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VUNNA ERFARENHETER VID ACS-KONGRESSEN, CINCINNATI, 1991.

(ACS= American Ceramic Society)

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Allmänt

Vid American Ceramic Society kongress i Cinncinnati, 1991, presenterades totalt 1300 föredrag. Kongressen var uppdelad i 11 st ämnesgrupper varav jag tog del av 46 st föreläsningar inom "Cement-division". Samtidigt kunde en mängd mätutrustning beses på en intilliggande utställning, vilken omfattade 1600 acres.

Hydratation

Våra forskningsresultat vid LTH, se bil 1, beträffande minskning av kemiskt bundet vatten, w_n, både hos cementpasta och betong när silikastoft finns närvarande föranledde följande kommentarer:

1) Prof. S Diamond ansåg att vi borde kontrollera minskningen i w_n med moderna metoder nämligen TG/DTA, där man i temperaturområdet 105° till 1050° kan se hur mycket vatten som avgår för varje tiotal grader i temperaturhöjning. Han ansåg att minskningen i w_n kunde bero på att kalciumhydroxid, C-H, övergår i kalcium-silikat-hydrat, C-S-H. Min omedelbara reflektion var att en omfördelning av C-H till C-S-H näppeligen kan påverka värdet på w_n. Med TG/DTA kan man vidare på sin höjd studera 15 grams prover varför metoden svårligen kan tillämpas på betong.
2) Prof. D Hooton hade vid sin institution funnit samma resultat som vi vid BML nämligen en minskning i w_n på lång sikt trots att tryckhållfastheten f_c ökat. Han hade ännu ej presenterat dessa resultat i någon publikation.

Kemisk krympning

Prof. Hooton (1991) presenterade värden från kemisk krympning, δw_n, hos cement och ev silikastoft vid vattencementtal, vct≈5, dvs fri tillgång till vatten. Försöket genomfördes i en sluten flaska med aluminiumkulor försedd med pipett. Flaskan roterades hela försöksperioden om 120 dygn för att undvika vattenbrist för någon del av cementen och det ev silikastoftet. Som resultat hade Hooton funnit 10-30% större kemisk krympning, δw_n, då silikastoft ingått i flaskan. Han hade då bestämt w_n först efter ytterligare 100 dygn dvs vid ca 220 dygns pastaålder. Han medgav att detta kan ha varit en felkälla om det skett en nedgång i w_n mellan 120 och 220 dygns ålder.

Självuttorkning

Ett flertal forskare hade, i likhet med oss vid BML, konstaterat den högpresterande betongens självuttorkande förmåga, bl a prof. D Hooton. L M Sheppard (1991) presenterar frostbeständigheten hos betong som funktion av relativa fuktigheten, RF (%), se bil 2. Vid betong utan tillsats av luftporbildande medel erhålles därvid enligt Sheppard följande "durability factor" :

W/(C+SF)	SF	RF	"Durability factor" (frostbeständighet,ASTM C666-A)
0.45, 0.60	-	>96%	< 7%
0.45	15%	94.5%	70%
0.32	15, 7.5, 0%	<92.5%	100%

W= vattenhalt i betongen
C= cementhalt i betongen
SF= silikahalt i betongen
RF= relativ fuktighet i betongen, 60 mm från ytan på prismor, fukthärdade i 14 dygn.
"Durability factor" har därvid bestämts enligt ASTM C666-A.

Polymerisation

Ett antal forskare berörde i sina föreläsningar den polymerisation som sker av cementpasta och betong om silikastoft finns närvarande.

1) Polymerisationen tros ha en gynnsam effekt från täthets- och beständighetssynpunkt.
2) Det är dock mycket svårt att med hjälp av röntgendiffraktion eller mikroskopi konstatera denna polymerisation.
3) Högst kedjor om fyra silika- och fyra syreatomer i rad kan tydligen kvantifieras med nämnda metoder.
4) Polymerisationen tros ske först när all C-H förbrukats, dvs först när PH sjunkit i cemenpastan resp betongen.
5) I min föreläsning om våra resultat vid BML, Lund, hänvisade jag till Kühl (1967) som visat att det vid polymerisation avges vatten. Detta kan förklara nedgången i w_n.

Flygaska

I USA ersätts en del av cementen med avfallsprodukten flygaska främst av ekonomiska skäl men även m h t miljön. Enligt forskningsrapporter vid kongressen kan så ske med upp till 30% av cementen utan hållfasthetsförluster uppstår i den färdiga betongen. Andra rapporter betonade dock vikten av att uppfylla vissa specifikationer vid valet av flygaska. Eljest kan allvarliga problem uppstå beträffande betongens beständighet. Någon rapport talade om allvarliga sulfatangrepp på betong med "dålig" flygaska redan inom 10 år från gjuttillfället.

Referenser

1967. H Kühl. Zement.VEB Verlag für Bauwesen. Berlin.
1991. L M Sheppard.Cement Renovations Improve Concrete Durability. ACS Bulletin. March.
1991. D Hooton. Chemical shrinkage of cement with and without silicafume. Proceedings at ACS 93rd Annual Meeting & Exposition.
1991. S. G. Fagerlund and S.B.Persson. Hydration of Highperformance Concrete. Proceedings at ACS 93rd Annual Meeting & Exposition, Cincinnati.

BILAGA 1

HYDRATION OF HIGH-PERFORMANCE CONCRETE

Abstract

Experimental studies carried out for 8 different water- cement ratios, 0.22-0.58, tot. 6 tons of concrete. 3 circular simulated columns poured out of each recipe, cured in water, in the air or externally tightened. Selfdesiccation indicates low values of relative humidity, RH even when concrete placed i water. RH=80% at a water- cement ratio of 0.24 after 3 months 50 mm from the surface. Compressive strength of drilled cores was related to chemically bound water: $f_3 = 1050(0.24 - w_n/C)$ where f_3 is compressive strength (MPa), w_n is chemically bound water and C cement content.

General

Research carried out during the last two years concerning High-performance Cementitious Systems at the Lund Institute of Technology, University of Lund, Sweden. The project is a prestudy for a $ 6-million programme that is about to start in Sweden concerning high-performance concrete. The research project mainly consists of the following parts (D=24h):

Cement paste	Hydration		120 D
	Chemical shrinkage		15 D
Mortar {			
	Desorption		60 D
		Self-desiccation	450 D
	Laboratory tests {	Strength	450 D
Concrete {		Hydration	450 D
	Field tests {	Pumped concrete (f_c=133 MPa)	90 D
		Element concrete(f_c=144 MPa)	180 D

Self-desiccation of concrete

The main purpose of the prestudy is to establish the connection between self-desiccation and strength for concrete. Totally 4 tons of concrete was fabricated as circular wheels with a diameter of 1 m and a thicknness of 0.1 m, see figure 1. The recipe contains 8 different types of concrete according to the table below:

No	C %	Silica % of C	SP62 % of C	w_0/C W/C	Wbr W/(C+S)	w_0/C_{eff} W/(C+2S)
2	12	-	-	0.58	0.58	0.58
3	12	-	2.4	0.47	0.47	0.47
4	12	10	1.7	0.48	0.44	0.40
5	16	-	2.0	0.33	0.33	0.33
6	16	10	1.9	0.36	0.33	0.30
7	18	-	4.6	0.25	0.25	0.25
8	19	10	4.4	0.24	0.22	0.20
9	19	10	6.6	0.22	0.20	0.19

w_0=water, C=cement, S=silica

The plane sides of the wheels were treated with 2 mm epoxi that is tight for moisture. 8 wheels were placed in water, 8 in the air and 8 were painted with 2 mm epoxi also on the circular sides. Figure 2 shows self-desiccation as a function of time. The results showes remarkeble low relative humidity as indicated below measuring 50 mm from circular side. :

No	C %	Silika % of C	SP62 % of C	w_0/C W/C	Wbr W/(C+S)	w_0/C_{eff} W/(C+2S)	Desiccation 450D Membran	Water	Air
2	12	-	-	0.58	0.58	0.58	97.5	97.5	84.5
3	12	-	2.4	0.47	0.47	0.47	91.5	97.5	79.0
4	12	10	1.7	0.48	0.44	0.40	85.0	95.0	74.0
5	16	-	2.0	0.33	0.33	0.33	82.0	95.0	75.5
6	16	10	1.9	0.36	0.33	0.30	76.5	92.0	71.5
7	18	-	4.6	0.25	0.25	0.25	74.5	89.0	65.5
8	19	10	4.4	0.24	0.22	0.20	72.0	84.0	67.5
9	19	10	6.6	0.22	0.20	0.19	71.0	78.0	70.0

w_0=water, C=cement, S=silica, D=24h

Figure 3 shows relative humidity as a function of water-cement ratio measuring 50 mm from cicular surface at an age of 450 D. Figure 4 shows an application of self-desiccating concrete on a floating slab. The water-cement ratio of the concrete was 0.32 and it had a relative humidity of 78% after 90 days (f_c=133MPa). A self-desiccating slab solves a lot of the problems connected with moisture.

