Table 1. Testing for Hardened Concrete Properties (those which affect durability)

Property	Methods	Comments
Permeability	ASTM C 1202 / AASHTO T 277 ("rapid chloride" test)	Measures ionic diffusion, or conductivity, which is close to permeability
Frost resistance (D-cracking, tests aggretates)	ASTM C 666 /AASHTO T 161 Pressure release method Iowa Pore Index Test ASTM C 88 /AASHTO T 104	— — — Magnesium sulfate
Frost resistance (freeze-thaw)	ASTM C 666	—
Frost resistance (salt scaling)	ASTM C 672 BNQ NQ 2621-900	— Bureau De Normalisation du Québec method
Frost resistance (air-void system)	ASTM C 231 / AASHTO T 152 ASTM C 173 / AASHTO T 196 ASTM C 138 / AASHTO T 121 Air-void analyzer (AVA) ASTM C 457	Pressure meter Volumetric Unit weight — —
Sulfate resistance	ASTM C 452 (portland cements) ASTM C 1012 (hydraulic cements)	For cements (mortars) only; none developed for concrete yet.
Alkali-silica reaction (evaluating aggregates)	ASTM C 1293 (preferred test) ASTM C 1260 (rapid test)	Concrete prism Mortar bar
Alkali-silica reaction (evaluating mitigation)	ASTM C 1567 Modified ASTM C 1293	Protocols available from PCA, AASHTO, and ASTM Protocols available from PCA, AASHTO, and ASTM
Abrasion resistance	ASTM C 131 or ASTM C 535 / AASHTO T 96 Acid soluble content ASTM C 779 or ASTM C 944	Los Angeles abrasion test for aggregate (most common test) For aggregate For concrete

National Concrete Pavement Technology Center

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This technical summary is based on chapter 5 of the IMCP Manual (Taylor, P.C., et al. 2006. *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual*, Ames, Iowa, Iowa State University [FHWA HIF-07-004] [www.cptechcenter.org/publications/imcp/]) and was sponsored by the Federal Highway Administration. (References for any citations in this summary are at the end of the chapter.)

CP Tech Center Mission

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.

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Technical Summary

A summary of chapter 5 (pages 105–170) of the *IMCP Manual* (reference information on page 4)

Hardened Concrete Properties (Durability)

This document is one of a set of technical summaries of chapters 1 through 10 of the *Integrated Materials and Construction Practices for Concrete Pavements: A State-of-the-Practice Manual* (IMCP manual). The summaries provide an overview of the manual and introduce its important concepts. To be useful for training, the summaries should be used in conjunction with the manual.

This summary covers the desired hardened concrete pavement properties that influence durability and describes how to optimize these properties to maximize pavement performance.

What are Hardened Concrete Properties?

Hardened concrete properties are those manifested after setting. These properties directly relate to the durability and long-term performance of the system.

Hardened properties can influence a pavement's service life, so they are often a chief concern. Controlling concrete properties in the following ways can help achieve the desired durability characteristics for a concrete pavement:

- Minimize permeability.
- Minimize alkali-silica reaction (ASR).
- Maximize frost resistance.
- Maximize abrasion resistance.
- Maximize sulfate resistance.

Minimizing Permeability

When permeability is minimized, fluids are largely kept from permeating the concrete system, which can slow or prevent subsequent durability problems.

To curtail permeability and the potentially resulting durability issues, the following guidelines apply:

- Keep the water-to-cementitious materials (w/cm) ratio as low as possible (within limits) (0.37–0.45).
- Use supplementary cementitious materials (SCMs) as appropriate (in particular, low-calcium fly ash can reduce permeability).
- Ensure adequate consolidation and curing.
- Minimize cracking (allows fluids to penetrate the surface).

Minimizing Alkali-Silica Reaction

Alkali-silica reaction (ASR) is the result of reactive silicate aggregates reacting with alkali hydroxides (i.e., unbalanced sodium [Na+] and potassium [K+] ions in pore solution) in the presence of water (figure 1). The resulting alkali silicates (ASR gel) expand as they absorb water, causing cracking and reducing the concrete's service life.

