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THE ROLE OF WATER IN ALKALI-SILICA REACTION

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ABSTRACT

As water plays a major role in the degradation of structures affected by Alkali-Silica Reaction (ASR), the coupling between the ASR-products formation and water movement has been studied to allow adequate modelling.

ASR-products are often said to be "water-absorbent". It is thus thought that concrete specimens would absorb all the more water as ASR would be developed. In order to assess this coupling effect, reactive and non-reactive concrete cylinders have been cast and kept in various storage conditions regarding water exchanges. Their behaviour does not confirm the major role of osmosis or imbibition.

Water increases concrete expansion when it is available <u>during</u> the ASR-products formation. After completion of the chemical reactions, any added water will <u>not</u> cause extra swelling. Water exchanges are the same for reactive and non-reactive concrete. These results allow to model separately water motions and ASR development in structures.

Keywords: Alkali-Silica Reaction, expansion, water, osmosis, imbibition, modelling.

INTRODUCTION

Who has ever seen a structure affected by ASR knows that water plays an essential role in this phenomenon: the more water the more severe the degradation. It has already been established that under a threshold estimated at about 80% Relative Humidity (RH) at 20°C (Olafsson 1986), and at about 90% at 40°C (Kurihara and Katawaki 1989), expansion stops. However, in the attempt of taking into account this determining factor while modelling the mechanical behaviour of ASR-affected structures, some questions must be answered more precisely:

- How does water influence concrete swelling?
- Do ASR-products formation favour water movements through absorption and osmosis effects leading to more significant swelling?

EXPERIMENTAL CONDITIONS AND METHODS

Materials

In order to assess the coupling effect of ASR-products formation and water movement, reactive and non-reactive concrete specimens have been cast. The materials and the concrete mixture design (Table 1) have been chosen to be similar to those used in some affected French bridges: the cement content is high (410 kg/m^3) and the aggregate are siliceous limestone known for their reactivity (containing 20% of reactive silica). The non-reactive aggregate is also limestone but free of reactive silica.

TABLE 1: Concrete Mixture Design

Materials	Weight (kg/m3)
Cement	410
Coarse aggregate (6-12.5 mm)	1050
Fine aggregate (0-6 mm)	700
Water (total)	196.8

The cement used is an Ordinary Portland Cement (OPC) containing 1.13 % Na_2O_{eq}. The total alkali content has been adjusted to 1.25% Na_2O_{eq} (5.125 kg/m^3) by adding potassium hydroxide to the mix water (for both reactive and non-reactive concrete).

Storage Conditions

Specimens are cylinders (24 cm high, 13 cm in diameter). They have been kept at 38°C in various storage conditions regarding water exchanges:

- immersed in water
- in saturated humidity (100% RH)
- in high but not saturated humidity (RH between 95 and 99%)
- wrapped in aluminium foils (no or low water loss).

Measurement Methods

Longitudinal expansions of the cylinders have been measured on three generating lines with a ball extensometer equipped with an inductive displacement sensor (LVDT). The standard uncertainty has been calculated, taking into account all the uncertainty sources including reproducibility with various operators (Larive 1998). The standard uncertainty is 20 µm/m for one measurement on a single generating line; it is 11 µm/m (0.0011%) for the average of three measurements.

Specimens have also been weighed in order to evaluate water exchanges (resolution: 0.1 g, maximum permissible error (k=2): ± 2 g).

RESULTS AND INTERPRETATION

Influence of Water on the Asymptotic Swelling

Experiments clearly confirm field observations: the more water absorption (seen by weight variation), the more expansion (Fig. 1).

