A NEW DEVICE FOR A.A.R. SWELLING PRESSURE DETERMINATION

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ABSTRACT

In this article we decribe a device which allows us to determine the expansion generated by alkali-silica reactions. It lets us measure not only the variations in volume of mortars and concretes subjected to a given confinement, but also the swelling pressure at a constant volume resulting from these reactions. It can also be used to define the counter-pressure which must be applied in order to cancel out the effects of a pathological expansion of mortars and concretes. With this device we have been able to characterise the reactivity of five aggregates of defined chemical and mineralogical compositions. This profile is completed with measures of permeability, porosity and identification by SEM

Keywords : alkali-aggregate reaction, swelling pressure, permeability, porosity.

INTRODUCTION

The deterioration of concrete structure due to alkali-silica reactions continues to arouse a growing interest and previous international conferences devoted to this subject have been witness to this. The large amount of research carried out both in laboratories and on site has been able to provide some essential points upon which authors agree (Regourd-Moranville 1989), (Bérubé & Fournier 1986), (Wang & Gillot1991), (Salomon & Gallias 1992).

We know, for example, that sensitive rocks generally contain silica minerals which are poorly-arranged, porous and metastable in normal conditions, or micro-cristalline quartz having undulatory extinction. Reactions are particularly frequent when the products are exposed either to tropical climatic conditions (hot and humid), or to alternate cycles of immersions, or even to freeze/thaw climatic cycles. The reactions prefer the presence of a high humidity, maintained by capillarity, or a surrounding relative humidity above 80%. The kinetic energy rate of these reactions can be slow and progressive, or the opposite; delayed and violent. They are notably accelerated by an increase in temperature.

The supposed consequences of the alkali-silica reactions are also very varied. They can go from a localised microfissuration to a widespread cracking; from a partial dislocation to the ruin of the structure. Several trials have been carried out in order to detect the reaction potentials and to orientate the choice of the aggregates. These trials generally concern the determination of the proportion of active silica, the measure of free expansion of mortar bars, or even the microscopic identifications.

However, the chemical reaction of the silica does not necessarily lead to an expansion, and the free expansion of a test core does not always represent the existence of a significant swelling pressure. Incidentally, in numerous civil engineering structures, reactions occur in surroundings which are often confined, and the expansion can be contained or even cancelled out by the surrounding counter-pressure. In order to calculate the actual noxiousness of an alkali-silica reaction, it is therefore essential to define the maximum value of the swelling pressure in a given confinement, and to know the extent of confinement needed to cancel out these expansions.

Experimental techniques and materials

The study is carried out with the help of an stainless-steel cell made to size for test cores of 80 mm in diameter and 140 mm in height (Fig 1). Its functioning is based on the same principle as for a classic triaxial cell with several significant differences:

* The measuring fluid is not water but an oil with a very limited compressibility;

* This oil circulates within a circular volume whose reduced dimensions allow very precise measures to be taken.

* A piston able to make micrometric displacements is joined onto the confinement mechanism. It allows a precise measuring of the variations in volume of the test core;

* A force detector, fixed rigidly between the piston and the upper support base, makes the mechanism independent and easily removable.

* The apparatus as a whole is kept in an enclosure regulated to a 1/10 of a degree.