To reduce the extent of ASR damage, one or all of the following actions can be taken:

- Choose nonreactive or reactive-nonreactive aggregate blends.
- Select low-alkali cements.
- Incorporate SCMs, especially low-calcium fly ash.
- Consider adding lithium compounds.

Maximizing Frost Resistance

Frost resistance refers to the ability to resist damages caused by winter weather conditions:

- Freeze-thaw damage.
- Salt scaling.
- D-cracking.
- Popouts.

Freezing and Thawing Damage

Freeze-thaw damage is due to water in concrete voids and capillaries that expands as it freezes. This expansion can cause pressures that exceed the concrete's strength and, as a result, cause cracking and increase the concrete system's permeability.

To bolster freeze-thaw resistance, take the following actions:

- Ensure a consistently adequate air-void system (figure 2).
- Use sound aggregates.
- Achieve strengths above 28 MPa (4,000 lb/in^2).
- Avoid poor finishing or curing practices by adhering to the following guidelines:
  - Protect concrete from cold temperatures not favorable for hydration.
  - Do not over-finish.
  - Do not work bleed water into concrete.
- Plan for concrete to have a low degree of water saturation when frost season arrives.

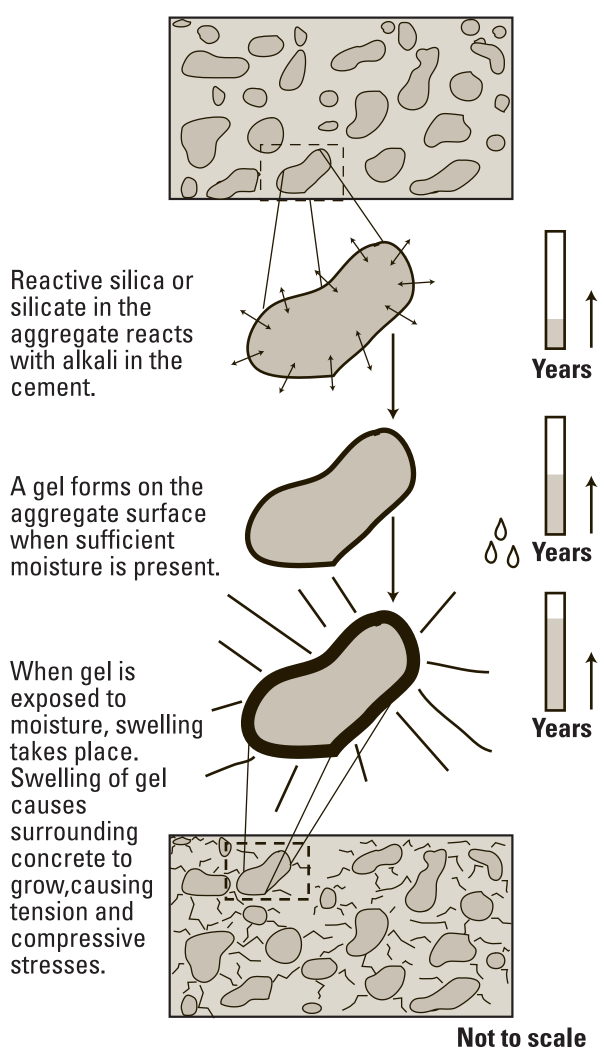

Figure 1. Alkali-silica reaction is an expansive reaction of reactive aggregates, alkali hydroxides, and water that may cause cracking in concrete (adapted from Emmons 1997).

D-Cracking

D-cracking is a serious problem that will compromise the integrity of the concrete. When aggregate is exposed to freeze-thaw cycles, water trapped in the pores expands upon freezing. The expanding water can cause pressures that eventually cause the aggregate particles to crack and deteriorate, resulting in D-cracking.