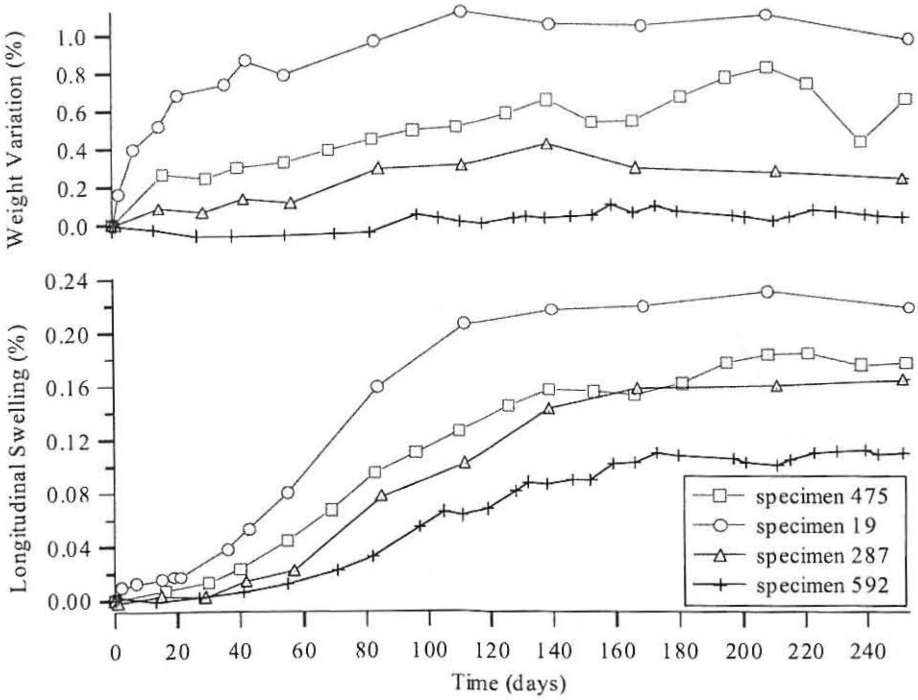

Fig. 1: Expansion & weight variation of reactive concrete cylinders (24 cm high, 13 cm in diameter) at 38°C (spec. 592 is wrapped under Al foil then kept with spec. 475, 19 & 287 in high but non saturated and non constant humidity conditions)

It can also be seen in Fig. 1 (specimen 592) that concrete expansion can be higher than 0.1% even without water ingress: the remaining water after cement hydration allows sufficient development of ASR to cause significant concrete swelling.

Effects of Water Supply Variations on the Swelling Development.

Fig. 2 shows that expansion curves of reactive concrete specimens at 38°C are affected by the external water supply history:

(A): After 140 days (arrows), swelling of specimen 286 falls when water supply does.

(B): Water supply variations when specimens are older do not affect expansion so much (arrows at 237 & 328 days).

(B): After 124 days (vertical line -VL), spec. 479 expansion increases with water supply.

(C): After 82 days (VL), spec. 593 expansion accelerates when external water supply starts.

(D): Expansion stops nearly instantly and decreases when water supply also does.

