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Full Length Research Paper

The effect of mineral admixtures and micronized calcite on alkali silica reaction expansions in the usage of aggregates from different origin

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This paper investigates the effectiveness of two zeolites with different reactive silica content, fly ash (FA), blast furnace slag (BFC), silica fume (SF), and micronized calcite (MC) in reducing expansion of concrete due to alkali-silica reaction. Also in this research, effects of three different cement usages were investigated by using accelerated mortar bar method, ASTM C1260. Five different aggregates, three natural sands, and two crushed sands were used for preparing mortar bars. All of these aggregates have been petrographically examined according to ASTM C295 standard and have been found out to be harmful to ASTM C 1260. Performances of the mineral admixtures were compared by examining the expansion due to alkali silica reaction (ASR). The aggregate and cement mixtures were tested with accelerated mortar bar test procedures including 10 and 20% replacement of mineral admixtures by weight of cement. 20% substitution levels of all admixtures were highly effective in inhibiting the ASR. The expansions of test specimens, in which mineral admixtures were used, were within the code-defined acceptable limits of ASTM C1260. According to the standard, different cement usage should not affect expansions in this accelerated test method. However, on contrary to ASTM C1260 statement, this research showed that the mixtures prepared with the same aggregate but different cements displayed different expansions at the end of 14 days. In addition, this different cement usage does not significantly affect the expansions.

Key words: Alkali silica reaction (ASR), natural zeolite (NZ), fly ash (FA), blast furnace slag (BFC), silica fume (SF), micronised calcite (MC).

INTRODUCTION

Cement is the most preferred building material, because it has superior durability over price ratio. The most crucial parameter about cement performance is certainly the components of cement included in concrete construction. It is possible to obtain friendly environmental and cost effective advantages by using pozzolonic mineral additives in concrete formulation. Durability problems in concrete and reinforced concrete subjected to aggressive environment cause damages in structures before predicted service life. By adding pozzolans to concrete, calcium hydroxide content of cement paste can be reduced and permeability of concrete can be decreased (Chindaprasirt et al., 2007).

One of the most severe durability problems of concrete structures is the alkali silica reaction (ASR). This reaction occurs between alkali hydroxide in Portland cement and aggregates that contain reactive silica. This specific reaction typically creates significant concrete expansion and damages which ends up with failure of construction (Stanton, 1940). ASR must have various factors to occur; alkali, reactive aggregate, and water. But when the water content is low, alkali-aggregate reaction may not occur (Hobbs, 1980). Throughout the world, ASR is really a

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severe concrete deterioration and also has a serious concern about concrete structures. Various researchers offered numerous theories that describe the mechanism of the reaction. A particular theory describes formation of ASR for the following reasons:

1) OH^- attacks the aggregate and stops its dissolution,
2) Dissolved silica reacts with alkalis (Na^+ or K^+),
3a) Due to osmotic pressure generated by alkali silica gel expansion of concrete occurs (Hansen, 1944),
3b) Due to mechanical pressure exerted by reaction products formation of cracks and widening of cracks are the consequences of expansion (McGowan and Vivian, 1952). The expansion of concrete depends on if the formation of the gel mechanism is swelling or non swelling type (McGowan and Vivian, 1952).

Despite the difficulty in understanding the ASR, there are several alternatives that can be used to control or even stop the destructive ASR expansion on concrete structures. These alternatives are: avoiding usage of reactive aggregate, usage of low cement content, usage of chemical additive, and partially replacing of alkali cement by supplementary materials. The third option has attracted much more attention by researchers because plentiful supplementary materials resources are available for use in concrete and also in mortars (Hobbs, 1989). Today, it is well known fact that supplementary materials known as mineral admixtures such as fly ash (FA), silica fume (SF), blast furnace slag (BFC), metakaolin, and zeolite are successfully used to control ASR expansion (Andiç, 2002). Potential effectiveness of zeolite in improving the performance of cement is compared with that of other pozzolanic materials. It is observed that the pozzolanic reactivity of natural zeolite (NZ) is between that of SF and FA (Poon et al., 1999).

