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HYDRATION AND STRENGTH OF HIGH-PERFORMANCE CONCRETE

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Introduction

In High-performance Concrete there is too little water for the cement to be completely hydrated. The large amount of unhydrated cement creates a potential risk for the long-term soundness of the concrete due to interior deterioration. Furthermore, High-performance Concrete exhibits a very dense interfacial zone between the aggregate and the paste which delays movements of water in the concrete. In concrete with a higher water-cement ratio a porous zone appears around the aggregate due to bleeding effects and water-film formation.

It was therefore of great interest to study the long-term effects on the hydration and the strength of High-performance Concrete when cured in different environments such as air and water. As a reference, membrane cured conditions were also studied. Since the expected difference was small it was essential to produce a specimen with very small variations in the concrete recipe.

Tested concretes

Quartzite sandstone combined with natural sand was used as aggregate. As binder, a low-alkali Portland cement (Degerhamn; specific surface 320 m^2/kg, Blaine) was used except for mixture 1 where a moderate alkali Portland cement (Slite Standard; 380 m^2/kg, Blaine) was used. For half the number of specimens, 10% silica fume (Micropoz) of the cement content was used. As a superplasticizer, naphthalene sulfonate (SP 62) was used. The proportions of the tested concretes are indicated in Table 1.

Table 1 Proportions of tested concretes (kg/m^3)

Recipe no	1	2	3	4	5	6	7	8	9
Quartzite 8-12	910	1145	1150	1155	1215	1160	1305	1305	1360
Natural sand 0-8	910	830	810	845	725	730	630	550	525
Cement	400	305	300	300	400	390	455	475	485
Silica fume	40	-	-	30	-	39	-	48	49
Naphthalene	14	-	7	5	8	7	21	21	32
Total water	150	172	140	143	130	139	114	115	107
w_o/C	0.38	0.58	0.47	0.48	0.33	0.36	0.25	0.24	0.22

Concrete of type no 1 was not pourable. The remaining types of concretes were cast in the shape of circular disks, 1 m in diameter and 0.1 m thick. The day after pouring both sides of their flat surfaces were covered with at least 2 mm epoxi plastic to eliminate moisture movement. The rim was exposed to water, to air or totally sealed (self-desiccation); Figure 1.

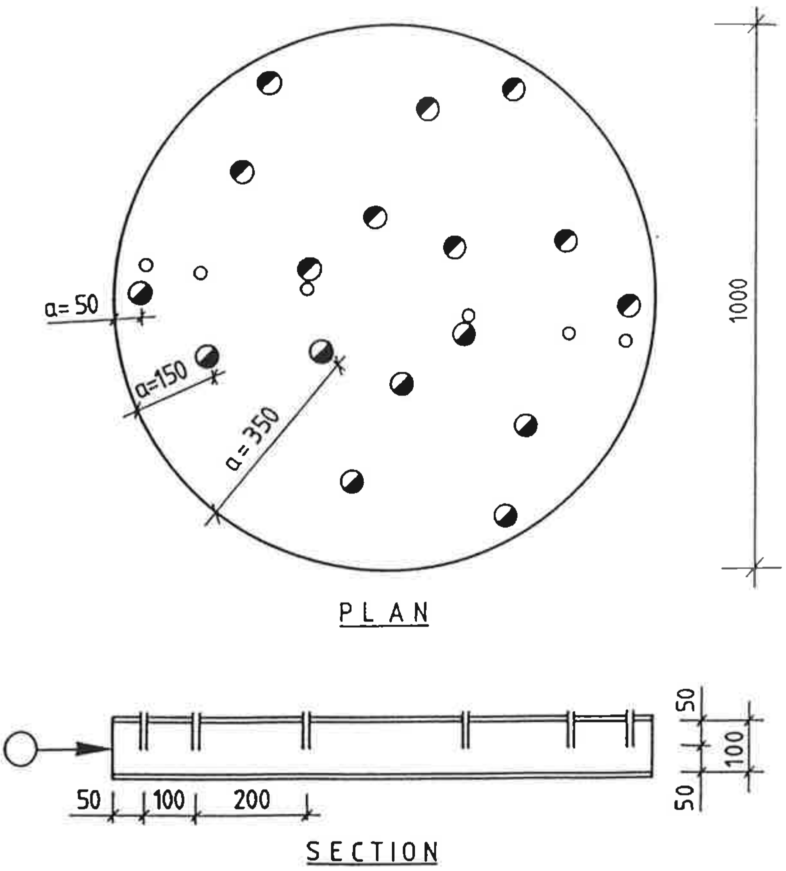

Figure 1. Plan and section of specimen.

