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A NORDTEST method for verification of self-desiccation in concrete

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Abstract

This article outlines a new NORDTEST method for verification of self-desiccation in concrete. The method involves measurements of the internal relative humidity (RH) on pieces of concrete at age 1 month. The measured RH is then compared with the requirements according to the owner. The new NORDTEST method for self-desiccation permits requirements to be made of the self-desiccation of high-performance concrete (HPC) in accordance with present demands on strength. During the development of the test method, experimental studies were carried out on nine concretes with water/cement ratio (w/c) varying between 0.32 and 0.50. Half of the concretes contained 5% silica fume. The experiments showed a significant effect of cement type, silica fume, and w/c on the self-desiccation in concrete. The test method was also verified in the field, both when manufacturing the concrete and on site. The method was developed after cooperation between the Technical University of Denmark and Lund University. The experimental studies were performed at the Division of Building Materials, Lund Institute of Technology, Lund, Sweden in 1995–1999.

Keywords: Alkalis; Cement; Concrete; Humidity; Pozzolan; Silica fume

1. Background and objective

Ever since the self-desiccating effect of high-performance concrete (HPC) came into practical use in Sweden 9 years ago, no damage on the building sites caused by moisture and fungus due to building moisture from HPC has been reported [1,2]. Still, there has been a demand from the owner or the contractor to control the quality of the concrete in a standard procedure as regards self-desiccation. Owners and contractors want to have a confirmation of the self-desiccating ability of the concrete. They also wish to know whether the concrete fully meets the demands in practical use. A requirement of self-desiccation is often connected to a time limit, i.e. the production of the building. Until now, requirements of concrete most often concern strength (for example, at age 1 month) or durability (for example, minimum 5% air-entrainment). When composing self-desiccating concrete, the manufacturer often compares the self-desiccating ability with the strength level of the concrete. This coupling of the mix design to strength often hinders the development of new compositions, i.e. use of alternative materials and methods when producing self-desiccating concrete, such as lightweight aggregate and air-entrainment. The "strength method" also leads to unnecessary high strength levels, for example, in dwelling houses, often more than three times as high strength as required. The water/ ratio (w/c) is the leading parameter for achieving self-desiccation, not the strength. It was the objective of this work to develop and use in practice a method for testing the self-desiccation of concrete at age 1 month.

2. Method

2.1. Requirements

The following requirements existed when the method was developed:

1. A rapid and safe method for collecting the concrete for the specimens,
2. Effective moisture insulation of the concrete during the curing period, and
3. Moisture measurement under realistic conditions.

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2.2. Procedure

It was practical to use the type of specimens that were used for strength tests in the manufacture of concrete. It was not feasible to use a cube, since its upper face was difficult to insulate moisture losses. Instead, standard cylinders, which were cast in steel cylinders (100 × 200 mm), were used in the methods. In this way, all the moisture of the specimen was kept in the specimen directly from casting. After demolding, the cylinder specimens were stored 3 × 3 in thick plastic pipes at 20 ± 2°C for 1 month. The plastic pipe, with its concrete cylinder content, was weighed on a 1-g accuracy scale before and after the 1-month storage in order to check for any moisture losses. The cylinders were tested for strength after 1 month. Parallel to the strength tests, fragments of concrete were collected from the inner face of the cylinders and put in glass pipes (Fig. 1). Rubber plugs rapidly tightened the pipes. The glass pipes, in turn, were stored for 1 day at 20 ± 2°C. During the measurement of moisture, the device was entered into the pipe and tightened towards the inner face of the pipe by an expanding rubber ring (Fig. 2). The measurement of relative humidity (RH) was carried out for 1 day at 20 ± 0.5°C. To meet the temperature requirement, the measurement was performed in a climate chamber. The concrete mix number, any losses of weight during curing, strength, and RH were noted in a protocol as shown in Table 1.