NZ controls ASR by decreasing the alkali ion concentration in the pore solution in concrete through ion exchange, adsorbing water, and pozzolanic reaction. Therefore, the formation of alkali silicate is stopped and the interface is improved (Feng and Hao, 1998). NZ may be used not just like a pozzolan but additionally like micro filler within the cement for general densification of microstructure. Incorporation zeolite will cause these significant micro structural improvements, which are the reason for the whole superior durability of concrete:

a) Reduction in calcium hydroxide component of Portland cement hydration in the past by the pozzolanic reaction,
b) Densification of the cement paste microstructure by mixed pore size and grain size refinements,
c) Improvement of aggregate paste zone by the combination of filler and pozzolanic reaction effects (Keyvani and Nasrollahpor, 2009).

Filling materials adding up to a certain amount of binder shows a filler effect or particle size effect in cementitious mixtures (Moosberg-Bustnes et al., 2004). This filler effect is defined as the arrangement of small particles that fill the voids and contribute to the increment of compressive strength without any chemical reaction. (ASTM C109, 2001; Paya et al., 2000). Chemical and physical properties of cementitious materials can be enhanced by adding limestone filler to mixture. Researchers claimed that, usage of limestone filler materials between 7 and 10% of cement in mixture improved the mechanical and durability properties of the concrete (Topçu and Uğurlu, 2003). Limestone fillers have no pozzolanic effect but react with alumina phase of cement and produce calcium monokarbo aluminate hydrates (Bonavetti et al., 1999). Calcite initially reacts with C_3A and C_4AF components of cement. Calcite particles integrate with cement paste during this reaction (Lawrence et al., 2005). In a study done by Petersson's et al. (2000) it is stated that; calcite filler accelerates hydration reaction. In the same study, it was observed that in the usage of cement with high C_3A and calcite filler at the same time in the mixture, hydration products become karboalumina hydrates with high binding capacity (Petersson, 2002).

In this study, experimental tests have two sections. In the first section, research was carried out on the effectiveness of mineral admixtures and micronized calcite (MC) on controlling ASR expansions. Admixtures were used at 10 and 20% by weight of cement and were compared because of their application and usage. SF was tested with the same test procedures with only 10% replacement by mass of cement because of its optimum use in concrete. The study tested a variety of aggregates from different quarries. For instance, highly reactive and medium reactive aggregates were subjected to expansion tests using ASTM C1260 method (ASTM C1260, 2007). 10 or 20% of the cement was replaced by an equivalent mass of mineral admixtures and micronized calcite. In the second section, effect of different cement usage to expansions due to ASR was investigated using the same method. In related standard it is stated that, because the specimens were exposed to a NaOH solution, the alkali content of the cement does not have significant effect on expansions.

MATERIALS AND METHODS

In this study, five different aggregates from varied quarries and four different cements were used. Cement type A was used for understanding the effectiveness of different admixtures in reducing ASR expansion. Cement types B, C, and D were used for investigating how different cement usage affects the expansions.

Cements

The binders were normal Portland cement CEM I 42.5R, as specified by European Standard EN 197-1 (EN 197-1, 2000). Table 1 shows their chemical composition and alkali equivalent (Na_2O equivalent or Na_2O_{-eq}) contents, and Table 2 shows their physical

Table 1. Chemical composition of Cement A, B, C, and D.

Oxide (wt%)	Cement			
	A	B	C	D
SiO_2	17.70	19.98	19.76	19.76
Al_2O_3	3.95	5.32	4.97	4.97
Fe_2O_3	3.76	3.31	2.66	2.66
CaO	62.45	63.38	63.25	63.25
MgO	1.05	1.06	1.06	1.06
SO_3	4.12	3.2	3.02	3.02
LOI*	4.82	0.9	1.78	0.34
Na_2O_{-eq}	1.03	0.87	0.54	0.73

*Loss of Ignition

Table 2. Physical properties of Cements A, B, C, and D.

