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THE EFFECT OF CURING CONDITIONS ON THE PROPERTIES OF SILICA FUME CONCRETE

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ABSTRACT

Two concrete mixes with 20% silica fume and water/cementitious ratios of 0.3 and 0.46 were compared with corresponding OPC concrete mixes. The effect of both cold and dry curing on the major engineering properties and the progress of the pozzolanic reaction was measured at ages up to 90 days. The long term effect was evaluated with further measurements after a year. The paper shows that silica fume (SF) which is a highly reactive pozzolanic material is very sensitive to low temperature curing and drying out during curing. This effect should be taken into account when designing silica fume concrete for durability and performance.

INTRODUCTION

It is well known that pozzolanic concretes gain strength slower than pure cement mixes, especially at low temperatures. Low temperature curing is likely to occur with silica fume concrete when it is used on site because its high strength and high cost make it most suitable for use in thin structural elements which have large surface areas which are difficult to insulate. At low temperatues low strengths have been observed in mixes with 10% replacement at 28 days (1) and in this report results for a range of engineering properties at different ages are presented for 2 mixes with 20% replacement. It has also been observed that permitting a silica fume mix to dry out at an early age has an adverse effect on its ultimate strength (2,3). This condition is more severe than is normally permitted, so to simulate site conditions a set of samples was treated with a curing membrane and then permitted to dry. In addition to the engineering properties the rate of the pozzolanic reaction has been measured by measuring the calcium hydroxide content by thermogravimetric analysis.

Experimental Methods

Two mixes were tested with water/cementitious ratios of 0.3 and 0.46. The pozzolanic mixes had 20% of the cement replaced by silica fume supplied by Elkem Chemicals from Norway. Quartzitic aggregate from a quarry in Nottinghamshire was used.

Details of the mixes are given in Table 1.

TABLE 1
Composition of the mixes used in the investigation

Mix	A	B	C	D
Cement (Kg/m^3)	344	430	252	315
Silica (Kg/m^3)	86	0	63	0
Water/(cem + silica)	.3	.3	.46	.46
Superplasticiser (% of c + s)	1.4	1.4	1.9	1.9
5-20 mm. aggregate/(c + s)	3	3	4	4
Fine aggregate/(c + s)	1.5	1.5	2.3	2.3
28 day strength (MPa)	113	80	88	55

A napthalene formaldehyde condensate superplasticiser was used which gave all of the mixes a slump of 150 ± 50 mm.

The paste was made with the same proportions without the aggregate.

Curing Conditions

The details of the three different curing conditions were as follows:

Curing Condition 1 (CC1) Control:	Curing in fog room (20 degrees centigrade) until test age.
Curing Condition 2 (CC2)	Treated with a curing membrane (Febcure Aluminium pigmented) and stored at 20 degrees centigrade at 70 percent RH for 7 days and then in water at 6 degrees centigrade until test age.
Curing Condition 3 (CC3) Low temperature:	Curing in water at 6 degrees centigrade until test age.

The one year samples were kept at 70% RH and 20 degrees centigrade for one year from the completion of their curing time.

Testing procedures for engineering properties:

The following engineering properties were measured at 3, 28 and 90 days using the relevant British Standard tests:

1 Compressive strength of 100 mm. cubes after curing
2 Compressive strength of 100 mm. cubes after curing and subsequent storage for 1 year
3 Modulus of rupture in flexure
4 Tensile (splitting) strength of 150 mm. diameter cylinders
5 Static modulus
6 Dynamic modulus by acoustic resonance

Testing procedure for calcium hydroxide content:

After curing times of 3,7,28 and 90 days paste samples were ground and then sieved through a 150 micron sieve. The free water was then removed by twice saturating them in acetone and drying them in nitrogen.

A second set of samples was drilled from the broken face of the one year concrete compressive test cubes.

Thermogravimetric analysis was carried out with a Stanton Redcroft TG750 thermobalance. The balance was connected directly to a microcomputer and the areas under the differential curves were measured by obtaining statistical best fits of normal distributions to them. Details of this procedure have been reported elsewhere (4).

RESULTS AND DISCUSSION

The results are shown in Figures 1 to 8. It should be noted in figure 2 that the ages given are the curing times which are one year less than the age at time of testing. A strict comparison between the calcium hydroxide contents shown is not possible because the initial values in figure 7 are for paste samples but the one year values in figure 8 are for samples drilled from concrete. For this reason the data in figure 7 has been converted into calcium hydroxide contents but this would not have given a valid result for the samples for figure 8 which contained some aggregate.

