



# The effect of trass and fly ash in minimizing alkali-carbonate reaction in concrete



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## HIGHLIGHTS

- Trass as cement replacement can reduce carbonate alkali reactivity.
- The compressive strength increased with using trass and fly ash up to 20%.
- Based on petrography, trass cannot control the reactivity in the long-term.
- The optimum percentage of fly ash to reduce ACR expansion was 20%.
- The size and the shape of aggregates can affect their reactivity effectually.

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## ABSTRACT

The influence of natural pozzolans on the controlling of the alkali-carbonate reaction (ACR) and the alkali-silica reaction (ASR) has not been studied comprehensively, regardless of the research studies conducted on utilizing natural pozzolans as supplementary cementitious materials. Nevertheless, the performance of natural pozzolans toward the ACR and ASR was investigated in recent studies. The primary purpose of this research is to evaluate the alkali-carbonate expansion of mortar specimens, which contain trass and fly ash in the short-term. For the short-term, the extent of expansion due to ACR was monitored for fourteen 7-day intervals. Based on the test result, fly ash and trass meaningfully reduced the expansion due to ACR in the short-term. Moreover, long-term test results for trass were presented as well. For the long-term, samples were kept at 80 °C in NaOH solution for curing in 56 days according to ASTM C1260 and 390 days according to ASTM C1293. The observations by optical microscopy have been conducted on thin sections.

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## 1. Introduction

Concrete durability against alkali-carbonate reaction (ACR) is one of the biggest problems in the long-term durability of concrete. The ACR is mainly the interaction of cement alkalis with argillaceous dolomitic limestone. This should be differentiated from the reactions of siliceous limestone, which are noticeable in alkali-silica gel and cracking due to the attack of basic solutions on the siliceous component of the aggregate [1]. The dividing line between the alkali-carbonate and alkali-silica reactions is not clear in many studies. The alkali-carbonate reaction is not as common as the alkali-silica reaction (ASR); however, ACR might be suspected wherever argillaceous dolomitic rocks are interbedded with other

types of dolomite or limestone [2]. Some researchers explored the sorption and expansion isotherms of the dolomitic limestone, and they found a sign of a gel-like material, and concluded that the mechanism was similar to ASR [3]. Tetsuya Katayama observed that ASR may play a role in the ACR and is involved in the ACR expansion and deterioration of concrete. He believed that ACR was a particular case of ASR [4,5]. This finding was confirmed by research by Grattan-Bellew [6]. In another study, researchers observed that the ASR can still happen in some non-siliceous carbonate rocks even with low contents of SiO<sub>2</sub> [7]. They noted that in carbonate rocks containing microcrystalline or cryptocrystalline quartz it is hard to prove that the deterioration is caused by ASR or ACR. Recently, researchers have used low alkali cement and pozzolanic materials to prevent the expansion in carbonate rocks [8,9].

Natural pozzolans are available in limited regions of the world. Chemical properties and the pozzolanic activities of natural

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pozzolans may vary with respect to the source [10]. All natural pozzolans are not equally effective in mitigating ACR and ASR expansion. Therefore, researchers need to evaluate natural pozzolans and their performances on the concrete. Typically, blended cement containing 35%, 45%, and 55% natural pozzolan shows outstanding performance for controlling the expansions caused by ACR and ASR [11]. Natural pozzolans are categorized depending on the rate of lime absorption. The trass is excavated from the volcanic tuff deposits, which are pyroclastic rocks that are made from volcanic eruptions. The pozzolanic activity of these materials is related to their siliceous ingredients and to their physical effects. The volcanic tuff hardens in reaction with water and lime [12]. Several research studies investigated the incorporation of natural pozzolans, such as trass and reported that they are certainly suitable as active fillers. However, there are still some issues like mixture proportion, manufacturing methods, long-term properties, and durability [13–16]. These natural pozzolans might be used in industries instead of other natural pozzolans due to their high amount of active silica and alumina content. The effect of trass on mitigation of alkali-carbonate and alkali-silica reaction has not been studied thoroughly, in spite of the limited research studies conducted on the use of natural pozzolans as a cement replacement in concrete.

Various methods of controlling ASR were recommended, such as utilization of low-alkali cement, limitations of the alkali content of the concrete, and incorporation of supplementary cementitious materials [17]. SCMs control expansion due to ASR by binding alkalis and limiting their availability for reaction with alkali-silica reactive aggregates [18]. The practice of fly ash and trass replacement with Portland cement has been effectively used to mitigate ASR expansion [19]. The effectiveness of the fly ash and trass depends on their composition. The performance tests should be conducted in the laboratory to evaluate the properties of SCMs. In principle, two groups of performance test methods exist, one using mortar bars and the other using concrete prisms [17]. It should be noted that the test conditions, such as temperature, alkali content, and humidity, have to be considered in different conditions.

