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Innovative Solutions – Benefiting Society

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PROCEEDINGS

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BELGIAN SPECIFICATIONS FOR FREEZE-THAW-RESISTANT PAVEMENT CONCRETE

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ABSTRACT

The Belgian standard specifications contain a number of clear requirements for the composition of concrete mixtures and the properties of fresh and hardened concrete. It is generally known that water and air content have a substantial impact on the frost susceptibility of a concrete surface – the former in a negative and the latter in a positive way. The water absorption test by immersion is a quite simple and rapid test; the result of which is a good indication for water-accessible pores and hence, to a certain extent, for durability. However, in some circumstances the test does lead to erroneous results. To have a better indication of the durability of concrete, scaling of the surface under freeze-thaw cycles in the presence of de-icing salts is tested.

This paper describes the relationship between the different parameters of the concrete, i.e. water content, water absorption, air content and resistance to scaling, in more detail. It also explains the influence of the choice of materials and concrete composition on resistance to scaling. The findings are illustrated by a number of examples of concrete mixtures.

KEY WORDS

CONCRETE COMPOSITION / DE-ICING SALTS / FREEZE-THAW RESISTANCE

1. INTRODUCTION

Suitable mix composition and good construction are essential for the durability of concrete. The Belgian standard tender specifications contain clear requirements for the composition of concrete mixtures, which are to ensure durability. Besides water/cement ratio and cement content, air content has a major influence. It is important to manufacture concrete as compact as possible, with a low content of water-accessible pores. In addition adequate air must be entrained in the concrete in the form of small bubbles, so as to interrupt the network formed by the pores and reduce stresses in the concrete. Other factors include sand content, total water content, and the addition of fine particles (such as pigments); they are not the subject of any requirements in the standard specifications, but do have a strong impact on the durability of hardened concrete. It is up to the concrete manufacturer to select the appropriate composition for the intended application.

This paper reviews the deterioration mechanism which occurs during freeze-thaw cycles in the presence or absence of de-icing salts. It continues with a short description of the tests for determining resistance to scaling. Finally, it focuses on the parameters that determine this resistance. A few examples of concrete compositions are presented to demonstrate the relationships between the results of the various tests and the need to check the properties involved.

2. DETERIORATION MECHANISM

The deterioration mechanism that occurs during freeze-thaw cycles in the presence or absence of de-icing salts is very complex and still not fully understood. It is assumed that the deterioration results from a combination of the occurrence of hydraulic pressure and osmotic pressure linked to the formation of ice lenses in the pores.

Hydraulic pressures are induced by the expansion of water when it turns into ice. It is generally accepted that this mechanism causes very little damage in concrete. A more important deterioration mechanism is the formation of ice lenses in the pores. When cooling, water in the capillary pores will freeze. This will occur first in the larger pores and subsequently in the smaller pores. The finer the pore, the lower the temperature will need to be for the water to freeze. The difference in vapour pressure will cause water to migrate from the smaller to the larger pores. The stresses induced by this migration of water will, at a given moment, exceed the tensile stresses in the concrete, which will result in scaling. On the other hand, the ice lens will push the water back. When turning to ice, water increases in volume by 9 %. This expansion will cause the as-yet unfrozen water to be expelled from the pore, resulting in stresses on the pore wall. The concrete will, consequently, suffer more deterioration when it is fully saturated. The presence of larger pores will also lead to more severe deterioration. On the other hand, any bubbles of entrained air present will reduce the connections between smaller and larger pores and also provide additional capacity for the expansion of frozen water.

The presence of de-icing salts will strengthen this effect. Only pure water will transform into ice; the salts will migrate to the remanent water in the pore. As a result, the concentration of salts in the pore water remaining in the partly frozen large pore will strongly increase. This will lead to wide differences in concentration between the pore water in the larger pores and the smaller pores. Osmosis, i.e., the tendency to restore balance, will cause further migration of water from the smaller to the larger pores, resulting in the build-up of even greater stresses.

3. TESTS FOR DETERMINING RESISTANCE TO SCALING

Three tests are very important for determining resistance to scaling. First, the entrained air content needs to be determined. This is determined in accordance with NBN EN 12350-7, § 5 (see figure 1). It is important to determine air content on the construction site itself; as the concrete may have lost entrained air during transport. That is why values measured on site are often lower than in the plant.