3. Application in laboratory

3.1. Effects of mix composition

First of all, it was important to check how the method functioned in a laboratory, primarily as regards sources of errors and accuracy [3]. The mix composition and main characteristics of the concretes tested in the laboratory are given in Table 2. The concrete had a high content of air in order to increase the workability and diminish the density. A high content of air did not affect the self-desiccation of the concrete [4]. At an early stage in the development of the testing method, it became clear that the temperature during curing, and especially during the measurement of RH, was of great importance. The temperatures at testing in the laboratory were therefore kept at 18°C, 20.5°C, and 23°C. Fig. 3 shows RH at age 1 month when testing in the laboratory.

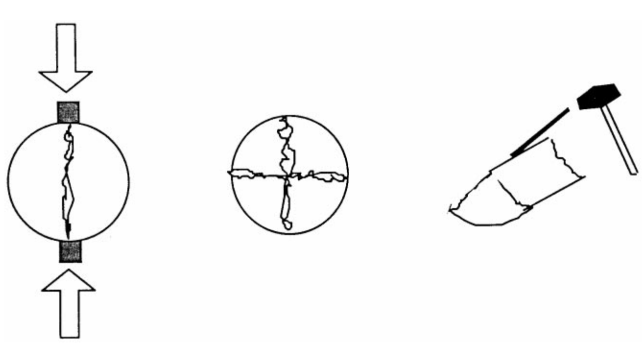

Fig. 1. Fragments of concrete were collected parallel to the strength tests from the inner face of the cylinders and put in glass pipes. Rubber plugs tightened the pipes.

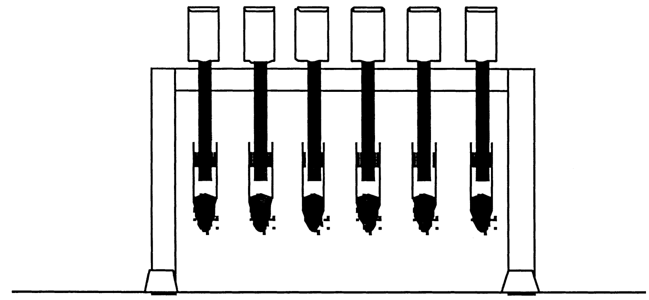

Fig. 2. During the measurement of moisture, the device was entered into the pipe and tightened towards the inner face of the pipe by an expanding rubber ring.

3.2. Conclusions of the laboratory tests

The following conclusions were drawn from the laboratory tests [3,5]:

1. Curing may be performed at 20 ± 2°C, with no significant effect on self-desiccation.
2. The measurement of moisture must be performed at 20 ± 0.5°C to achieve the required accuracy of RH ± 2%.

Table 1
A form for the NORDTEST method for self-desiccation of concrete

Mix number			
Date of casting			
Weight at demolding (g)			
Testing date			
Weight at testing (g)			
Moisture losses (g)			
Compressive strength (MPa)		Displayed value	Calibrated value
Specimen 1			
Specimen 2			
Specimen 3			
Average strength	Device number	Displayed value	Calibrated value
RH (%)			
Specimen 1			
Specimen 2			
Specimen 3			
Average RH (%)			

Table 2
Composition and characteristics of concrete in laboratory tests (kg/m^3) [3]

