Requirements and recommendations to frost durable concrete – an overview

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ABSTRACT

Requirements and recommendations for frost durable concrete from standards and specifications from Europe, North-America and Asia, various international organizations and construction projects are reviewed, compared and discussed. This is done based on exposure or "load" (wetness/saturation/situation, de-icers, frost, etc.), material or "resistance" (air voids, w/b, binder type, strength etc.), execution (pumping, casting, finishing, curing etc), and tests (air voids, porosity, strength, various frost tests). Finally, some practical examples of the specification together with examples of need of stringency and some occurring peculiarities in testing are given. Also the large variation in how frost durability is perceived in different parties of the decision-, planning-, execution- and commissioning process around the world are discussed and illustrated.

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1. INTRODUCTION AND SCOPE

Frost deterioration of concrete is seen as progressive scaling, spalling and crumbling of particles from a surface or/and cracking of the volume of the concrete. The cracking can eventually be visible at the surface, or there can be a combination of scaling and cracking. Frost damage can happen with the simultaneous presence of low temperatures and a wet surface, and the surface damage is amplified in the presence of de-icers such as salts during exposure to frost.

With some experience into the topic, it is easy to imagine that agreeing on how to make frost durable concrete structures based on the huge amount of research results available in the literature would be both a vast and likely impossible task. The many experimental results, theories, models and test methods presented over the years have given a large number of data that are difficult to unify for practical purposes. Another approach would be to review the standards, requirements, and recommendations published internationally. Design and building based on a review of the latter three types of documents are, therefore, an easier task than to review experimental results, theories, and models. Design and building are based on loads on and resistance of the structure in question. For frost exposure, this is less clearly defined than for most types of mechanical loads on a concrete structure. Frost durability of concrete is often described as its ability to withstand repeated freeze-thaw cycles throughout a defined life of a structural element while exposed to periodical wetting and drying, often in combination with deicers (road salt, sea water, urea, etc.) It is the country standards, norms and regulations for concrete that stipulate:

- the exposure (wetness/saturation, chlorides, frost, etc.) to base the design on,
- the material requirements (air void requirements, w/b-ratio, binder composition, strength, etc.) to select for that exposure,
- the production techniques and rules (placing arrangements, finishing, curing) to apply for making the concrete frost resistant and
- the test methods (air voids, frost tests, porosity, strength, etc.) for the final product to confirm compliance.

The approach to frost durable concrete varies much from country to country. Numerous committees and unions with their sets of recommendations in addition to national standards have worked with this topic. Selection of the reviewed documents in this paper is limited to standards and recommendations from the USA (ACI, AASHTO, ASTM), Canada (CSA, BNQ), Norway (NS-EN), Sweden (SS, SIS), Danmark (DS), Germany (DIN, ZTV, BAW), Russia (SP, GOST, SNiP) and China (GB/T). The scope is to give an organized and systematic overview of the documents relevant to frost exposure requirements and recommendations including examples for application.

2. DOCUMENTS, EXPOSURE, MATERIALS PROPERTIES, EXECUTION AND TESTS

Based on the available documents reviewed [1] it seemed most convenient to use the following division given in table 1:

Table 1 - List of the main tables in [1]

	Table 2	Overview of the documents included in the review
Load	Table 3a	Classification for freeze-thaw exposure conditions. LOAD
	Table 3b	Summary of exposure classes from the reviewed standards and specifications
Resistance	Table 4	Material requirements. RESISTANCE
Execution	Table 5	Production and execution of concrete works. Requirements and recommendations
Tests	Table 6a	Tests for frost durability – material characterization
	Table 6b	Tests for frost durability – freeze-thaw tests
	Table 7	Overview of requirements for frost durable concrete

2.1 Documents

Table 2 in [1] is a rather large 1-page table, yet limited to only 53 different documents from Europe, North-America and Asia divided into exposure classes, material requirements, production- and execution-standards and recommendations, and freeze-thaw tests. By going into all sorts of details this could, of course, have been a much higher number of documents since such standards, specifications, etc. link to other technical documents. However, the cited 53 documents include the central national standards, requirements from professional organizations such as ACI and large construction owners such as road- and bridge authorities and oil companies. We, therefore, think Table 2 in [1] represents a broad overview and is very useful to the parties of the decision-, planning-, execution- and commissioning process.

