Providing Sulfate Resistance in Severe Exposure Conditions

By Mark R. Lukkarila

Naturally occurring sulfates are common in soils within certain regions of the United States and Canada, especially the western United States and prairie provinces of Canada. The severity of the damage caused by sulfate attack is dependent on the exposure conditions; concrete mixture proportions (water-cementitious material ratio is very important); and quantity of sulfates in the soil, rock, or water. Shotcrete is often in contact with the ground (for example, slope stabilization) or rock formations in mining and tunneling applications. When sulfates are in the soils, water, or rock with which shotcrete will be in contact, it is important to know at what level of sulfate is present. Once the level of sulfate is known, a strategy to mitigate sulfate attack must be developed. Without mitigation, sulfate attack will deteriorate shotcrete over time and may ultimately result in failure.

The primary mechanisms involved with sulfate attack are the formation of ettringite ($CaO \bullet Al_2O_3 \bullet 3CaSO_4 \bullet 32H_2O$) and the formation of gypsum ($CaSO_4 \bullet 2H_2O$). The formation of ettringite can lead to expansion and the formation of gypsum can lead to softening of the concrete paste and loss of strength.

In specifications, the ASTM C150 cement type that is specified depends on the severity of the sulfate exposure. Soils are classified as Exposure Classes S0, S1, S2, or S3. Exposure Class S0 is the least severe and there are no limitations on cement type. Exposure Class S3 is the most severe. Many specifications still require the use of Type V portland cement or Type V combined with a supplementary cementitious material (SCM) for concrete in the most severe sulfate environments (S3). Prior to 2008, Type V portland cement combined with a pozzolan was the only option in ACI 318, "Building Code Requirements for Structural Concrete and Commentary,"[1] for Exposure Class S3.

Type V portland cement will always be an excellent option for mitigating sulfate exposure. There are instances, however, when concrete suppliers have limited silo space or Type V portland cement is not readily available. Ready mix suppliers that use Type I or Type II portland cement for the bulk of their work would need to replace the Type I or Type II in one of their silos with a Type V for their concrete mixtures if they do not have the silo capacity to accommodate an extra cement.

In 2008, ACI 318 was revised to allow alternatives to specifying or using Type V portland cement when Exposure Class S3 conditions are encountered on a project. This involves using blended hydraulic cement or a Type II, Type III, or Type V portland cement in combination with an effective SCM to mitigate sulfate attack.

The provisions in ACI 318-11 list the types of cementitious materials allowed for the different exposure classes. For the most severe class (S3), Table 4.4.1 lists ASTM C150 Type V plus a pozzolan or slag, ASTM C595 Type IP (high sulfate resistance) or Type IS (HS) plus a pozzolan or slag, or an ASTM C1157 HS blended cement plus pozzolan or slag. However, Table 4.5.1 allows for alternative combinations of cementitious materials in lieu of Type V for sulfate exposures in Section 4.5 (Fig. 1). A suitable alternative to Type V combined with an SCM for Exposure Class S3 is determined by performing an ASTM C1012/C1012M test for a period of 18 months. If the expansion after 18 months is less than 0.1%, the cementitious system is considered a suitable alternative to Type V with a pozzolan for Exposure Class S3.

The use of pozzolans in the concrete mixture as a partial replacement of portland cement has several benefits. One of the most important is the reduction in permeability of the hydrated cementitious paste. Sulfates can attack concrete through physical and chemical mechanisms. The ability of hardened concrete to resist the ingress of aggressive solutions such as sulfates will greatly increase the service life of the concrete in severe environments. Pozzolans react with calcium hydroxide, a product of cement hydration, and form calcium silicate hydrate. The calcium silicate hydrate produced during the reaction between the pozzolan and calcium hydroxide continues to fill pore space in the hydrated cement paste over time. This greatly reduces the permeability of the concrete.

The partial replacement of Type II portland cement with a pozzolan also reduces the C_3A

4.5 — Alternative cementitious materials for sulfate exposure

4.5.1 — Alternative combinations of cementitious materials to those listed in Table 4.3.1 shall be permitted when tested for sulfate resistance and meeting the criteria in Table 4.5.1.

TABLE 4.5.1 — REQUIREMENTS FOR ESTABLISHING SUITABILITY OF CEMENTITIOUS MATERIALS COMBINATIONS EXPOSED TO WATER-SOLUBLE SULFATE

Exposure Class	Maximum expansion when tested using ASTM C1012		
	At 6 months	At 12 months	At 18 months
S1	0.10 percent		
S2	0.05 percent	0.10 percent*	
S3			0.10 percent

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

R4.5 — Alternative cementitious materials for sulfate exposure

R4.5.1 — In the 2008 version of the Code, ASTM C1012 is permitted to be used to evaluate the sulfate resistance of concrete mixtures using alternative combinations of cementitious materials to those listed in Table 4.3.1 for all classes of sulfate exposure. More detailed guidance on qualification of such mixtures using ASTM C1012 is given in ACI 201.2R.[4.6] The expansion criteria in Table 4.5.1, for testing according to ASTM C1012, are the same as those in ASTM C595 for moderate sulfate resistance (Optional Designation MS) in Exposure Class S1 and for high sulfate resistance (Optional Designation HS) in Exposure Class S2, and the same as in ASTM C1157 for Type MS in Exposure Class S1 and Type HS in Exposure Class S2.

Fig. 1: ACI 318-11 requirements for alternative cementitious materials for sulfate exposure[1]

content of the cementitious component of the concrete mixture. This is important because C_3A is known to be a contributing factor to sulfate attack. It is important to note that most specifications do not allow the use of Class C fly ash. The reason for this is that Class C fly ash contains a significant quantity of C_3A.

The importance of a strategy for mitigating sulfate exposure cannot be overstated. Contact a consultant or your shotcrete material supplier to determine what materials and shotcrete mixture proportions would be appropriate for the anticipated exposure conditions.

References

1. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary," American Concrete Institute, Farmington Hills, MI, 2011, 503 pp.

2. ASTM C1012/C1012M-13, "Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution," ASTM International, West Conshohocken, PA, 2013, 8 pp.

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