately 0.5 N at maximum. This equals a maximum load of 0.001 MPa on the specimen. These transducers were thoroughly tested over a four year period, showing excellent properties. According to independent calibration tests, the sensitivity of the transducers is approximately 160 mV per mm per V input. Examples of calibration constants are shown in

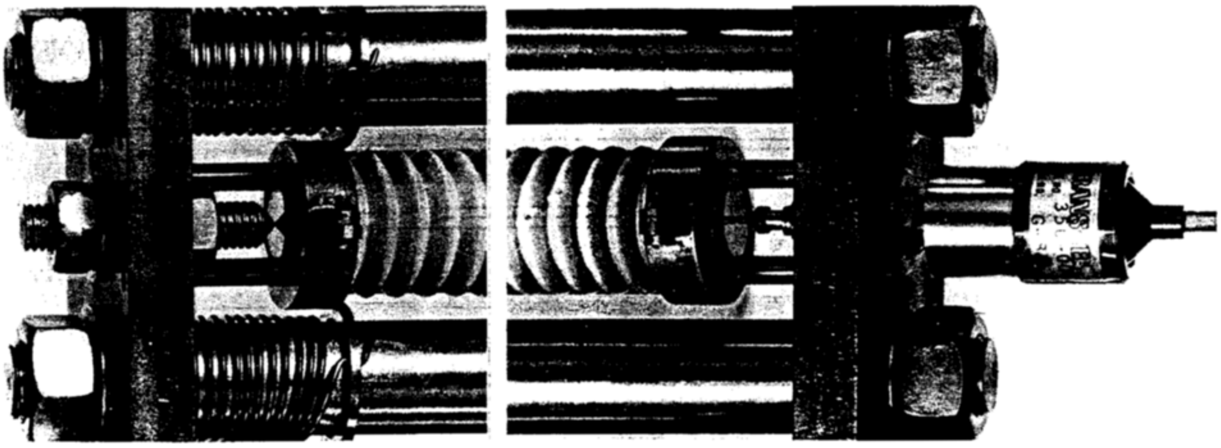

Fig. 2 The specimen is gripped with coil springs at one end (left), and the changes in length are recorded with a displacement transducer at the other end (right). The test specimen is guided by two supporting rods.

Table 1 Sensitivity of the three transducers over a three year period

Date	Sensitivity (mV mm^{-1} per V input)		
July 1988	159.0	157.4	156.8
November 1991	160.8	159.2	158.5

Table 1. In the present set-up the accuracy of the transducers is not a limiting factor for the total accuracy of the dilatometer.

3.3 Moulds

Each mould consists of a plastic tube and two brass end closures. The plastic tube is made of 0.5 mm polyethylene and is corrugated in order to ensure unimpeded longitudinal deformation. Longitudinal deformation of the tube of 10000 microstrain equals a force of 0.5 N. Fig. 3 shows the end closure. The inside corrugation of the end closure ensures a tight grip on the plastic tube.

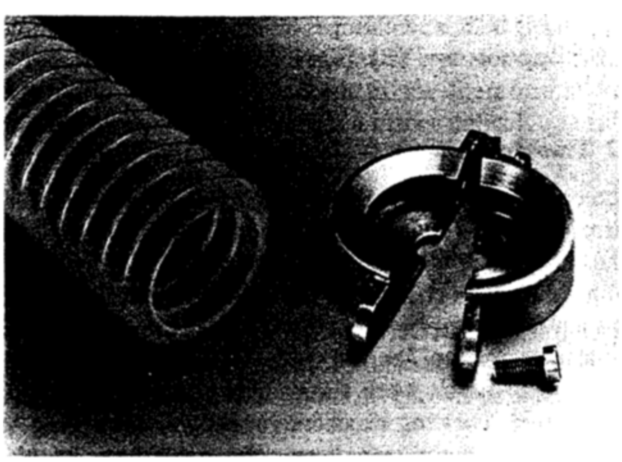

Fig. 3 The brass end closure has an inside corrugation as shown. This ensures a tight grip on the plastic tube.

After pouring, a ϕ15 mm brass disc is fixed to the end closure. This disc serves as a plane surface of contact for the transducer and the stop pin, as shown in Fig. 2.

The mould effectively restricts loss of moisture from the cement paste. During a two week test period less than 0.5% of the initial water content in the specimens was lost by evaporation.

3.4 Data acquisition

Measurements were sampled every 15 min by a Campbell Scientific CR10 datalogger. The data recorded include signals from three displacement transducers and six copper–constantan thermocouples.

3.5 Accuracy of measurements

The dilatometer has been used for several years in support of research projects investigating the effects on the autogenous deformation of cement paste of the addition of silica fume. A recent project [7, 8] reports on more fundamental aspects of the dilatometer.

