Evaluation practice development of concrete frost resistance in the European Union countries
Freeze-Thaw & Frost Resistance Assessment Development Needs
Considerations - Overview

- Recent review & background (CEN/TS 12390-9)
- Some important issues remain unsolved
- The moisture issue
- Summary

Härdtl (2018)
Recent review & Background
Testing hardened concrete - Part 9: Freeze-thaw resistance with de-icing salts - Scaling

Prüfung von Festbeton - Teil 9: Frost- und Frost-Tausalz-Widerstand - Abwitterung

This Technical Specification (CEN/TS) was approved by CEN on 25 April 2016 for provisional application.

The period of validity of this CEN/TS is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the CEN/TS can be upgraded into a European Standard.

CEN members are required to announce the existence of this CEN/TS in the same way as for EN, in order to make the CEN/TS available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force. On
Principle set-up of the three testing methods in CEN/TS 12390-9

- Casting, curing (submerged + dry 20/65 % RH), re-saturation
- Sawn(cut) or moulded test surface
- One-dimensional heat-flow (2 of the methods)
- 1 or 2 (CDF) F-T cycle(s) / 24 h
- National acceptance criteria
“ISSUES” raised

Shortcomings – CLAIMED – leading to revision request
• Large scatter of test results
• Harsh, “brutal test” not relevant for western/south of Europe
• “Non-existing” F-T cycle
• Strict acceptance criteria
• Effect of carbonization = fair ranking of mix design?
Scatter by nature ....

Siebel & Breit (1999)

IF conducted by a well performing laboratory ...
Selection of F-T cycle ….

IS a matter of reducing scatter …:

To change, we would need research support on damage sensibility to $\Delta T$ (scatter) – or on alternative accelleration.

*Geiker et al (2008)*

**Fig. 11** Heat flow (given as apparent heat capacity) as a function of temperature. Cement paste, w/c = 0.5 after 75 days of hydration at 15°C [31]
Severity is also a matter of ....

**Acceptance limits** for scaling (kg/m²), which is a **NATIONAL** or **DESIGN** responsibility (as for any other test ……)

BUT the method is perhaps suitable only between 50 g/m² and 3-4 kg/m²?

Round Robin Test is now under planning for providing precision data for test duration of 14 – 28 – 56 F-T cycles, facilitating more differentiated criteria.

Meaning: Some countries could stop after 28 (14?) cycles.
Effect of carbonation

For some binders, carbonization leads to densification of the microstructure. Not so with slag.

Previous pre-conditioning did not prescribe exposure to carbonation, which provided for (unfair) positive conditions with high slag contents.

Carbonation is now included (CO$_2$ concentration limits).

*Utgenannt & Petersson (2012)*
Annex A: Alternative application

Alternative application may follow from specific objectives, such as but not limited to:

- Adoption of the testing method for concrete product testing, on samples with different geometry
- Other age dependent properties development
- Acceptance limits – differentiation of severity
- Such adoption with different time frames, properties and acceptance limits, and in particular;
- Adoption of the basic principles of the testing method but for research on certain mechanistic phenomena
Alternative application – Concerns 1 & 2

- other age dependent properties development
  - Deviation from standard age testing initiation:
  - Hydration / “Curing” (what does it take …?)
  - Change in moisture history and level of carbonation may apply (Significance of which is explained)
- differentiation of severity
  - Apply measures as indicated (adequate scaling level + nos. of cycles)

f) The temperature cycle: Changing non-linear relation between temperature

c) Standard start of testing is at 31 (Slabs)

d) Top surfaces and surfaces cast against formwork

a) Geometry and number of samples:

h) If samples are extracted from in-situ structures
BUT some important issues remain unsolved:
Field experience vs. assessment by testing

1. No good correlation between the tests – across cement/binder type
2. Large impact of different pre-treatment - across cement/binder type (prolonged water curing is NOT the answer)
3. Need to develop more close-to practice moisture-load (saturation) curing, using field observation as “benchmark”.


Härdtl (2018)
FUTURE EN 206 development – What does it mean for F-T

- Combination of prescriptive & performance approach
  - Properties severity classes; XF1 – 4 replace by “xf mm”? 
  - Properties resistance classes; Define XF/14&28, XS/14&56?
  - = Issues of TC 104 BUT with TG 4 impact, esp. “XF non-saline”
  - Testing methods able to classify/distinguish design and products w r t such classes > differentiation, precision & (lab/field correlation based;) acceptance limits
  - Deemed-to-satisfy design values for cost efficiency
  - Innovation & product value increase via performance testing, i.e. need to (better;) assess product performance, irrespective of future EN 206 concept.
EN 206 development dependent – or NOT

- Convergence into one salt-scaling test?
  - Currently
    - Reference method Slab Test / “Borås Test”
    - CDF
    - Cube test
  - No direct between-test correlation
  - Existing lab/field correlation incl. acceptance criteria?
  - Transfer from TS to EN (2022?) > One Method
EN 206 development dependent – or NOT

- Questioning of current XF 3 (EN “non-saline”) applied procedure(s) and acceptance criteria, especially for non-CEM I
- Several countries miss sustainable criteria for environment without salt
  - No formal opening of non-saline testing (alt. “beams”)
  - Scarce experience of non-saline testing or Field/Lab relation
- Some apply non-saline testing, but;
- Are current procedures (“scaling” or “beam”) relevant for exposure conditions & types of mechanisms in field?
Non-saline environment = Internal cracking ? = XF3 ???

CEN/TR 15177 1(3): “BEAM-Test”

Submerged until 28d of age
Freezing in air
Thawing in water at $T_w = 13 (+/- 8) ^oC$
Internal cracking = XF3 ???

CEN/TR 15177 2(3): “Slab-Test”

Alternative damage detection methods
Internal cracking = XF3 ???