Strength and hydration of concrete

About 1000 cores were drilled out of the wheels and tested by compressive strength. The same cores were dried out for at least 1 month and then ignited during 16 h. Figure 5 shows compressive strength as a function of w_n/C, where w_n is chemically bound water and C cementcontent. For a concrete with 10% silica fume out of cement content following relationship has been established (f_3 is compressive strength and w_0 water originally added to the concrete):

$$f_3 = 1050 \cdot (0.24 - w_n/C) \text{--------(age: 90 D)}$$
$$f_3 = 500 \cdot (w_n/w_0 - 0.19) \text{--------(age: 90 D)}$$
$$f_3 = 1020 \cdot (0.24 - w_n/C) \text{--------(age: 450 D)}$$
$$f_3 = 580 \cdot (w_n/w_0 - 0.20) \text{--------(age: 450 D)}$$

Figure 6 shows compressive strength as a function of w_n/w_0. Figure 7 shows development of w_n/C for concrete as a function of time. For concrete with 10% silica fume out of the cement content there is a significant decrease at the age of 450 D.

Hydration of cement-paste

To investigate the development of hydration as a function of time, cement-pastes containing between 0 and 20% silica fume out of the cement content were cast. The water-cement ratio was 0.30 for half the number of mixtures, and the water-(cement+silica) ratio was 0.30 for the other half. The pastes were covered with water 1 h after casting. At the age of 16 h each mixture was crushed and placed in 10 cans and covered with water. During a period of 120 D the cans were emptied of water at different ages and dried out in 105° for 1 month. The specimen was then ignited at 1050° for 16 h to establish the value of chemically bound water.

Figure 8 shows w_n/C as a function of time at different contents of silica fume. There is a decrease in w_n/C starting at the age of about 80 D when the pastes contains more than 10% silica.

Figure 9 shows w_n/C as a function of time at different contents of silica fume when the water-(cement+silica) ratio was 0.30 . wn/C increases more in pastes without silica than in pastes with silica. At the age of about 80 D the values of w_n/C are equal irrespective of the content of silica.

The results concerning the decrease in w_n/C are verified by Gjörv, Norway (1991), see figure 10.

Figure 10 shows non-evaporable water as a function of time at a water-(cement+silica) ratio of 0.30 for different contents of silicafume.

Desorption of mortar

10 different types of mortar were cast according to the table below:

No	C %	Silica % of C	SP62 % of C	w_0/C W/C	Wbr W/ (C+S)	w_0/C_{eff} W/ (C+2S)	w0=water, C=cement, S=silica
1	46	10	4.4	0.24	0.22	0.20	PC(A/MS/MA/G)
2	25	-	-	0.56	0.56	0.56	PC(A/HS/LA/G)
3	24	-	2.4	0.46	0.46	0.46	"
4	28	10	1.7	0.47	0.43	0.39	"
5	36	-	2.0	0.33	0.33	0.33	"
6	39	10	1.9	0.35	0.32	0.29	"
7	45	-	4.6	0.25	0.25	0.25	"
8	54	10	4.4	0.24	0.22	0.20	"
9	55	10	6.6	0.22	0.20	0.18	"
10	54	10	4.4	0.24	0.22	0.20	PC(R/HS/MA/G)

Each mixture was cast in 20 glass pipes. Each week 2 pipes were crushed. The water content was established in one pipe and the relative humidity in the other.

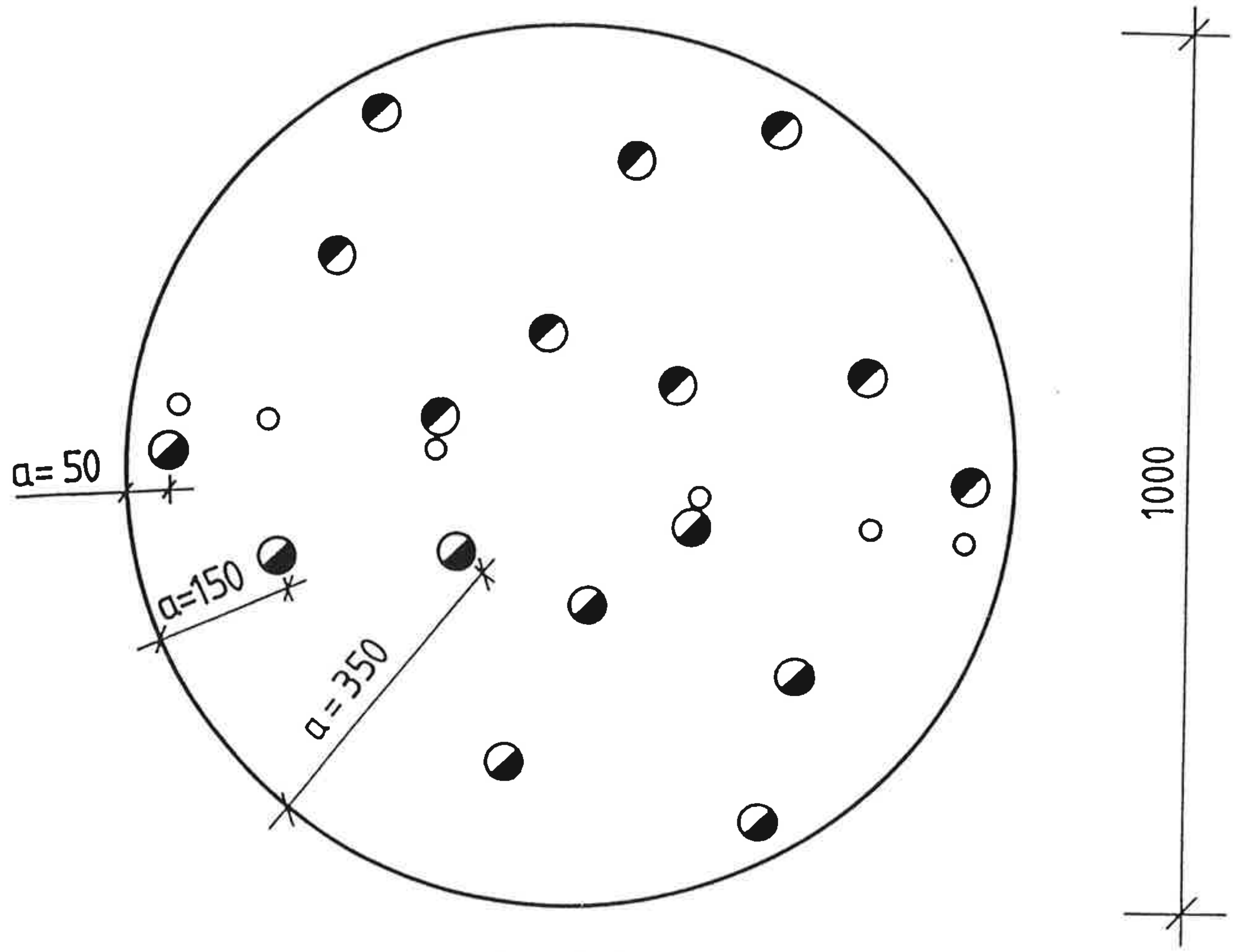
Figure 11 shows the ratio of evaporable water and cement, w_e/C, as a function of relative humidity. At lower values of w_0/C the curves get more and more horizontal.

Chemical shrinkage of mortar

Mortar according to the list above cast 5 mm thick in glass cans, see figure 12, 10 out of each mixture.

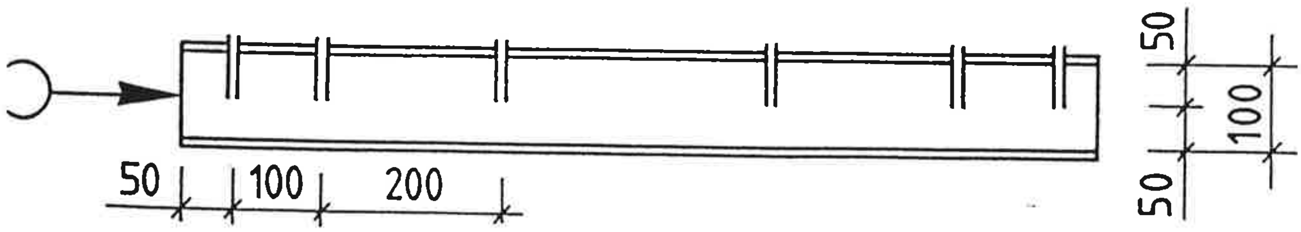
Figure 12 shows section of can for investigation of chemical shrinkage. The cans were filled with water 1 h after casting. Contraction, δw_n, was measured and one can was crushed daily for the content to be dried out at 105° for 1 month. The mortar then was ignited for 16 h to establish chemically bound water, w_n.

Figure 13 shows the specific volume at chemical shrinkage, k, as a function of water-cement ratio ($k=1-\delta w_n/w_n$). Figure 14 shows the specific volume at chemical shrinkage, k, as a function of cement content ($k=1-\delta w_n/w_n$). There seems to be a reinforcing effect of the sand in the mortar. If recalculations are made for cement-paste, a value of k=0.74-0.75 is established, which is equal the values presented by Powers (1960).



PLAN

På två st cylindrar per ålder och avstånd mätes tryckhållfasthet; på en st mätes spräckhållfasthet.



SEKTION

(A) = Periferin utsatt för vatten

(B) = -"- fri betongyta med RF 40- 60%

(C) = -"- sluten med 2 mm EP 91

Figure 1. Concrete specimen fabricated as a circular wheel with a diameter of 1 m and a thickness of 0.1 m.

