

## Sulfate Attack of Concrete



Chemical attacks on concrete refer to the deterioration and damage caused by various chemical substances that react with components of the concrete. These reactions can compromise the integrity, strength, and durability of concrete structures. One of the most common types of chemical attacks on concrete is sulfate attack.

Sulfate attack causes expansion and cracking in concrete due to the infiltration of  $\text{SO}_4$  ions. As concrete cracks, its permeability increases, allowing water to penetrate more easily and accelerating the deterioration process.

### Types of Sulfate Attack

Sulfate attack in concrete refers to the deterioration and damage of concrete structures caused by the reaction of sulfate ions ( $\text{SO}_4^{2-}$ ) with components of the concrete, primarily the cement paste. This reaction leads to the formation of expansive products that cause internal pressure, resulting in cracking, spalling, and overall loss of structural integrity. Sulfate attack can significantly reduce the lifespan and durability of concrete structures. There are two main types of sulfate attack:

#### 1. External Sulfate Attack:

- Occurs when sulfate ions from external sources, such as soil, groundwater, seawater, or industrial effluents, penetrate into the concrete.
- Common sources include gypsum, sodium sulfate, magnesium sulfate, and ammonium sulfate.
- The sulfate ions react with the hydrated cement compounds, particularly calcium hydroxide and tricalcium aluminate ( $\text{C}_3\text{A}$ ), forming gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) and ettringite ( $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{CaSO}_4 \cdot 32\text{H}_2\text{O}$ ). These products have a larger volume than the original compounds, causing expansion and cracking.

#### 2. Internal Sulfate Attack (Delayed Ettringite Formation):

- Results from sulfate compounds present within the concrete mixture itself, typically due to the use of sulfate-bearing materials like certain types of aggregates or cement.
- This type of attack often occurs at elevated temperatures, where ettringite formation is initially suppressed during the early hydration period and later forms as the concrete cools and becomes saturated with moisture.
- Delayed formation of ettringite leads to internal expansion and cracking similar to external sulfate attack.

### Effects of Sulfate Attack on Concrete:

- **Expansion and Cracking:** The reaction of sulfate ions with hydrated cement compounds, particularly calcium hydroxide and tricalcium aluminate ( $\text{C}_3\text{A}$ ), leads to the formation of expansive products like gypsum and ettringite. These products increase in volume, causing internal stress and leading to cracking and spalling of the concrete surface.
- **Increased Permeability:** Cracking due to sulfate attack increases the permeability of the concrete, allowing more aggressive agents, such as water, chlorides, and additional sulfates, to penetrate deeper into the concrete. This worsens the deterioration process.
- **Loss of Strength:** The expansive forces generated by the formation of ettringite and gypsum can disrupt the concrete matrix, reducing the bond strength between the aggregate and the cement paste. This results in a loss of compressive and tensile strength of the concrete.

- **Spalling and Surface Damage:** The expansion and cracking often cause surface layers of the concrete to break off or spall, leading to rough and uneven surfaces. This not only affects the aesthetics but also exposes deeper layers of the concrete to further attack.
- **Disintegration of Concrete:** Severe sulfate attack can lead to complete disintegration of the concrete. The cohesive properties of the cement paste are compromised, causing the concrete to crumble and lose its structural integrity.
- **Reduction in Durability:** Overall, sulfate attack reduces the durability of concrete structures. The continuous expansion, cracking, and loss of material make the concrete more susceptible to other forms of deterioration, such as freeze-thaw cycles, chloride-induced corrosion, and mechanical wear.
- **Corrosion of Reinforcement:** Increased permeability and cracking due to sulfate attack can allow chlorides and moisture to reach the steel reinforcement within the concrete, leading to corrosion. Corroded steel expands, causing further internal pressure and exacerbating the cracking and spalling.
- **Aesthetic Degradation:** Sulfate attack often results in visible damage such as cracking, spalling, and surface discoloration, which negatively impacts the appearance of the concrete structure.

## Prevention and Mitigation

Sulfate attack of concrete can be prevented or mitigated (lessened) through several measures designed to limit the exposure of concrete to sulfate ions and to enhance the concrete’s resistance to such exposure. Here are three key strategies:

### 1. Use Sulfate-Resistant Cement:

- **Low-C<sub>3</sub>A Cement:** Use cements with low tricalcium aluminate (C<sub>3</sub>A) content, such as Type V Portland cement, which is specifically designed to resist sulfate attack.
- **Blended Cements:** Incorporate supplementary cementitious materials like fly ash, slag, or silica fume to reduce the permeability of the concrete and improve its sulfate resistance.

### 2. Optimize Concrete Mix Design:

- **Low Water-Cement Ratio:** Use a low water-cement ratio to reduce the porosity and permeability of the concrete, making it more difficult for sulfate ions to penetrate.
- **Proper Curing:** Ensure proper curing of concrete to achieve maximum hydration and strength, which enhances durability and resistance to chemical attack.
- **Quality Aggregates:** Use high-quality, non-reactive aggregates to minimize the potential for internal sulfate sources.

### 3. Environmental Control:

- **Soil Treatment:** Modify the surrounding soil to reduce sulfate concentrations or improve drainage to minimize contact with sulfate-laden water.
- **Proper Drainage:** Ensure proper drainage around concrete structures to prevent standing water and reduce exposure to sulfates.

## Can Admixtures Help?

Admixtures can help prevent or mitigate sulfate attack on concrete. Many admixtures work by making the concrete denser and less permeable, which limits the ingress of sulfate ions and other aggressive agents. Some admixtures chemically alter the concrete to make it less reactive with sulfates. For example, pozzolanic materials consume calcium hydroxide, which would otherwise react with sulfates.

**Strengthening the Matrix:** By refining the microstructure and increasing the amount of C-S-H, admixtures strengthen the concrete matrix, making it more resistant to internal expansion and cracking caused by sulfate attack.

Table 1: Types of Admixtures and How They Contribute to Enhancing Sulfate Resistance:	
FLY ASH	Reacts with calcium hydroxide in the cement paste to form additional calcium silicate hydrate (C-S-H), which densifies the concrete matrix and reduces permeability, making it more resistant to sulfate ingress.
SILICA FUME	Highly reactive pozzolan that significantly reduces the permeability of concrete and enhances its durability against sulfate attack.
SLAG CEMENT	Ground granulated blast-furnace slag (GGBFS) undergoes a pozzolanic reaction with calcium hydroxide (a product of Portland cement hydration) to form additional calcium silicate hydrate (C-S-H). This reaction reduces the amount of free calcium hydroxide, which is highly susceptible to sulfate attack, thus enhancing the sulfate resistance of the concrete.
WATER-REDUCING ADMIXTURES	These admixtures reduce the water content in the concrete mix without compromising workability, resulting in a lower water-cement ratio and a denser, less permeable concrete matrix.
SUPERPLASTICIZERS	High-range water reducers (superplasticizers) allow for even lower water-cement ratios, further improving concrete density and sulfate resistance.
AIR-ENTRAINING ADMIXTURES	While primarily used for improving freeze-thaw resistance, air-entraining admixtures can also enhance the durability of concrete by reducing permeability and providing space for expansive reactions to occur without causing damage.