Physical properties		A	B	C	D
Specific gravity		3.14	3.15	3.12	3.10
Setting time	Initial (min)	129	170	210	160
	Final (min)	191	210	240	245
Soundness (Le chatalier) (mm)		1.0	1.0	1.0	0.5
Fineness	Specific Surface-Blaine(cm^2/g)	3950	3590	3680	3770

properties. Cements used in this study were labeled as Cement A, B, C, and D. Na_2O_{-eq} content is calculated in the equation below:

$$Na_2O_{-eq} = Na_2O + 0.658\ K_2O \quad (1)$$

Aggregates used in investigating the effect of mineral admixtures on ASR

The aggregates have different origin and mineral composition. Mineral compositions of aggregates were taken from petrographic examination results conducted in accordance with ASTM C295 (ASTM C295, 2011). Chemical composition was derived from the tests conducted in geochemistry laboratory. First aggregate is a natural sand obtained from Sakarya river and in this study it is named as S1 aggregate. Second aggregate is a crushed aggregate stone obtained from Istanbul region and it was named as S2 aggregate. Third aggregate is a natural sand obtained from İstanbul region named as S3 aggregate. Tests were performed according to ASTM C1260 standard and 14 days expansions were recorded.

Aggregates used in investigating the effect of different cement usage on ASR

Fourth aggregate is a crushed aggregate stone obtained from Istanbul region. Researchers take crushed aggregate samples from two different parts of the same quarry. The purpose is to determine if these samples act differently regarding to ASR expansions. Hereafter, these aggregates were named as S4-1 and S4-2 aggregates. Fifth aggregate is natural sand obtained from Istanbul region named as S5 aggregate. Tests were performed according to ASTM C1260 standard, and 14 days expansions were recorded. Mineralogical composition of all aggregates were shown in Table 3 and chemical composition of aggregates were shown in Table 4.

Supplementary materials

In this experiment, supplementary materials consist of two NZ with different reactive silica content, FA, BFC, silica fume, and micronized calcite. In this section, effectiveness of mineral admixtures was investigated. Mixtures were prepared with three different aggregates and one selected cement labeled A. Replicates are two for each mixture, therefore we have two mortar bars (25 × 25 × 225 mm) for each mixture:

1) Control mixes,
2) 10 and 20% replacement of FA,
3) 10 and 20% replacement of BFC,
4) 10 replacement of silica fume,
5) 10 and 20% replacement of NZ with high silica content,
6) 10 and 20% replacement of NZ with low silica content,
7) 10 and 20% replacement of micronized calcite.

In the second part of this study, effect of different cement usage to ASR expansions was investigated. Mixtures were prepared with five aggregates (S1, S2, S3, S4, andS5) and three cements (B, C, D) therefore we had 15 mixtures in total. Chemical composition and physical properties of supplementary materials are shown in Tables 5 and 6, respectively. NZ used in this study are labeled as zeolite with high reactive silica content (HRZ) and low silica content (LRZ).

Table 3. Minerological compositions of S1, S2, S3, S4-1, S4-2, and S5 aggregates.