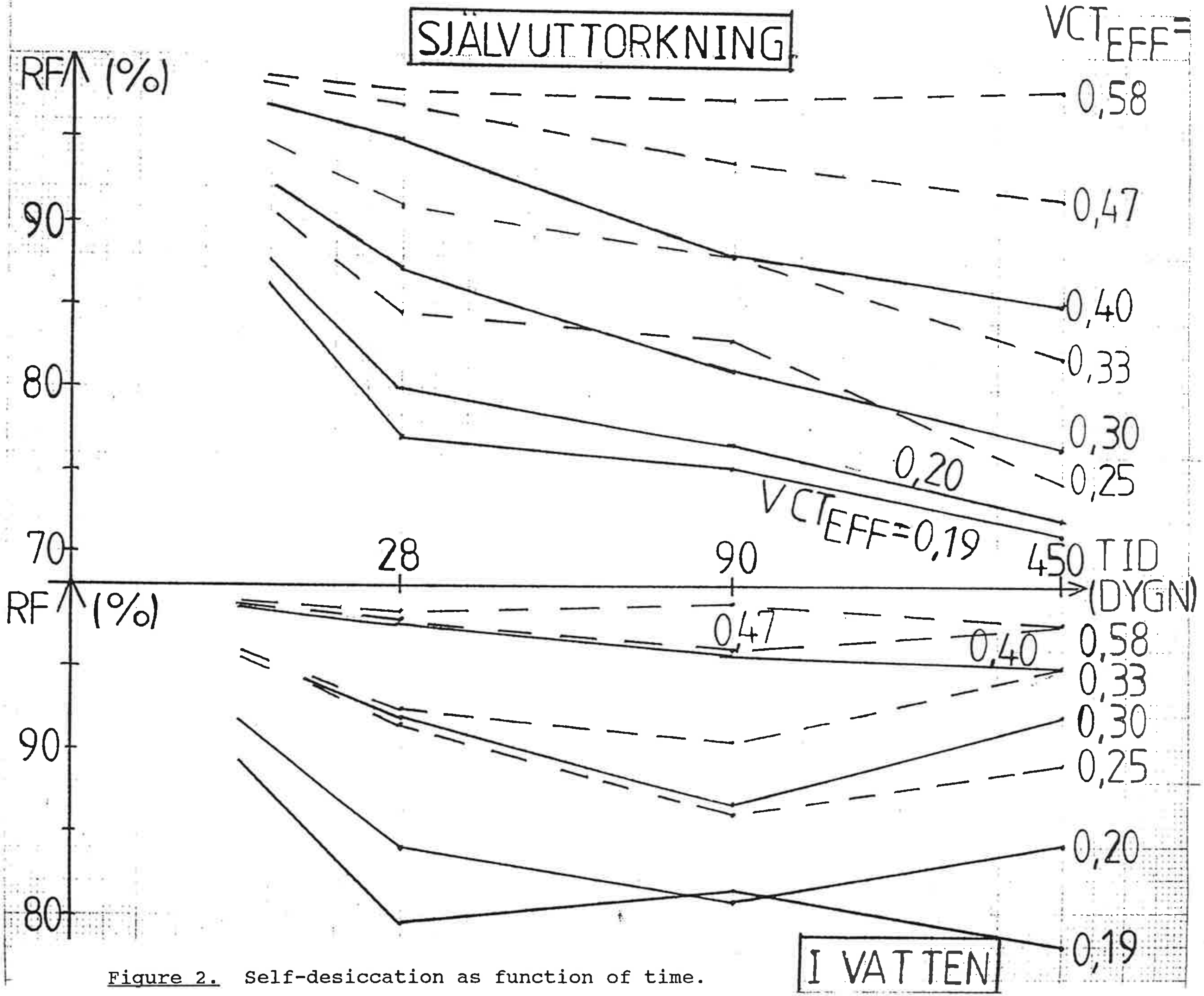


Figure 2. Self-desiccation as function of time.

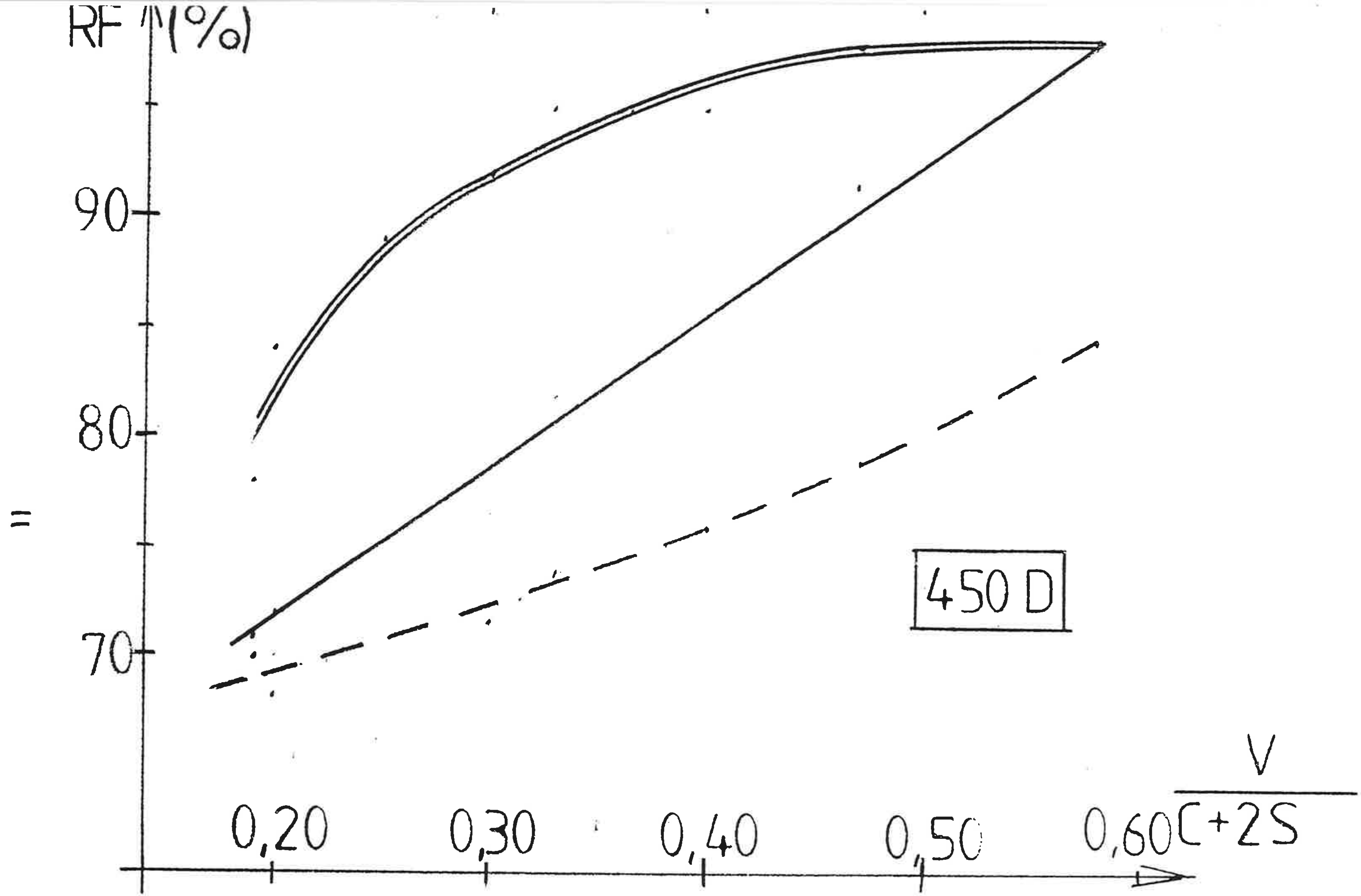
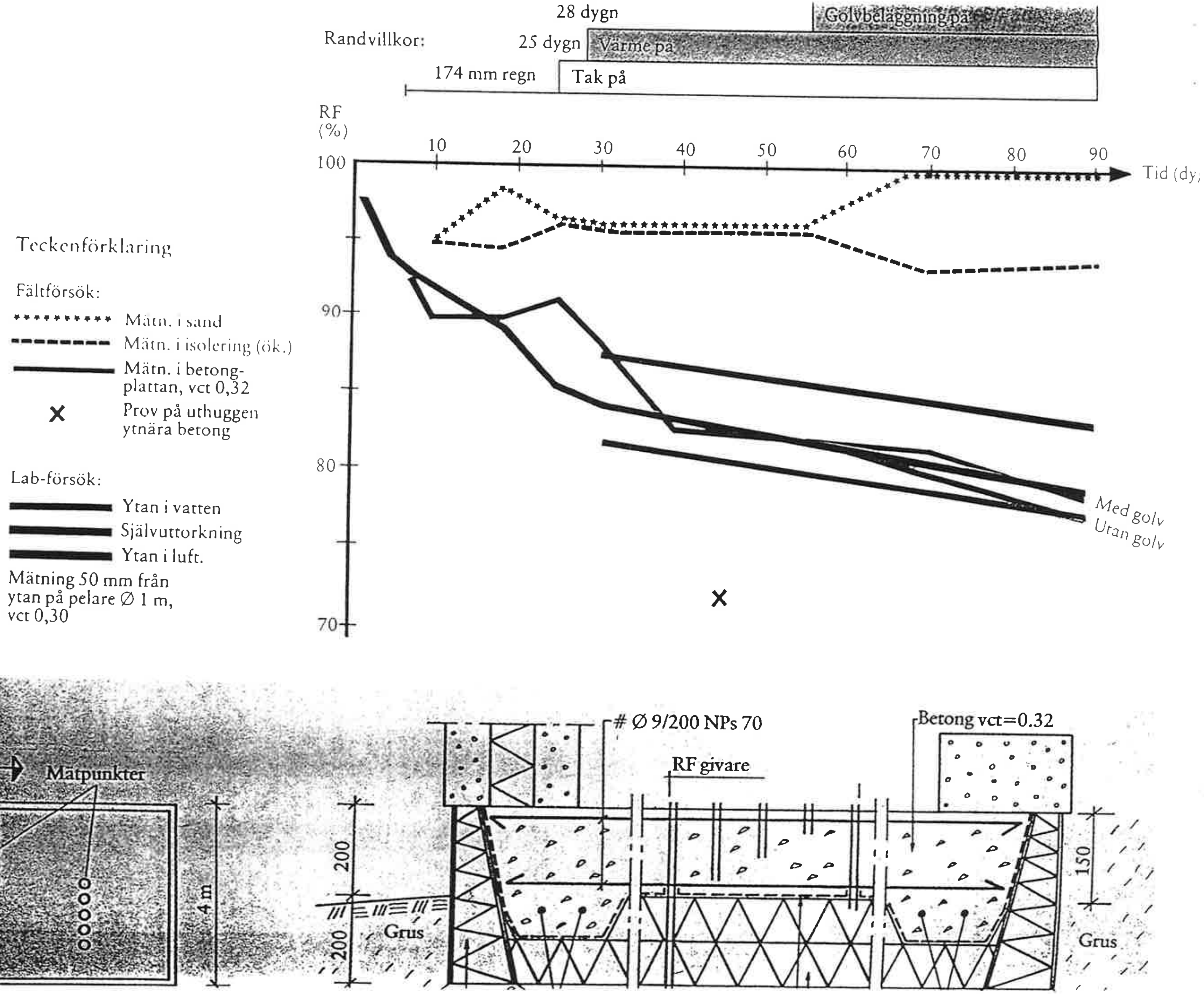


