CARBONATION OF CONCRETE WITH SILICA FUME AND FLY ASH

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Tests of the carbonation rate of concrete with silica fume and fly ash are in progress at the Swedish Institute for Cement and Concrete Research (CBI). The tests are carried out on ordinary concrete with standard Portland cement and concrete with an admixture of 15 and 40% respectively of fly ash and 10 and 20% respectively of silica fume After storage for 2 1/2 years the depth of carbonation was measured by means of the phenolphthalein method. The results show that if the various mixes are compared on the basis of the same water-binder ratio the rate of carbonation is not affected to any noteworthy extent by the admixture of silica fume, while the admixture of fly ash increases the rate of carbonation. If, on the other hand, the mixes are compared on the basis of the same 28-day strength it can be seen that the admixture of silica fume and fly ash gives a somewhat higher rate of carbonation.

Keywords: Carbonation, silica fume, fly ash.

1 INTRODUCTION

It is very important to know the rate of carbonation of concrete since reinforcement steel embedded in carbonated concrete can corrode. The rate of carbonation can thus be altogether decisive in some cases for the service life of the structure.

The admixture of silica fume and fly ash in concrete has become interesting in recent years. It is thus very important to know the effect which these materials have on the durability of the concrete, carbonation being one of the many influencing factors in this regard.

Against this background CBI is engaged in testing the effects of admixtures on, inter alia, the rate of carbonation. Ordinary concrete with standard Portland cement and concrete with an admixture of 15 and 40% respectively of fly ash and 10 and 20% respectively of silica fume are tested in the investigation. The specimens are stored in climate chambers with 50% RH, 80% and outdoors under a covering roof.

2 CARBONATION - RATE-CONTROLLING FACTORS

The environment in concrete is normally highly alkaline. The pore solution has a pH value between 12.5 and 13.5. A saturated calcium solution has a pH value of about 12.5. The fact that the pH value in the pore solution in concrete exceeds 12.5 is due to the presence of soluble alkalines (Na^+ and K^+). When the cement hydrates considerable quantities of calcium hydroxide ($Ca(OH)_2$) are liberated.

When carbon dioxide, which occurs in air, then penetrates the concrete it reacts with the calcium hydroxide and the calcium oxide included in the hydration products and forms calcium carbonate. When this reaction takes place the pH value drops to less than 9. As a result of this change in the pH value from 12.5-13.5 to less than 9 the steel is no longer passive and begins to corrode.

Since carbon dioxide, CO_2, penetrates the concrete from the surface the carbonation will begin in the surface layer and then penetrate as a front in the concrete. The rate of carbonation will then theoretically follow a square root relation, see Fig. 1. In reality the curve probably flattens out with time, one of the reasons being that the outermost layer of the concrete does not have quite the same properties as further in and that it takes a long time before Portland cement concrete is fully hydrated.

The rate of carbonation is theoretically dependent on:

- o The diffusion-tightness of the concrete against CO_2
- o The possible absorption of CO_2 in the concrete
- o The ambient concentration of CO_2

In practice this means that the rate of carbonation is dependent on the moisture state, W/C, cement type, cement content, compaction and curing.

Factors such as the moisture state and the ambient CO_2 concentration cannot be adjusted in a given environment. The following "adjustable" factors thus remain:

- o The composition of the concrete: mainly the W/C, cement type, cement content, admixture (for example, silica fume, fly ash)
- o The after-treatment of the concrete: compaction and curing.

The service life of the structure from the carbonation-corrosion point of view can thus be controlled by adjusting these factors and, of course, by selecting a suitable thickness for the concrete cover.

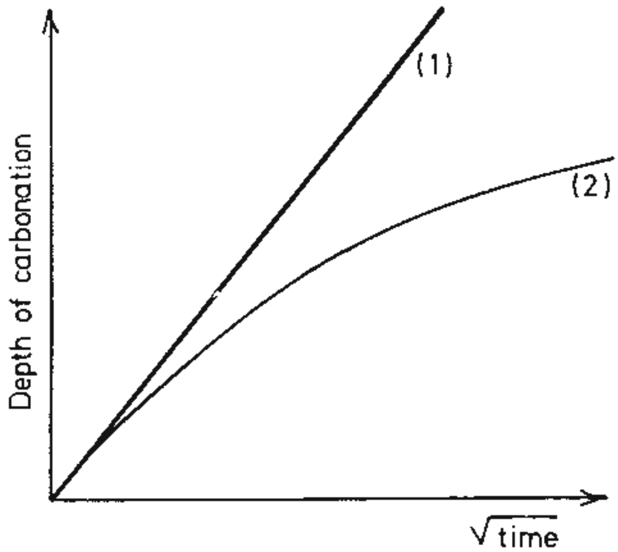

FIG 1. Two principles for describing the penetration of the carbonation front in concrete.
1. The square root principle
2. New principle put forward by Schiessl /14/