Material/concrete	32L	32N	32NS	38L	38N	38NS	50L	50N	50NS
Quartzite sandstone, 12–16	669	686	725	532	535	549	407	417	434
Quartzite sandstone, 8–12	137	141	149	258	259	266	320	329	343
Natural sand, 0–8 mm	704	722	763	747	750	771	830	852	887
Natural sand, 0 mm (filler)	107	110	93	43	43	44	32	33	34
Cement	395	405	428	343	345	354	274	281	293
Granulated silica fume, s	–	–	21	–	–	18	–	–	15
Air-entrainment (fir oil; g)	43	44	50	34	35	35	26	26	27
Superplasticizer (melamine)	3.4	3.5	3.6	1.7	1.7	1.8	0.9	0.9	1.0
Water-reducing agent	1.7	1.8	1.9	0.9	0.9	0.9	1.0	1.1	1.1
Total water including moisture	127	131	137	131	131	135	136	138	144
w/c	0.32	0.32	0.32	0.38	0.38	0.38	0.50	0.50	0.50
Air content (% by volume)	12.5	10.5	6.0	13.0	13.0	10.5	15.5	13.5	11.0
Aggregate content (vol.%)	0.75	0.75	0.75	0.76	0.76	0.76	0.80	0.80	0.80
Slump (mm)	90	100	80	140	170	150	200	180	180
Density (fresh state; kg/m^3)	2145	2200	2330	2090	2100	2175	2000	2050	2150
28-day cylinder density[a]	2280	2330	2370	2280	2260	2290	2060	2150	2200
Curing at 18°C (kg/m^3)[b]	2290	2330	2350	2300	2260	2280	2040	2150	2210
Curing at 20.5°C (kg/m^3)[b]	2290	2320	2390	2290	2270	2310	2100	2180	2190
Curing at 23°C (kg/m^3)[b]	2270	2340	2380	2260	2250	2290	2040	2130	2210
Air-content (loss; ΔA; %)[c]	6.5	6.0	2	9.0	7.5	5.5	3.0	5.0	2.5
Air-content (cured; %)[d]	7.5	6.0	5.5	5.5	7.0	6.5	14.0	10.0	10.0
28-day cylinder strength[a]	47	51	71	51	38	51	20	27	33
Curing at 18°C (MPa)[b]	47.0	53.0	72.0	56.5	41.0	54.5	20.5	26.5	32.5
Curing at 20.5°C (MPa)[b]	49.5	51.0	74.0	52.0	39.5	52.0	21.9	30.0	33.0
Curing at 23°C (MPa)[b]	45.0	48.0	67.0	44.0	34.5	46.0	18.5	24.0	33.0

[a] Average of nine cylinders.
[b] Average of three cylinders.
[c] $100[(\rho_{28d}/\rho_{fresh}) - 1]\%$.
[d] $A_{fresh} - \Delta A + 1.5\%$. L = low-alkali cement, N = normal-alkali cement, NS = normal-alkali cement and 5% silica fume, 32 = w/c (%).

3. Concrete with normal-alkali Portland cement (Slite Standard) obtained about 5% lower RH after 1 month than concrete with low-alkali Portland cement (Degerhamn Plant) did.
4. Concrete with low-alkali Portland cement and 5% silica fume obtained about 5% lower RH after 1 month than concrete without silica fume did.
5. Concrete with normal-alkali Portland cement and 5% silica fume obtained the same RH after 1 month as concrete without silica fume did.

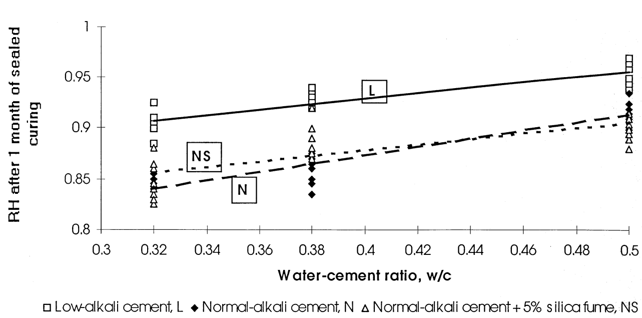

Fig. 3. RH of the concretes at age 1 month, which were tested in the laboratory. L = low-alkali cement, N = normal-alkali cement, S = 5% silica fume.

4. Field tests

4.1. General

The new NORDTEST method was used at a building site in Malmö and at a concrete factory in Trelleborg, Sweden. Standard cylinders were fabricated on the building site [6]. The same procedure was performed at the factory in Trelleborg, i.e. samples of concrete were taken and cast directly from the transport of concrete. The selection of testing samples coincided well with normal concrete production, both from the concrete factory and the building site directly. Table 3 shows the mix composition of the tested concrete in the field [6].