Figure 1 – Determination of air content in accordance with NBN EN 12350-7

A second check is the determination of water absorption as described in NBN B15-215. This test provides a good indication for water-accessible pore content, but no direct measure of resistance to scaling. It measures the quantity of water-accessible pores and expresses it in relation to dry mass, as shown by the equation below. The water saturated mass is measured by total immersion of the specimen in water. After at least 48h of immersion, the sample is taken out of the water and weight after drying the surfaces with a shammy. Once constant weight is obtained ($M_{saturated}$) , the specimen is dried at 105 °C (M_{dry}) A lighter test specimen absorbing the same amount of water will, therefore, have a higher water absorption coefficient.

$$Water\ absorption\ coefficient\ [\%] = \frac{M_{saturated} - M_{dry}}{M_{dry}} * 100$$

The third step is the actual determination of resistance to scaling. In this test the concrete is subjected to freeze-thaw cycles in the presence of de-icing salts. The cycles are based on the former draft standard ISO-DIS 4846.2. This test is prescribed in the specifications to be executed only if the water absorption coefficient is too high.

The degree of scaling during the test will be largely depending on the choice of test method. In the near future, the transition to the slab-test as described in CEN/TC 12390-9 will be done. The ISO-DIS method varies from the slab-test not only by the type of de-icing salt, but also by the precision according to which the temperature variation is done, as can be seen in Figure 1. Only a minimum temperature and a maximum temperature are determined to be reached in a certain time. Both test methods consist of different cycles of frost thaw to which the sample is submitted in contact with a solution (pure water or salt solution). The frost-thaw resistance is measured by means of the material loss at the surface during and after the cycles.

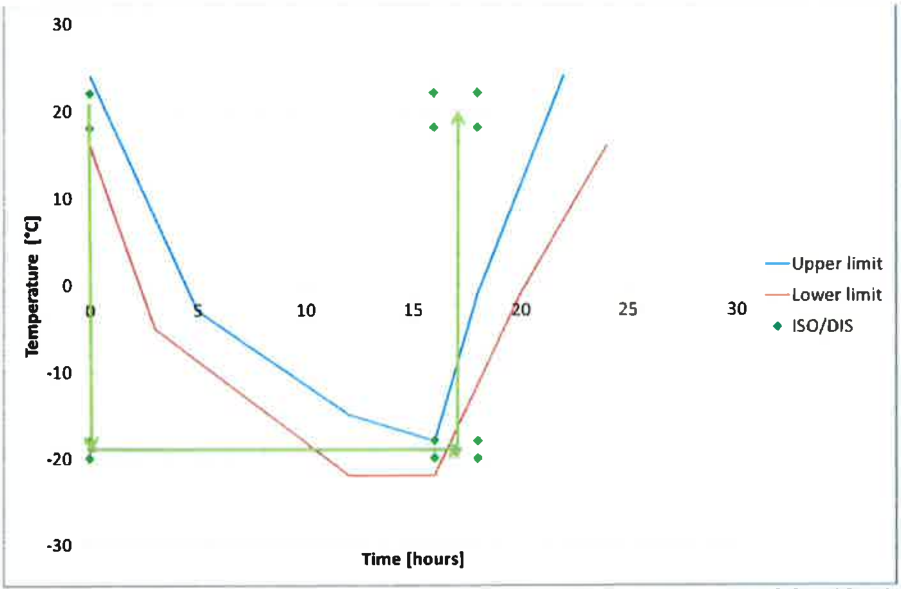

Figure 1 : Temperature variation over 1 cycle for the Slab-Test and the ISO-DIS 4846-2

As is shown in a previous research [Vandewalle,2009], following parameters are important for a good and reliable interpretation of the results and alter for the different test methods:

- type of surface in contact with the solution (upper surface, caste surface, total surface,...);
- height of the sample;
- conditioning of the specimens prior to the test;
- pre-treatment of the surface of the fresh or hardened concrete: broaming, sawing, grinding, ...;
- frost-thaw cycle: maximum and minimum temperature, duration, cooling and heating rate,...
- type of de-icing salt;
- thermal insulation;
- place where the temperature on which the system is guided;
- cooling and heating system (in water or in air).

The slab-test as well as the test according to the former draft standard ISO-DIS 4846.2 is carried out on cores with a diameter of 113 mm at least 90 days after casting. The other parameters can be found in Table 1.