3 TESTING

Concrete prisms (15x15x30 cm) with an admixture of 10 and 20% respectively of silica fume and 15 and 40% respectively of fly ash were manufactured. The composition of the constituents is presented in Table 1. The Portland cement was replaced directly (kg for kg) by the admixture materials and the percentage is based on the total quantity of binder. Each mix was manufactured in three different qualities. The consistence was kept constant at a slump of between 8 and 11 cm. Since the admixtures used influence the consistence, the W/C was permitted to reach whatever value it might reach. In certain cases a superplasticizer, Peramin 3183, was added in a quantity of approximately 1% of the quantity of binder.

TABLE 1. Chemical Composition of Cement, Silica fume and Flyash (weight -%)

Material	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	Na_2O	K_2O	Loss of ignition	Spec surface m^2/g
OPC	62,6	19,9	4,3	2,02	3,26	3,54	0,26	1,25		
Silica fume	0,07	96	0,23	0,08		0,13	0,20	0,37	2-4	22
Fly ash	7,3	49,2	25,4	7,3	0,9	2,5	0,4	2,1	2,9	

With the exception of a few "random samples" which received inadequate curing (directly to 50% RH), the specimens were moisture-cured immediately after casting and vibration in 100% for 24 hours. They were then removed from the moulds and cured in water for 7 days. They were then placed in climate chambers at 20°C and 50% and 80% RH respectively and outdoors sheltered under a covering roof (rain shelter).

Simultaneously with the prisms, cubes (15x15x15 cm) were also manufactured and, after the same treatment (but curing in 50% RH only) they were tested with regard to their compressive strength after 28 days. The results are presented in Fig. 2.

After 2 1/2 years of storage the depth of carbonation was measured by means of the phenolphthalein method.