The results indicate that the diversity of the test specimens seems to limit the accuracy of the measurements. During a 2 week test the measuring signal from the invar reference specimen normally varies less than 10 microstrain, while the deviation between two cement paste test specimens is typically 200 microstrain before setting and 20 microstrain after setting. Fig. 4 shows an example of measurements carried out simultaneously on two identical cement pastes. The distinct break in the curves at approximately 4.5 h is coincident with the setting of the cement paste. This was confirmed by a Vicat test.

As shown in Fig. 4 the courses of the two curves differ more before than after setting. The lower degree of accuracy before setting is most likely due to the fact that the measuring point is not firmly anchored to the cement paste. As long as the cement paste has not set, the linear deformation of the paste is guided by the corrugated plastic tube. In addition, the pre-setting deformation is

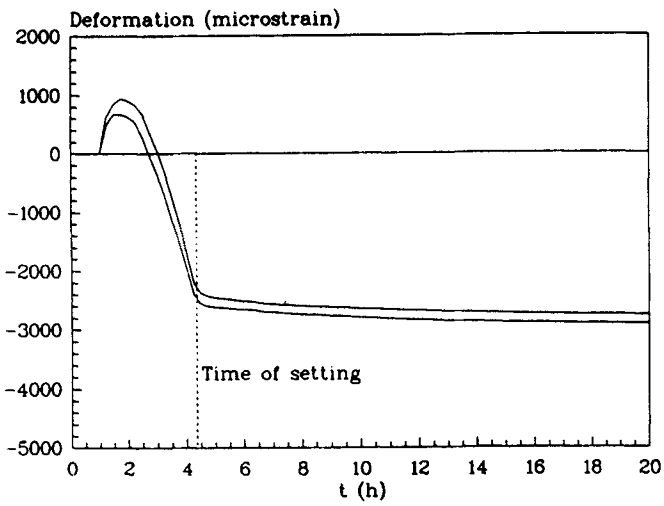

Fig. 4 Early age autogenous deformation of cement paste with $w/c = 0.25$ and 0% silica fume at 30°C. The curves represent simultaneous measurements of two identical specimens. Time is measured from water addition. The deformation ε has been defined as 0 on the first measurement 1 h after water addition.

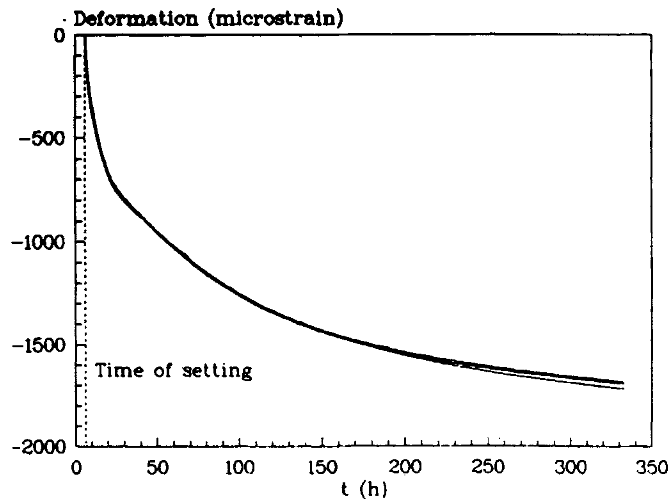

Fig. 5 Autogenous deformation during 2 weeks at 30°C of cement paste with $w/c = 0.25$ and 10% silica fume. Three curves are shown, and two of the measurements were performed simultaneously. Time is measured from water addition. The deformation ε has been defined as 0 at the time of setting.

caused by rather weak forces, of the order of 0.1 MPa [7]. Fig. 5 shows a typical example of repeatability after setting which, as shown, is substantially better than before setting.

4. CONCLUDING REMARKS

The dilatometer is not limited to the measurement of the autogenous deformation of cement paste. It can be used for measuring other types of deformation of solids and of liquids. In an earlier set-up the dilatometer has, for instance, been used for measuring the coefficient of thermal expansion of hardened cement mortar [9].

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RESUME

Dilatomètre de mesure de la résistance endogène de la pâte de ciment Portland

On envisage différentes techniques de mesure de la déformation endogène de la pâte de ciment. On décrit un nouveau dilatomètre conçu spécialement pour mesurer cette déformation. Cet instrument a pour caractéristique de permettre l'encapsulation de la pâte de ciment dans des moules cannelés, ce qui prévient la perte d'humidité et gêne de façon insignifiante le durcissement de la pâte de ciment. De plus, grâce à l'encapsulation, on peut commencer les mesures peu de temps après le coulage.