A = Lower base

B = Cell body

C & C' = Air voult

D = Middle base

E = Upper base

P = Piston

I & K = Steel rods

H = pressure gauge

F = Sample

N = Membrane

L = Micrometer

G = Force gauge
M = Micro-piston

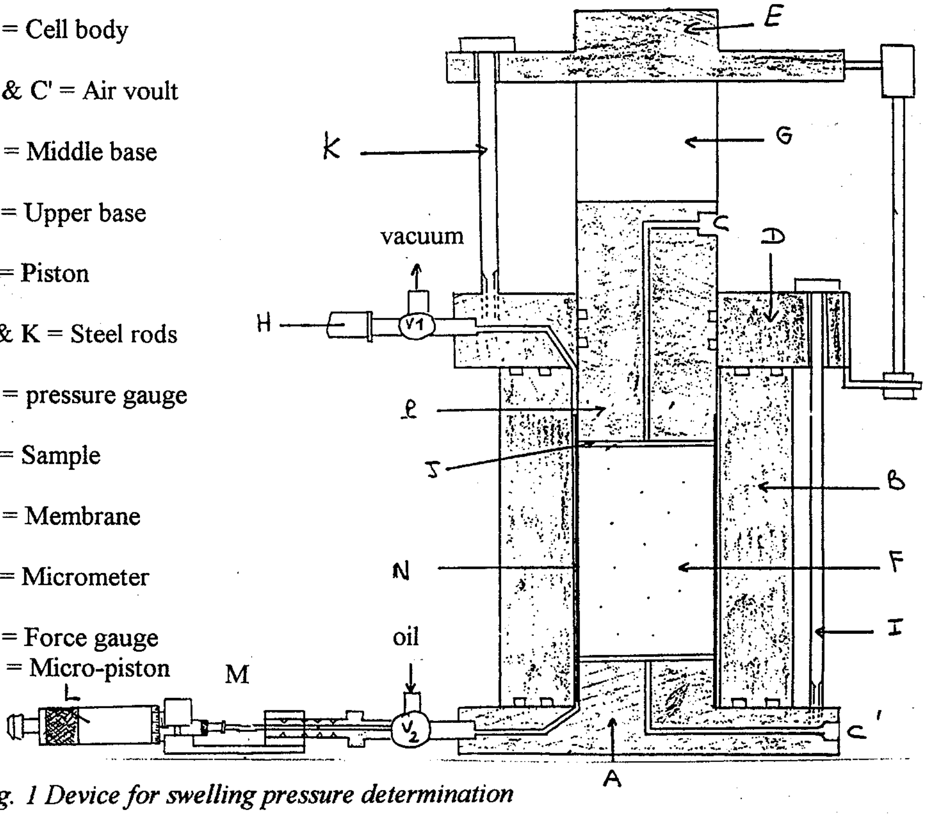

Fig. 1 Device for swelling pressure determination

Aggregates: We have chosen five well-defined silica aggregates whose precise chemical and mineralogical profile has been formulated :

* Aggregate n° 1 contains 90.53 % silica. It is composed of quartz, feldspars plagioclases, muscovite and calcite.

* Aggregate n° 2 contains 91.22 % silica. The main constituent minerals are : quartz, opal, chlorite, illite.

* Aggregate n° 3 contains 99.8 % silica. It is composed uniquely of small particles of microcristalline quartz presenting an average undulatory extinction below 30°.

* Aggregate n° 4 contains 99.6 % silica; its mineralogical composition is identical to that of granulate n° 3.

* Aggregate n° 5 contains 9 % silica. It's a limestone containing very little clay and silicon. This silica appears in the form of small particles of roughly-crystallized quartz and small deposits of calcedony.

Cement: We have used a Portland cement (CPA55) containing at least 97 % clinker and 1.23 % alkali.

Mortars: The mortars have been prepared following the procedure of the NFP18585 norm related to the dimensional stability. They have been moulded in cylindrical moulds ($\Phi = 80$ mm; h = 140 mm). They are removed from the moulds after 24 hours at 20 °C and 90 % humidity. The test cores are then kept at 38 °C directly in the measuring cell.

Experimental conditions: The cylindrical test cores are impregnated with 0.1N soda. A hole 2 mm in diameter and 70 mm in depth is made in the test cores at their fabrication to allow an effective impregnation into the centre of the test core. A O-ring arranged on its upper side prevents the preferential circulation of the soda between the mortar and the membrane. The pressure of the impregnation fluid is at 0.3 MPa. The initial pressures, lateral and axial, are of 2 MPa and 6 MPa respectively.