S1	**Mineral**	**Quartz**	**Feldspar**	**Mica**	**Turmaline**	**Garnet**	**Chlorite+Epidote**	**Calcite**	**Ferric oxide**
	Modal (%)	78-82	5-6	1	0,5	1	1	2-3	1-2
S2	**Mineral**	**Quartz**	**Feldspar**	**Mica**	**Clay+Carbonate**		**Opaque**		
	Moda (l%)	30-35	10-15	15-20	30-35		3-4		
S3	**Mineral**	**Quartz**	**Feldspar**	**Calsite+Aragonite**	**Rock particles**		**Ferric oxides**		
	Modal (%)	84-86	2-3	1-2	10-12		< 0.5		
S4-1	**Mineral**	**Quartz**	**Feldspar**	**Mica**	**Calcite**		**Opaque**		
	Modal (%)	90-94	3-5	1	3-4		1-2		
S4-2	**Mineral**	**Quartz**	**Feldspar**	**Mica**	**Calcite**		**Opaque**		
	Modal (%)	85-90	2-4	1	7-8		1-2		
S5	**Mineral**	**Quartz**	**Feldspar**	**Calsite+Aragonite**	**Rock particles**		**Ferric Oxides**		
	Modal (%)	90-92	1-3	0,5-1	5-6		< 0.5		

Table 4. Chemical compositions of S1, S2, S3, S4-1, and S4-2, S5 aggregates.

Oxide (wt%)	S1	S2	S3	S4-1&S4-2	S5
SiO_2	56.55	60.64	50.30	61.6 - 60.9	50.8
Al_2O_3	10.46	4.74	19.27	3.3 - 3.5	18.9
Fe_2O_3	3.80	2.19	9.52	2.6 - 2.7	9.40
CaO	12.54	16.97	3.71	16.1 - 15.8	3.93
MgO	2.31	0.70	4.40	0.78 - 0.83	4.33
K_2O	2.07	2.01	3.15	1.97 - 1.92	3.22
Na_2O	2.07	0.91	1.81	0.98 - 0.99	1.76
TiO_2	0.50	0.14	1.10	0.19 - 0.22	1.15
P_2O_5	0.14	0.07	0.19	0.05 - 0.07	0.17
MnO	0.12	0.12	0.14	0.10 - 0.13	0.16
Cr_2O_3	0.03	0.01	0.02	0.01 - 0.04	0.01
LOI	9.16	11.21	5.99	11.3 - 11.6	6.03

Table 5. Chemical compositions of fly ash blast furnace slag, and silica fume, and micronized calcite.

Oxide (wt%)	Fly ash	Blast furnace slag	Silica fume	High reactive zeolite	Low reactive zeolite	Micronised calcite
SiO_2	58.58	40.4	91.0	66.06	66.18	0.04
Relative SiO_2	-	-	-	57.10	38.18	-
Al_2O_3	23.4	11.7	0.58	11.32	12.92	0.03
Fe_2O_3	6.97	1.1	0.24	1.26	2.33	0.03
CaO	1.55	33.6	0.71	1.35	1.35	-
MgO	2.76	6.98	0.33	3.14	2.61	0.45
SO_3	0.45	0.13	1.06	-	-	-
$CaCO_3$	-	-	-	-	-	99.45
LOI	0.75	0.75	1.84	12.75	10.57	-
K_2O	2.78	-	3.72	0.10	0.64	-
Na_2O	2.13	-	0.29	3.04	3.13	-
Na_2O_{-eq}	3.96	-	2.74			-

Table 6. Physical properties of fly ash blast furnace slag, and silica fume, and micronized calcite.

Physical properties		Fly ash	Blast furnace slag	Silica fume	Micronised calcite	High reactive zeolite	Low reactive zeolite
Specific gravity		3.12	2.80	2.20	2.7	2.21	2.38
Setting time	Initial (min)	-	105	-	-	-	-
	Final (min)	-	150	-	-	-	-
Soundness (Le chatelier) (mm)		1.0	1.0	-	-	-	-
Fineness	Specific surface-blaine (cm^2/g)	4.357	5.285	200.000 (BET)	-	23.890	20.660
	Maximum sieve size (µm)	-	-	-	20	-	-

