Sulphate Attack on Concrete

Dr. Safeer Abbas
Assistant Professor
Civil Engineering Department
UET Lahore, Pakistan
Sulphate Attack

In foundations and slabs on grade
Sulphate Attack

Many theories often conflicting

Different manifestations and terminology

- Sulfate attack
- Salt crystallization
- Physical salt attack
- Delayed ettringite formation
- Thaumasite formation
- Salt hydrations distress (SHD)
Sulphate Attack

Hydration of Portland Cement

Creates the First Problem — Calcium Hydroxide

Schematic of the Reaction

\[ \text{C}_3\text{S} \] or \[ \text{C}_2\text{S} \] + \[ \text{water} \] → \[ \text{Calcium Silicate Hydrate (C-S-H) (strength)} \] + \[ \text{Calcium Hydroxide (durability problems)} \]
Sulphate Attack

Reaction of $C_3A +$ Gypsum + Water
Produces another Target for Sulphate Attack
Monosulphoaluminate (Monosulphate)

\[
C_3A + 3C\bar{S}H_2 + 26H \Rightarrow C_6A\bar{S}_3H_{32}
\]

\[
2C_3A + C_6A\bar{S}H_{32} + 4H \Rightarrow 3C_4A\bar{S}H_{12}
\]
Early Research on Sulphate Attack

Main Conclusions

- Calcium aluminate ($C_3A$) content of the cement is the main factor influencing sulphate attack
  - The lower the better
  - If sulphates involved, then keep $C_3A$ content to less than 8%
  - Early research led to development of Type 50 cement
Sulphate Attack: Process I:

Expansion Cracking Mechanism:

- Diffusion of Sulphates into Pore Structure
- Chemical Reaction of Sulphates with Calcium Aluminate Compounds
- Tendency for Expansion as Ettringite Tries to Occupy a Greater Volume than Reactants
- Stress Build-up Within the Microstructure
- Cracking
- Spalling, Corrosion, etc.
Normal Mechanism of Sulphate Attack

Permeation of Sulphate Ions, followed by Reaction

- Calcium Hydroxide (hydration product)
- Sodium Sulphate
- Gypsum
- Sodium Hydroxide

Gypsum + Mono-Sulpho-Aluminate (hydration product) + Water → Ettringite

Very large volume expansion
Normal Mechanism of Sulphate Attack

Mechanism I
Chemical Sulphate Attack
Sulphate Attack: Process II

Strength Reduction Mechanism

- Diffusion of Sulphate Ions into Pore Structure
- Chemical Reaction with Calcium Hydroxide to Form Gypsum
- Progressive Undermining of Microstructural Framework due to:
  - Removal of Calcium Hydroxide, porosity increase
  - Moderate Expansion of Gypsum (if sulphate concentration > 1000 ppm)
- Substantial Strength Reduction and Promotion of Cracking
Sulphate Attack: Process II

Mechanism 2
Leaching
& Physical
Attack
Surface Softening (Magnesium Sulphate only)

- Surface Softening due to Reaction between C-S-H and Magnesium Sulphate
  - C-S-H + Magnesium Sulphate
  - Gypsum + Magnesium Hydroxide + Silica Gel
    - Not a binder

- Magnesium Hydroxide Insoluble: may tend to partially seal surface
- Significant strength reduction due to reduction in X-section
Damage due to Salt Crystallization
Damage due to Salt Crystallization
Factors Influencing the Extent of Attack

- **Nature of the Attacking Solution/Environment**
  - concentration of sulphate ion
  - type of cation — sodium, magnesium, etc.?
  - pressure head — permeation & diffusion?
  - moisture (wetting-drying) — capillary suction?
  - temperature (heating - cooling)
  - volume of solution (ions replenished or solution static? — determines pH of solution
  - presence of other ions — e.g. chlorides?
Factors Influencing the Extent of Attack

- Quality of the Material being Attacked
  - proportions (quantity of paste), transition zone
  - degree of hydration (how much CH present), $C_3S$ content of the cement
  - porosity & pore size distribution (permeability)
  - chemistry of cementing materials (calcium aluminates, sulphates, alkalis)
  - chemistry of aggregates (sulphates, alkalis)
  - strength (resistance to disruptive pressures)
  - history (microcracking, etc.)
  - presence of carbonates (limestone fines or $CO_2$)
Consequences of Attack

- Large scale volumetric expansion
- Cracking
- Scaling and spalling due to salt build-up during wetting and drying cycles
Preventing Sulphate Attack

- Produce an impermeable concrete
- Reduce the amount of hydrated calcium sulpho-aluminates
  - reduce $C_3A$ content of cement
    - use Type 50 cement
  - Gypsum still forms (only when sulphate concentration high) but expansion minor compared to ettringite
- Reduce the amount of Calcium Hydroxide
  - use pozzolans, reduce amount of Portland cement
  - reduce the $C_3S/C_2S$ ratio
Concrete Exposed to Sodium Sulphate
Test Methods

- ASTM C1012 and C452 based on continuous immersion of specimen, not a valid representation, measures expansion only
- Field investigations remove evidence due to coring water, water used in cutting, polishing, etc.
Sulphate Attack

Chemical Attack

External Sulphate Enters Concrete System from Outside

Diffusion Into and Within Microstructure

Conditions for Formation of Ettringite at Later Ages

Deterioration

Internal Sulphate Already In Concrete at Casting Time

Heat Treatment (Delayed Ettringite Formation)

Diffusion Within Microstructure

Excess Sulphate (Oversulphated Cementing System)

Conditions for Formation of Ettringite at Later Ages

Deterioration

Physical Attack

Salt Crystallization

Salt Hydration

Deterioration
Thaumasite Form of Sulphate Attack

\[ \text{sulfates} + \text{calcium silicate} + \text{calcium carbonate} + \text{water} \]

\[ \Downarrow \]

thaumasite
\[(\text{CaSiO}_3 \cdot \text{CaSO}_4 \cdot \text{CaCO}_3 \cdot 1 \text{H}_2\text{O})\]
What happens when Thaumasite Form

- The cement paste is converted to a soft mushy mass
- Consistency similar to toothpaste
- Loss of strength and binding ability in the cement paste
- Expansive disruption is not characteristic
Case Studies: UK Bridges