Compressive strength

800 cores (40 mm in diameter) were drilled out of the disks at different distances from the surface. Compressive strength, f_3, was tested on cylinders 80 mm in length using interlayers of hardboard. The results indicate very small differences related to distance from the exposed surface. The compressive strength as function of time is given in Figure 2. The effective water-binder ratio, $w_o/(C+2S)$, is indicated to the right of the figure. (w_o = mixing water, C= cement, S= silica fume).

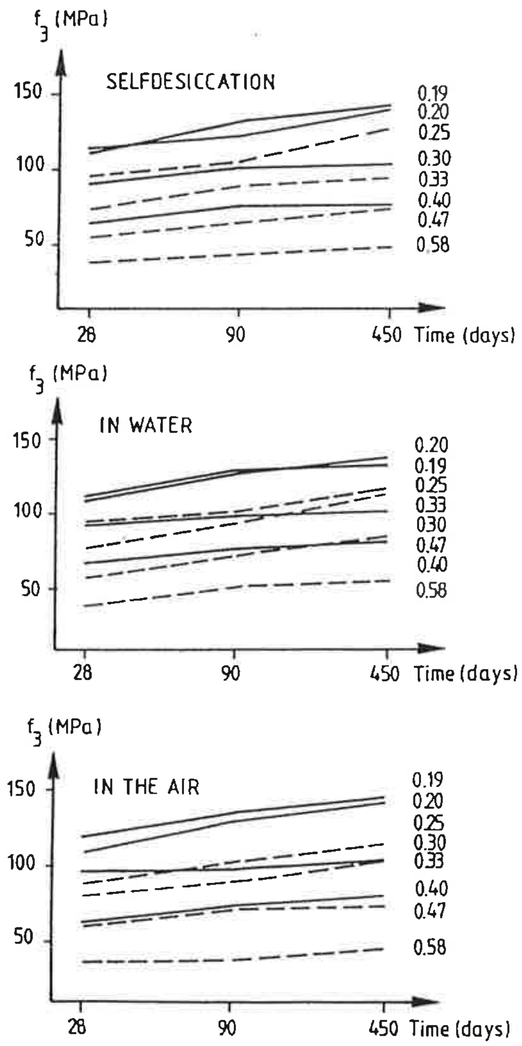

Figure 2 Compressive strength, f_3, as function of time.
(—— = 10% silica fume, --- = no silica)

Because of self-desiccation, compressive strength increases less for concetes with silica fume than for concretes without silica fume. Concerning self-desiccation see also **Nilsson (1984), Fagerlund and Persson (1991) and Persson (1992).**

Split tensile strength

More than 200 cores for split tests were drilled out of the disks at positions very close to cores meant for compressive tests. The split strength tests were also carried out with interlayers of hardboard, width 4.5 mm. In Figure 3 the split strength is indicated as function of the compressive strength. Each mark represents 27 measurements (totally 648 measurements).