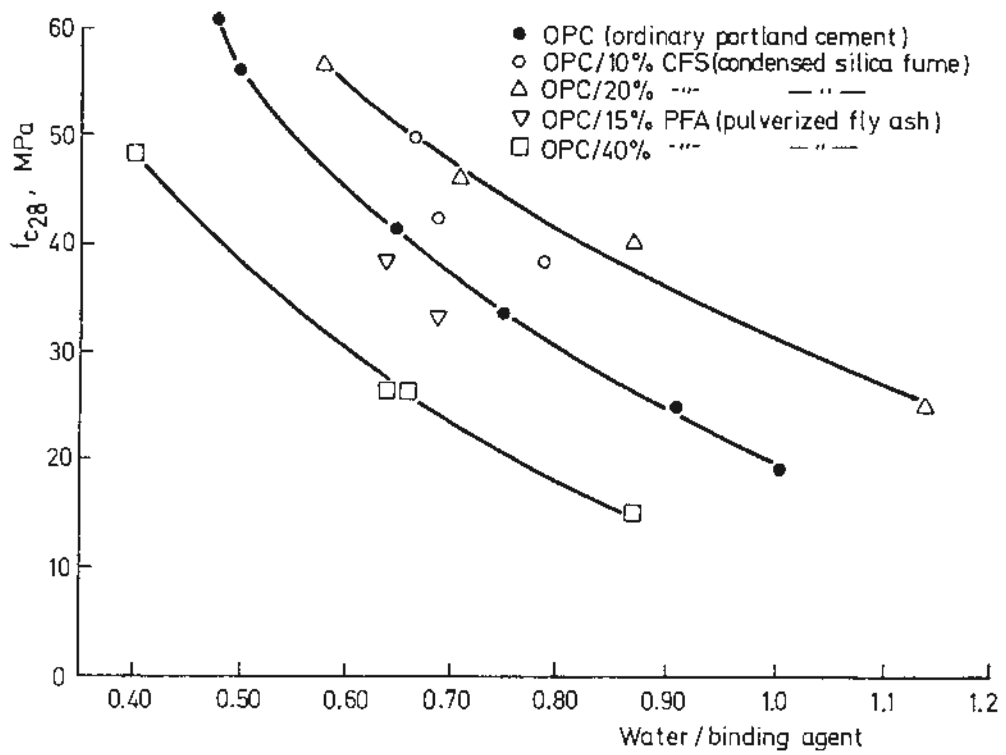

FIG 2. Compressive strength after 28 days. (7 days watercured) versus waterbindingagentratio for portland cement concrete, silica fume concrete and fly ash concrete.

4 RESULTS

Figs. 3, 4 and 5 present the depth of carbonation measured in the specimens as a function of the water-binder ratio (W/B) after 2 1/2 years exposure in 50% RH, 80% RH and outdoors sheltered under a roof. The results show that if a comparison is made on the basis of the same water-binder ratio, the silica fume does not have any marked influence, while the fly ash admixture gives a marked increase in the rate of carbonation.

It can also be noted that the rate of carbonation outdoors under a roof is lower than at 50% RH but higher than at 80% RH.

As can be seen in Fig. 2, the compressive strength of the concrete is influenced by the admixture of silica fume or fly ash. If, instead, the depth of carbonation is plotted as a function of the 28-day strength the relation presented in Fig. 6 is obtained. This figure shows that there is a clear relation between the compressive strength and the rate of carbonation. The rate of carbonation shows a tendency to be higher for concrete with an admixture of silica fume or fly ash compared with corresponding Portland cement concrete.

Fig. 3 (50% RH) also presents the results of measurements carried out on specimens which were not, at any time, moisture-cured. The results indicate that concrete with silica fume or fly ash is damaged to approximately the same extent as Portland cement if it is not moisture-cured, in other words the rate of carbonation increases to a similar extent.

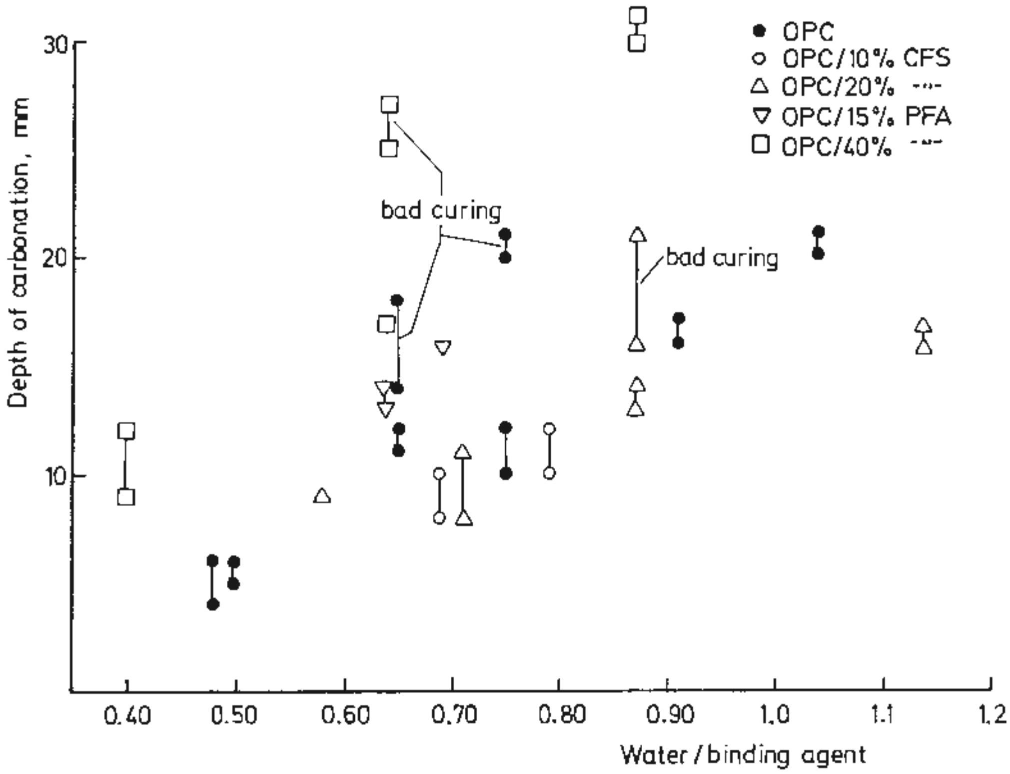

FIG 3. Measured minimum and maximum depth of carbonation for concrete stored for 2 1/2 years in 50% RH.