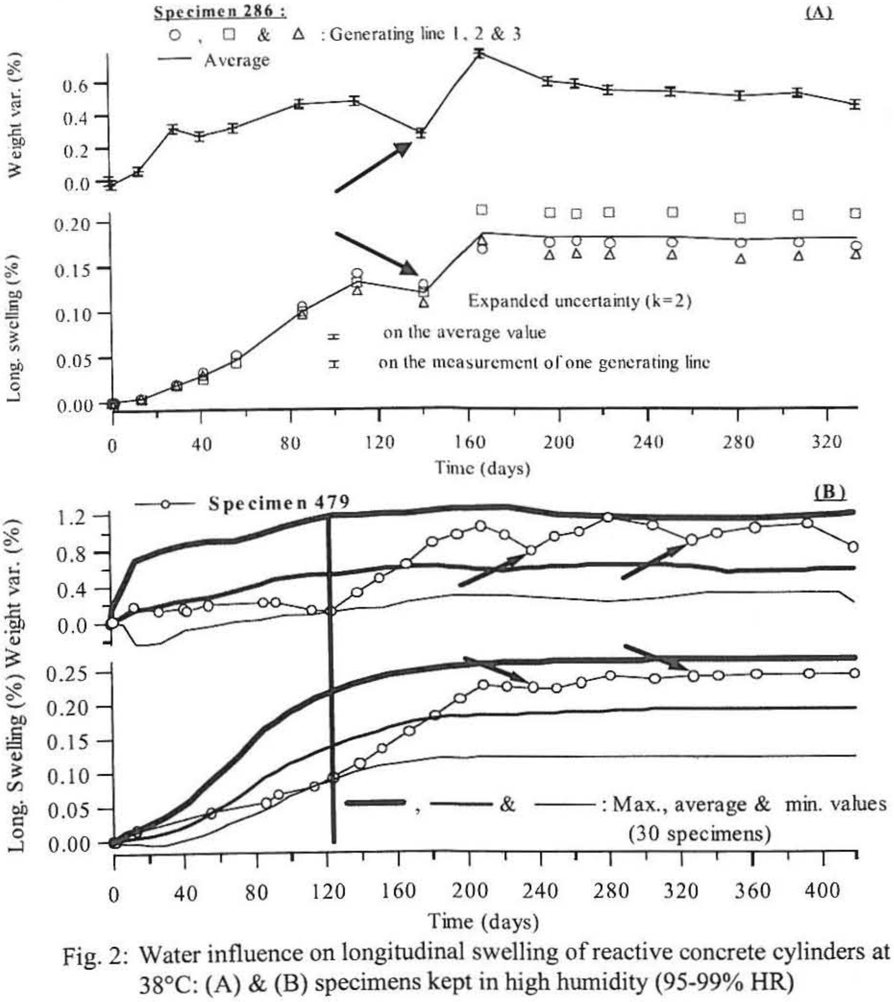

Fig. 2: Water influence on longitudinal swelling of reactive concrete cylinders at 38°C: (A) & (B) specimens kept in high humidity (95-99% HR)