4.2. Procedure

The following procedure applied after the sampling:

1. After curing for 1 day in a steel mould, the cylinders were placed in thick plastic pipes. Plugs with rubber rings tightened the ends of the plastic pipe.
2. The cylinders were stored at 20 ± 2°C for 1 month until testing of moisture.
3. The pipes with content were weighed before and after the curing period. Accuracy: ± 1 g.

Table 3
Mix composition and characteristics of concrete tested in the field (kg/m^3) [6]

Material	38K	38S	40G	44L	68R	70GV
Coarse aggregate, 16–25 mm				804		927
Coarse aggregate, 11–18 mm	928	716	920		753	
Gravel, 0–8 mm	881	886	718	999	1153	1028
Glass filler	60	99	62		35	17
Cement (Slite Standard)	456	518	552	419	289	269
Superplasticizer (polycarboxylic ether)[a]	2.72	2.18				
Air-entrainment (fir oil)[b]	0.91			0.6		
Water including all moisture	174	199	219	184	197	188
Coarse aggregate content	0.50	0.42	0.54	0.45	0.39	0.47
Density	2500	2420	2471	2405	2429	2429
Air content (%)	2.6	1.2	1.1	5.6	1.4	2.6
w/c	0.38	0.38	0.40	0.44	0.68	0.70
Mixing time (s)	246	300	121	192	158	113
Slump (cm)	14	> 28	10.5	12	–	14.5
Slump flow (cm)		56 × 63				
Flow time until 50-cm diameter (s)		4.5				
Workability	Good	Good	Good	Good	Good	Good
Strength, 28 days (factory, 20°C, MPa)	54	58	43	38		31
Strength, 28 days (site, 20°C, MPa)	45	61	46	37		30
RH, 28 days (factory, 20°C, %RH)	86	86.5	87	92		97
RH, 28 days (site, 20°C, %RH)	85.5	86	87	90		97

[a] Dry content, 42%.
[b] Dry content, 10%.

4. At age 28 days, the cylinders were tested for strength. Fragments were taken from each compressive test and placed in glass tubes (Fig. 1). The tubes were tightened by rubber plugs and stored at 20 ± 2°C for 1 day.
5. One day after the strength testing, a dew point meter was entered into the tube with fragments and tightened with an expanding rubber ring towards the glass (Fig. 2).
6. The dew point meter was measured for another day, and the value on the display calibrated according to ASTM E 104-85 [7].

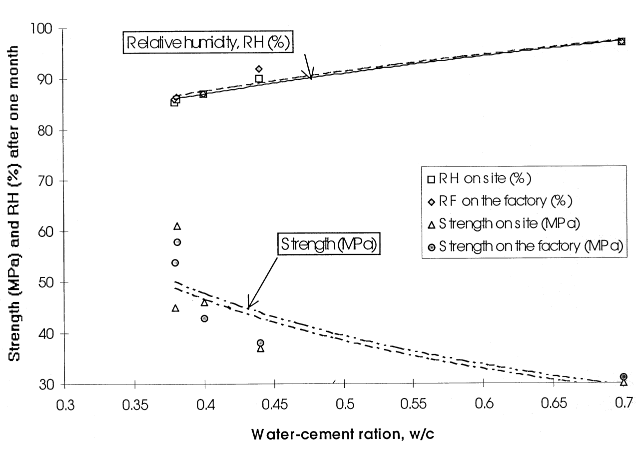

Fig. 4. RH and strength at age 1 month vs. w/c [3].

4.3. Results

Results of the NORDTEST method are given in Table 3 and Fig. 4. Fig. 4 shows RH and strength at age 1 month vs. w/c. The results reflect both the accuracy (± 2% RH) and the variations in the production of concrete. The temperature during the measurement was held at 20 ± 0.5°C. The value on the display of the dew point meter was read after 1 day.