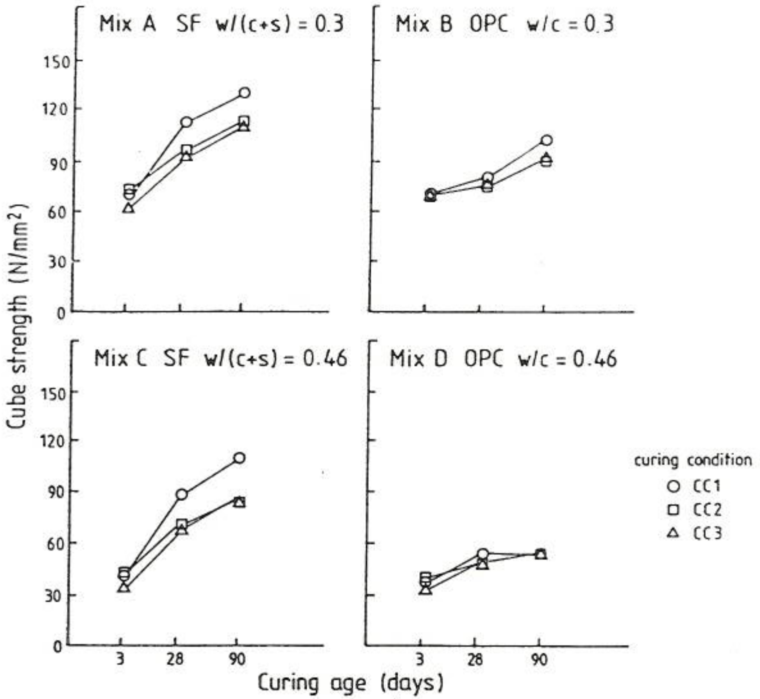

Figure 1. Compressive strengths of 100mm cubes immediately after curing.

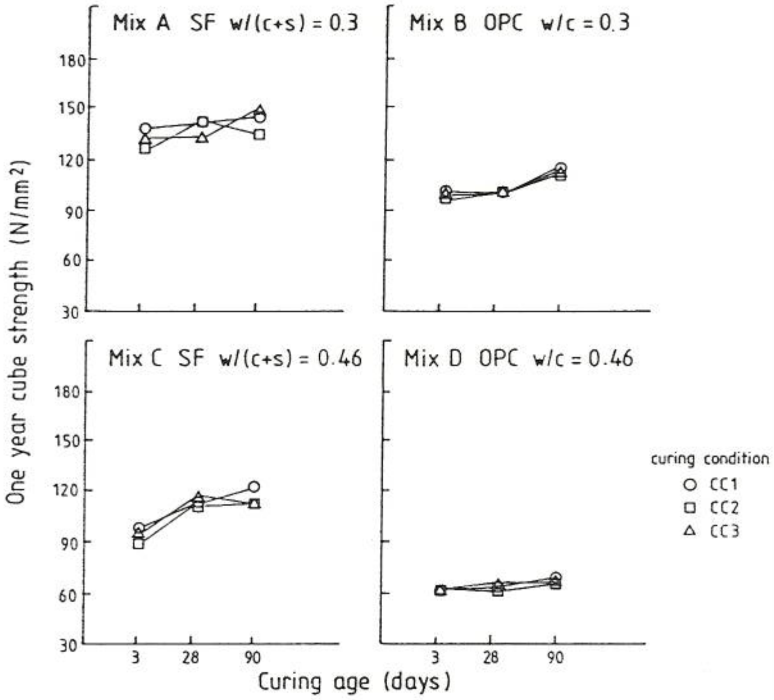

Figure 2. Compressive strengths of 100mm cubes after being stored for 1 year in a room at 20 degrees for curing.

Extensive failure of the aggregates was observed in the stronger samples. In some of the samples tested in flexure all of the aggregate visible on the exposed faces was broken and no failure of the bond with the matrix was observed. The authors are therefore in no doubt that, for example, the maximum observed compressive strength of 148.9 N/mm^2 is well below the ultimate potential of the mix if a stronger aggregate is used. This phenomenon applies equally to all of the samples and should not affect the ranking.

