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Research Article

Comparison of short- and long-term ASR test methods on cementitious composites

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ABSTRACT

Concrete has a significant place in construction structures, is a material that can be easily damaged due to incorrect design, incorrect material selection. Concrete may be damaged by physical and chemical factors. One of these factors is the alkali-silica reaction (ASR). ASTM C1260, is a short-term test method, and ASTM C227, is a long-term test method, are used to measure effect of alkali-silica reaction. In this study, the effect of fly ash additive use with 0, 5, 10, 15, and 20 wt.% replacement of cement was investigated in short- and long-term ASR test methods. For this purpose, while samples prepared for ASTM C1260 were kept in NaOH solution 14-days, samples prepared for ASTM C227 were waited 360-days in normal water solution. As a result; mortar bars with 20% fly ash additive ratio were classified as harmless for ASR in both test methods.

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1. Introduction

Alkali–silica reaction (ASR) is a chemical reaction that forms between aggregates having reactive silica forms and alkali oxides, resulting from expansion. As a result of the chemical reaction, alkali-silica gels are formed in the concrete. This material has high water absorption capacity. When the concrete is in a humid environment, those gels swell by absorbing water. Swollen gels cause stresses in the concrete and cause capillary cracks. This phenomenon is called "Alkali-Silica Reaction (ASR). This reaction simply occurs in two stages. In the first stage, ASR gel products are created by the combination of reactive silica gels with alkali and then, in the second stage, the created alkali-silica gels expand in the presence of moisture in the environment at a suitable temperature. The resulting expansion also causes cracking and deterioration of concrete over time (Demir and Arslan, 2013; Demir and Sevim, 2017; Demir et al., 2018).

The damage caused by ASR in concrete was first introduced as a case by Stanton in North America in 1940 and has since been known in many countries (Stanton, 1940; Fronhnsdorff, 1978). Many studies have been published since Stanton, but the ASR mechanism has not yet been fully understood (Hobbs, 1998; Diamond and Penko, 1992; Helmuth et al., 1993; Copra and Bournazel, 1995). Studies are carrying out minimizing the effect of ASR, one of these is the use of mineral additives. The use of mineral additives can improve the compressive strength, permeability and void structure of mortar and concrete over time (Bagel, 1998). Due to the hydration process associated with mineral admixtures, the total void ratio of concrete or mortar is reduced (Dongxue et al., 1997). Mineral additives such as silica fume and fly ash are also known to reduce ASR expansions (Monteiro et al., 1997; Ramlochan et al., 2000). To investigate the effects of these mineral additives, accelerated test method (ASTM C1260) is generally preferred. While samples prepared for ASTM C1260 are kept in NaOH solution for 14 days (ASTM C1260-14, 2014), samples prepared for ASTM C227 should be waited 360 days in normal water solution (ASTM C227-10, 2010).

In this study, fly ash was replaced by cement in 5, 10, 15, 20 wt.% and mortar bars were prepared for both test methods. The prepared mortar bars were exposed separately to both test methods and resulting ASR effects were compared.

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2. Experimental Program

For the test samples to be prepared in the study, cement with an amount of alkali ratio over 0.6% is required for the formation of ASR in both test methods. Cement met the specified alkali content was used in the preparation of the samples. The chemical content of the cement used in this study is given in Table 2. Aggregates with the same particle size distribution were used for each test bar. The particle size analysis of these aggregates is given in both test methods. The particle size distribution analysis for the aggregate in the experimental methods is given in Table 1.

Table 1. Particle size distribution requirements.

Sieve Size		Percent (%)
Passing	Retained	
4.75 mm (No. 4)	2.36 mm (No. 8)	10
2.36 mm (No. 8)	1.18 mm (No. 16)	25
1.18 mm (No. 16)	600 μm (No. 30)	25
600 μm (No. 30)	300 μm (No. 50)	25
300 μm (No. 50)	150 μm (No. 100)	15

The aggregates to be used for both test methods were sieved according to the particle size distribution ratios indicated in Table 1 and prepared by mixing according to the desired ratios.