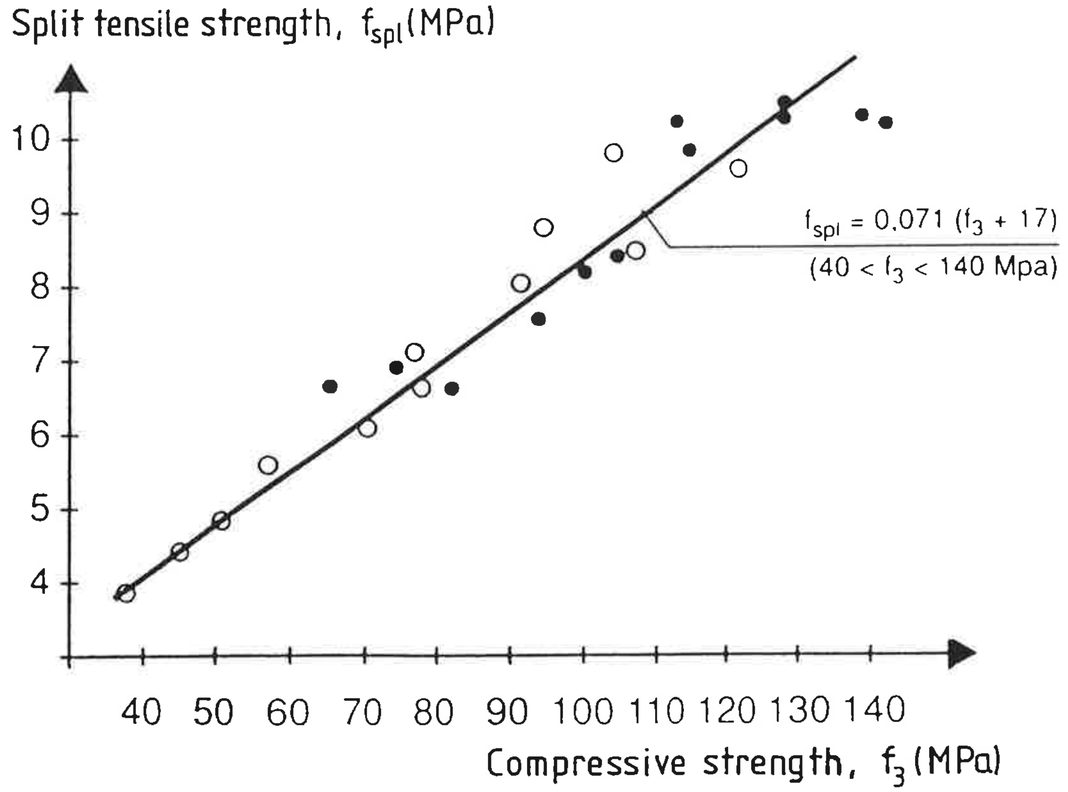

Figure 3. Split tensile strength, f_{spl}, related to compressive strength, f_3. (• = 10% silica fume of the cement content, o = no silica fume).

Furthermore there was a slight tendancy of decreasing relative split strength at 450 days of age as compared with 90 days of age at low values of the water-cement ratio, especially when silica fume was present. In Figure 4 split tensile strength, f_{spl}, is indicated as a function of time. The effective water-binder ratio, $w_o/(C+2S)$, is indicated to the right of the figure. (w_o = mixing water, C= cement, S= silica fume).

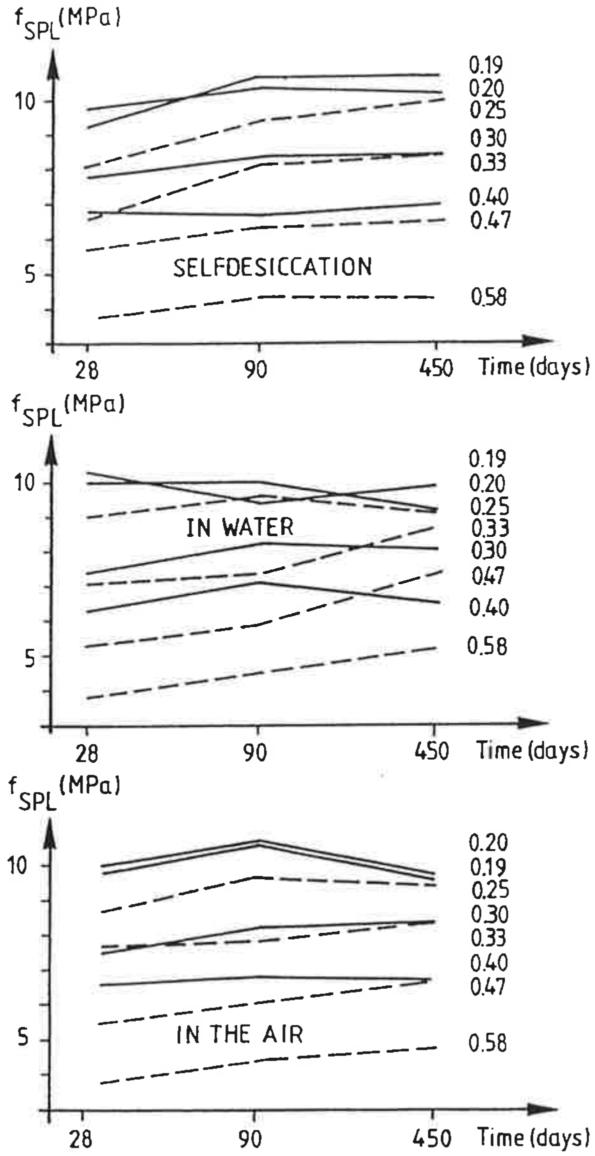

Figure 4 Split tensile strength, f_{spl}, as function of time.
(—— = 10% silica fume, --- = no silica)