D-cracks are closely spaced cracks parallel to transverse and longitudinal joints. Over time, these cracks multiply outward from the joints toward the center of the pavement slab to form a characteristic D-shaped crack (figure 3). Although easily identified, D-cracking cannot be stopped once it begins.

To reduce the risk of D-cracking, take some or all of the following measures:

- Select aggregates not prone to freeze-thaw deterioration.
- If marginal aggregates must be used, reduce the maximum particle size.
- Provide a good drainage system that helps potentially damaging water drain out of the concrete pavement system, especially if frost-susceptible aggregates are used.

Salt Scaling

Scaling is a type of physical deterioration aggravated by the use of deicing salts and freeze-thaw cycles (figure 4). Deicing salts can exacerbate frost damage by increasing the number of freeze-thaw cycles and triggering cracking, scaling, and disintegration of the concrete pavement. Deicer scaling is best controlled by following the same precautions as those listed for freeze-thaw damage.

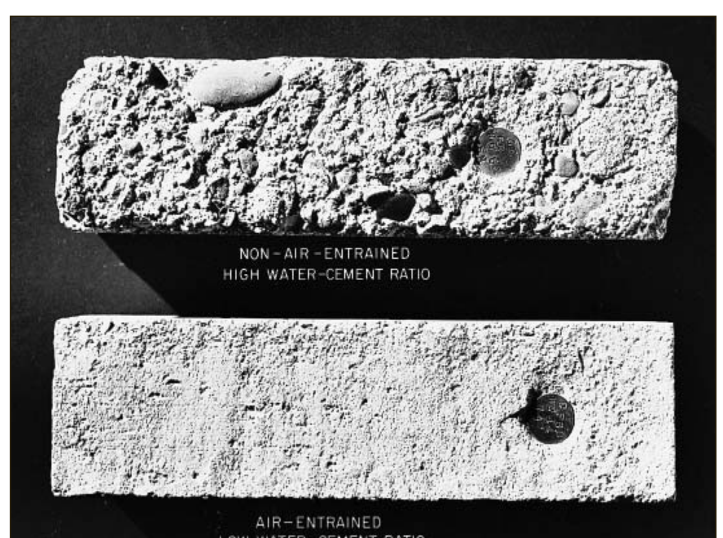

Figure 2. Speciments subjected to 150 freeze-thaw cycles. Air-entrained concrete (bottom bar) is highly resistant to damage from repeated freezing and thawing (by Portland Cement Association).

Popouts

A popout is a fragment that breaks out of the concrete surface, leaving a shallow, typically conical, depression. Unless numerous, popouts are considered a cosmetic detraction that do not usually affect the service life of the pavement. To minimize popouts that can result from freeze-thaw cycle effects, avoid aggregates containing weak, porous particles, which have low weather resistance.

Maximizing Abrasion Resistance

Abrasion resistance refers to concrete's ability to resist surface wear, which is especially important for maintaining skid resistance.

To achieve a concrete system that is resistant to abrasion, take the following actions:

- Select hard aggregates (such as granite or traprock).
- Use concrete with high compressive strength.
- Ensure proper finishing and curing.