RESULTS

Measures of expansion

The trial consists in recording the variations of the lateral pressure versus time. These variations represent the changes in size of the test core and are all the more significant if the aggregate is reactive.

Table 1 gives the relative variations in volume ($\Delta V/V$) measured after 15 days in a confinement of 2 MPa, as well as swelling pressures which correspond to them. It is obvious that these values are not the maximum that will be attained if the experiences last much longer. The aim of this procedure is to help detecting in a short time experience, how reactive an aggregate is

Table 1: Volume variations and swelling pressure

	ΔV/V %	**Swelling pressure (MPa)**
mortar n°1	0,35	6,2
mortar n°2	0,36	6,3
mortar n°3	0,10	3,4
mortar n°4	0,10	3,5
mortar n°5	0,35	6,2

We can see that the mortars 1, 2 and 5 swell three times more than the mortars 3 and 4; they give swelling pressures of 6 MPa. These three mortars 1, 2 and 5 are the very ones which turn out to be potentially reactive when we conduct a typical trial of the french norm.NFP 18-585.

Determination of air permeability

The air permeability represents a solid's aptitude to let a fluid pass through it at a defined pressure gradient. This permeability allows us to observe very slight variations in the state of the microfissure of the materials.

For our measures, we have used a air permeameter whose lateral airtightness is guaranteed by a rubber membrane tightly fastened around the sample thanks to a lateral confinement produced by air compressed to 0.2 MPa. The results are expressed in millidarcy (mdy) (1 mdy = 1.013x 10-11 cm^2).

The results in table 2 show that, with the exception of mortar 3 which is made up of fine aggregates (0.315 mm), all the mortars studied turn out to have an initial permeability of around $5*10^{-12}$ cm^2. These permeabilities decrease by about 50 % after a trial period of 15 days. The recorded decreases can be explained by the accelerated hydration of the cement under the combined effect of the temperature and saturating humidity. They can equally be due to the formation of gel-type new phases which fill in the fissures and reduce the permeability.

Table 2 :Air permeability variations

	Permeability (10^{-12} cm^2)		
	Initial	**Final**	**Variations**
mortar n°1	3,14	1,72	- 45 %
mortar n°2	6,08	4,05	- 33 %
mortar n°3	10,84	6,38	- 41 %
mortar N°4	5,06	1,82	- 64 %
mortar n°5	5,16	2,13	- 59 %

Measure of absolute porosity

The absolute porosity is calculated from the actual and apparent densities of the mortar. The apparent density is obtained by measuring the Archimedian thrust which acts upon the sample when it is plunged into mercury. The actual density is measured on a powder from the sample ground down to 80 µm.

The initial porosities are all of around the same percentage (around 14 %). During the trial, the porosities of mortars 1, 2 and 5 decrease by 2 % whilst those of mortars 3 and 4 only decrease by 1.2 %. This decrease can also be explained by the formation of increasingly numerous liaisons between the constituents of the mortar or by the formation of inflating gel.

In conclusion, we can observe two types of behaviour : On the one hand mortars 1, 2 and 5 which display the greatest swelling (0.35 %), a noticeable reduction in permeability (around 40%), and a decrease in porosity of around 2%. On the other hand samples 3 and 4 which swell relatively slightly, (0.10%), and whose porosity varies just as slightly (1.2 %) even if the permeability decreases noticeably.

However, each of our experiments lasts 15 days and it is not certain that this timespan is long enough to obtain a significant development of the alkali-silica-reaction gels. In order to identify the eventual presence of these gels within the mortars studied, we have gone on to carry out a microscopic examination of the newly-formed structures.