Hydration

About 450 core fragments from the compressive tests were dried out at 105°C for 1 month. Hydration was then established by igniting 250 g concrete fragments for 16 h at 1050°C. Relations established between hydration factor, w_n/w_o, and water- cement ratio, w_o/C, see figure 5 (each mark is 18 measurements). (w_o= mixing water, w_n= chemically bound water ,C= cement content)

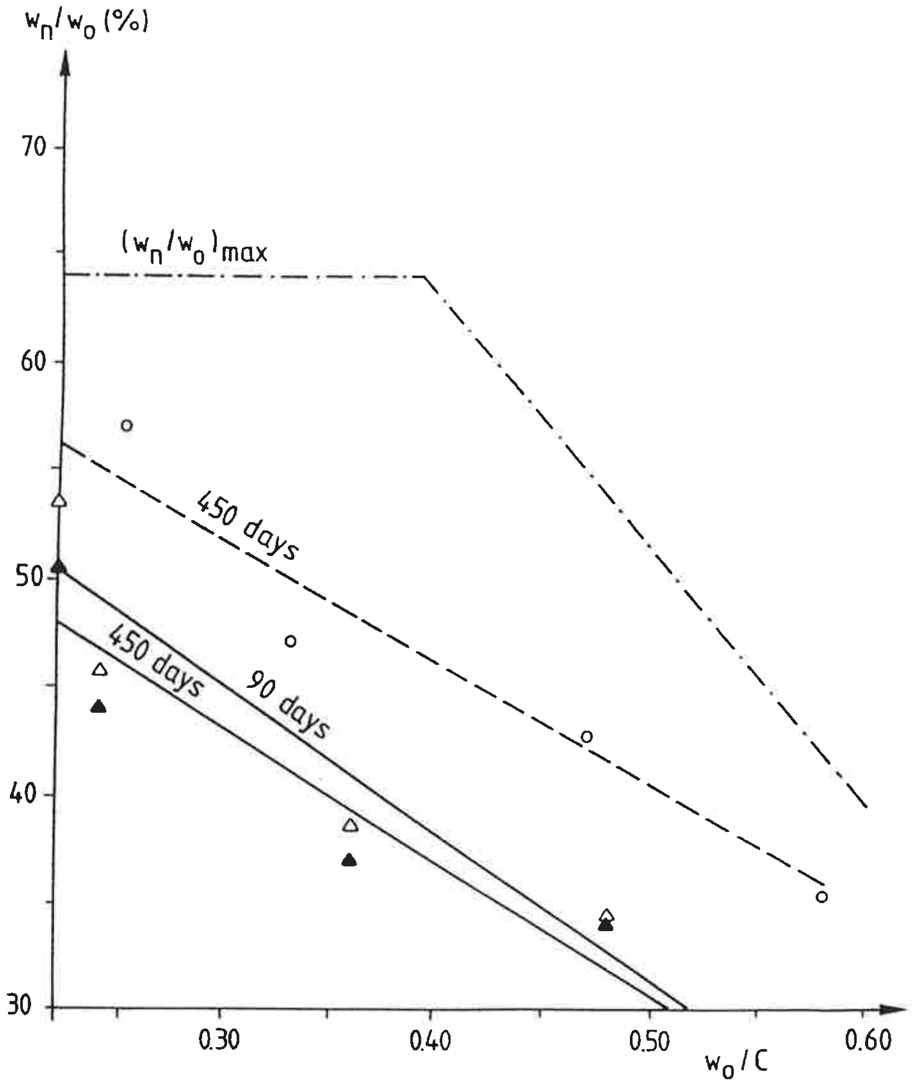

Figure 5. Hydration factor, w_n/w_o, as function of water-cement ratio. Figures indicate number of mixture. (—— = 10% silica fume, --- = no silica fume).

The maximum value of the hydration factor is 0.64 for concretes with a water-cement ratio less than 0.39; **Persson (1992)**. For concretes with silica fume the value of w_n/w_0 starts to diminish at an age of about 90 days (dehydration). This is most probably due to polymerisation; see **Kühl (1967)**.

<u>Effect of silica fume and of aggregate on compressive strength</u>

As the very same cores were tested for compressive strength and ignited, a relationship between the hydration factor, w_n/w_o, and the compressive strength, f_3, was established according to Figure 6 at an age of 450 days.