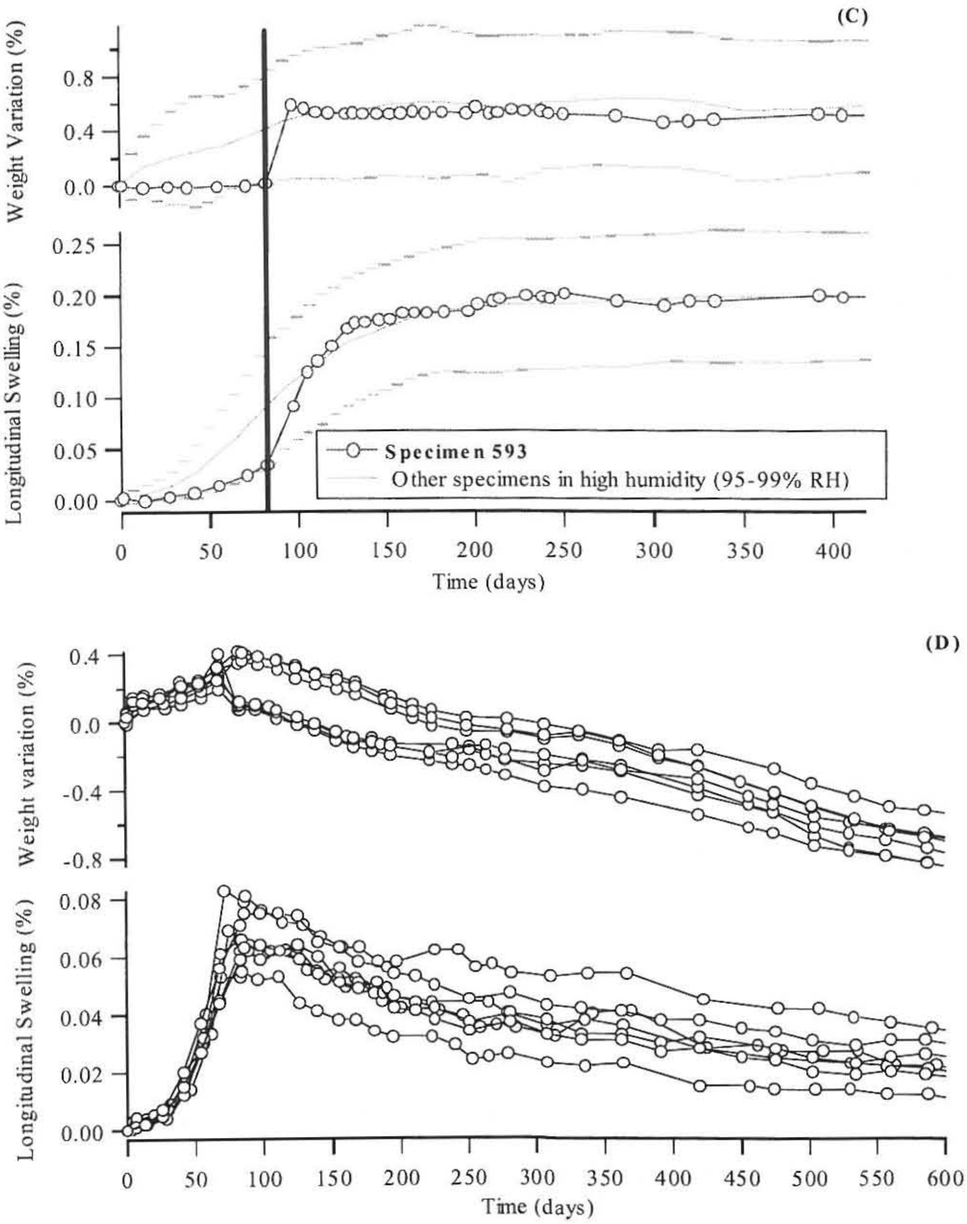

Fig. 2 (continued): Water influence on longitudinal swelling of reactive concrete cylinders at 38°C: (C) Specimen without water exchange then kept in high humidity ; (D) Specimens kept in high humidity then submitted to slow drying conditions.

Osmosis or Imbibition: Not the Major Cause of Concrete Swelling

ASR-products are often called gels although some are precipitates or even crystals (Bérubé and Fournier 1986), (Dron and Brivot 1996), (Larive 1998). They are also said to be "water-absorbent", *i. e.* to cause concrete disruption through their swelling by sorption or imbibition of liquid water (Dent Glasser 1979). The previous observations of reactive concrete specimens do not contradict this hypothesis: the more water the more expansion (Fig. 1 & 2).

But, IF osmosis or imbibition were the major cause of swelling:

- Whenever a concrete specimen absorbs water, its expansion would increase.
- ASR-products would generate more water absorption in reactive than in non-reactive concrete specimens.

During 447 days, 3 non-reactive and 3 reactive specimens have been stored at 38°C in high humidity (95-99% HR). Among all the others specimens kept in similar storage conditions, these six specimens were those which have absorbed the least water. The 3 reactive ones were also those which have swollen the least. Assuming that their low expansion was due to their low water absorption, the six of them (reactive & non-reactive) have been immersed in water. The ASR-products were expected to absorb water and, consequently, to cause a larger weight variation and increase of expansion for reactive specimens.

It can be seen in Fig. 3 that:

- After immersion in water, reactive and non-reactive specimens have absorbed the same (large) quantity of water: not more for the reactive than for the non-reactive ones.
- The expansion increase corresponding to water immersion has been very small and was the same for reactive and non-reactive specimens.

Attention is drawn on the fact that results depend on the specimen age when water absorption occurs (Fig. 2 (A) & (D): younger specimens do swell when water comes in). In fact, it is not only a question of age, as can be seen on Fig. 4: reactive concrete specimens submitted to dessiccation for 561 days at 38°C, 30% RH expands very quickly when immersed in water.

Another phenomenon must be taken into account: not only expansion but also ASR-products formation stops when there is not enough water inside the concrete: scanning electron microscopy has been used to look for ASR-products inside many concrete specimens kept in various storage conditions (Larive 1998). It has been shown that the quantity of ASR-products is far inferior when there is no external water supply and that there are nearly no products formation at all when specimens dry.

We therefore concluded (on the basis of both macroscopic and microscopic observations) that there is a threshold below which there is not enough water for the chemical reactions between alkalis, hydroxides and silica to occur. This threshold, corresponding to the end of the swelling, has been estimated on the basis of the expansion curves of numerous specimens at about -0.15 mass % for our concrete mixture design (Fig. 5). It depends on the alkali content (Tomosawa et al. 1989). When chemical reactions and swelling have been stopped by a lack of water, they can be reactivated very quickly when water comes back (Fig. 4 – Expansion of similar non-reactive drying specimens immersed in water is far inferior and slower).