Table 3 : Porosity variations

	Porosity (%)		
	Initial	**Final**	**Variations**
mortar n° 1	13,2	11,3	- 1,9 %
mortar n° 2	18,0	16,0	- 2,0
mortar n° 3	14,7	13,5	- 1,2
mortar n° 4	16	16	0
mortar n° 5	13,5	11,5	-2

Characterization of the reaction products by SEM

The observation is made after having dessicated the test tube at 70 °C on samples of widths of 2, 4 and 5 cm. The visualization is focussed upon surfaces of rupture obtained by bending. The results of the analysis are the following:

Mortar 1 which contains quartzite, is well hydrated and rich in CSH. Not a trace of alkali-reaction gel has been detected in this sample.

Mortar 2 which contains opal is well hydrated and encloses significant quantities of alkali-silica-reaction gel. This gel is present in the pores and at the contact of the aggregates (Figures 2 and 3). The negatives show that this gel has undergone a noticeable shrinkage due without doubt to the dessication at 70 °C. Its volume appears to be very unstable so it could expand considerably. Figure 4 shows that the gel is covered over by crystallized minerals which are pink in colour. This could be rhodésite. These minerals are not characteristic of the alkaline reaction but they are often present in this type of breakdown.

Mortar 3 contains silica sand, it is well hydrated and rich in CSH and in portlandite. These two constituents are the products of the hydration of the bicalcic and tricalcic silicates. Significant proportions of portlandite have notably crystallized in the pores. Not a trace of alkali-silica-reaction gel has been detected in this sample.

Mortar 5 which contains pure quartz, is equally well hydrated but only presents a slight development of hydrates in the pores. There is not a trace of an alkali-silica reaction either.

Finally mortar 4, which contains a silica limestone , is equally well hydrated, and very rich in CSH and portlandite. Relatively significant quantities of hydrated

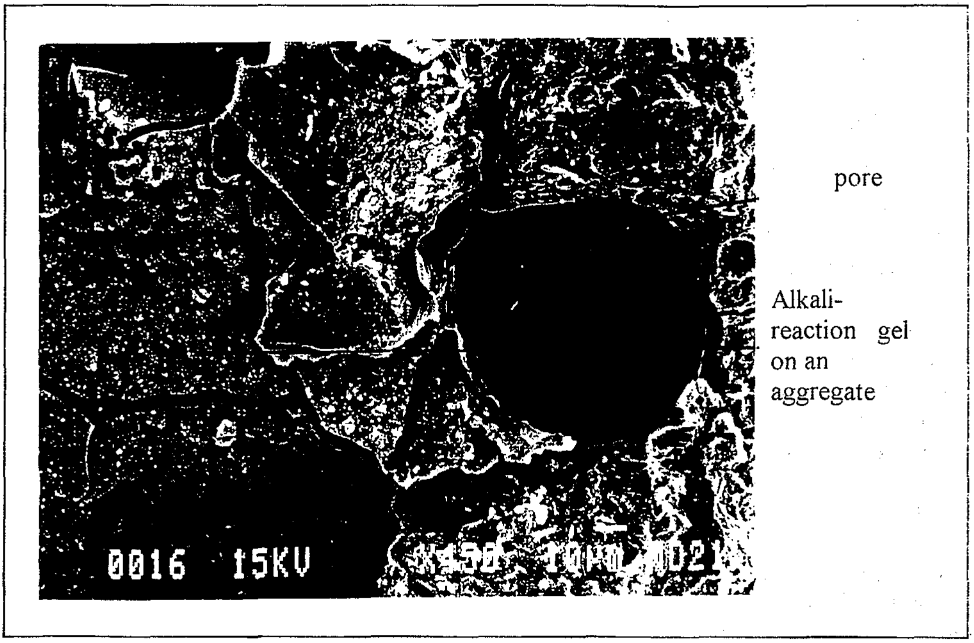

Fig. 2 SEM micrograph - Detail at a low magnification of an aggregate covered wih alkali-reaction gel