Methods and testing

The efficiency of two NZ, FA, BFC, SF and MC in controlling ASR expansion were investigated by using the accelerated test method of ASTM C1260 (similar to CSA A23.2-25A-M94 method). They contained 10 and 20% replacement level of mineral admixtures and MC by weight of cement. Based on the test method, mortar bars were produced by using 1 part of cement to 2.25 parts of aggregates. Additionally, the water to total cementitious materials (w/c) was kept at 0.47. Two mortar bars (25 × 25 × 225 mm) were cast for each mortar mixture. After 24 h, mortar bars were removed from the molds and stored in a water bath with tap water at 90°C for a period of 24 h. After this preconditioning, the length of mortar bars were measured (initial reading). Then they are placed into storage containers filled with 1normality (1N) of NaOH solution at 80°C for the duration of the test. Subsequent length readings were made using comparator on 1th, 3th, 5th, 7th, and 14th days. Expansions were measured as mortar bars changes in length. In the second part, effect of different cement usage to ASR expansions in ASTM C1260 method was investigated. Based on the test method, fifteen different mortar bars containing S1, S2, S3, S4, and S5 aggregate, and B, C, and D type of cements were used while preparing the mortar bars. The same procedure was followed for the entire test.

RESULTS

Mineral admixtures and micronized calcite

Control bars

Expansion results of control bars prepared with all aggregates and four cements were shown in Table 7. Average of all the expansions were calculated for cement A, B, C, and D, respectively. Aggregates showing higher expansion than 0.2% at the end of 14 days are defined as highly reactive aggregate by researchers (Touma et al., 2000). Considering the average of 14 days expansions, S1, S2, and S4-1, S4-2 aggregates can be included in this highly reactive aggregate class. Aggregates showing expansion between 0.10 and 0.20% at the end of 14 days was defined as potentially reactive aggregate by researchers (Touma et al., 2000). Considering the average of 14 days expansions S3 and S5 aggregate can be included in this potentially

Table 7. Expansion results of control bars.

Cement	S1	S2	S3	S4-1	S4-2	S5
A	(1.27+0.60)/2	0.32	0.24	-	-	-
B	0.82	0.47	0.16	0.42	0.29	0.16
C	0.63	0.51	0.18	0.36	0.22	0.15
D	0.54	0.46	0.20	0.40	0.27	0.16
Average	0.74	0.44	0.20	0.39	0.26	0.15

Table 8. Expansion results of mortars containing fly ash blast furnace slag, and silica fume.

Time (Days)	Control bar	10% fly ash	20% fly ash	10% blast furnace slag	20% blast furnace slag	10% silica fume
S1 aggregate						
1	0.02	0.04	0.03	0.01	0.01	0.01
3	0.24	0.07	0.04	0.03	0.01	0.01
7	0.49	0.17	0.05	0.15	0.01	0.02
14	0.60	0.28	0.06	0.26	0.01	0.09
S2 aggregate						
1	0.03	0.03	0.00	0.01	0.01	0.01
3	0.09	0.04	0.01	0.07	0.05	0.02
7	0.23	0.07	0.02	0.18	0.11	0.03
14	0.32	0.08	0.02	0.23	0.14	0.05
S3 aggregate						
1	0.00	0.02	0.00	0.00	0.00	0.02
3	0.01	0.02	0.00	0.01	0.01	0.02
7	0.16	0.03	0.02	0.07	0.02	0.03
14	0.24	0.05	0.02	0.12	0.03	0.06

reactive aggregate class.

Fly ash, blast furnace slag, and silica fume

Expansions of mortar bars prepared with FA, BFC, and silica fume, and their control bars are given in Table 8. Figure 1, 2, and 3 presents the expansion results up to 14 days for the mortar bars cast with three mineral admixtures and S1, S2 and S3 aggregates.

Natural zeolite with high and low reactive silica content

Expansions of mortar bars prepared with high and low silica content of NZ and their control bars are given in Table 9. Figure 4, 5, and 6 present the expansion results up to 14 days for the mortar bars cast with 10 and 20% of replacement for both NZ with high HRZ and LRZ, and S1, S2, and S3 aggregates. Silica content is coming from $Si0_2$ composition of the material. Reactive silica content means the reactive part of SiO_2 which plays an important role on ASR with alkalis from cement.

