Concrete Surface Engineering for Cultural Heritage

Luc Courard
University of Liège, Belgium
Situation of our infrastructure today
Factors contributing to the degradation of concrete structures (BCA, 1997)

- low cover: 12%
- environment: 39%
- poor quality concrete: 16%
- poor quality detailing: 7%
- poor workmanship: 4%
- wrong specification: 2%
- failure joint/waterproofing: 13%
- inadequate conceptual design: 16%
- wrong material selection: 8%
Factors contributing to the failure of repair (Tilly, 2004)

- Incorrect design: 33%
- Material: 18%
- Workmanship: 16%
- Diagnosis: 12%
- Weather (during works): 14%
- Others: 3%
- Unknown: 4%
Concrete churches in Liège county: pathologies

Saint-Hubert
Saint-Francis of Sales
Holy Heart and Our Lady of Lourdes
Saint-Martin
Saint-Vincent
Saint-Virgin Maria
Saint-Juliana
Saint-Georges
Saints Peter and Paul

Corrosion
Cracking
Humidity

Repair: how to select materials?

Condition 1: spreading / wettability
Condition 2: physico-chemical interaction
Condition 3: mechanical interlocking

Principles

(L. Courard, Parametric Study for the Creation of the Interface between Concrete and Repair Products. Mat. Struct., 33 (January-February 2000), 65-72.)
Concept of compatibility for strong, long-lasting adhesion

- substrate
- repair material
- environment

Concrete Surface Engineering

Definition

Scientific and technological approaches addressing all surface-related considerations, notably those pertaining to **adhesion of a surface treatment** intended to improve the properties of the substrate, such as its resistance to corrosion and abrasion, or its aesthetic properties.

Surface engineering covers all phenomena involved in the preparation of the substrate near-to-surface layer and adherence of a surface treatment in given conditions.

Example: hydrophobic treatment

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What is surface concrete, of what is it made?

Skin

Bulk concrete

= \frac{1}{2} d

(with d: maximum size of aggregates)

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What is the effect of water at the interface?

\[ \gamma_{SV} = \gamma_{SB} + \gamma_{BV} \cdot \cos \theta \]

\[ \gamma_{SA} = \gamma_{SB} + \gamma_{AB} \cdot \cos \theta \]

\[ \gamma_{S} = \gamma_{SA} + \gamma_{A} \cdot \cos \theta_{A} \]
\[ \gamma_{S} = \gamma_{SB} + \gamma_{B} \cdot \cos \theta_{B} \]

Equilibrium: the difference between tensions of adhesion is inferior to interfacial tension

\[ \gamma_{B} \cdot \cos \theta_{B} - \gamma_{A} \cdot \cos \theta_{A} < \gamma_{AB} \]

No equilibrium: liquid B will expulse liquid A

\[ \gamma_{B} \cdot \cos \theta_{B} - \gamma_{A} \cdot \cos \theta_{A} > \gamma_{AB} \]

the liquid with the higher tension of adhesion will expulse the other one from the surface

Effect of water at the interface

\[ W_{a_{SL}} = \gamma_{LV} (1 + \cos \theta) \]

(Hygro-thermal application conditions and adhesion. L. Courard, A. Darimont, R. Degeimbre and J. Wiertz. Fifth International Colloquium Industrial Floors ’03, (Ed. P. Seidler, Technische Akademie Esslingen), Ostfildern/Stuttgart, Germany (21-23 January 2003), 137-142)
What are the effects of surface texture (roughness)?

Devices for the measurement of surface texture

**Mechanical profiling**
- Measured area: 200 x 200 mm²
- Stylus shape: truncated cone
- Stylus diameter: 1 mm
- Measurement pitch: 1 mm

**Atos I 3D Digitizer**
- Fringe patterns
- Measured area (range): 120 x 100 - 1000 x 800 mm²
- Spatial resolution: 0.04 - 1 mm

(Combination of mechanical and optical profilometry techniques for concrete surface roughness characterization. F. Perez, B. Bissonnette and L. Courard. Mag. Concrete Res, 61(6) 2009, 389-400)
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Texture (roughness / waviness) vs. Surface preparation technique

- Scabbling
- Shotblasting
- Polishing

Roughness vs. adhesion

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Roughness vs. microcracking

NT – no treatment; WJ – water jetting – pressure 124 psi/250MPa; SB – sandblasting; SCR – scabbling; J+SB – jack hammering of weight 7,14,21 kg + sandblasting

Degradation of historical concrete buildings and monuments

**Causes**
- quality of concrete → evaluation?
- insufficient concrete cover → evaluation?
- freeze-thaw cycles

**Effects**
- corrosion of steel reinforcement by carbonation
- disintegration

**Needs**
- resistance to carbonation
- aesthetics requirements
- water repellency
  
  (+ compatibility issues)