

IMPROVING CONCRETE SULFATE RESISTANCE WITH SLAG CEMENT

Sulfate attack is a common form of concrete deterioration. It occurs when concrete comes in contact with water containing sulfates (SO_4). Sulfates are found in soils, seawater, and wastewater treatment plants. Waterborne sulfates react with hydration products of the tri-calcium aluminate (C_3A) phase of Portland cement, and with calcium hydroxide ($\text{Ca}(\text{OH})_2$) to form an expansive crystalline product called ettringite. Expansion due to ettringite formation causes tensile stresses to develop within the concrete. When these stresses become greater than the concrete's tensile capacity, the concrete begins to crack.

HOW SULFATES DETERIORATE CONCRETE

- Low permeability of the concrete.
- High concentration of the sulfates in solution exposed to the concrete.
- High C_3A cement content.
- Calcium Hydroxide $\text{Ca}(\text{OH})_2$ content.

HOW SLAG CEMENT MITIGATES SULFATE ATTACK

- Slag cement does not contain C_3A , so its addition in concrete dilutes the total amount of C_3A .
- Slag cement reduces concrete permeability, making it harder for sulfates to penetrate into the concrete. Concrete with slag cement will achieve very low permeability results < 1000 coulombs.
- Slag cement reacts with excess $\text{Ca}(\text{OH})_2$ to form additional calcium hydrate gel. This decreases the amount of $\text{Ca}(\text{OH})_2$ in the concrete and reduces the concrete permeability.