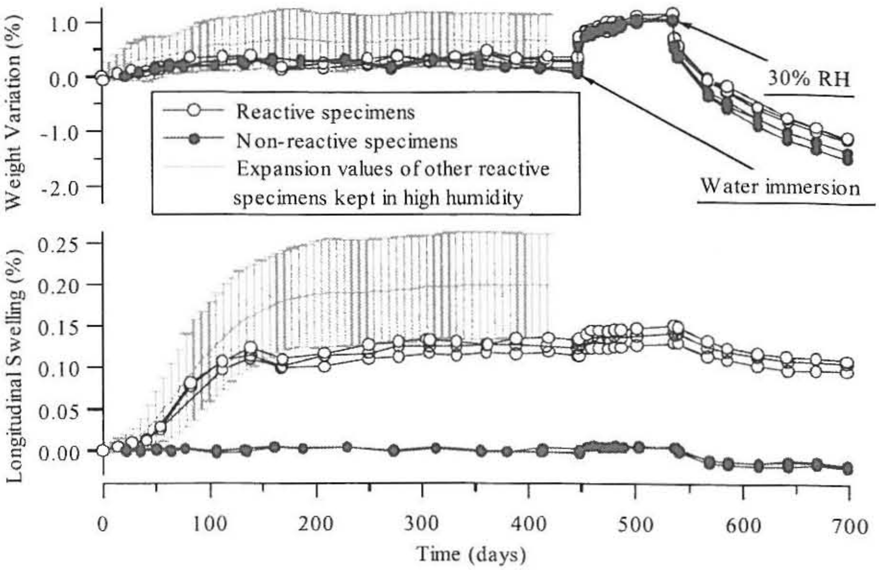

Fig. 3: Reactive and non-reactive specimens among reactive others at 38°C in high humidity