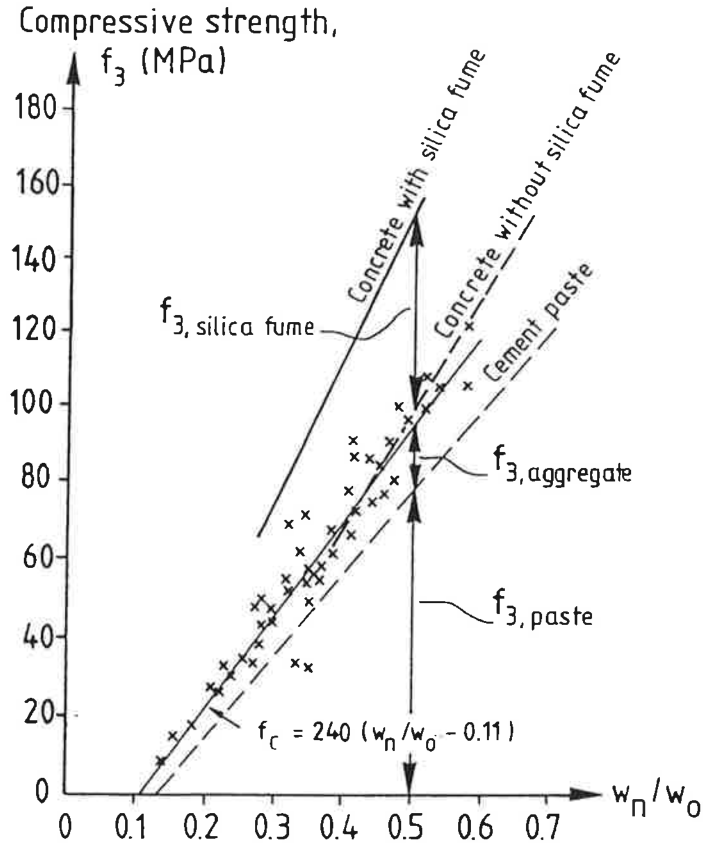

Figure 6 Compressive strength, f_3, as function of hydration factor, w_n/w_o. (——— = 10% silica fume of the cement content, – – – = concrete without silica fume, x——x = cube results acc to **Powers (1948)** for cement paste; — — — = recalculated to cylinders).

At the hydration factors, w_n/w_o, between 0.30 and 0.60 the concrete with silica fume exhibits a substantial increase in compressive strength, $f_{3,\text{silica fume}}$, expressed as (MPa):

$$f_{3,\text{silica fume}}=50\bullet(w_n/w_o+0.40) \qquad \text{for } 0.30<w_n/w_o<0.60 \text{ ------(1)}$$

where $f_{3,\text{ silica fume}}$ is the increase in compressive strength due to 10% silica fume, w_o mixing water and w_n chemically bound water.

In Figure 6 results on compressive strength for a low-alkali Portland cement paste are indicated; **Powers (1948)**. The results presented in the figure were recalculated from cubes 50 mm to cores 40 mm (length 80 mm); **Berglund (1992)** according to (MPa):

$$f_3\approx210\bullet(w_n/w_o-0.14) \qquad \text{------(2)}$$

where f_3 is the compressive strength of a cylinder, w_o is mixing water and w_n is chemically bound water.

The effect of the aggregate on the compressive strength, $f_{3,\text{aggregate}}$, was then established as the difference between the dotted line and the equation (2) as shown above (MPa):

$$f_{3,\text{aggregate}}\approx100\bullet(w_n/w_o-0.28) \qquad \text{for } 0.30<w_n/w_o<0.60 \text{ ------(3)}$$

where $f_{3,\text{aggregate}}$ is the effect of the aggregate on the compressive strength of a cylinder, w_o is mixing water and w_n is chemically bound water.

Conclusions

Compression and split strengths for 8 types of construction concrete together with hydration were tested over a time of 450 days. The concrete was exposed either to water or to air, or self-desiccated. The specimen was formed as a simulated circular column, diameter 1 m and thickness 0.1 m. About 1200 cores of these "columns" are tested. Compression strength displayed 10% increases between 90 and 450 days of age. However, values of split strength indicate a drop of about 5% at low water-cement ratio. Measurements of hydration of high strength concrete displayed drops of values between 90 and 450 days of age when the recipes contain silica fume. Without silica fume there was a continued increase in the hydration.

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