The performance of fly ash in controlling expansion depends on alkalinity in the solution saturating the concrete pores and the availability of calcium content in the system. The existence of calcium has been debated, and the mechanisms are poorly understood [20]. Usage of enough fly ash has shown to be effective to stop development of ASR in concrete with aggregates showing a pessimism [17]. In binders containing fly ash, the C–S–H phases are low in calcium due to the pozzolanic reaction. In the study by Thomas, the effect of moderate levels (e.g. 20–30%) of low-calcium Type F fly ash in mitigating ASR was evaluated by the long-term field performance besides laboratory experiments [21]. The fly ash was found to be more operative in reducing the alkalinity of the pore solution and controlling ASR expansion [22]. However, Buck and Mather [23] reported that some fly ashes, when used at a very low replacement percentage, caused more expansion, especially with low-alkali cement. The reason could be the additional water-soluble alkalis provided by the fly ash to the system. The effectiveness of the fly ash in controlling of ASR might be dependent on the initial alkali content of the mixture and on the alkali content of the fly ash.

The main purpose of this paper is studying the effect of trass and fly ash as a cement replacement in concrete under the short-term and the long-term experiments. For short-term, the extent of expansion due to ACR was monitored at 7-day intervals. For long-term, samples were kept at 80 °C in NaOH solution for curing for 56 days according to ASTM C1260 and 390 days according to ASTM C1293. The observations by optical microscopy have been conducted on thin sections.

## 2. Experimental investigation

### 2.1. Materials

#### 2.1.1. Cementitious materials

Low alkali Portland cement (Type II) and Class F fly ash were used in this experiment [24]. Physical properties, chemical composition oxides and calculations Bogue's compounds of cement used are given in Table 1. Trass pozzolans were obtained from pozzolanic deposits located in South-East of Iran complying with Class N of ASTM C 618 were used [24]. Physical and chemical properties of trass are presented in Table 1. Pozzolanic activity of the pozzolan was also measured according to ASTM C311 [25] and is shown in Table 1. Mineralogical phases present in the pozzolan used were identified by XRD as shown in Table 2.

The microstructure of the OPC and trass as observed through a scanning electron microscope (SEM) are shown in Fig. 1. The OPC particles were mainly spherical as shown in (a). It was observed that some areas were rounded and totally crystallized. It is indicated that most particles in the trass image are irregularly shaped, porous with a few spherical particles, as displayed in (b).

#### 2.1.2. Aggregates

Micrite aggregates were used in this study. The petrography analysis was conducted on aggregates using thin sections and transmitted light with crossed polars in order to classify the relative proportion, distribution and types of dolomite. Fig. 1(a) displays the heterogeneity of the microcrystalline to cryptocrystalline calcite distribution in limestone aggregate. In addition, dolomite crystals detected were in the lozenge lateral shape in the image (b). Based on Fig. 2, it could be noticed that the aggregate contains about 80% calcium carbonate. As shown in Fig. 3, the XRD analysis displayed that the limestone aggregate contained principally calcite with 6% dolomite. A minor amount of Quartz, Illite, Smectite, Pyrite, and Anhydrite were also observed.

### 2.2. Methodology

#### 2.2.1. Casting and curing

Mortar samples were prepared according to ASTM C1260 [26] and ASTM C1293 [27] to study the effect of trass on the expansion of samples due to ACR. Although length change measurement for up to 14 days is suggested in ASTM C1260, this practice was continued up to 56 days to provide more information on ASR of mortars' samples expansion containing trass and fly ash. Table 3

**Table 1**  
Physical properties and chemical analysis of cement, trass and fly ash.

|                                | Cement Type II | Trass | Fly Ash |
|--------------------------------|----------------|-------|---------|
| <i>Physical tests</i>          |                |       |         |
| Specific gravity               | 3.15           | 2.33  | 2.17    |
| Blaine, m <sup>2</sup> /kg     | 3040           | 5780  | 4110    |
| Passing 45 mm, %               | 92.1           | 87.5  | 88      |
| <i>Chemical analysis, %</i>    |                |       |         |
| SiO <sub>2</sub>               | 23.53          | 60.5  | 57.65   |
| Al <sub>2</sub> O <sub>3</sub> | 6.12           | 18    | 26.9    |
| Fe <sub>2</sub> O <sub>3</sub> | 3.98           | 5     | 4.26    |
| CaO                            | 59.87          | 6.75  | 2.32    |
| MgO                            | 2.13           | 2.75  | 1.51    |
| SO <sub>3</sub>                | 1.6            | 0.1   | –       |
| Na <sub>2</sub> O              | 0.31           | 1.6   | 0.11    |
| K <sub>2</sub> O               | 0.51           | 1.4   | 1.48    |
| LOI                            | 1.85           | 1.13  | 8.12    |
| C <sub>3</sub> S               | 37.86          | –     | –       |
| C <sub>2</sub> S               | 34.01          | –     | –       |
| C <sub>3</sub> A               | 17.08          | –     | –       |
| C <sub>4</sub> AF              | 11.05          | –     | –       |

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