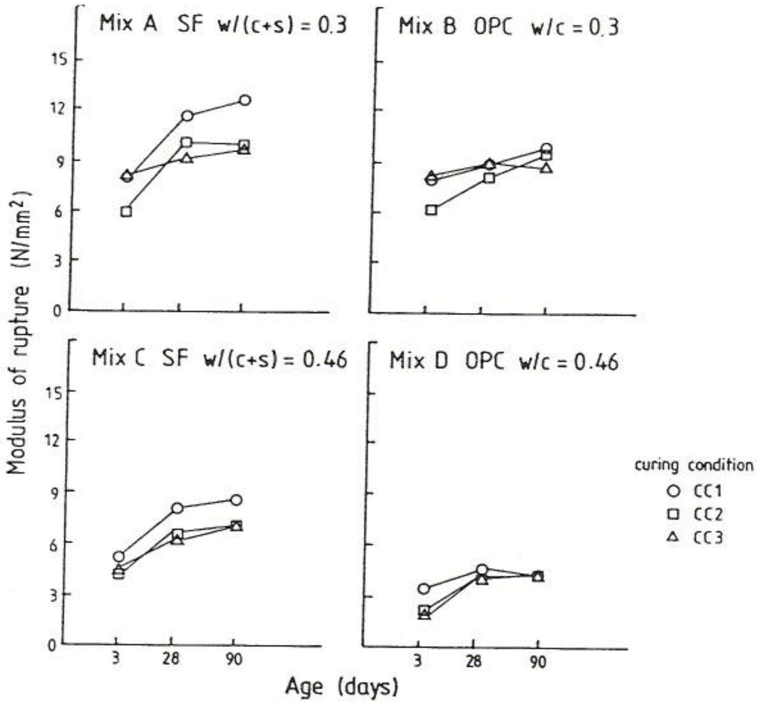

Figure 3. Modulus of rupture of 100mm*100mm*500mm concrete samples.

Samples tested after initial curing

The beneficial effects of silica fume are derived from both a mechanical filling effect and the pozzolanic reaction (5). Figure 7 shows that in the cold tank (Curing Condition 3) the pozzolanic reaction is very small even at 90 days. A considerable diversity of results has been noted in the literature presumably caused by different fumes and curing temperatures (6) but this observation would not appear to be unusual. The effect of this observed attenuated pozzolanic reaction is that the mechanism of any improvement from the silica fume in the CC3 samples must be mainly derived from the filling effect. Thus (see figs. 1-6) the compressive strength and the modulus of rupture which are most affected by curing condition must depend mostly on the pozzolanic reaction.

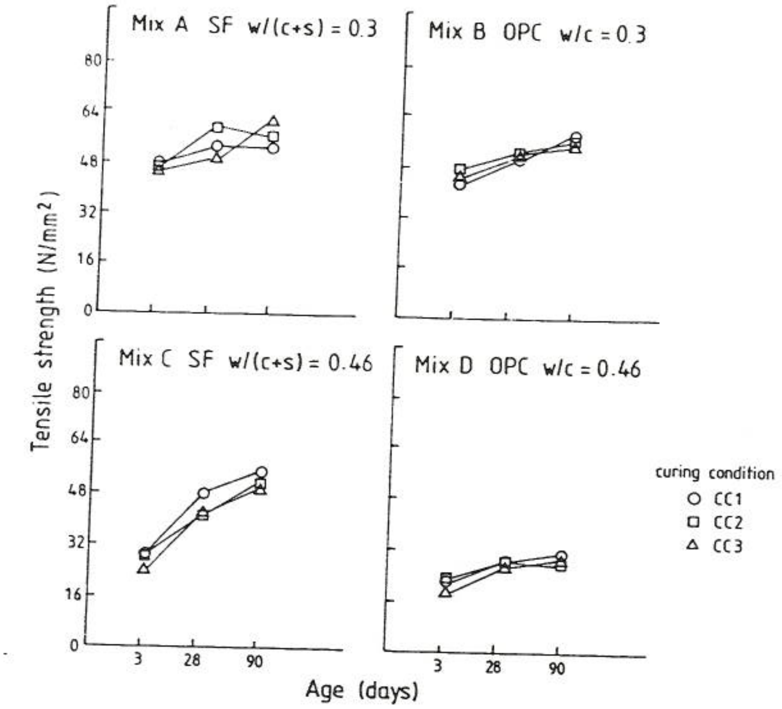

Figure 4. Tensile strength obtained by splitting 150mm diameter concrete cylinders