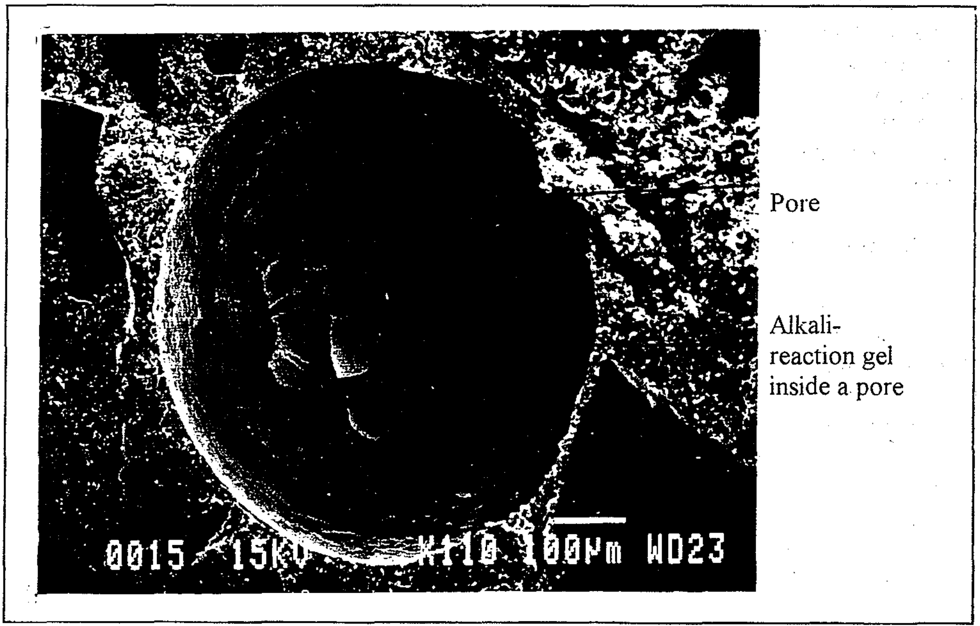

Fig. 3 SEM micrograph - Detail of the previous plate at a moderate magnification

aluminates have developped in the pores; it can be tricalcic aluminate or gehlenite. Not a trace of alkali-silica-reaction gel has been detected in this sample.

In all, one single mortar presents definite traces of gel whilst three of them undergo an obvious expansion. Two considerations could explain this result :

On one hand, we could consider that, as we have shown in a previous publication (Prince & Perami 1991), (Prince & Perami 1992), alkali-silica reactions do not always produce gels. In this case, the absence of an identification of the gel in the SEM can not be accepted as a sufficient reason to affirm the non-reactivity of an aggregate.

On the other hand, we could also imagine that some of the deterioration attributed to alkali-silica reactions are the result of delayed crystallizations in the normal phases of the cement in a greatly-confined environment. In this case, damage can result whatever the nature of the aggregates and the alkali content of the cement.

A good characterization of the reactivity of the aggregates must therefore include not only microscopic or chemical determinations, but above all effective measures of actual swelling in a defined confinement.

CONCLUSION

With the help of the device described in this study, we have been able to determine on one hand the maximum values developed in 15 days within the mortars, and on the other hand the corresponding variations in volume. These pressure are certainly not the maximum that would be reached if the experiences had lasted severals months or years. However, they give a good indication of how reactive the aggregate are.

We have examined the reactivity of five aggregates with defined chemical and mineralogical characteristics. Three of these aggregate have undergone expansion but these expansion do not always correspond to the presence of a gel identifiable by SEM. We have further noted that these inflations are accompanied by a decrease in porosity and permeability. It therefore seems that the reaction products partially fill in the existing pores before going on to create a new fissuration.

The results show just how essential it is to associate the measures of actual inflation in a given confinement with the chemical or microscopic determinations in order to evaluate the actual noxiousness of the alkali-silica reactions.

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Fig. 4 SEM micrograph - Detail at high magnification. Strips of minerals developed on the surface of the gel

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