Figure 3. Relative humidity as a function of water-cement ratio measuring 50 mm from the cicular surface at the age of 450 D. D=24h.



<u>Figure 4.</u> Application of self-desiccating concrete on a floating slab.

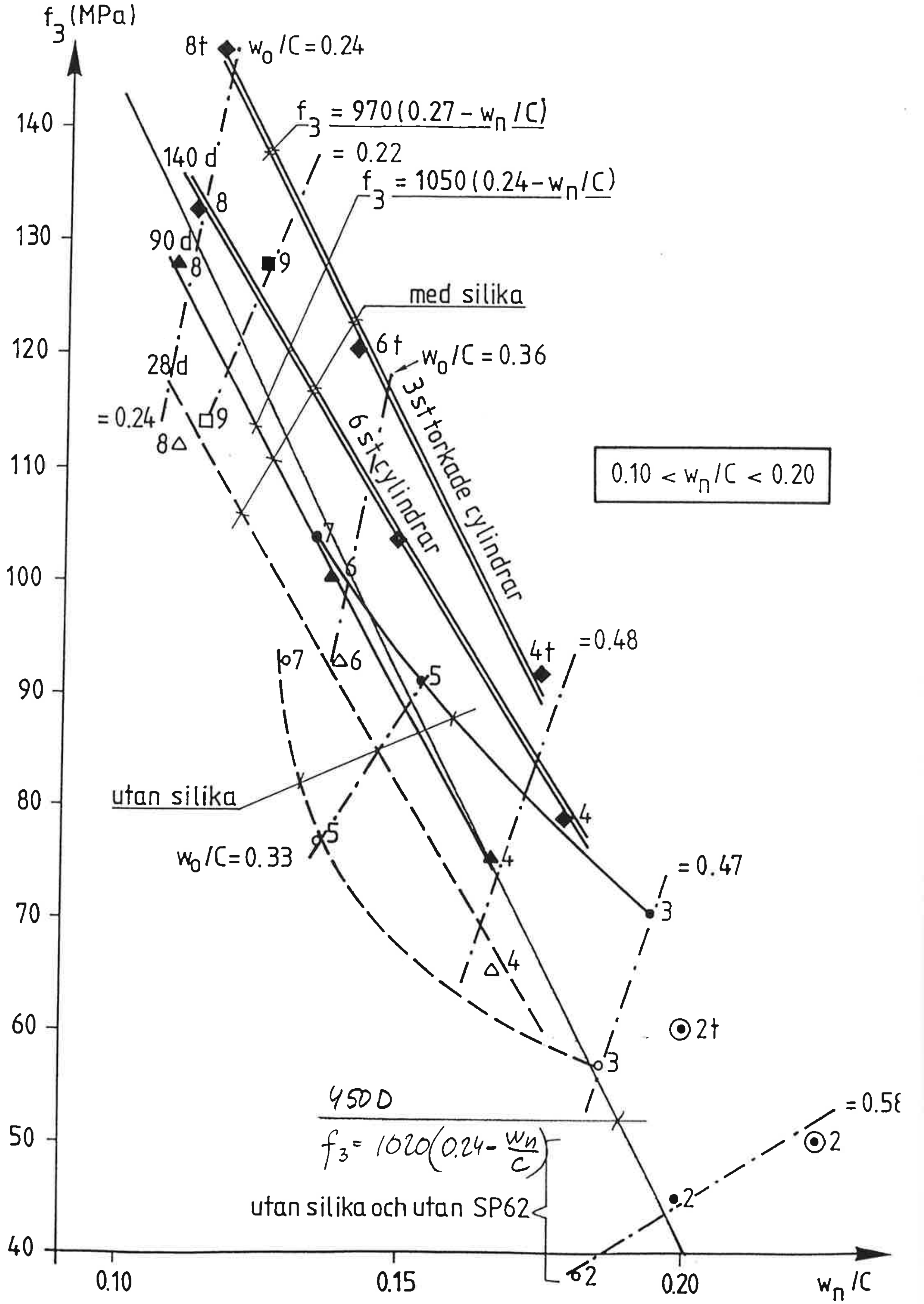


Figure 5. Compressive strength as a function of w_n/C, where w_n is chemically bound water and C cement content.

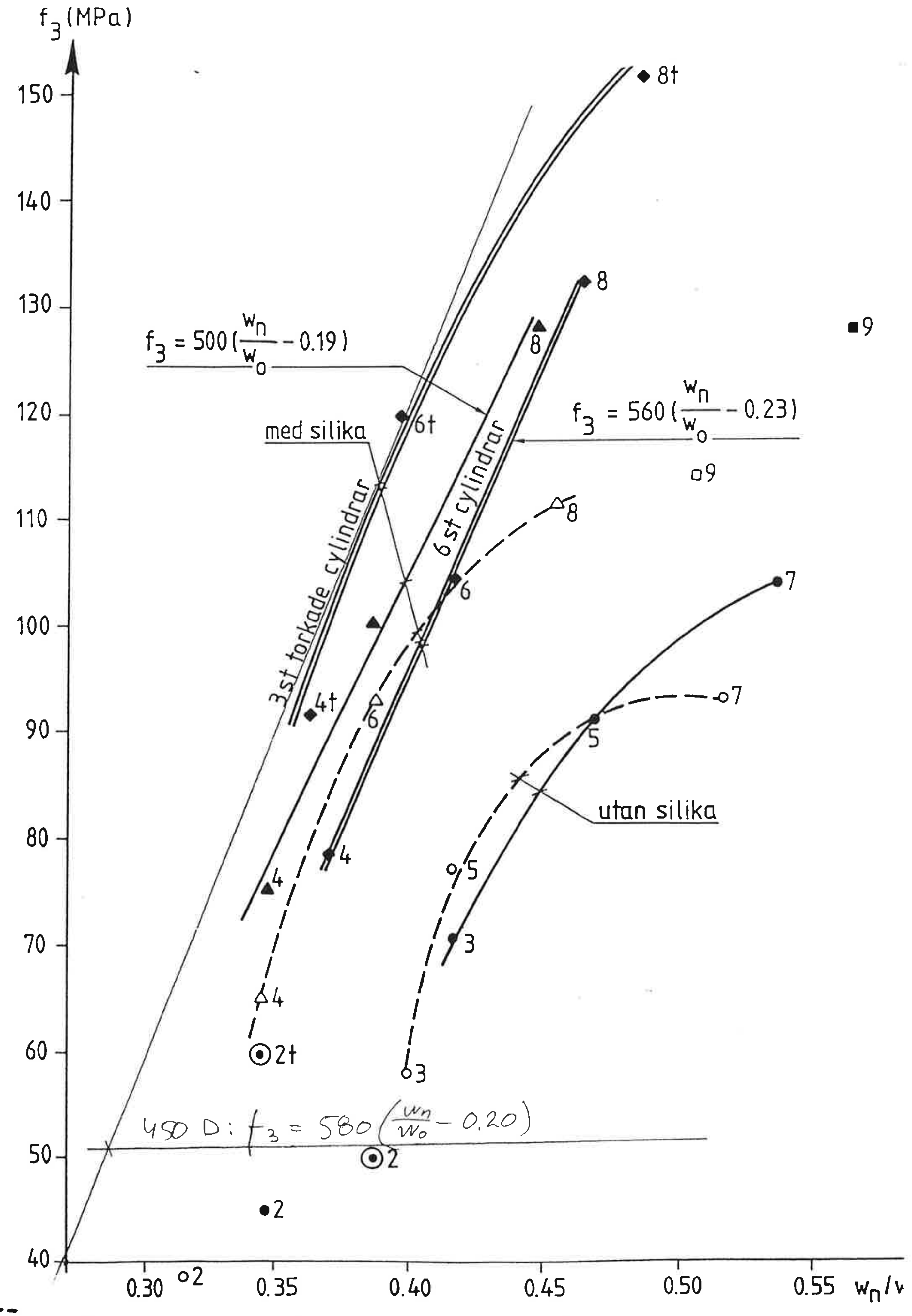


Figure 6. Compressive strength as a function of w_n/w_0.