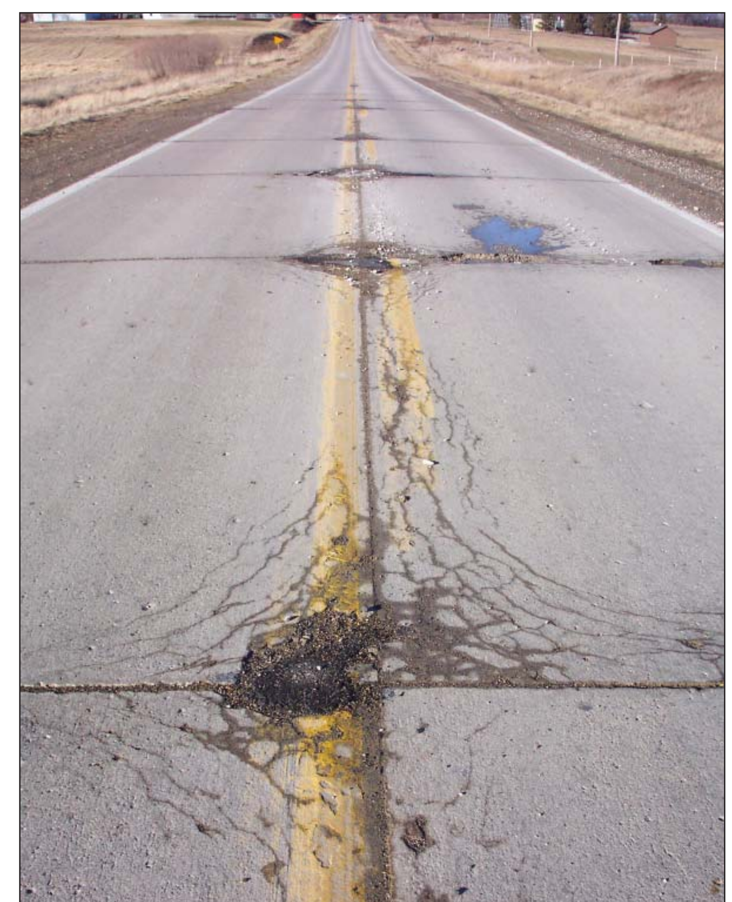

Figure 3. D-cracking multiplies outward from pavement joints.

Maximizing Sulfate Resistance

Sulfate resistance is concrete's ability to resist damage from external sulfates over a period of years. When sulfates penetrate into the concrete system, they react with water and aluminate (C_3A) products, causing loss of strength and sponginess.

To mitigate sulfate damage, the following steps can be taken:

- Use low-aluminate, sulfate-resistant cements, such as Types II and V.
- Appropriately select and proportion supplementary cementitious materials.
- Maintain w/cm ratio of 0.4 or lower.

Evaluating Hardened Concrete Properties

Common test methods for hardened concrete properties that influence pavement durability are listed in table 1.

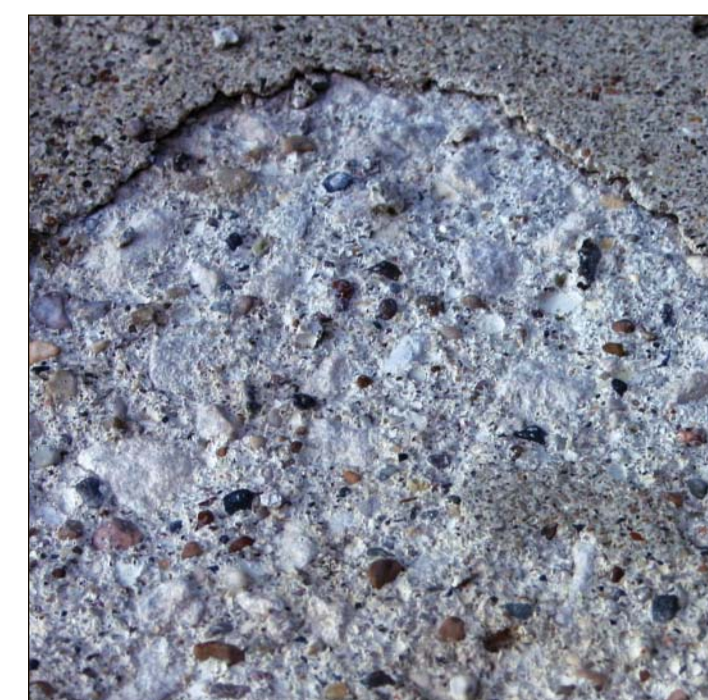

Figure 4. Scaled concrete surface, which is a sign of low frost resistance, results from lack of air entrainment, use of deicers, and poor finishing and curing practices.