2.2 Load (=exposure) and Resistance (=material)

Tables 3a, 3b and 4 in [1] make up a main body of the work. They show the big differences in how frost exposure and material parameters central to obtain durability against frost are seen among different parties in the building process worldwide. Some of the differences, particularly for exposure, pertain to real differences in exposure. A sort of consensus seems to be division onto wetness and to what extent deicers are present. Other differences could be linked to local perceptions and practices for how to obtain frost resistant materials. In general water/binder ratio, strength and air entrainment are basic parameters that there is more agreement on whereas how to use supplementary cementitious materials seems to be more different, difficult or not treated.

2.3 Execution – tests on fresh concrete

Table 5 in [1] is an effort to give an overview of another vast but more practical topic. Our purpose with this has been to help the reader to focus on the main operations of concrete works: mixing, transportation/delivery of fresh concrete, placing and finishing, surface protection and curing. Inevitably, this also includes some tests, eg. fresh concrete sampling and measurements at mixing and delivery/site/after casting and finishing operations are done. The outcome depends on execution, so the question of how to characterize this is obviously difficult, and we have tried to show how for example sampling of air void measurements vary, and the possible methods. Also, some fresh density- and workability tests are listed.

2.4 Tests

Table 6a in [1] is a rather "small" 1-full-page table giving an overview of indirect tests: These include hardened air void content, Protective Pore ratio (PF), i.e. the air void volume as a fraction of total porosity and air void spacing and total fresh air void content. For each country the table lists the relevant performance- (= freeze/thaw-) tests and acceptance criteria for those relative few countries that have such links. Hence, this table shows the testing tools available for requirements and recommendations based on laboratory testing.

Table 6b in [1] is much larger (3 pages) giving an overview of the main frost test methods worldwide. Each of the 3 pages is split in: Samples, Freeze-thaw cycles, Test set-up and Expression of test results. This makes it easier to get an idea about the great difference in how these tests work and how differently they express frost damage. So, in addition to the big difference between frost damage when expressed as surface damage and (internal) cracking, there are large variations in how to characterize these two forms of damage. Scaling can be rated visually, expressed as dried particles lost from the surface or as overall mass loss or -change of remaining specimen. Internal cracking is rated by relative dynamic modulus measured in various ways (resonance frequency, ultrasonic pulse velocity), length change measured in various ways or loss of strength. In addition, we believe there are large differences in how scaling and cracking are provoked in the different tests as well as to what extent the two forms of damage can contribute to each other, for example amplify each other.

3. EXAMPLES OF RECOMMENDATIONS AND REQUIREMENTS

3.1 Frost exposure in Europe - Norway

In Table 2 below an excerpt of the first part of Table 7 in [1] is shown generally for Europe and specifically for Norway of how exposure description and material proportions can be combined to give a specification. Table 7 in [1] is a full 5-page table giving a complete overview of requirements and recommendations worldwide with the information organized for each country into exposure class, material requirement, laboratory tests, and execution.

Table 2 – Excerpt from Table 7 in [1]