CEN/TR 15177 3(3): “CIF”

German Criteria in BAW: $E_{\text{DYNN28}} \geq 75\%$ and possibly also scaling criterium
Concerns regarding Lab/Field Relation

• XF 3:
  • Nos. of F-T cycles must be defined ?!
  • Lab/Field & Scaling (?) criteria: Definition of degree of saturation – in relation to field service conditions - prior to testing ?
  • Slowly developing binders: Develop realistic degree of hydration for the frost exposure “load”, including the influence of carbonation on the moisture exchange and F-T test results
Validation of internal cracking as performance criterion?

- **DAfSt Heft 577 (H.Müller)** (extracts & part-summary;)
  - Degree of saturation in lab test exceeds that of real structures (verified at various depths from the surface)
  - It remains **unclear** to what extent reduction in lab $E_{DYN}$ may be used as a measure for the damage to be expected under real-life conditions in XF3 (and; CIF/ $E_{DYN}$ more frequently exhibits negative classification than Cube Test scaling)
STRAIN - TEMPERATURE CYCLES

Comparison between a frost susceptible and a not frost susceptible concrete

Suitable for product (testing;) criteria ?
Revisiting the moisture issue:
A key issue for Testing Performance - Moisture history, exposure & properties

Some of this w-filled volume would otherwise not be available to capillary suction – but possibly by F-T “pumping” under water.

Independent of hydration development:

- **Standard Curing**
  - Water storage during chemical shrinkage
  - Slower hydration ➤ Increased [Cap. saturation]

[Diagram showing water storage and hydration development over time]

Rønning (2001)
A key issue for Testing Performance - Moisture history, exposure & properties

Carbonation is considered positive to CEM I performance, implying that the plastic curing effect is attributed to the limited moisture exchange.

Rønning (2001)
A key issue for Testing Performance
- Moisture history, exposure & properties

Scaling in 3 % Salt (56 Cycles) vs. Weight Gain
during Resaturation and Freeze-Thaw Test.

Resaturation with Fresh Water.

Mod.Std.: Cutting at age 7 days

Rønning (2001)
Degree of saturation in service …..?

Capillary Degree of Saturation
Mix 305 : Top Surface
(February - April 1998)

In field: Fluctuation of density & UPV but not systematic – when durable

Rønning (2001)
Moisture conditions in field: German XF4 & XF2

bast Heft B70 (F.Tauscher)

Bild 5.6: Verlauf des Sättigungsgrades und der Betontemperatur, die über 3,5 Winter am Brückenpfeiler der Brücke in Berlin, A 10, bestimmt wurden [5]

Bild 5.9: Verlauf von Sättigungsgrad und Temperatur in einem Luftporenbeton in XF2 [5]
HC NOR Test series 1997 – 2016 ..... Salt-Frost-Scaling
Relevance of moisture load significance lab vs field ?

Swedish Cement and Concrete Research
Institute: Peter Utgenannt, Nov. 2016
Typical visual assessment «Degree 1» exhibit (all below)

Filled dots - with air
Unfilled dots - without air
Concrete with W/B-ratio 0.35 - 0.45
SUMMARY
SUMMARY 1 – TECH.

Postulates

• High w/c ► High moisture load ► Pressure relief is critical ► Specific surface & Spacing factor important
• Low w/c ► Less and differentiated moisture load in field ► Specific surface and Spacing factor less obvious relation
• Slow developing binders ► Moisture load is age / mature depended (to a higher extent)
• Effect of pre-curing (options?) on Lab/Field not sufficiently clear, especially for “non-CEM I”: Improve in-field mapping, especially under non-saline conditions!
• Moisture pumping effect – to which level/extent?
• PERFORMANCE TEST should be applicable for qualifying “products” outside prescriptive design rules.
• Prescriptive rules (“deem-to-satisfy”) need to be all-round and conservative (cover all).
SUMMARY 2 - POLICIES

• Some principles are at stake
  • Palette of testing procedures, rather than differentiation of acceptance criteria?
  • Various “min. temp.”?
  • Various $dT/dt$?
  • (Limitations of applicability of testing methods?)
• Concept & criteria for XF3 still missing!
• Needs for product diversification/assessment still not satisfactory – and difficult to meet before testing regime is coherent
• Must combine basic research, and industrial (manufacturers + owners;) and social (environmental & standardisation;) needs
• Expressed interest in Germany, France, Switzerland, Nordic.

We will hardly agree on mechanisms, but PERHAPS on std. exposure?
SUMMARY 3 – Road map advice CEN

- Possibly issue amendment to the CEN/TS (2018?)
  - New RRT based precision data
- Influence research agendas, Organisational:
  - TG 4 to act as information mapping/exchange & co-ordination
  - Key national and intl. projects
  - RILEM TC, for Nord./Eur./Over-seas co-operation?
- Influence research agendas, Content:
  - Exposure conditions vs. moisture load
  - Moisture load field / moisture lab exposure (interruption), $W_F$
  - Non-saline field exposure: Assessment of damage & How to represent (acceleration) in lab
- Framework focus
  - Possible EN 206 Performance concept /Resist. Classes
  - Irrespective of above: Differentiation of severity (classes)
  - Irrespective of above: Low(er) clinker containing cem/concr.
References

- Härdtl, R.: Personal communication, 2018
- Tauscher, F.: Frost-Tausalz Widerstand von Beton in Brücken und Ingenieurbauwerken an Bundesfernstrassen (Freeze-thaw resistance of concrete in bridges and engineering works of federal roads), Berichte der Bundesanstalt für Strassenwesen, Heft B 70 (in German)
- Utgenannt, P.: Project report on testing in commission, Swedish Cement and Concrete Research Institute / RISE, Borås, November 2016