MIX DESIGN OPTIONS FOR MITIGATING SULFATE ATTACK

Moderate Sulfate Resistance Equivalent to T-II Cement < 0.10% Expansion

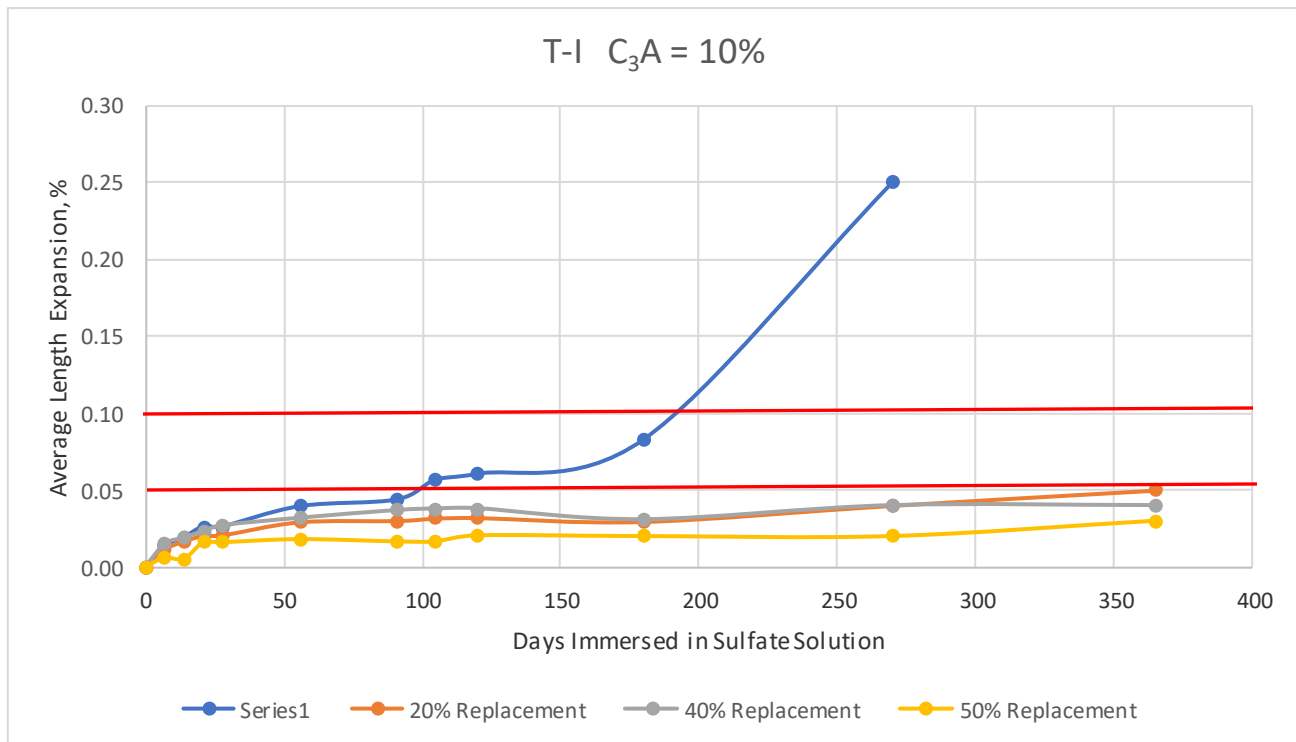
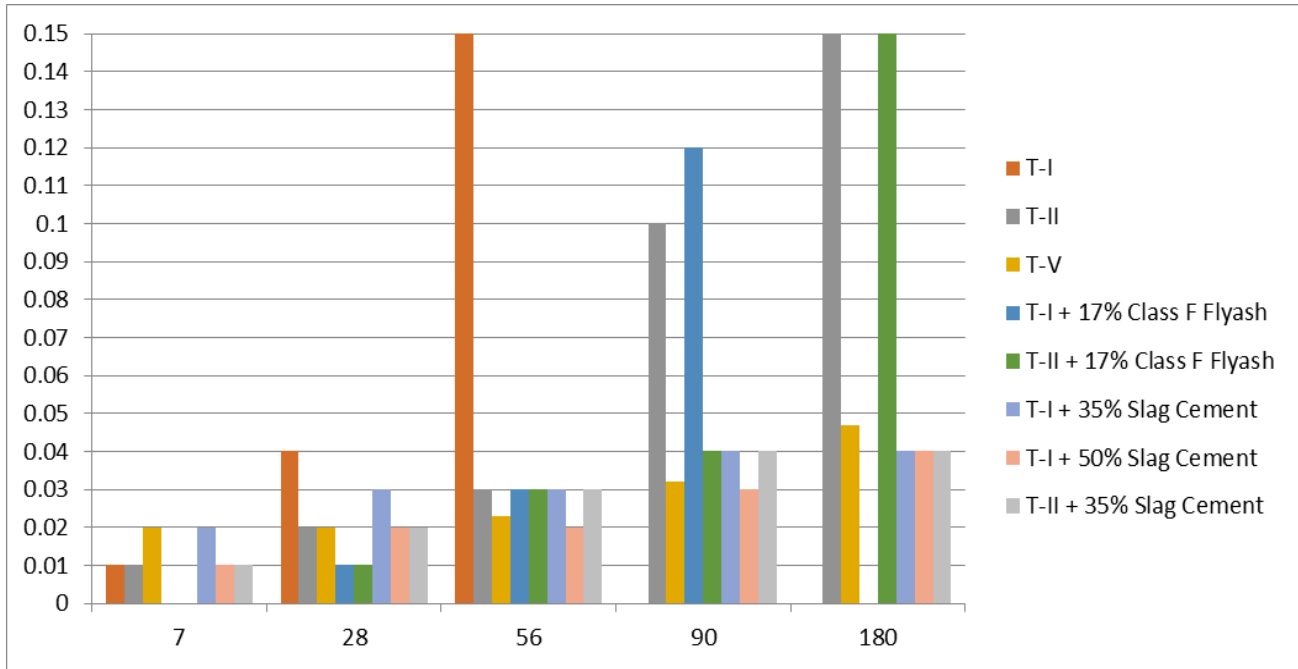
T-I + 25% - 50% Slag cement (varies with C_3A content)