Table 1: Parameters for different test methods

Test method	Number of samples	Height of samples	Number of cycles and duration	De-icing salt	Surface in contact with electrolyte	Pre-treatment	Example
Slab-test	4	50 ± 2	56 24 h	3% NaCl	Upper surface	7D under water at 20°C + 21 D at 20°C and 65% R.H.	
ISO-DIS	3	45 ± 2	30 24 h	3% $CaCl_2$	Upper surface	7D under water at 20°C + 21 D at 20°C and 65% R.H.	

The procedure described in the standard must be followed very carefully to allow good interpretation of results. For example, the size of the specimen strongly affects the result. A higher specimen will be less subject to scaling than a lower specimen, even if the composition of the concrete is the same. Pavement concrete is tested on core samples 113 mm in diameter and 50 mm in height, extracted from the road. The test is performed after ninety days of curing.

The relation between the results of the SLAB test and the results obtained following the former ISO/DIS 4846.2 method is not clearly determined. Tests made on concrete samples prepared in the laboratory indicate a higher precision for the SLAB test as for the ISO/DIS test. A linear progress in scalling is observed. First results indicate a more severe scalling by using the slab test in comparison to the ISO/DIS test, increasing the amount of material loss by a factor 2 to 4.

4. INFLUENCE FACTORS IN CONCRETE COMPOSITION AND CHARACTERISTICS

4.1 Water/cement ratio, water content, and cement content

Water/cement ratio is generally known to be a measure of the quality of concrete. The lower the w/c ratio, the higher the strength values (compressive strength, tensile strength) will be, the lower the water-accessible porosity and, consequently, the better the resistance to freeze-thaw deterioration.

Water content must be kept as low as possible in order to obtain compact concrete with low porosity. On the other hand, a certain amount of water in the concrete mixture remains necessary to achieve good workability for a sufficient period. Admixtures (such as plasticizers and superplasticizers) do play an important role in restricting the dosage of water while still ensuring adequate workability, but they have their limitations. An overdose of admixtures may result in a creamy and sticky mixture, which in practice is poorly workable for the contractor who has to pour it.

Adequate cement content is another prerequisite for high-quality concrete; the additional hydration products make it possible to obtain a closed mixture. However, this only applies if the w/c ratio is adapted so as to avoid increasing the water content in the composition of the concrete. This means that when the cement content of a composition is increased – for example because the maximum particle size, D_{max}, is decreasing –, the w/c ratio must be reduced in order to be able to keep using the same amount of water in the mixture. For road pavement concrete the ideal total amount of water to optimize both durability and workability factors is 180 l per m^3.

The standard tender specifications already allow for this, as illustrated by table 1 below reproducing requirements for traffic classes B1-B5 in the standard specifications 250 of the Flemish road authority.

Table 2: Standard tender specifications of the Flemish Road authority for cement content and w/c ratio

D_{max} (mm)	Minimum cement content (kg/m^3)	Maximum w/c ratio
$20 < D_{max} \leq 31.5$	400	0.45
$6 < D_{max} \leq 20$	400	0.45
$D_{max} \leq 6$	425	0.42

4.2 Sand content

Sand content will have a double effect. First, a higher sand content will require more water and/or superplasticizer to provide similar workability, which will affect the porosity of the hardened concrete. Second, a high sand content will increase the mortar content of the concrete mixture, thereby increasing the risk of deterioration under freeze-thaw cycles in the presence of de-icing salts. Ideally the sand content (0/2 mm particle size fraction) in conventional pavement concrete 0/20 should be limited to 600 kg/m^3. As the maximum particle diameter becomes smaller, a greater mortar phase will be necessary to coat the aggregates. This means that the sand content will be higher and that more air will have to be entrained into the concrete (see Section 4.4) [Ployaert, 2013 and Pilate, 2013].

4.3 Pigments

Pigments too will affect the workability of the concrete. The addition of fine material will again result in lower workability of the mixture, with a consequent need to use more admixtures or increase water content. Nevertheless, it is possible to obtain durable coloured concrete provided the rules of good practice are observed with respect to mix composition: continuous grading with a limited amount of sand (about 3 % of the total inert skeleton), adequate cement content with the w/c ratio (max. 0.50) adapted to achieve optimum water content, and a sufficient amount of entrained air (about 4 %) in the fresh mixture to ensure durability [Ployaert, 2013 b]. In any case, it is highly inadvisable to try and improve workability by adding water.