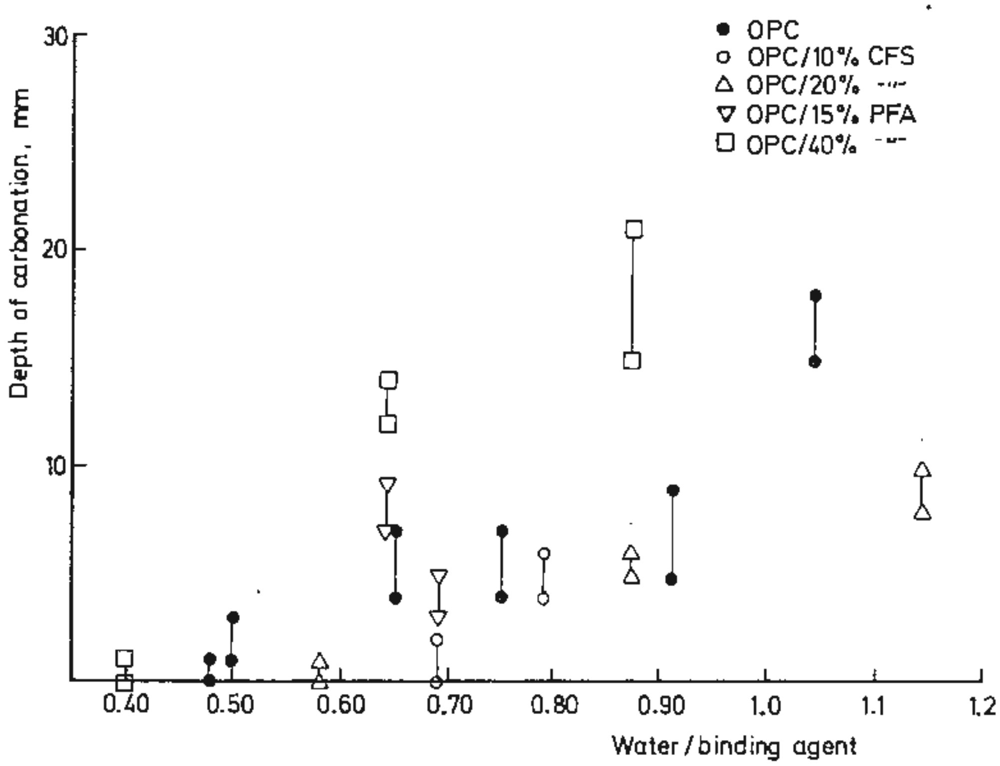

FIG 4. Measured minimum and maximum depth of carbonation for concrete stored for 2 1/2 years in 80% RH.

