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Do the geometry and aggregates size influence external sulfate attack mechanism?

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HIGHLIGHTS

- Five specimen geometries and three granular skeletons were studied.
- Tested specimens followed the same expansion path whatever the geometry.
- Influence of specimen geometry and aggregates size on formed sulfate-rich phases.
- Common correlation between leached and precipitated volume variations.
- Cylindrical geometry is recommended for performance testing.

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ABSTRACT

ESA performance testing protocols are mainly a set of exposure conditions, monitoring strategy, and specimens configuration. Although the large feedback on the representativeness of exposure conditions and the relevance of monitored parameters, the effect of specimen configuration still deserved to be studied. In order to investigate the effect of composition and geometry on ESA degradation progress and performance evaluation, an experimental campaign was conducted in this study. Among the 8 tested specimen configurations, 5 geometries (prismatic, cylindrical and 3 hollow cylindrical geometries) and 3 compositions (concrete, concrete equivalent mortar and standard mortar), the cylindrical mortar specimen was selected as the most adapted configuration, in term of ESA degradation expression, for the adopted performance testing procedure. The different configurations lead to the same overall mechanism of degradation but the geometry and the composition influenced the magnitude of some chemical or physical degradation parameters, due to couplings between chemical and mechanical degradation.

1. Introduction

Sulfates present in groundwater or soils surrounding a concrete structure seriously affect its durability. In order to design the most durable structure with the lowest maintenance costs, durability specifications take progressively larger sections in standards. Different kinds of durability specifications have been established. Prescriptive or "deemed-to-satisfy" approaches were first adopted in standards. They consist in recommending mixtures that have been already tested on sites for long time and showed an acceptable durability when exposed to environmental actions. However, new cement and concrete mixtures are being developed by cement and concrete industries to meet new technical and environmental requirements. These cement-based materials cannot be qualified using the prescriptive approach. Thus new technologies are needed to follow the rhythm of innovation in the construction industry. Numerous laboratory studies have been conducted to optimize testing procedures and related indicators and develop reliable performance-based specifications [1–5].

The sulfate resistance level of cements can be assessed by preparing realistic concrete specimens and exposing them to conditions which are representative of field conditions. Unfortunately, unless the concretes are of low quality (high W/C, poorly compacted) several years of exposure is required to provide any meaningful discrimination between resistant and non-resistant cements [6,7]. Consequently there is a need for accelerated test procedures or analysis to provide reliable assessment within a timescale of weeks or months.

Many configurations of external sulfate attack (ESA) performance tests were developed, showing various combinations of exposure conditions, monitoring strategies, and specimen

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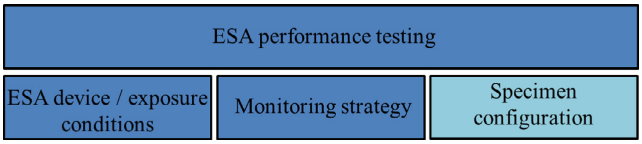

Fig. 1. Main parameters of ESA performance testing.

compositions and geometry (Fig. 1). Some existing experimental ESA protocols are described in standards ASTM C1012, GOST 4789 prescribed protocols, and others adopted at national level such as SVA, Wittekindt (VDZ modified) (1960), Koch and Steinegger, SIA 262/1 protocols [8], etc.

Exposure conditions

In typical ESA performance tests as described in the literature [9–11], the specimens are exposed to aqueous solutions of magnesium, calcium, or sodium sulfate of various concentrations. The temperature and sometimes the pH are controlled. The specimen is exposed to wet/dry cycles, to partial immersion, or to continuous immersion, involving different mechanisms of degradation [12–14].

Monitoring strategy

The expansion of samples exposed to sulfate solution forms till present the most widely adopted performance criterion for the durability classification, in addition to other familiar parameters monitoring such as mass, compressive strength, flexural strength and specimens visual appearance. Nondestructive techniques such as elastic dynamic modulus and ultrasonic pulse velocity are also used [15–19]. For the new cements incorporating supplementary materials (especially slag and fly ash) microscopic chemical degradation are likely to become more pronounced in the degradation process without revealing macroscopic manifestations as swelling. Thus monitoring strategies have been oriented towards microscopic analysis through DRX, TGA, SEM and EDS [20,21]. Other monitoring approaches consist of the combination between macroscopic and chemical monitoring parameters to estimate microscopic evolutions [22]. The analysis performed in this study allows to describe the ESA degradation mechanism from the mineralogical evolutions to mechanical damage of the specimens induced by crystallisation pressure [23], in a way to get general indicators of the performance of tested materials [24].

Configuration of specimens

Many specimen compositions such as cement paste, mortar or concrete are adopted in the existing performance tests. They depend on the objective of the study, the monitoring procedure, and existing experimental devices specifications. For microscopic mineralogical characterization for example, aggregates-free compositions are more adapted [25]. During ESA, the cement paste reactivity is mainly responsible of the physicochemical properties evolution at the different scales. The various granular skeletons induce different pore networks and different interfacial transition zones (ITZ) between aggregates and paste impacting the ions transport and physical properties inside the specimens.

Different geometries and sizes of specimens are used. Prismatic, cylindrical even spherical specimens of various dimensions were actually designed [3,26]. Even molds and casting methods induce different types of heterogeneities. Physicochemical and mechanical heterogeneities are likely to influence specimen performances even for a given tested composition under controlled exposure conditions.

Composition and geometry of tested specimens are major parameters related to the tests acceleration in literature, without paying enough attention to their influence on the ESA mechanism and the assessment of cementitious materials durability, which is the objective of the study presented in this paper. The configurations of ions transport actually depend on specimens geometries and compositions, thus different thermodynamic equilibrium could be set inducing different mineralogical evolutions inside the specimens.

Despite many studies and research projects aiming to develop relevant ESA experimental performance tests, the definition of tested specimens has not come to a consensus among concerned research committees. For instance, European Committee of Standardization / Technical committee 51 (CEN / TC51) has provided guidelines in CEN / Technical Report 15697:2008 [27]. In this report over then 250 papers and reports published during the period 1970–2006 were identified to assess the different sulfate resistance techniques employed and their possible influence on the cement performance evaluation. The objective of this report was to review existing performance specifications and test methods on sulfate attack, to provide the technical basis for improved performance standards, and to provide criteria for evaluation, selection, and use of cementitious materials for sulfate attack resistance. The main experimental choices made in the experimental study, such as exposure conditions and monitoring strategy, are in agreement with their recommendations. The influence of composition and geometry of tested specimens on the chemical and physical evolutions induced by the main phenomena of ESA were assessed through the method designed by Massaad et al. [24].

First the experimental program is described. Five specimens geometries and three compositions were studied in this work. The exposure conditions were characterized by controlled pH and realistic sulfate concentration [3]. Then the main steps of monitoring strategy approach and indicators are defined [24]. The analysis and discussion of the experimental results first deal with the effect of geometry then aggregate size. For each parameter some recommendations are finally given.

2. Experimental program

Five geometries of specimens and three compositions were studied in this work. The variation of these parameters is likely to influence the behavior and relative performance of specimens,

Table 1
NSR cement composition.

Clinker composition													
	C_3S				C_2S				C_3A			C_4AF	
(%)	67.9				13.1				6.4			10.4	
Cement chemical composition													
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	SrO	TiO_2	P_2O_5	MnO	Cl
(%)	19.4	5.1	2.9	63.1	1.8	3.6	0.9	0.2	0.1	0.3	0.3	0.1	0.079