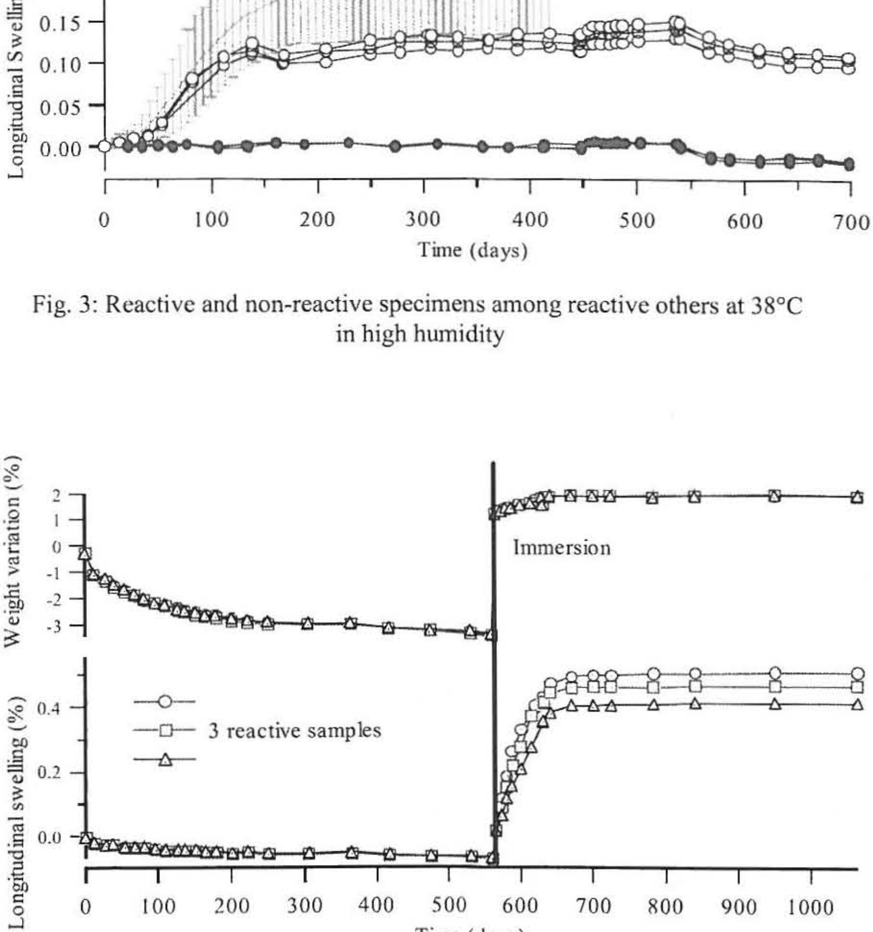

Fig. 4: Reactive specimens kept at 38°C, 30% RH then immersed in water

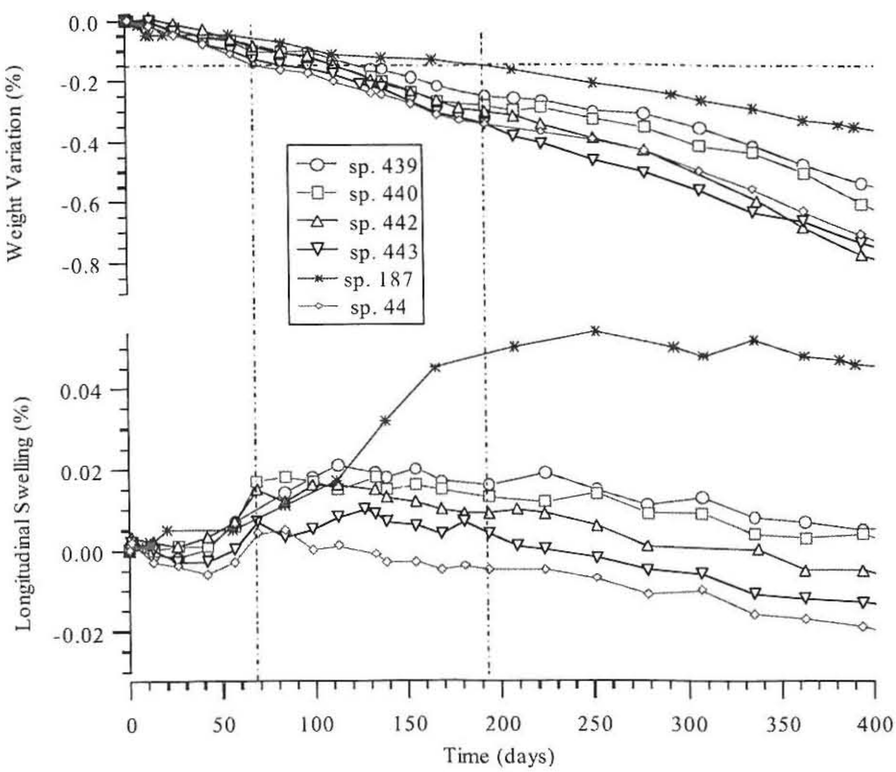

Fig. 5: Reactive specimens loosing water at 38°C (all wrapped under Al foil and kept at about 30% RH)

CONCLUSION

The main results can be summarised as follows:

1. Reactive concrete specimens do not absorb more water than non-reactive ones: water motion is not affected by ASR. Osmosis or imbibition is not the major cause of swelling. No specific model needs to be developed to predict water movement in ASR-affected concrete.

2. ASR-expansion increases with external water supply. The determination of expansion in various storage conditions can be used to assess the influence of water content on concrete swelling. Such tests would also be very interesting on cores extracted from ASR-affected structures to evaluate their residual potential expansion as a function of the external environment.

3. Irregular external water supplies irreversibly affect concrete expansion.

4. Concrete swelling can reach 0.1% even without water ingress, thus leading to potential structural degradation.

5. Expansion and ASR-products formation both stop when concrete losses more than a certain amount of water (-0.15 mass % for our concrete mixture design design at 38°C). They both can be reactivated very quickly when water comes back.

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