ASTM C1260 and ASTM C1260 are test methods used to measure the effect of mineral and chemical additives on length expansions caused by alkali silica reaction. ASTM C1260 is a short-term test method, resulting in 16 days. ASTM C1260 is preferred in ASR studies because it gives results in a short time. In mortar bars to be prepared according to ASTM C1260, aggregates should be 2.25 times bigger than the amount of cement and water/cement ratio of 0.47 are required. The dimensions of the mortar bars to be prepared are 25×25×285 mm. Samples prepared according to ASTM C1260 are kept in 1N NaOH solution. NaOH solution required for curing is obtained by mixing 40 g NaOH to 900 g water. Mortar bars prepared in accordance with ASTM C1260 are poured into molds. Samples poured into the molds are kept in the mold for 24 hours. After 24 hours, the samples are removed from the mold. Removed samples are stored at 80°C in 1N NaOH solution for 24 hours. After this time the first measurement is done, then after keeping samples in 80°C in NaOH solution again for 7 and 14 days, other measurements are being done, too, then the test being resulted. Expansion values are calculated after the measurements. Risk assessment is performed according to the obtained expansion results. Samples with an expansion rate greater than 0.2% are considered risky for ASR. Samples with an expansion rate between 0.2% and 0.1% are considered as risky with acceptable risk and samples with an expansion rate below 0.1% are considered risk-free for ASR.

ASTM C227 test method is a test method that lasts at least 180 days. In mortar bar samples to be prepared according to ASTM C227, aggregates should be 2.25 times bigger than the amount of cement and the water/cement ratio should be 0.47. The mortar bars should be in 25×25×285 mm dimensions. Samples prepared according to ASTM C227 are being poured into molds. After the samples are being kept in the mold for 24 hours, the first readings are made. Samples prepared according to ASTM C227 should be kept on 38°C water without contact to water and in upright position. The 2, 7, 28, 90, 180-days length expansion values of the samples are measured, and the expansion rates are calculated. According to ASTM C227, cement mortar bars are evaluated with the expansion values obtained in 6-month periods for the alkali silica reaction. According to ASTM C227, samples that are above 0.1% expansion rate are considered as risky for ASR. Samples below 0.1% expansion rate are considered safe for ASR.

When the ASTM C1260 and ASTM C227 test methods are compared, it is seen that the preparation steps of the mortar bars are the same. The aggregate gradation, the required cement alkali ratio and the water/cement ratios to be used for the mixture are given the same. The two test methods have different curing conditions. Samples prepared according to ASTM C1260 are kept in 80°C in 1N NaOH solution, while samples prepared according to ASTM C227 are kept on the water surface having a temperature of 38°C for at least 180 days without contact with water.

Mortar bars were prepared with the same amount of water, cement and aggregate content according to the water/cement/aggregate ratio specified in ASTM C1260 and ASTM C227. 0%, 5%, 10%, 15%, 20% fly ash substitutes were made in the prepared mortar bars. The prepared mortar bars are in 25 × 25 × 285 mm dimensions. The mortar bars were removed from the mold after being kept at 23 ± 2°C for 24 hours. After the mortar bars were removed from the mold, they were kept in the curing environments prepared according to the test methods for the periods specified in the test standards. The chemical properties of cement and fly ash used in the preparation of mortar bars are given in Table 2.

Table 2. Chemical properties.

Chemical Composition (%)	Cement	Fly Ash
SiO_2	18.79	57.11
Al_2O_3	5.05	19.27
Fe_2O_3	2.54	9.21
CaO	63.28	5.31
MgO	2.23	2.03
K_2O	0.83	2.39
Na_2O	0.28	0.64
SO_3	3.44	0.13
$Cr2O_3$	0.03	0.02
Mn_2O_3	0.06	0.08
TiO_2	0.26	0.90
Loss on Ignition	3.20	3.24
Na_2O+0,658×K_2O	0.82	-

After the samples prepared by using aggregate, cement, water and fly ash substitution rates given in Table 3, removed from the mold, the steps for the two test methods continued differently. Mortar bars subjected to ASTM C 1260 test method were kept in 80 ± 2°C normal water for 24 hours and the first length measurements were made. Samples were measured after being kept in 80 ± 2°C 1N NaOH solution for 14 days and the test being resulted after measurement.