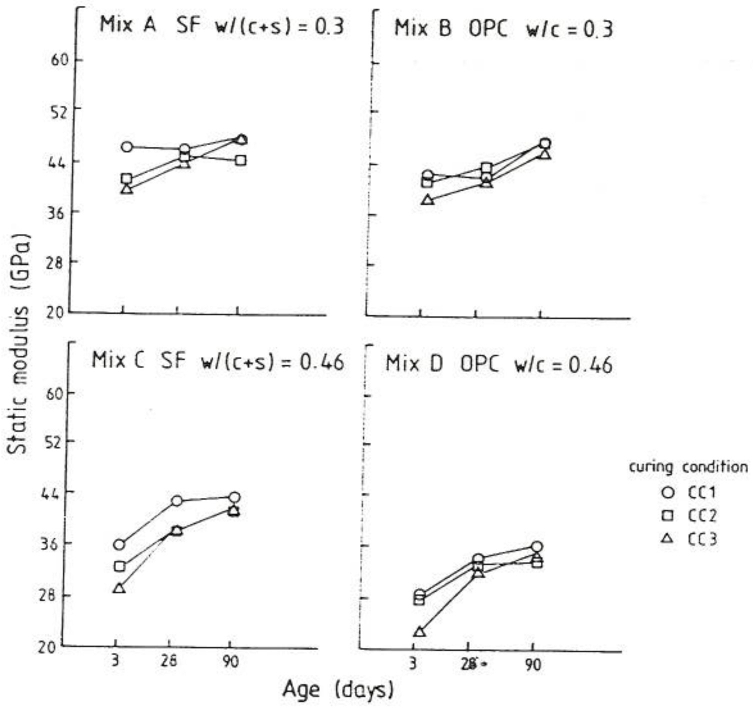

Figure 5. Static modulus of 100mm*100mm*500mm concrete beams.

One year samples

Although there is some variability in the readings due to differing amounts of aggregate in the samples Figure 8, shows that even in the CC3 samples the pozzolanic reaction is virtually complete. From Figure 2 it may be seen that the dependence on curing condition is almost eliminated and the highest strength of all was from the 90 day CC3 sample. These strengths will be very close to the ultimate values and the differences may be assumed to be permanent. Mix C shows the beneficial effect of a short curing period at 20°C with a curing membrane to avoid drying out. The main difference in procedure between the 3 and 28 day CC2 samples was that the 28 days samples were placed in the cold tank between the ages of 7 and 28 days while the 3 day samples were kept at 20 degrees centigrade. While this had very little effect on the other mixes it caused a gain in mix C. This indicates that silica fume concrete is more sensitive to curing temperatures at early ages and that the effect of cold curing is only temporary.

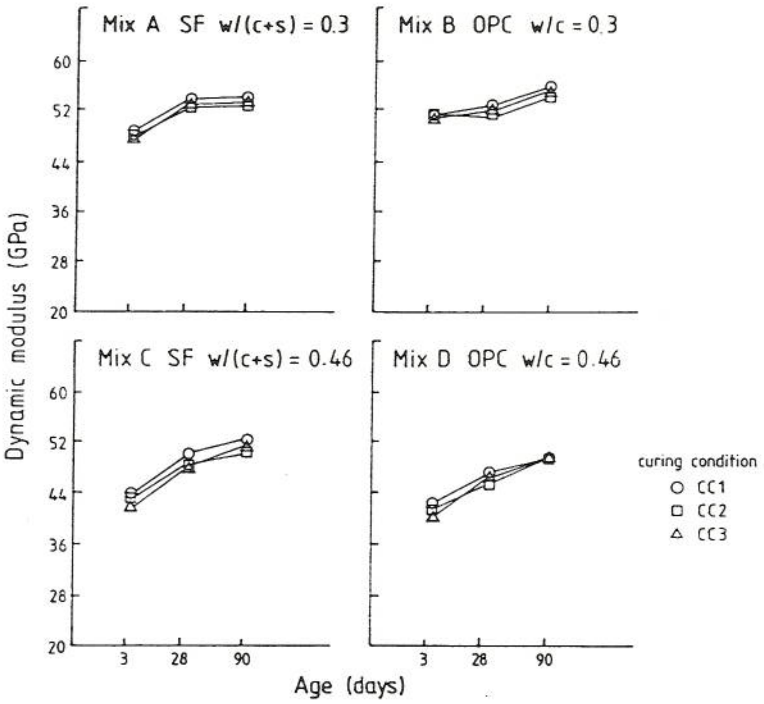

Figure 6. Dynamic modulus obtained by measuring the acoustic resonance of 100mm*100mm*500mm concrete beams.