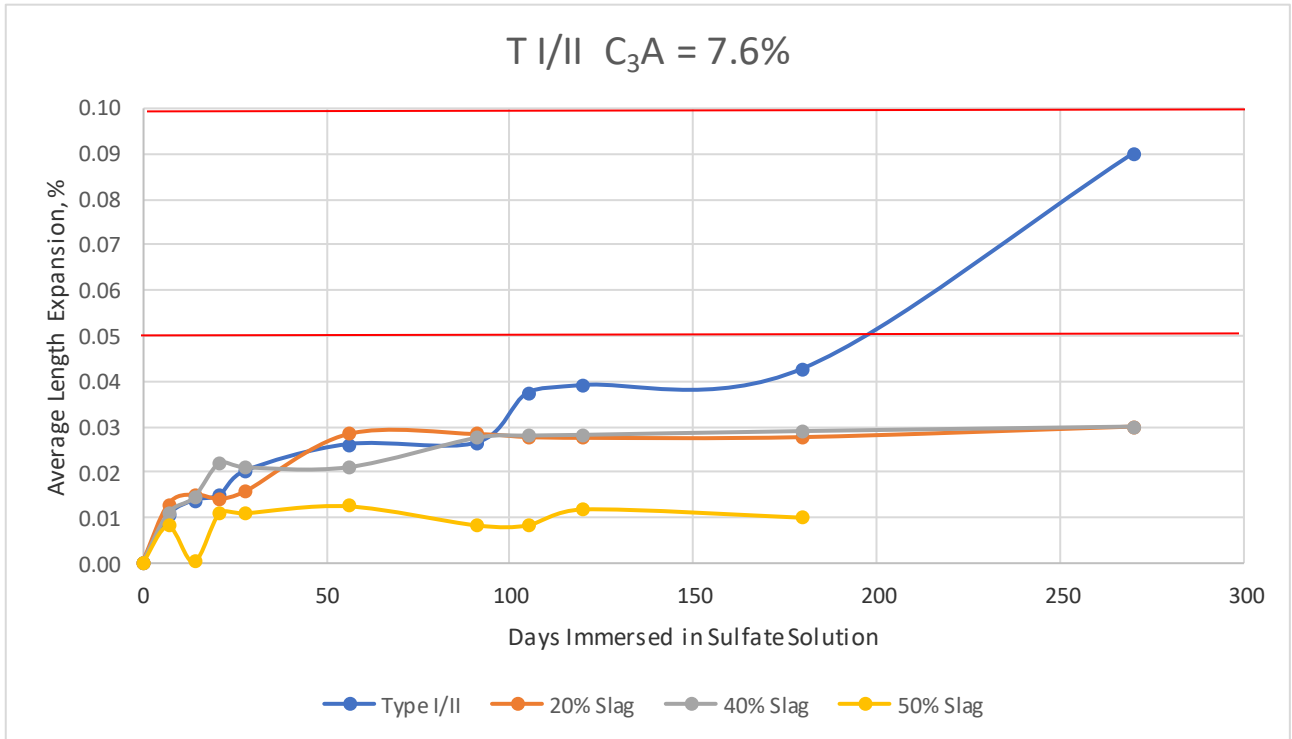
High Sulfate Resistance Equivalent to T-V Cement < 0.05% Expansion

T-I + 50% - 65% Slag cement (varies with C_3A content)