The samples subjected to ASTM C227 test method were taken from the mold and first length measurements were being made. After measurement, samples were kept in a test apparatus which was prepared to avoid any contact with water on 38 ± 2°C normal water for 360 days. During this period, interim measurements of 7, 28, 90, 180-days were made and the final length measurements were made after 360 days, then the test was resulted.

Length expansions at the end of both test methods and length expansions during tests were calculated. ASR effect was determined with length growth ratios obtained from these test methods. ASR effect was determined as stated in related standards and comparisons were made for both experimental standards.

Table 3. Mixture amounts of cementitious composites (g).

Ingredient	Reference	5% FA	10% FA	15% FA	20% FA
Cement	440	418	396	374	352
Aggregate	990	990	990	990	990
Water	206.8	206.8	206.8	206.8	206.8
Fly Ash	0	22	44	66	88

3. Experimental Results and Discussion

As a result of the expansion values obtained from the studies, expansion rates were calculated. Expansion rates of the samples kept under curing conditions specified in ASTM C1260 are given in Fig. 1. Expansion values of the samples kept under curing conditions specified in ASTM C227 are given in Fig. 2.

When the expansion rates given in Fig. 1. of the samples kept under curing conditions according to ASTM C 1260 were examined; fly ash additive for mortar bars seems to reduce ASR effect. The fly ash additive ratio was 20% at most. When fly ash additive ratio was performed up to 20%, the ASR effect decreased with increasing substitution rate.

When the expansion rates of the samples kept under cure conditions in accordance with ASTM C227 were examined, it was observed that the additive ratio of fly ash reduced the ASR effect. In the study, fly ash replacement was made for ASTM C227 at the rate of 20%. The ASR effect was reduced as fly ash additive ratio increased up to 20%, including 20% additive ratio. When these results are compared, it is possible to say that ASTM C227 and ASTM C1260 give a similar result. The expansion values obtained as a result of the studies for both experimental methods are given in Table 4, comparatively.