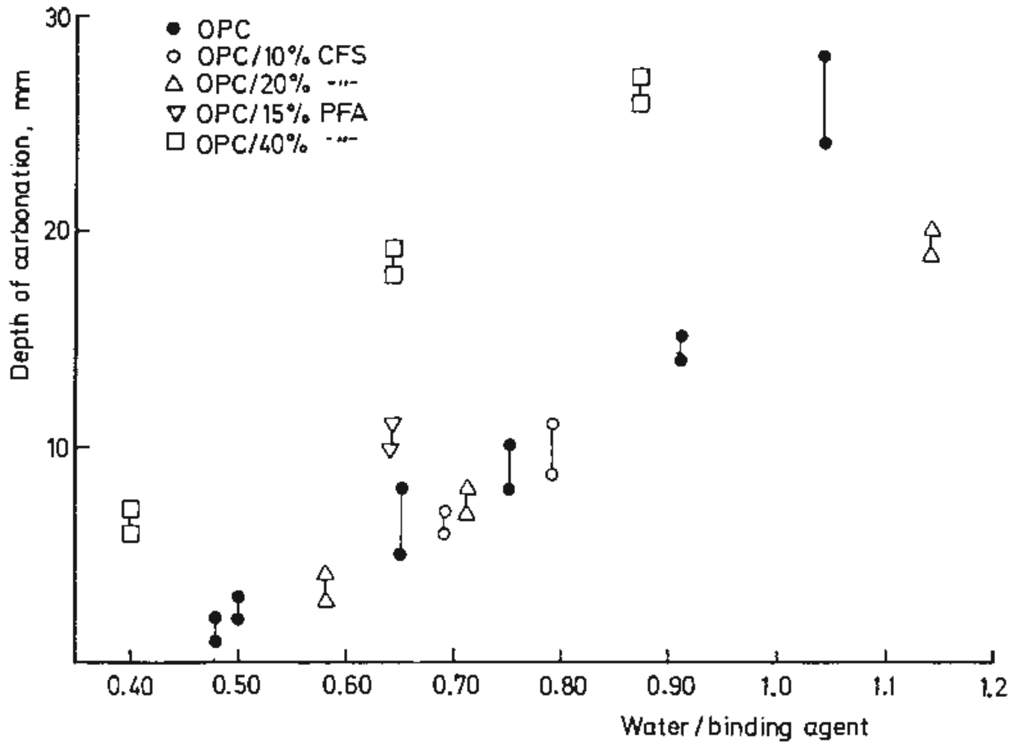

FIG 5. Measured minimum and maximum depth of carbonation for concrete stored for 2 1/2 years outdoors (sheltered from rain).

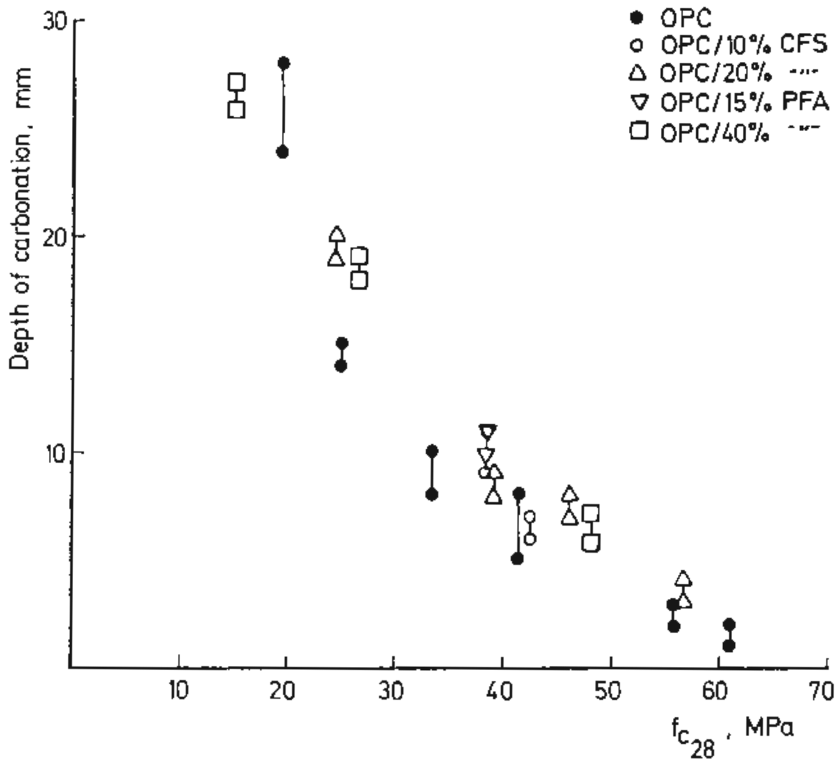

FIG 6. Measured minimum and maximum depth of carbonation for concrete stored 2 1/2 years outdoors (sheltered from rain) versus compressive strength after 28 days.

5 DISCUSSION

Concrete with silica fume admixture

The results for water-cured concrete with an admixture of silica fume obtained in this investigation agree well with results from other investigations. In an investigation carried out at CBI /2/ the depth of carbonation was measured on 6 year old specimens, W/B 0.55, which had been cured in 50% RH. The results showed that no effect could be noted from an admixture of 10-25% silica fume at the same W/B.

The depth of carbonation has also been measured at CBI in drilled-out cores taken from 2-5 year old concrete structures with an admixture of silica fume (7-12.5% SiO) The results, see /2/, showed approximately the same or a lower rate of carbonation compared with the corresponding Portland cement concrete with the same W/B. An investigation made by Vennesland /11/ also shows that an admixture of silica fume (10-20% SiO) does not affect the rate of carbonation at a constant water-binder ratio.