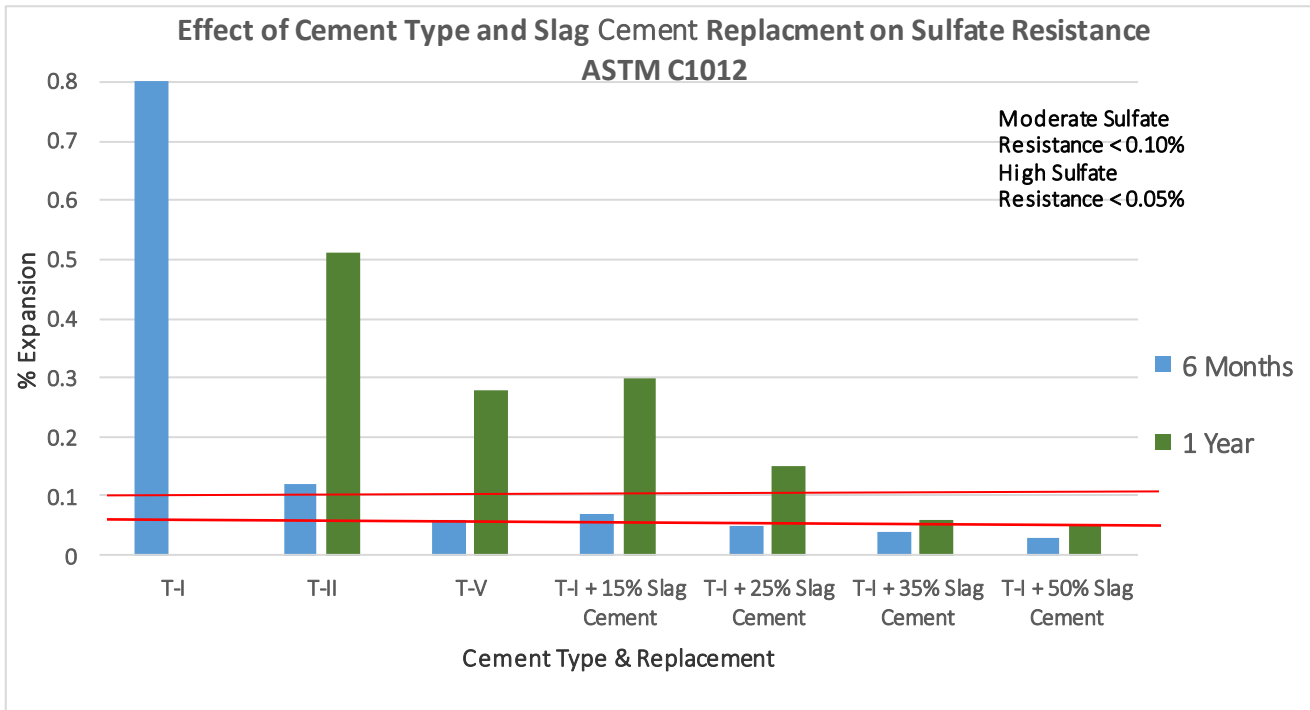
T-II + 35% - 50% Slag cement (varies with C_3A content)

TEST RESULTS





Slag Cement Association



ACI 318 Building Code - Durability Requirements

ACI Table 4.2.1 Exposure Categories and Classes

| S Sulfate | Severity | Class | Water- soluble sulfate (SO ₄) in soil, % by weight | Dissolved% Sulfate (SO ₄) in water, ppm |
|--------------|----------------|-------|---|--|
| | Not applicable | S0 | SO ₄ <0.10 | SO ₄ <150 |
| | Moderate | S1 | 0.10 ≤ SO ₄ <0.20 | 150 ≤ SO ₄ <1500 Seawater |
| | Severe | S2 | 0.20 ≤ SO ₄ ≤ 2.00 | 1500 ≤ SO ₄ ≤ 10,000 |
| | Very severe | S3 | SO ₄ >2.00 | SO ₄ >10,000 |

ACI Table 4.3.1 Requirement for Concrete by Exposure Class

| Exposure Class | Max w/Cm | Min f' _c , psi | Cementitious Mat'ls - Types | | | Calcium Chloride Admixture |
|-------------------|-------------|------------------------------|--------------------------------|--|------------------------------------|----------------------------------|
| | | | ASTM C150 | ASTM C595 | ASTM C1157 | |
| S0 | N/A | 2500 | No Type restriction | No Type restriction | No Type restriction | No Type restriction |
| S1 | 0.50 | 4000 | II | IP (MS), IS (<70) (MS) | MS | No restriction |
| S2 | 0.45 | 4500 | V | IP (HS), IS (<70) (HS) | HS | Not permitted |
| S3 | 0.45 | 4500 | V + pozzolan or slag cement | IP (HS) + pozzolan or slag cement or IS (<70) (HS) + pozzolan or slag cement | HS + pozzolan or slag cement | Not permitted |

ACI Table 4.5.1 Requirements for Establishing Suitability of Cementitious Materials Combinations
Exposed to Water-Soluble Sulfates

| Exposure Class | Maximum Expansion When Tested Using ASTM C 1012 | | |
|----------------|---|--------------|--------------|
| | At 6 Months | At 12 Months | At 18 Months |
| S1 | 0.10% | | |
| S2 | 0.05% | | |
| S3 | | 0.10% | |
| | | | 0.10% |

The 12 month expansion limit applies only when the measured expansion exceeds the 6 month maximum expansion limit.

See ACI 318 Chapter 4 for commentary and additional information.