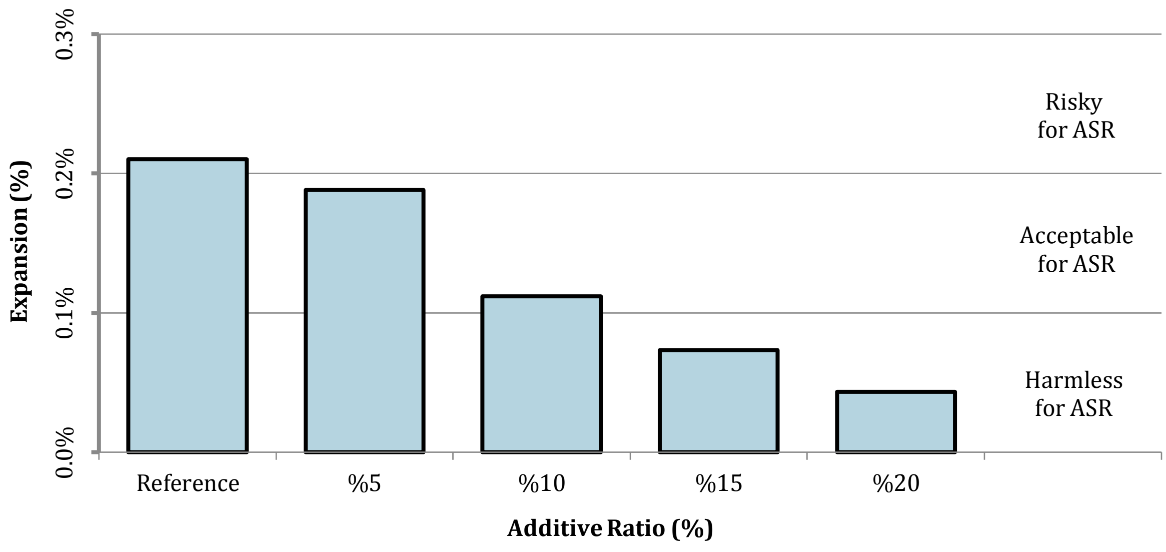

Fig. 1. Expansion ratios of the samples kept under curing conditions specified in ASTM C1260.

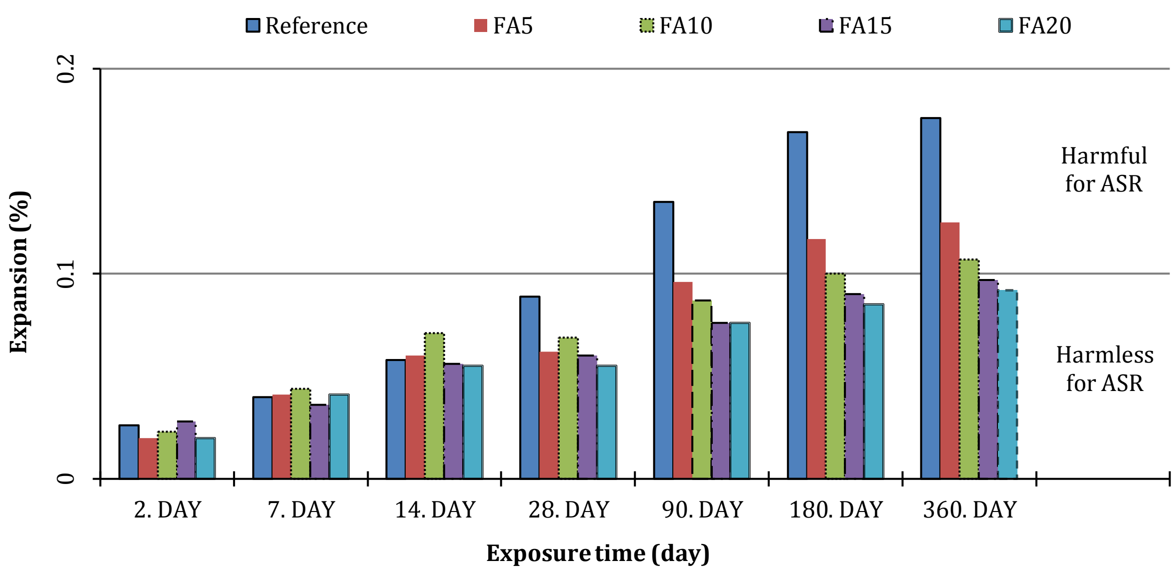

Fig. 2. Expansion values of mortar bars incorporating fly ash according to ASTM C227.

Table 4. Length expansion rates (%).

Additive Ratio	ASTM C1260 (14 day)	ASTM C227 (360 day)
0% (Reference)	0.210	0.175
5%	0.188	0.125
10%	0.112	0.107
15%	0.073	0.097
20%	0.044	0.092

When the comparative values given in the table were examined, the reference sample was considered as risky for ASR by staying above the risky ASR limit in both experimental methods.

According to the ASTM C 1260 test method, the reference sample expanded more than 0.2%, which is the limit value for harmful ASR. As a result, it was considered as harmful ASR. 5% and 10% fly ash substitute mortar bars were classified as acceptable harmful ASR according to ASTM C1260, remaining between 0.1% and 0.2%.

15% and 20% fly ash additive ratio were remained below 0.1% limit value and classified as harmless. When ASR effect was examined according to the short-term test method, it was seen that fly ash additive ratio reduces the ASR effect as well as 20% fly ash replacement reduced the ASR effect by 80% in comparison to the reference sample (Fig. 3).