Country / Organization, Project	Exposure class, area, decisive parameter		Material requirements										
			Max w/c (effective w/c)	Min cement (binder) content, kg/m³	Max (Min) SF content, %	Max FA content (Max Fa/C ratio), % or kg/m³	Min air content in fresh / hardened** concrete (for aggregate D_{max}, mm), %	Max electric conductivity, Coulombs	Frost resistance, cycles (frost res. class or min. durability factor,%)	Quality of macro-porosity in hardened concrete: Min specific surface, mm²/mm³	Quality of macro-porosity in hardened concrete: Max spacing factor (single results) L, mm	Min concrete comp. strength (strength for cement), MPa or class	Water impermeability class (Durability class)
General Europe EN 206:2013	XF1		0,55	(300)*	11	(33)						C30/37	
	XF2		0,55	(300)*	11	(33)	4					C25/30	
	XF3		0,50	(320)*	11	(33)	4					C30/37	
	XF4		0,45	(340)*	11	(33)	4					C30/37	
Norway NS-EN 206:2013 +NA:2014	XF1		0,60	(250)*		(35)							M60
			0,45	(300)*		(35)							M45
			0,40	(330)*	(6)	(35)							M40
		XF2 XF3	0,45	(300)*		(35)	4						MF45
		XF4	0,40	(330)*	(6)	(35)	4						MF40

Now, to be stringent about the example in Table 2 a few points could be mentioned. Normally, for XF4 to make a concrete that will also pass the severe European EN-TS 12390-9 performance test with 3 % NaCl on sawn surfaces, additional requirements could be needed. More specifically this would be to require air void spacing factor less than approximately 0.2 mm in the finished cast specimen. There could also be cases where concrete mixes pass the severe test without air entrainment. Furthermore, certain SCMs react very differently to carbonation than OPC and other SCMs, simultaneous internal cracking during scaling testing would accelerate scaling and so on. The EN-TS 12390-9 test is known for being very severe, so in practically all cases where concrete passes this test, it will also be durable under similar severe field conditions. Now similar peculiarities can be seen for other countries and other tests, such as for example what is the relevance that scaling occurs sometimes in the ASTM C666 Procedure A test, even when there is no internal damage?

3.2 Frost durability as perceived in different countries

If one should list down the requirements for concrete in a certain exposure from material requirements and testing to execution, quality assurance and handover, the results in different countries will vary in parameters, numbers, and level of detailing, see Figure 1.

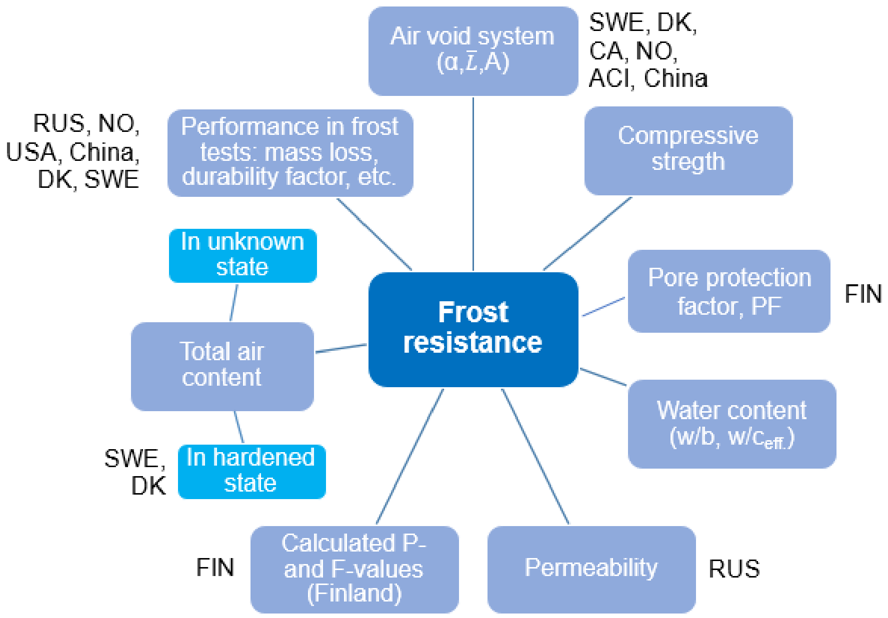

Figure 1 - The meaning of frost resistance in different countries

Figure 1 shows, concerning material requirements, how variable the definition of frost-resistant concrete can be, depending on which country one is going to design and build the structure in.

REFERENCES

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