4.4 Air content

Air content is one of the most important parameters in ensuring the durability of concrete. Especially in compositions with coarse aggregates having a maximum particle diameter smaller than or equal to 20 mm, the amount of mortar will increase and so will the risk of deterioration. Adding an air-entraining agent will result in small air bubbles being formed in the concrete. These will be situated in the hardened cement stone / mortar phase and will help to reduce the pressures resulting from the formation of an ice lens and from the extraction of water from the finer pores.

It is important that, one the one hand, the diameter of these bubbles should not become to great and that, on the other, the bubbles should not be spaced too far apart. This can be verified by microscopic analysis of the hardened concrete. Ideally the diameter of the air bubbles should range between 10 and 100 µm and the spacing factor should not exceed 200 µm.

4.5 Combination of air content – water absorption – strength

The addition of air will have an impact on other properties of the concrete such as specific density, strength and water absorption. Generally it can be stated that specific density and strength will decrease, whereas water absorption will increase.

The effect of higher air content on concrete strength is obvious. Entraining air into the material will result in lower density and consequent lower strength. This fact is allowed for in the standard tender specifications, by setting lower requirements for the compressive strength of air-entrained concrete. Also, a minimum requirement for compressive strength implicitly sets a limit to entrained air content. As illustration, the specifications of the SB 250, version 2.2 (prescriptions set up by the Flemish road authorities) are summarized in Table 3. These limits will change slightly in the new version which will be available from the end of 2014 on. E.g. the limit for air content of the bottom layer in a double layered concrete pavement will be omitted since this will not influence the resistance to scalling and will on the other hand improve the strength and the adhesion between both layers.

The effect on water absorption is less clear. In principle, the use of an air-entraining agent will have but a limited impact on the absolute amount of water absorbed by a test specimen, i.e., on the water absorbed by the capillary pores at the surface. On the other hand, the bubbles of entrained air are situated deeper in the bulk of the specimen and not at the surface, which reduces their influence on capillary action. What does change is the water absorption coefficient. As described earlier, this is the ratio between the amount of water absorbed by the specimen and the dry mass of the specimen. Since the latter will decrease with the addition of an air-entraining agent to the concrete, an equal amount of absorbed water will result in a higher water absorption coefficient being measured. This does not mean that the concrete will not resist the action of de-icing salts. On the contrary, research has shown that concrete with adequate entrained air content does have a high resistance to the action of de-icing salts, even if its water absorption coefficient is higher than allowed in the standard tender specifications.

Table 3: Specifications of the SB 250, version 2.2

	D_{max} of aggregates [mm]	Cement content [kg/m³]	Water/cement ratio [%]	Air content [%]	Max. individual water absorption [%]	Max. average water absorption [%]	Max. mass loss according to ISO/DIS [g/dm²]
Building class B1- B5 (heavy trafficked roads)							
Top layer (one or two layers)	> 20 mm 6,3 mm < D_{max} ≤ 20 mm ≤ 6,2 mm	≥ 400 ≥ 400 ≥ 425	≤ 0,45 ≤ 0,45 ≤ 0,42	- ≥ 3 ≥ 5	6,5 6,8 7,0	6,0 6,3 6,5	5
Under layer (two layers)	≥ 20 mm	≥ 375	≤ 0,45	(≥ 3)	-	-	
Building class B6- B10, BF (low trafficked roads and bicycle lanes)							
Top layer (one or two layers)	> 20 mm 6,3 mm < D_{max} ≤ 20 mm ≤ 6,2 mm	≥ 350 ≥ 375 ≥ 400	≤ 0,50 ≤ 0,50 ≤ 0,45	- ≥ 3 ≥ 5	6,5 6,8 7,0	6,0 6,3 6,5	10
Under layer (two layers)	≥ 20 mm	≥ 350	≤ 0,50	(≥ 3)	-	-	

To illustrate this by an example, a trial was made in which several parameters such as content of air-entraining agent, amount of water, and water/cement ratio were varied. The concrete was a mixture for municipal roads with 375 kg/m³ of CEM III/A 42.5 N LA and a D_{max} = 20 mm. The results are presented in Table 4. Two findings are important here.

First, it can be stated that the concrete mixtures with increasing dosages of air-entraining agent (mixtures 3, 4 and 5) exhibited higher resistance to scaling, although the measured values of water absorption coefficient were too high. As explained above, this is due to the lower specific density of the concrete.

A more hazardous situation existed where the air content of the concrete was too low (mixtures 1 and 2). Adequately low water absorptions were measured in this case, and the strength values were OK as well. Only, the air contents measured on the fresh concrete were too low. Apart from that, the two mixtures appeared to meet the requirements and to be durable. However, high values were measured for scaling, indicating that the concrete would be sensitive to deterioration in the presence of de-icing salts.