4.4. Discussion

Fig. 5 shows RH estimated according to Eq. (1)

$$\emptyset = [A\ln(t) + B](\mathrm{w/c}) + C\ln(t) + D \quad (1)$$

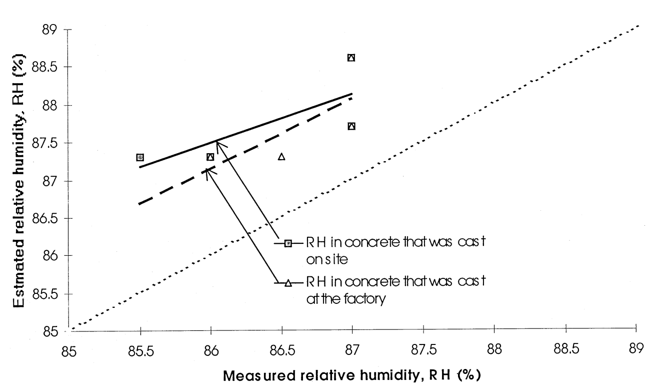

Fig. 5. RH estimated according to Eq. (1) vs. RH measured in field tests [6]. Both concretes that were cast at site and at the factory.

Table 4
Constants in Eq. (1) [3]

Cement type, silica fume/constants	A	B	C	D	R^2
Low-alkali cement	0.0378	0.185	− 0.042	0.83	.63
Normal-alkali cement	0.0588	0.219	− 0.059	0.79	.75
Normal-alkali cement + 5% silica fume	0.0351	0.223	− 0.051	0.78	.59

vs. RH measured at the field tests [6]. Eq. (1) was obtained at the laboratory tests illustrated above [3].

$$R^2 = 1 - \frac{\Sigma(Y_\mathrm{i} - Y_\mathrm{m})^2}{(\Sigma Y_\mathrm{i}^2) - \frac{(\Sigma Y_\mathrm{i})^2}{n}} \tag{2}$$

ln(t) denotes the natural logarithm of the concrete age (month); A, B, C, D denote constants given in Table 4; R^2 denotes an accuracy parameter in Eq. (2) to be >.5; Y_i denotes the measured value; and Y_m denotes the measured average value.

Fig. 5 shows that the concrete producers (in spite of small variation in the results within an accuracy of ± 2% RH) were able to verify that the concrete after 1 month obtained the same RH during self-desiccation in the field as in the factory. The quality of the concrete was proved to be high, since the variation in RH of the same type of concrete was small. This type of documentation was of great importance, both for economic reasons and for the construction time of the project. Furthermore, the concrete producer was able to verify in what way changes in the mix composition affected the self-desiccation of the concrete [6]. The new NORDTEST method also permits the owner to define requirements as regards the self-desiccating quality of the concrete, as provided by the standard procedure.

Estimation of self-desiccation in HPC may be performed according to a newly developed computer program [8]. Required data are w/c, age and type, and amount of silica fume. The program also estimates strength (split tensile and compressive), the elastic modulus, Poisson's ratio, creep and shrinkage, and the creep coefficient of HPC.

5. Summary and conclusions

In this article, a new NORDTEST method for self-desiccation in concrete was described. The methods measure the RH in concrete at age 1 month after a specified sealed curing. RH was measured on control cylinders parallel to the production of the concrete. RH measured during self-desiccation was compared with RH as required by the owner or the contractor. The new Nordic method allows for demands as related to RH in the concrete, besides the normal strength specification and air-entrainment. The following conclusions were drawn [9]:

1. The method showed significant differences in RH of concrete with varying w/c.
2. The method was successfully applied on a building site in Malmö and a factory in Trelleborg.
3. Variations in the results reflected both the accuracy in measurement (± 2% RH) and possible variations in the concrete production.
4. With the new method, concrete producers and contractors can verify the quality of the concrete as regards self-desiccation.
5. Concrete producers may verify in what way changes in the mix composition affect RH during self-desiccation.
6. The owner may use the method in the specification of a project on how to define self-desiccation according to a standard procedure.

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