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On the long-term strength losses of silica fume high-strength concretes

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Contribution by H. Roper

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Only if internal drying, presumably due to self-desiccation, takes place under moist curing conditions can the mechanism proposed by the authors of this paper explain the results of long-term strength studies of silica fume concretes presented at a recent International Conference.

Atlassi¹ presented results on continuously cured concretes which displayed a 'drastic decline' in compressive strength at 250 days, compared with that measured at 90 days. She explained this to be a result of low workability, and intended to check the results. Mak *et al.*² showed a significant strength decrease in the 28–60 day concrete strengths of cylinders stored in lime-saturated water baths. Sirivivatnanon *et al.*³ presented data for a European silica fume, which showed a decrease in strength between 90 and 365 days, even though curing was continued over that period. It seems probable that the three groups, all working independently of one another, are observing a real effect which should not be lightly dismissed.

First, have the authors come across the strength loss phenomenon under conditions favouring continued hydration, or is it observed only when moisture loss to the surroundings may occur? The second, more general, question which must be asked is: since it appears from the references that only certain of the concretes in each set show this aberration, what differentiates them from the rest? It would seem that apart from drying, some other cause for strength

losses in the long term may be active. One suggested cause is late expansive hydration reactions which may be delayed due to incomplete dispersion of the silica fume during mixing. Long-term dimensional change studies conducted in the future to measure potential self-desiccation shrinkage, or alternatively unacceptable hydration-induced swell, may provide the information required.

Reply by the Authors

The Authors thank Mr Roper for his interest in their Paper, and for having referred to recent works not available when the Paper was being written (at least in Europe).

The main thesis supported by the discussor can be summarized as follows.

- (a) Owing to its low water-cement ratio, high-strength concrete can display an internal self-desiccation
- (b) When cured in water, a moisture gradient appears in the specimens between the wet skin and the dry core
- (c) As in the case of air-curing, the gradient leads to self-stresses, and these self-stresses, superimposed to an external loading, give apparent strength losses; such strength losses would have been found by the three groups of researchers
- (d) An alternative mechanism could be a set of late

expansive reactions presumably due to insufficient dispersion of silica fume in the fresh concrete.

With respect to argument (a), the Authors agree that a low water-cement ratio leads to self-desiccation. This self-desiccation may increase the natural absorption of water by any concrete specimen cured in water. To highlight this phenomenon, one may refer to gammadensimetry tests performed by the Authors over 3 months.⁴ The water penetration has been monitored in specimens of the three concretes (control, HSC and VHSC) (Fig. 1). One may note that for the highest water-cement ratio (i.e. in the case of this particular HSC) no water goes inside the concrete. For the control concrete a little water gain appears, but with a very low gradient. For the very high strength concrete (water-cement ratio 0.26) a very slight water penetration occurs in the first month, but the phenomenon completely stops between one and three months, presumably because of the high watertightness of the mature material. When compared with the gradients occurring in air-cured concrete (see Figs 9 and 11 of the Paper), it may be reasonably assumed that these gradients will not create significant strength losses. Moreover, this concrete has shown continuous strength growing up to four years, when cured in water at 20°C.

Let us now come back to the papers referred to by Mr Roper.

Atlassi has performed cube tests (150 mm) on some HSC cured in water. On two concretes, she found a 'drastic decline' between 90 and 250 days. However,

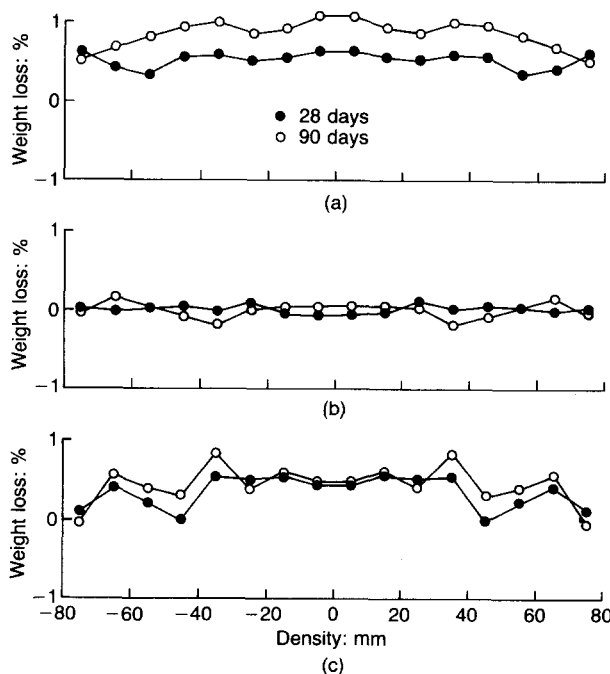


Fig. 1. Water losses in concrete specimens cured in water at 20°C as monitored¹ by gammadensimetry: (a) control concrete; (b) high-strength concrete; (c) very high-strength concrete (same mixtures as in the Paper)

she says elsewhere in her paper that 'in some cases, only one cube was tested at 250 days so the last part of the curves [namely strength development versus time] can only be seen as an indication of the tendencies.' If it is referred to the high scatter of cube tests when the strength is above 100 MPa, and to the presumably poor homogeneity of low-workability HSC, it seems reasonable to wait for additional data from Atlassi before concluding that there is a real strength-loss phenomenon.

In the paper by Sirivivatnanon *et al.* no mention is found in the text of strength drops. However, on two figures a slight decrease of strength (about 2 MPa) may be noted. The tests seem to have been performed on cylinders, with no special capping process. At this strength level the standard deviation of the test can be estimated in the range 2–4 MPa. Thus, a strength decrease of 2 MPa may not be considered statistically significant.

Mak *et al.* have especially emphasized the effect of curing on the strength development of HSC. They have tested four concretes under nine curing regimes. Only one concrete (the one giving the highest strength) with one curing regime (cured in lime-saturated water at 50°C) shows a strength retrogression. Here: the cylinders have been capped with a high-strength sulphur capping compound; it is specified in the paper that 'the range between two cylinders tested at each age did not exceed 5%'; the strength retrogression is about 5–6 MPa (strength at 28 days is about 120 MPa).

Therefore, the strength loss, though very limited, is probably statistically significant. As the rate of water penetration is accelerated by the temperature, a mechanism involving a moisture gradient between skin and heart can be assumed. However, from an engineering point of view, this case of hot curing is of little relevance.

As far as the other mechanism is concerned (point (d)), the Authors have carried out a number of autogenous shrinkage measurements on various HSC recipes.^{5,6} They have never seen any late swelling phenomenon.

To conclude, in the many papers published in the last 10 years and dealing with the strength development of HSC under a standard curing regime (in water at 20°C) no significant strength retrogression has been pointed out (to the Authors' knowledge). On the other hand, with some HSC cured in air this phenomenon has been found and confirmed,^{7,8} and seems to be related to moisture gradients inducing self-stresses in the specimens.

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