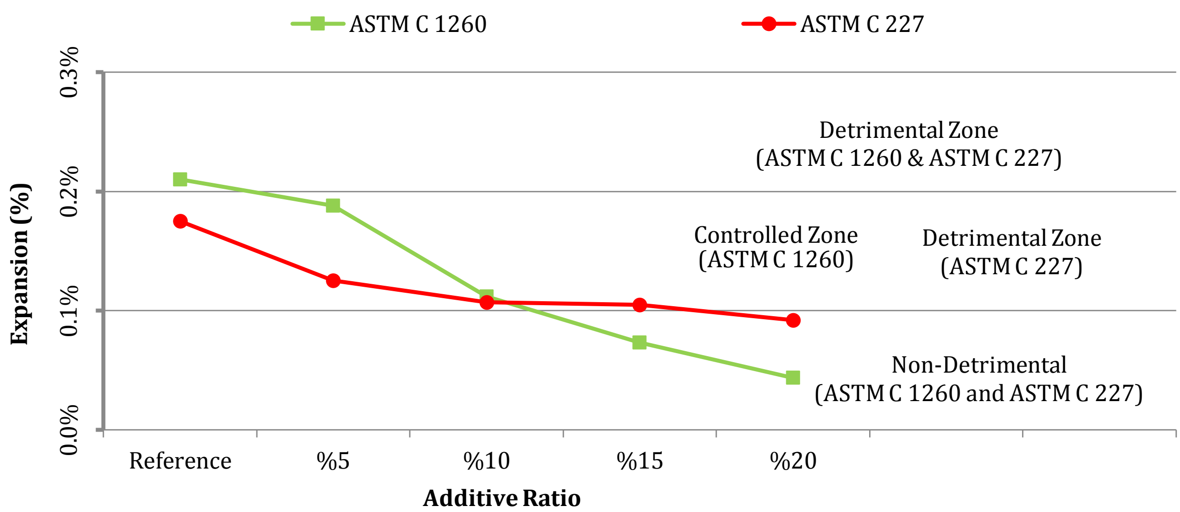

Fig. 3. Length change expansion ration of mortars bars having different fly ash replacement.

According to ASTM C227 test method, the reference sample remained in the harmful area by showing an expansion above 0.1% limit value. According to this test method, 5%, 10% and 15% fly ash replacement were evaluated as harmful ASR. Samples with 20% fly ash was below 0.1% expansion limit and classified as harmless for ASR.

When both experimental methods were compared, the reference sample was classified as harmful ASR. While mortar bars with 5% and 10% additive ratio are classified as acceptable ASR according to ASTM C1260, they are classified as harmful ASR according to ASTM C227 test method. Mortar bars with 15% fly ash additive ratio was classified as acceptable ASR according to ASTM C1260, whereas it was classified as harmless ASR according to ASTM C227 test method. Mortar bars with 20% fly ash additive ratio were classified as harmless for ASR in both test methods.

The sample preparation steps of both test methods appear to be the same. However, the difference in curing conditions constitutes the difference of the two test methods. In this study, it was seen that long-term and short-term test methods gives approximately the same result. It is understood that ASTM C1260 short-term test method does not give a healthy result in long-term experiments. It has been seen that the use of long-term test methods to learn the effect of ASR on cement in later ages will give more healthy results.

4. Conclusions

In this study, the differences between the accelerated test method ASTM C1260 and ASTM C227 test methods were compared. As a result of the study, it was observed that the samples with the same preparation phases can produce different results depending on the amount of material in the content. In studies related to ASR, chemical ASR test methods can be used to examine whether these differences are mediated by ASR or otherwise. As a result of the test methods of ASTM C1260 and ASTM C227, the expansion ratios were different in the long term.

Publication Note

This research has previously been presented at the 3rd International Conference on Advanced Engineering Technologies (ICADET'19) held in Bayburt, Turkey, on September 19-21, 2019. Extended version of the research has been submitted to Challenge Journal of Structural Mechanics and has been peer-reviewed prior to the publication.

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