



The use of calcium sulfoaluminate cement to mitigate the alkali silica reaction in mortars

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HIGHLIGHTS

- Calcium sulfoaluminate cement has a low alkali content and low pH.
- An alkali silica reaction test is adapted to study this reaction with both cement.
- An expansion measurement and microstructural observation were conducted.
- Calcium sulfoaluminate cement is a good candidate to mitigate the alkali silica reaction.

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ABSTRACT

The mitigation of the alkali silica reaction in concrete has been the interest of many studies by using low-alkali cement or supplementary cementitious materials. In this paper, calcium sulfoaluminate cement, characterized by its low alkali content and low pH, is used as a mean to reach this goal.

Therefore, the main objective is to verify if the composition of a sulfoaluminate cement paste can mitigate the alkali silica reaction compared to that of a Portland cement. The reactive flint aggregate from north of France was used to initiate the alkali silica reaction phenomena with two types of cements: Portland cement CEMI 52.5 N from Holcim, and calcium sulfoaluminate cement Alpenat from Vicat. Alkalis were added by introducing NaOH or NaCl in the mortar mixing solution; six mortars were made. Two references – with Portland or sulfoaluminate cement – without addition of extra amount of alkali, and the four other mortars with either NaOH or NaCl. The results show that, for the reference mortars non expansion/alteration has been detected during the test duration of 140 days. For Portland cement mortar, with same alkali content but coming from two different sources (NaOH or NaCl), the expansion is almost the same. The expansion measurements show that the using of calcium sulfoaluminate cement can mitigate the alkali silica reaction in mortars by reducing its expansion 7 times compared to that of Portland cement mortars. This result was confirmed by the microstructural observations, where the frequency of the alterations – due to the alkali silica reaction – is much less in sulfoaluminate based mortars than the one of the alterations in Portland based mortars.

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1. Introduction

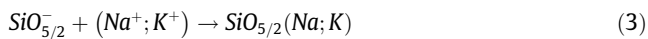
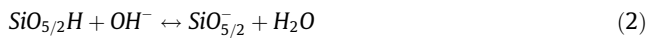
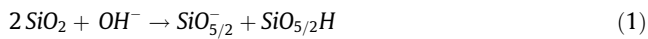
The alkali silica reaction (ASR) is the most widespread form of the alkali aggregate reaction (AAR). This reaction was first identified by Thomas Stanton in 1940s in the state of California [1,2]. The ASR is a deleterious reaction that affects the durability of concrete structures. This chemical reaction takes place between

hydroxyl ions present in the pore solution of hydrated cement paste and certain reactive siliceous phases present in some aggregates used in concrete [3–5]. The product of that reaction is called ASR gel. Different mechanisms can explain the expansion and cracking of concrete elements such as the theory of imbibition pressure [6–8], the theory of ion diffusion [9] the theory of crystallization pressure [10], the theory of gel dispersion [11], and the theory of electrical double-layer repulsion [12]. The mechanism of ASR has been described using different models [3,5,13–15]. This process is essentially designated by three main steps [16]:

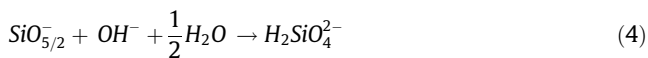
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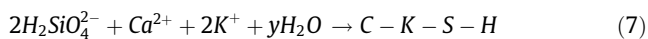
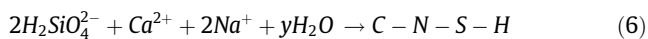
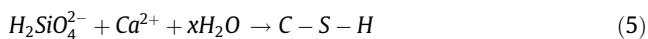
- Step 1: The first stage of the ASR is when reactive forms of silica are exposed to the highly alkaline solution. The OH^- ions present in the pore solution, attack the aggregate silanol and siloxane groups (Eqs. (1)–(3))



- Step 2: The continuous attack of the silanol groups by OH^- ions present in the pore solution results in formation of dissolved silica ions (Eq. (4))



- Step 3: Precipitation of silica ions by the cations of the pore solution of concrete is liable to C-S-H and/or C-(N,K)-S-H phase formation, in the $(\text{H}_2\text{SiO}_4)^{2-}$ case (Eqs. (5)–(7))



The presence of Portlandite, $\text{Ca}(\text{OH})_2$, is also considered as an important factor that has an influence on the expansion due to ASR. In fact, $\text{Ca}(\text{OH})_2$ acts as a source for OH^- and Ca^{2+} ions. Therefore some of the alkali incorporated in silica gel may be replaced by Ca^{2+} ions, which were then recycled into the concrete pore solution [2].