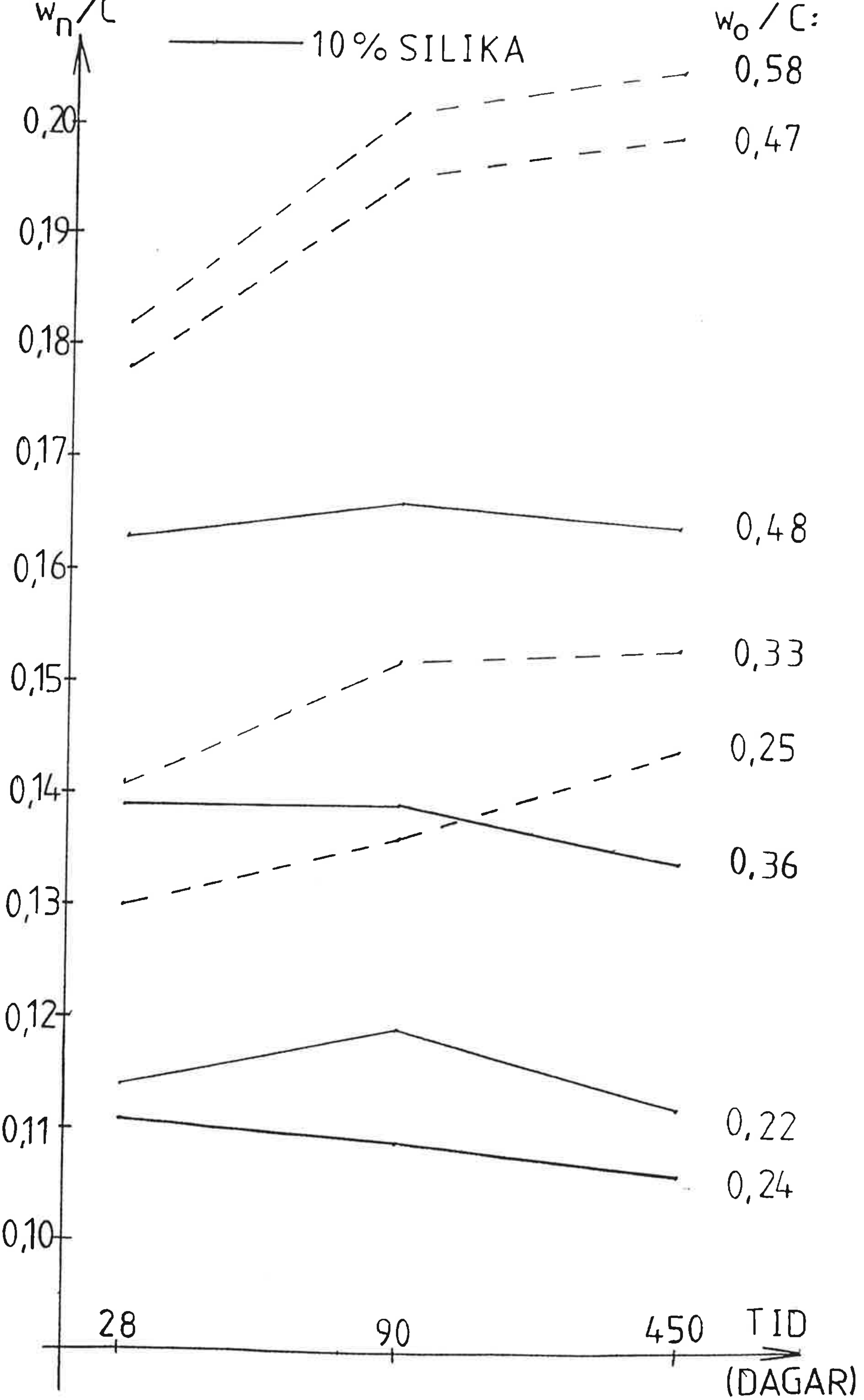


Figure 7. Development of w_/C for concrete as a function of time.

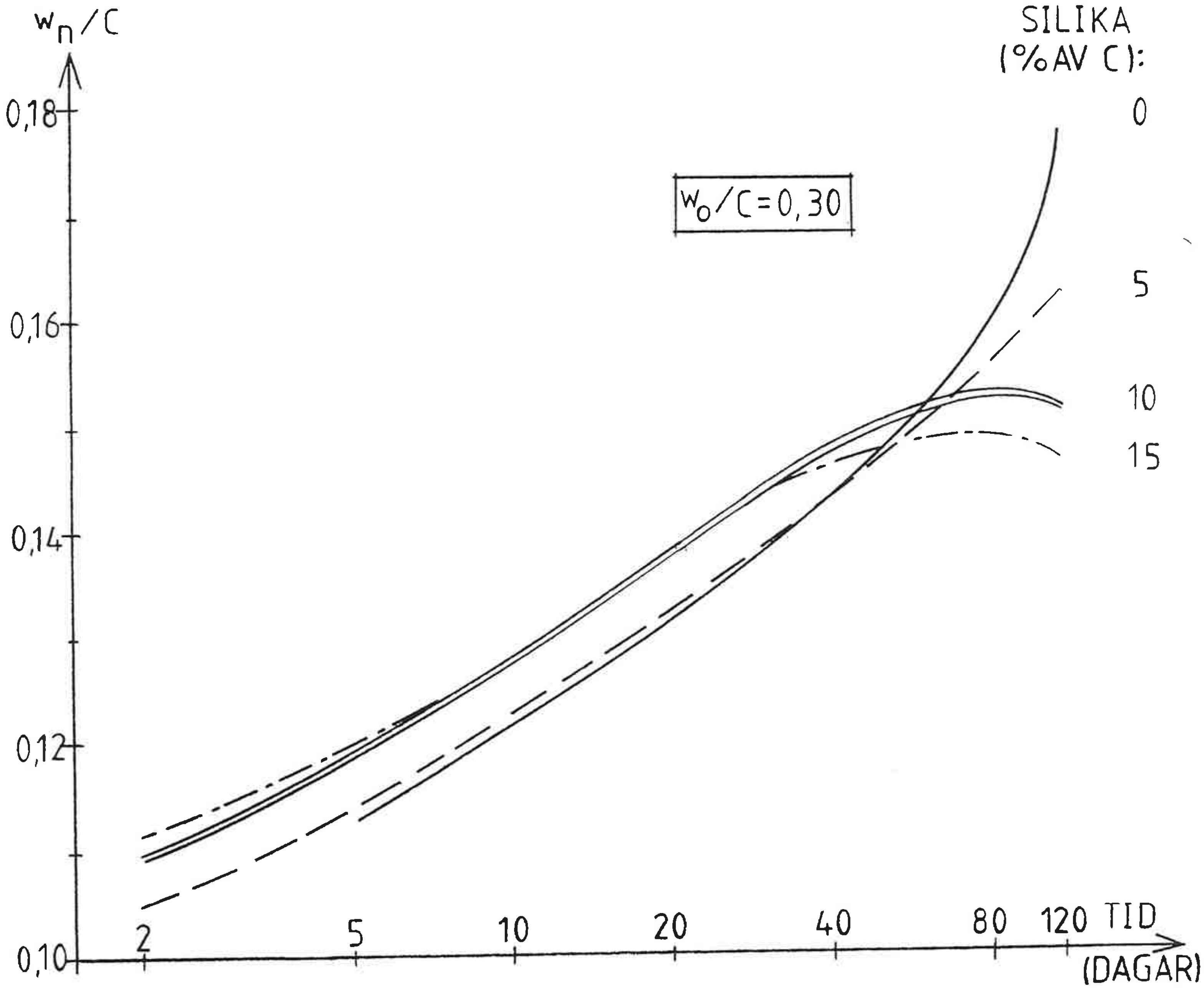


Figure 8. w_n/C as a function of time at different contents of silica fume.