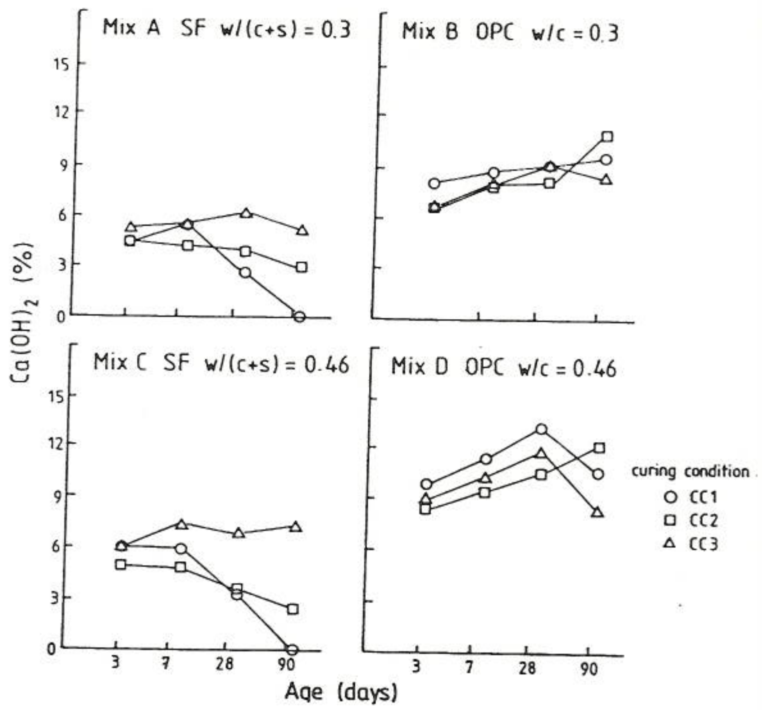

Figure 7. Calcium hydroxide content from thermogravitmetric analysis of paste samples.

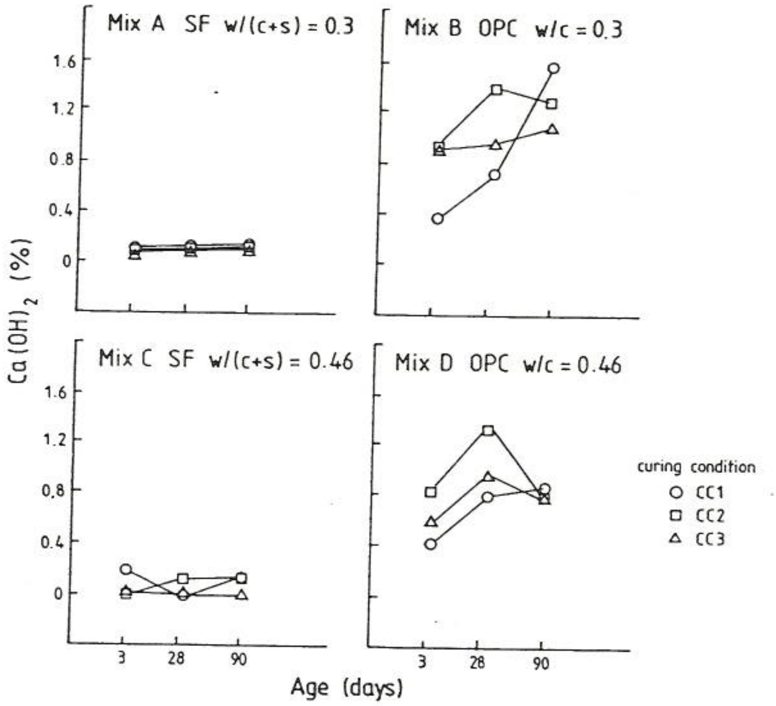

Figure 8. The mass loss in the calcium hydroxide peak detected by TG analysis in samples drilled from a freshly broken inner face concrete cubes kept in a room at 20 degrees for one year after curing.

CONCLUSIONS

1. At 6 degrees centigrade even after 90 days the pozzolanic reaction is barely detectable in silica fume concrete and benefits derived from it will not be observed.

2. The effect of cold curing is totally corrected by raising the temperature even if no additional water is provided.

3. Silica fume concrete is more sensitive to changes in temperature and time of curing than OPC concrete.

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