

*The use of slag cement is an extremely effective way of reducing the potential for sulfate attack.*

*Slag cement reduces the permeability of the paste and prevents the intrusion of aggressive sulfates.*

## WHAT IS SULFATE ATTACK?

**Sulfate attack** is a common form of concrete deterioration. It occurs when concrete comes in contact with water containing sulfates ( $\text{SO}_4$ ). Sulfates can be found in some soils (especially when arid conditions exist), in seawater, and in wastewater treatment plants.

Waterborne sulfates react with hydration products of the tri-calcium aluminate



Figure 1: The Hap Cremeans water treatment plant in Columbus, OH used 30% slag cement with Type II portland cement to achieve sulfate resistance.

( $\text{C}_3\text{A}$ ) 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 in the concrete. When these stresses become greater than the concrete's tensile capacity, the concrete begins to crack. These cracks allow easy ingress for more sulfates into the concrete and the deterioration accelerates. Sulfates also cause chemical disintegration of some of the cement hydration products.

Principal factors that affect the rate and severity of sulfate attack are:

1. Permeability of the concrete.
2. Concentration of sulfates in the waterborne solution.
3.  $\text{C}_3\text{A}$  content.
4.  $\text{Ca}(\text{OH})_2$  content.

## MITIGATING SULFATE ATTACK

One of the most common ways of protecting against sulfate attack is to reduce the alumina content by limiting the  $\text{C}_3\text{A}$  in portland cement. Historically, Type II portland cement (with  $\text{C}_3\text{A}$  between 5 and 8 percent) and Type V portland cement

(with  $\text{C}_3\text{A}$  less than 5 percent) have been specified for moderate and severe sulfate environments, respectively. The use of slag cement is also an extremely effective way of reducing the potential for sulfate attack<sup>1</sup>.

## HOW DOES SLAG CEMENT MITIGATE SULFATE ATTACK?

The use of slag cement reduces the likelihood of sulfate attack in three ways:

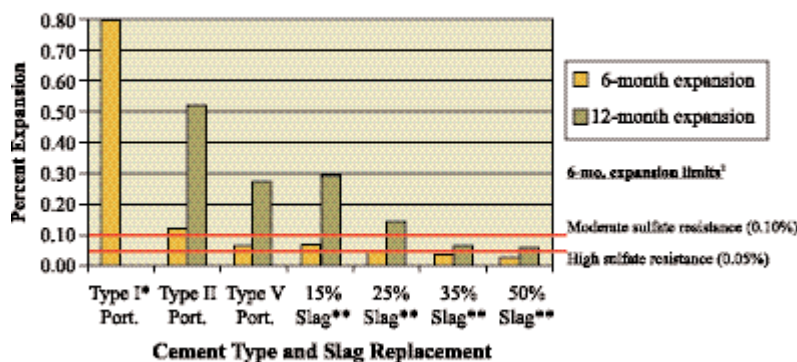
1. Slag cement does not contain  $\text{C}_3\text{A}$ , so its addition in concrete dilutes the total amount of  $\text{C}_3\text{A}$  in the system.
2. Slag cement reduces concrete permeability, making it harder for sulfates to penetrate into concrete.
3. Slag cement reacts with excess  $\text{Ca}(\text{OH})_2$  to form additional calcium-silicate hydrate gel (the "glue" that provides strength and holds the concrete together). This decreases the total amount of  $\text{Ca}(\text{OH})_2$  in the system.

# MITIGATING SULFATE ATTACK

Used in the proper proportions, slag cement can give a Type I cement the sulfate resisting properties of a Type II cement (usually 25 to 50 percent slag cement replacement for portland), and it can give a Type I or a Type II cement the sulfate resisting properties of a Type V cement (usually 50 to 65 percent slag cement replacement for portland).

The sulfate resistance of Type I, II and V portland cements compared with a portland-slag cement combinations, tested in accordance to ASTM C1012, is shown in Figure 2. For this combination of materials, 15 and 25 percent slag cement replacement achieved moderate sulfate resistance, and 35 and 50 percent achieved high sulfate resistance, based on ASTM C989 six month expansion limits.

**Figure 2: Effect of Cement Type and Slag Cement Replacement on Sulfate Resistance (ASTM C1012)**



\*Type I sample failed at 244 days  
 \*\*Slag cement combined with Type I portland

As with all concrete mixtures, trial batches should be performed to verify concrete properties. Results may vary due to a variety of circumstances, including temperature and mixture components, among other things. You should consult your slag cement professional for assistance. Nothing contained herein shall be considered or construed as a warranty or guarantee, either expressed or implied, including any warranty of fitness for a particular purpose.

## References

1. ACI 201.2R-92, *Guide to Durable Concrete*; American Concrete Institute, Farmington Hills, Michigan, 1992.
2. ASTM C1012-95a, *Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution*, American Society for Testing and Materials, West Conshohocken, PA, 2001.
3. ASTM C989-99, *Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars*, American Society for Testing and Materials, West Conshohocken, PA, 2001.

## About the Slag Cement Association...

The Slag Cement Association is the leading source of knowledge on blast-furnace slag-based cementitious products. We promote the increased use and acceptance of these products by coordinating the resources of member companies. We educate customers, specifiers and other end-users on the varied attributes, benefits and uses of these products.

*Slag cement can give a Type I cement the sulfate resisting properties of a Type II cement, and it can give a Type I or a Type II cement the sulfate resisting properties of a Type V cement.*



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