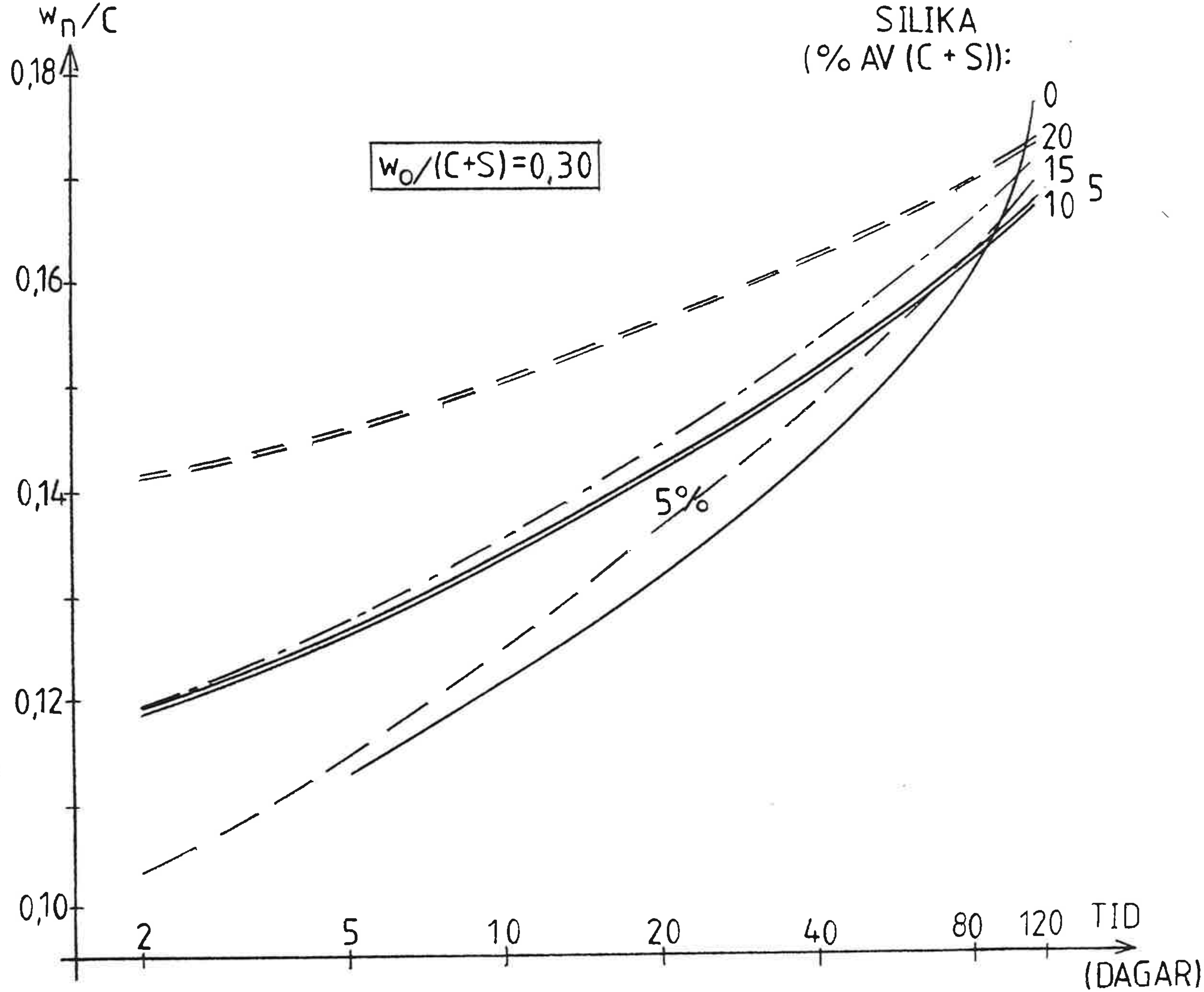


Figure 9. w_n/C as a function of time at different contents of silica fume when the water-(cement+silica) ratio was 0.30.

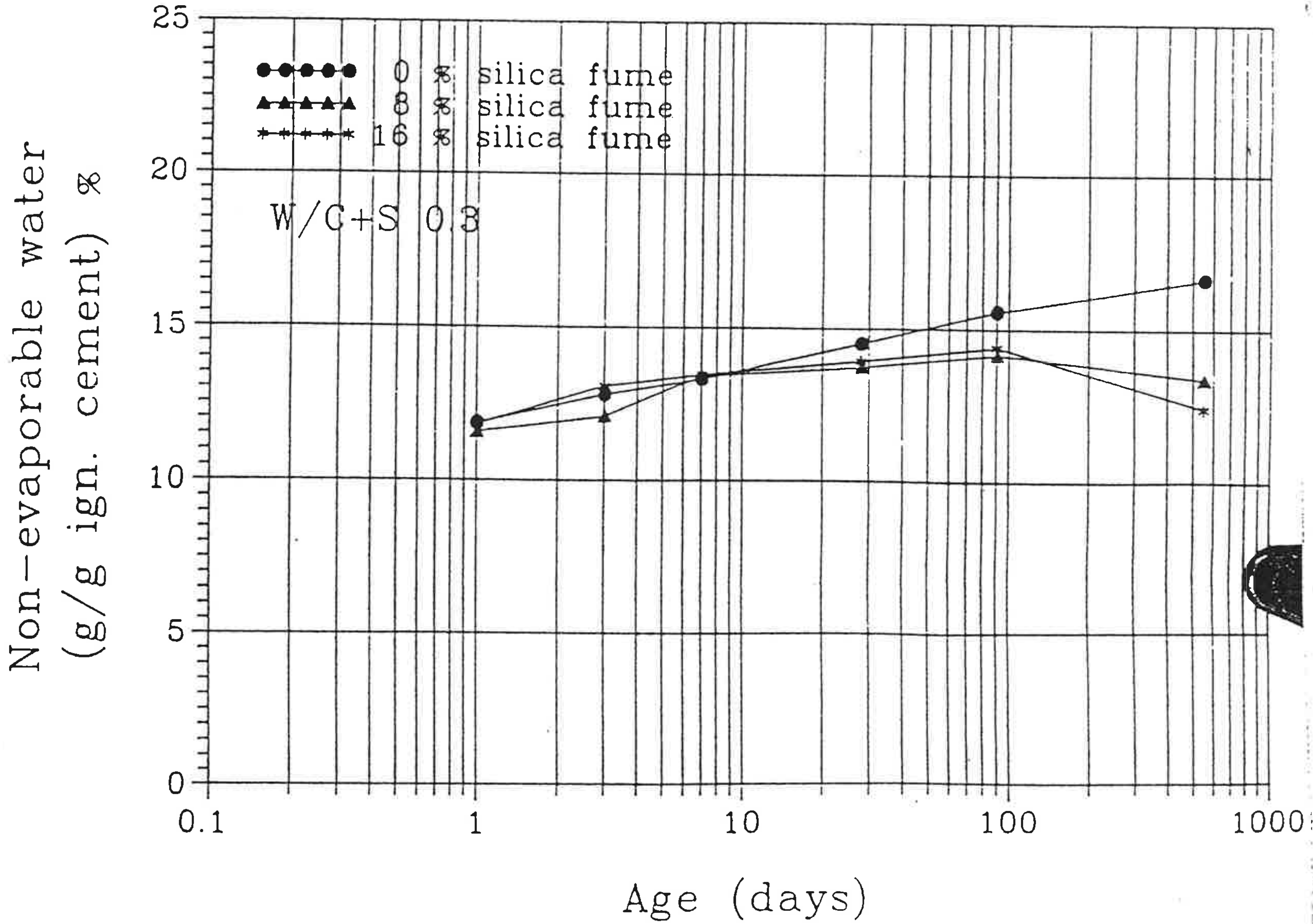
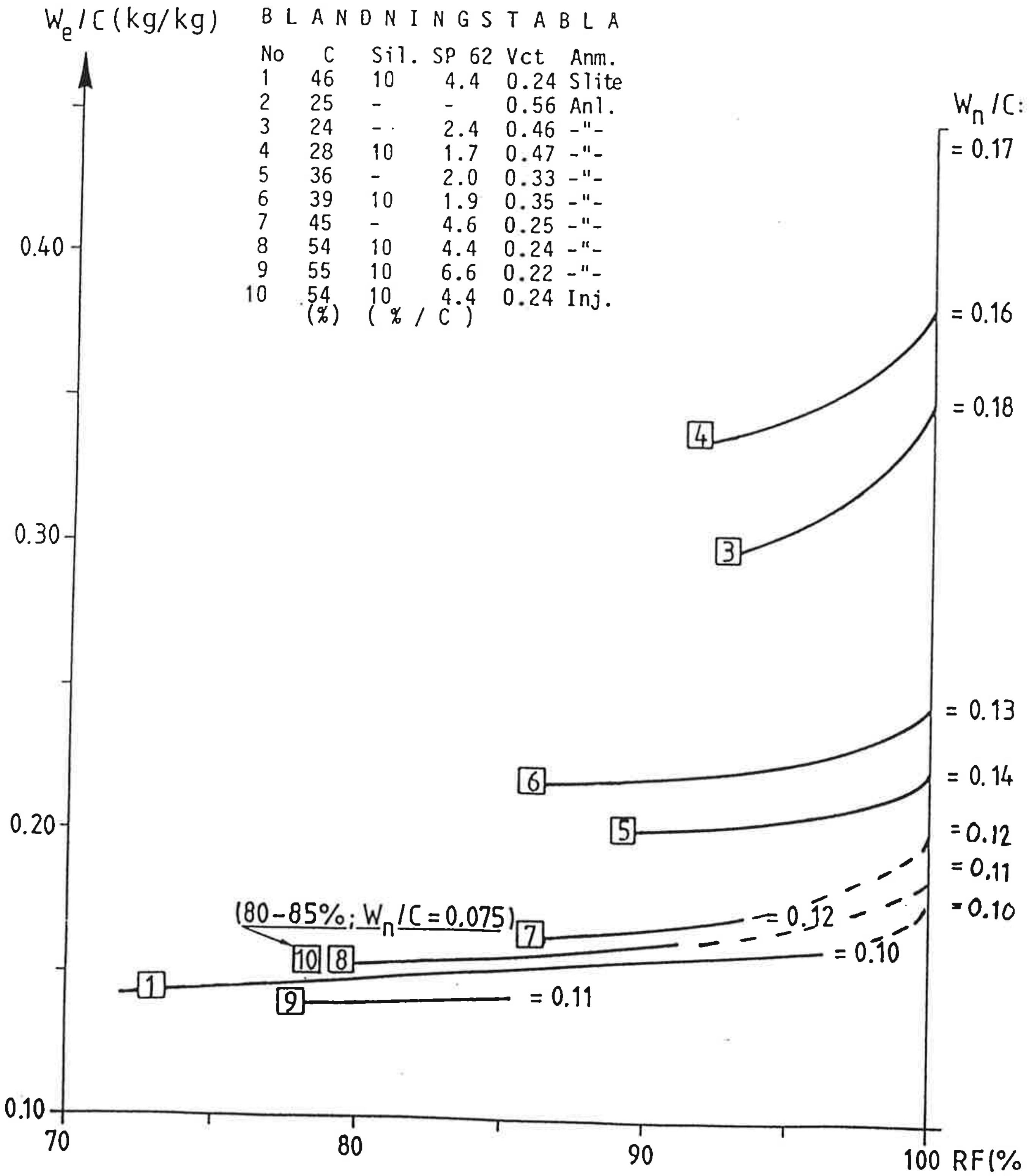