Many studies have been conducted to mitigate the ASR reaction in concrete, and to give recommendations on how to prevent dangerous consequences of this reaction, such utilization of low-alkali cement, limitations of the alkali content of the concrete, and incorporation of supplementary cementitious materials SCM [8,15,17]. Thomas (2011) shows that SCMs control expansion due to ASR by binding alkalis and limiting their availability for reaction with alkali-silica reactive aggregate [15]. Another method to reduce the ASR is the addition of lithium salts. Bulteel et al. (2010) demonstrated that lithium ions have an inhibitor role on ASR due to the small quantities of ASR products formed [18,19]. Chatterji et al. (1979) showed that the expansion due to ASR could be mitigated by leaching out of the $\text{Ca}(\text{OH})_2$ from concrete. Also, it was observed that the reactive silica did not cause any severe expansion if there was no calcium available in the binder [20]. Chappex and Scrivener (2012) showed that increasing the aluminum in the Portland pore solution – by adding aluminum rich SCM (Metakaolin) – can reduce the dissolution of disordered silica even in high pH solutions restricting therefore the ASR [21,22]. The authors showed also, that this fact is due to the absorption of the aluminium on the surface of the silica in the aggregates. In addition, Abbas et al. (2017) showed that increasing the alumina content by partial substitution of Portland cement with rice hush reduce the ASR [23]. This reduction is attributed to the formation of calcium alumino-silicate hydrate (C-A-S-H) gel, which helps to increase the alkali binding capacity leading to reduce the release of alkalis. The same result is obtained when glass powder is added to as a cementitious material to the concrete [24,25].

Here, in this paper, the main objective is to verify if the composition of calcium sulfoaluminate (CSA) cement paste can mitigate

the ASR of an aggregate known for its reactivity in ordinary Portland cement (OPC).

Today, no work on the behavior of CSA cement with respect to ASR has been done. This type of cement appears interesting to be used in the study of ASR because of the following characteristics:

- CSA cements are known to not contain a large amount of alkali, therefore the quantity of this latter supplied by CSA cement is negligible [26,27].
- The amount of Portlandite produced during the hydration of CSA cement is very low, due to the absence of C_3S and small quantities of C_2S present [28,29]. As mentioned before, the presence of Portlandite could increase the ASR [2,20].
- Consequently, the pH of the interstitial solution of the CSA cement is much lower than that of OPC [30–37]; it has been shown that the pH of the pore solution has an influence on the progress of ASR [38]. Furthermore, the lower pH of the CSA cement pore solution, suggests that ASR would be less important in contact with a CSA cement paste [39].

Therefore, two main questions were asked in this article:

- 1) Are the tests (standardized or not) used for the study of ASR with OPC suitable to investigate this reaction with CSA concrete?
- 2) Would a reactive aggregate be as reactive with CSA cement as with OPC?

In order to answer these interrogations, the experimental conditions must be adapted in order to study – in a comparative way – the ASR of a reactive aggregate on mortars realized either with OPC or with CSA cement.

2. Experimental investigation

2.1. Materials

2.1.1. Reactive aggregate used

The material used in this study is a flint-type reactive aggregate coming from the north of France. The aggregate described by Bulteel et al. (2002, 2004) [16,40] has the following characteristics. X-ray fluorescence examination gives a composition close to 99% SiO_2 and X-ray diffraction of the aggregate detected only quartz lines [16]. This latter is mainly present in the form of micro/crypto quartz and chalcedony. These phases are known to be very reactive.

The aggregate is crushed and ground to obtain a [0.16–5 mm] size distribution using sieves in order to replace the natural sand in the mortar. Then, the recomposed sand is washed with water to remove the fine particles (<0.16 mm). This step is essential, given that those particles can mitigate the ASR. Finally, the recomposed sand was dried at 100 °C during 24 h.

2.1.2. Cementitious materials

Two types of cements were used in the mortar formulations. The ordinary Portland cement CEMI 52.5 N from Holcim (OPC) (density of 3.1 g/cm^3 and Blaine fineness of 4300 cm^2/g) and the sulfoaluminate cement Alpenat from Vicat (CSA) (density of 3.01 g/cm^3 and Blaine fineness of 4650 cm^2/g). The composition of these two cements is represented in the Tables 1 and 2 for OPC and CSA cement respectively. The alkali content ($\text{Na}_2\text{O}_{\text{eq}}$) in CSA cement is 2 times less than in OPC. It is value corresponds to 0.34 and 0.77% by weigh of $\text{Na}_2\text{O}_{\text{eq}}$ for CSA cement and OPC respectively.

2.2. Methodology

2.2.1. Mortar design

The mortar formulation is based on a part of the mortar test: AFNOR P 18-594 (2015) [41] with some modifications. First, the mortars are cured in a bath at 60 °C and 100% relative humidity until the testing date, instead of autoclaving at 127 °C for 5 h. This condition is chosen according to a previous study [42]. The latter shows, that under this condition of curing, the percentage of 2.83 $\text{Na}_2\text{O}_{\text{eq}}$ is enough to generate an expansion. Therefore, in our study, 2.83% of $\text{Na}_2\text{O}_{\text{eq}}$ is applied instead of the 4% as indicate by the standard. Regarding the standard, the increasing of $\text{Na}_2\text{O}_{\text{eq}}$ percentage in order to initiate the ASR is done by adding NaOH to the mixing solution. In all previous studies, this test was applied with OPC [42,43].

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