It is, therefore, extremely important to determine not only strength and water absorption coefficient, but also the air content of the fresh concrete. If this content is too low, the concrete will have limited resistance to freeze-thaw cycles in the presence of de-icing salts.

Table 4: Properties of different types of concrete with varying air content [Ployaert, 2012]

	Mixture 1	**Mixture 2**	**Mixture 3**	**Mixture 4**	**Mixture 5**	**Mixture 6**
Plasticizer	No	Yes	Yes	Yes	Yes	Yes
Air-entraining agent	No	No	Yes	Yes	Yes	Yes

W/c ratio	0.49	0.45	0.45	0.45	0.45	0.45
Slump Vebe	40 mm 4.0 s	40 mm 4.0 s	25 mm 4.0 s	45 mm 3.0 s	35 mm 3.5 s	65 mm 2.0 s
Air content	0.8 %	1.3 %	2.4 %	4.5 %	5.7 %	8.3 %
Loss in mass under freeze-thaw cycles	25.1 g/dm²	14.0 g/dm²	10.8 g/dm²	7.1 g/dm²	6.3 g/dm²	3.9 g/dm²
R'c 90 d	73.6 N/mm²	82.0 N/mm²	73.0 N/mm²	65.9 N/mm²	58.9 N/mm²	44.6 N/mm²
Abs_m	6.0 %	5.6 %	5.5 %	6.4 %	6.2 %	7.3 %

5. RECOMMENDATIONS AND CONCLUSIONS

Mix composition is a very important consideration in manufacturing durable concrete. The interaction between the various parameters plays a role in this process. Cement content, water content, w/c ratio, sand content, mortar content and the dosage of air-entraining agent must meet specific requirements if the concrete is to have adequate resistance to scaling.

In determining resistance to the action of de-icing salts, the test for resistance to scaling is the most important tool. If the results of this test are below the limit values, the concrete will resist. Water absorption as such gives an indication, but will underestimate the resistance in the instance of a concrete mixture with high entrained air content. If this air content is too low, the water absorption coefficient will overestimate the resistance to scaling and deterioration may occur, even if the requirements for water absorption are met.

As a result, it is very important to determine air content on the construction site itself. If it fails to meet applicable requirements, the composition of the concrete mixture must be corrected to ensure durability. The presence of entrained air becomes more important as mortar content increases and the mixture requires more water (smaller coarse aggregates, higher sand content, more pigment). Hence it is crucial to provide the necessary means for verification and to perform verification measurements on a regular basis, to make sure that the requirements set in the standard specifications actually lead to durable concrete surfaces.

6. REFERENCES

- Handleiding voor de toepassing van luchtbelvormers in wegbeton. Toepassing, mengselontwerp en keuring. Opzoekingscentrum voor de wegenbouw, A73/02, Brussel, 2002. [In Dutch or French]
- C. Ployaert, “Naar een optimale samenstelling van wegenbeton”, FEBELCEM publication, 2010. [in Dutch or French]
- C. Ployaert , “Ontwerp van betonconstructies bestand tegen vorst-dooicycli en dooizouten”, FEBELCEM, Dossier Cement en Beton, bulletin T-4, november 2012. [in Dutch or French]
- C. Ployaert, Inter-Beton; L. Rens, FEBELCEM, « L’influence du rapport sable/ciment sur la qualité des bétons routiers » ; Congrès belge de la Route, Liège, 2013. [in French]
- O. Pilate, Sagrex; C. Ployaert, Inter-Beton, « La granulométrie correcte des sables pour une qualité optimale des bétons routiers », Congrès belge de la Route, Liège, 2013. [in French]

- C. Ployaert, Inter-Beton; L. Rens, FEBELCEM, « Influence de l'ajout d'un colorant sur la résistance aux sels de deverglaçage d'un béton routier »,Congrès belge de la Route, Liège, 2013. [in French]
- Lucie Vandewalle and Winne Figeys, KULeuven; Christian Pierre and Olivier Germain, CRIC-OCCN; Olivier De Myttenaere and Anne Beeldens, "Test methods comparative study of concrete resistance against freeze-thaw cycles as described in CEN/TS 12390-9, ISO-DIS 4846-2 AND NTN-018", BRRC - CONMAT 2009.