Figure 10. Non-evaporable water as a function of time at a water-(cement+silica) ratio of 0.30 for different contents of silica fume. Reference: Gjörv (1991).



B L A N D N I N G S T A B L A

No	C	Sil.	SP 62	Vct	Anm.
1	46	10	4.4	0.24	Slite
2	25	-	-	0.56	Anl.
3	24	-	2.4	0.46	-"-
4	28	10	1.7	0.47	-"-
5	36	-	2.0	0.33	-"-
6	39	10	1.9	0.35	-"-
7	45	-	4.6	0.25	-"-
8	54	10	4.4	0.24	-"-
9	55	10	6.6	0.22	-"-
10	54	10	4.4	0.24	Inj.
	(%)	(% / C)			

Figure 11. Ratio of evaporable water and cement, w_e/C, as a function of relative humidity.

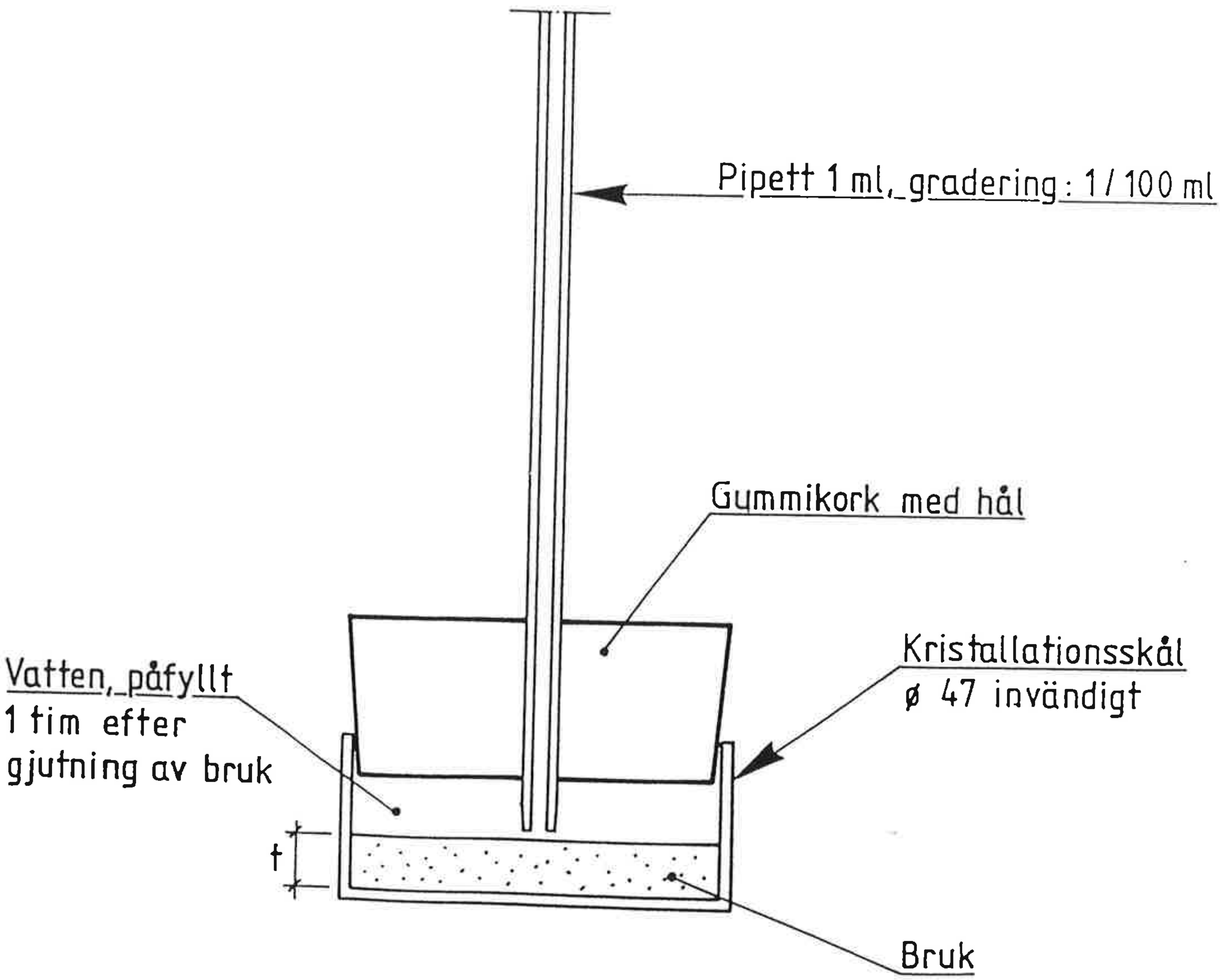


Figure 12. Section of can for investigation of chemical shrinkage.

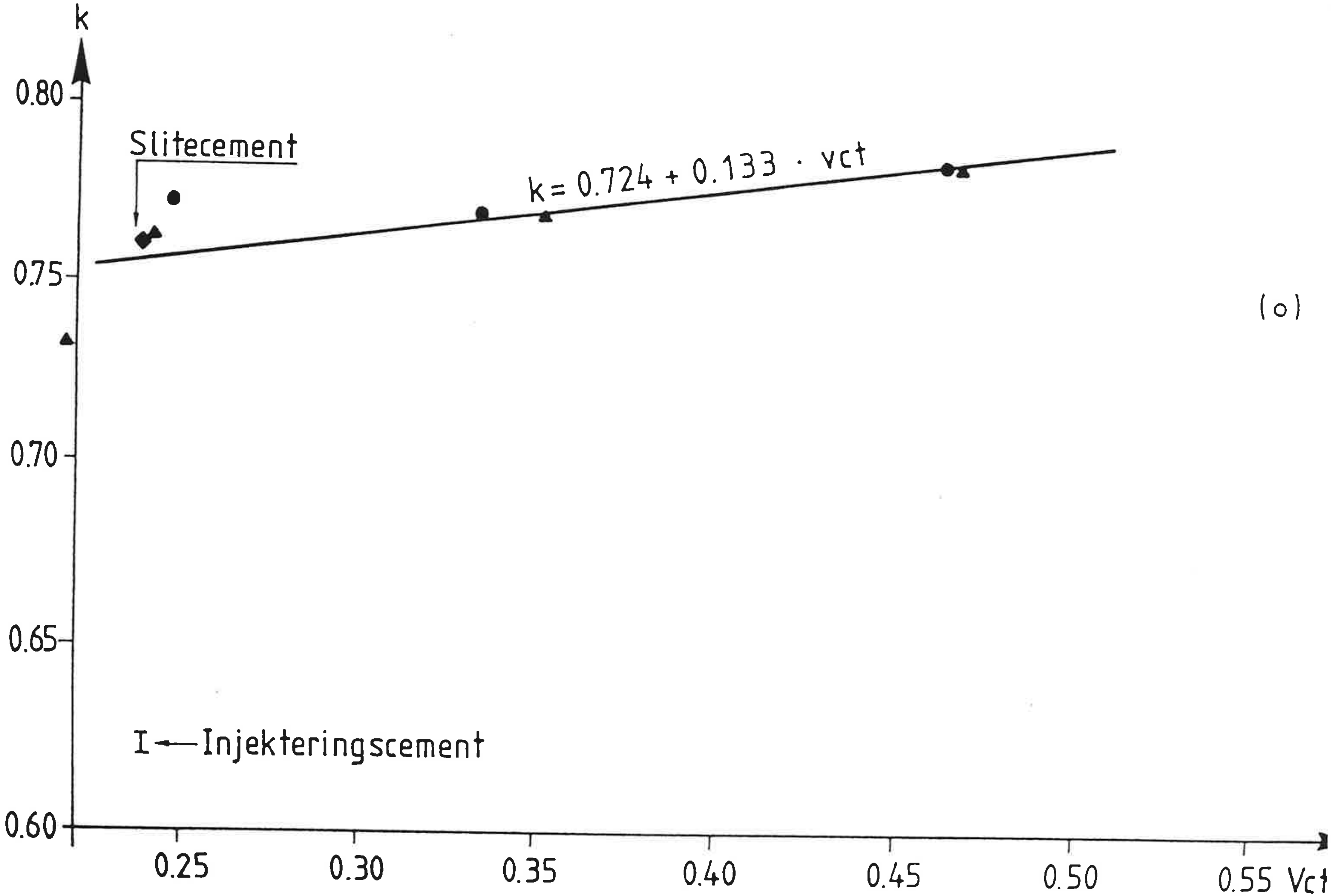


Figure 13. Specific volume at chemical shrinkage, k, as a function of water-cement ratio ($k=1-\delta w_n/w_n$).