Maage and Skjøldsvold have studied the carbonation of 3-7 year old structures with and without silica fume. They note that concrete with silica fume has a slightly higher rate of carbonation than has Portland cement concrete at the same strength /12/.

When cement is replaced with silica fume, weight for weight, the concrete becomes denser with a finer pore structure, see for example /10/. On the other hand the CaO which can carbonate is reduced. As a result the rate of carbonation is approximately the same. The results show clearly that it is not only calcium hydroxide which can carbonate but also CaO included in other hydration products. If it was only calcium hydroxide which carbonated the silica fume concrete, which has very little calcium hydroxide, would carbonate extremely rapidly.

Since the density of the silica fume concrete also affects its compressive strength, silica fume concrete has a higher strength than Portland cement concrete at the same W/B. This means that the silica fume concrete carbonates somewhat more rapidly than does Portland cement concrete at the same 28-day strength.

Unfortunately no structures older than about 7 years exist. This makes it difficult to estimate how continued hydration will affect the rate of carbonation in the long term.

The results obtained from this investigation and from an investigation carried out at CBI /2/ show that the omission of moisture-curing does not accelerate the carbonation for silica fume concrete to a greater extent than for Portland cement concrete. This fact is difficult to explain, however, since the hydration of silica fume concrete is slow at the beginning. Other investigations, for example /12/, show, on the other hand, that silica fume concrete is sensitive to poor curing.

Concrete with fly ash admixture

The rate of carbonation in concrete in which cement has been replaced, weight for weight, by fly ash proved to be considerably higher in this investigation than for Portland cement with the same W/B. This can be explained by the slow hydration of the fly ash concrete, which also manifests itself in a lower 28-day strength, see Fig. 2. Similar results are presented by Samarin et al /3/. Rondahl /9/ has compared the rate of carbonation for fly ash concrete (30% fly ash) with Portland cement concrete with the same W/B. No difference could be noted except for concrete with a high W/B (0.80), when the fly ash concrete carbonated more rapidly. The explanation is probably that the fly ash cement was more finely ground in this case so that the 28-day strength became the same (faster hydration at the beginning).

The results of this investigation show a tendency towards a higher rate of carbonation, at the same compressive strength, for concrete with fly ash. Several authors present results which indicate that concrete with or without fly ash but with the same 28-day strength and consistence, have approximately the same rate of carbonation /13/, /4/, /3/, /7/, /6/, /5/. In most of these investigations the tests were in progress for 4 years or more. Contradictory results are presented by Ho et al /8/ who note that fly ash concrete has a higher rate of carbonation than pure Portland cement concrete with the same compressive strength. A probable explanation is that Ho measured the depth of carbonation after no more than 4 weeks. This gives an unfavourable result for the slowly hydrating fly ash concrete.

This information from the literature indicates that even 2 1/2 years exposure, on which the results in the present investigation are based, is too short a time to draw conclusions concerning the effect of fly ash on the rate of carbonation in the long term.

The slow hydration of fly ash concrete should also influence its sensitivity to poor curing. It is difficult, however, to demonstrate any such effect on the basis of the results in the present investigation. Butler et al /4/ and Maage and Skjøldsvold /12/ on the other hand present a greater negative effect of drying out on the rate of carbonation for fly ash concrete than for Portland cement concrete.

6 CONCLUSIONS

The results of the present investigation show that if the rate of carbonation for pure Portland cement concrete is compared with that for concrete with an admixture of 10-20% silica fume and an admixture of 15-40% fly ash respectively at a <u>constant waterbinder ratio</u>, it can be noted that

- o The silica fume admixture has no effect
- o The fly ash admixture gives a higher rate of carbonation

If, on the other hand, the same comparison is made based on a <u>constant 28-day strength</u> the conclusions are that

- o There is a clear relation between the rate of carbonation and the compressive strength.
- o An admixture of silica fume or fly ash tends to increase the rate of carbonation.

It should be noted here that these conclusions are based on measured results obtained after the specimens have been exposed for 2 1/2 years. This may be too short a time bearing in mind the fact that the admixtures give the concrete a slow hydration.

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