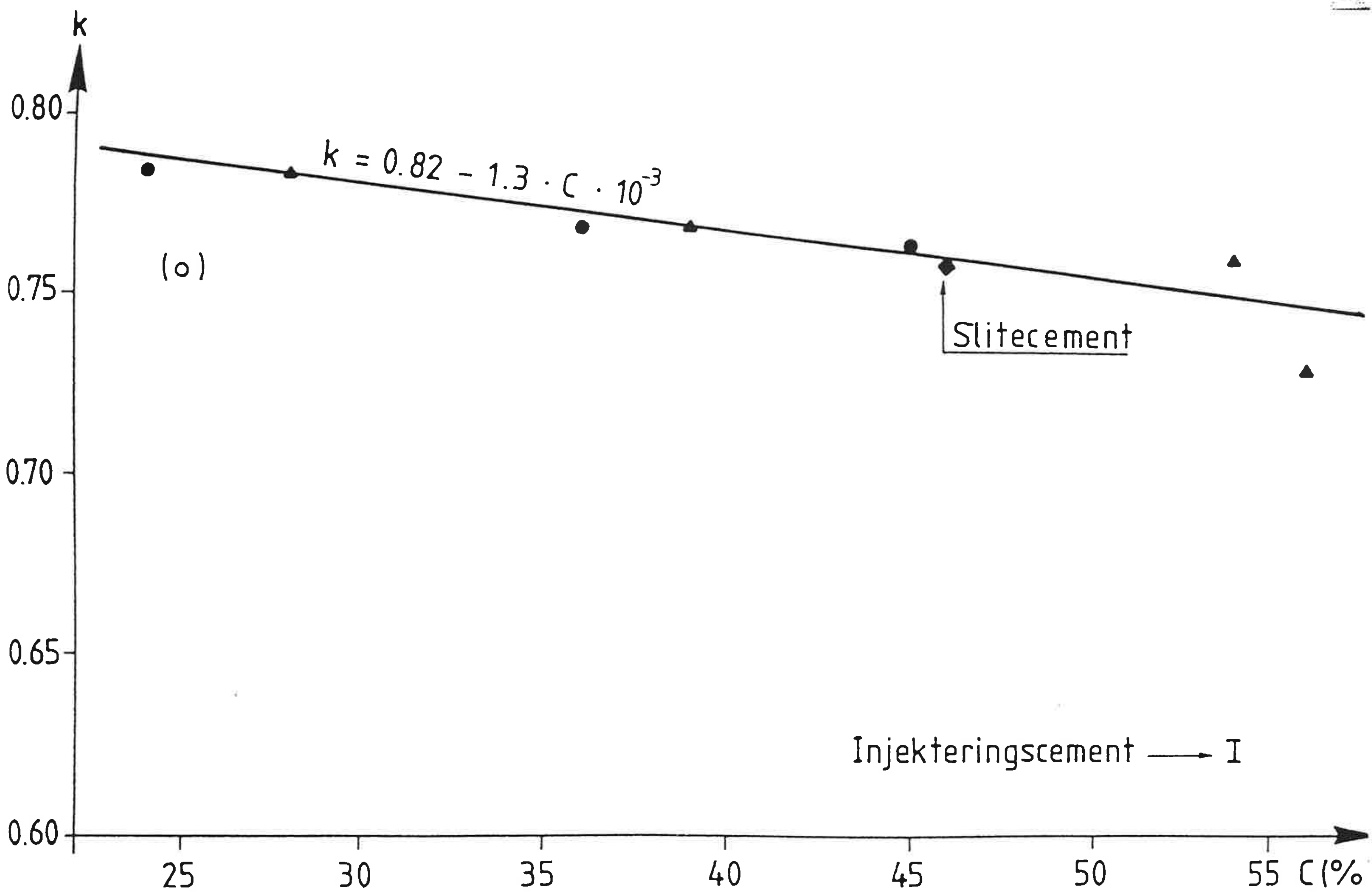
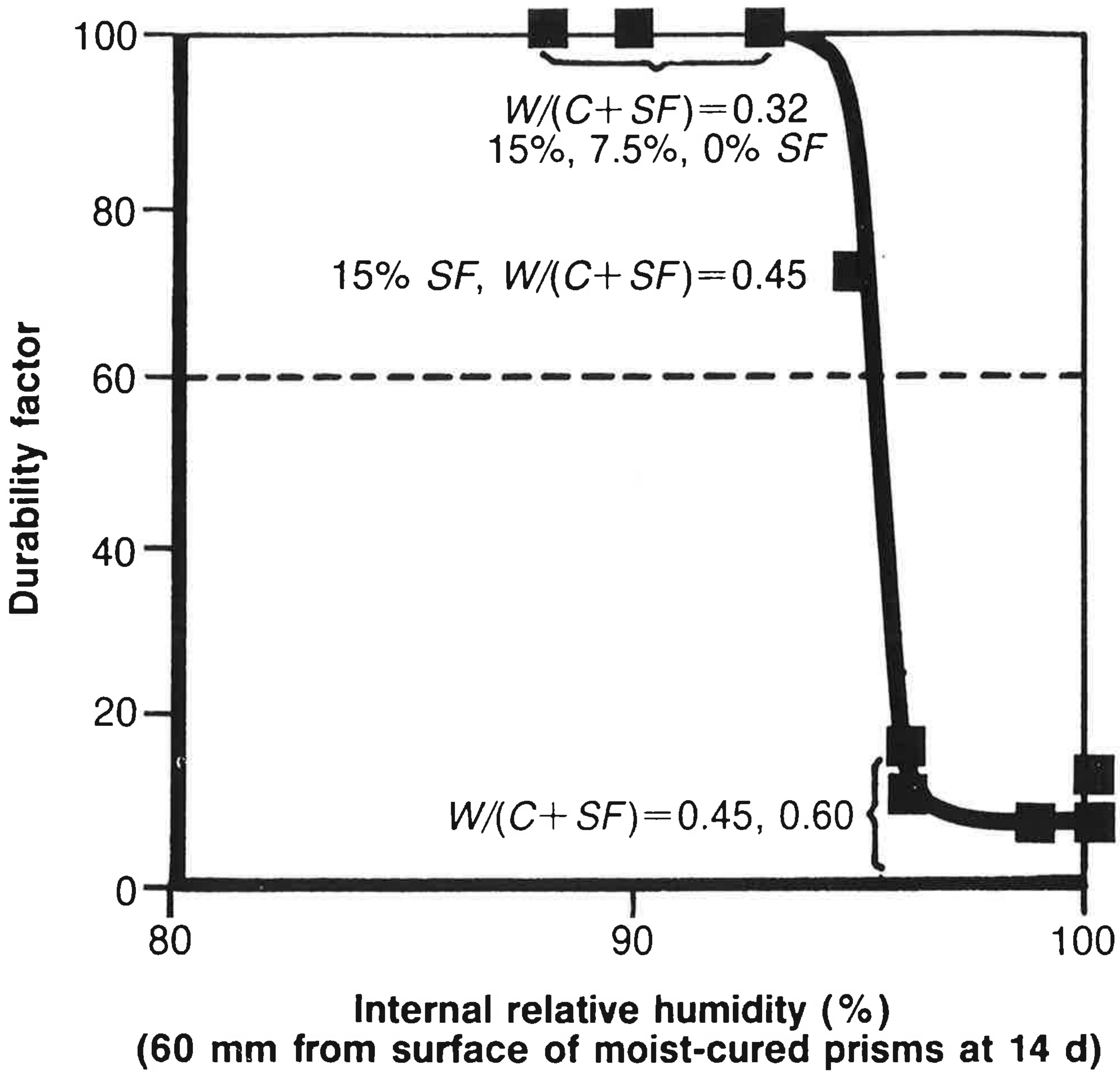


Figure 14. Specific volume at chemical shrinkage, k, as a function of cement content ($k=1-\delta w_n/w_n$).



Influence of self-desiccation on freezing and thawing performance. Researchers at the University of Toronto found that lowering the water to (cement plus silica fume) ratio increases self-desiccation, as does increased content of silica fume. Durability factor is according to ASTM C666-A. *W/(C+SF)* is water to (cement plus silica fume) ratio. *SF* is silica fume.