Micronized calcite

Expansions of mortar bars prepared with MC and their control bars are shown in Table 10. Figure 7, 8, and 9 presents the expansion results up to 14 days for the mortar bars cast with 10 and 20% replacement of MC and S1, S2, and S3 aggregates.

Different cement usage

In this part of the study, mortar bars were prepared with S1, S2, S3, S4, and S5 aggregates and Cement B, C, and D. Expansions of mortar bars prepared with different cements are given in Table 11. Expansions of mortars regarding to cement type and prepared with one picked

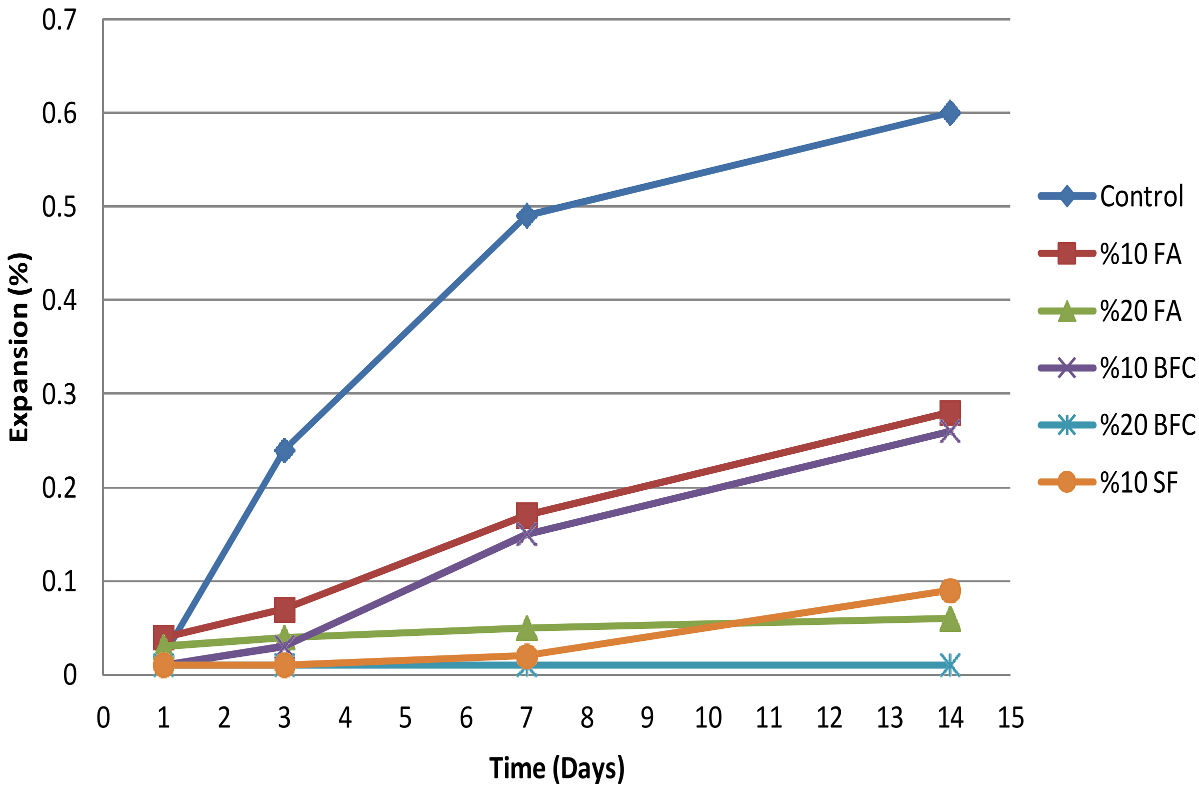

Figure 1. Effect of fly ash, slag, and silica fume on mortar bar expansions containing S1 aggregate with time at various replacement levels.

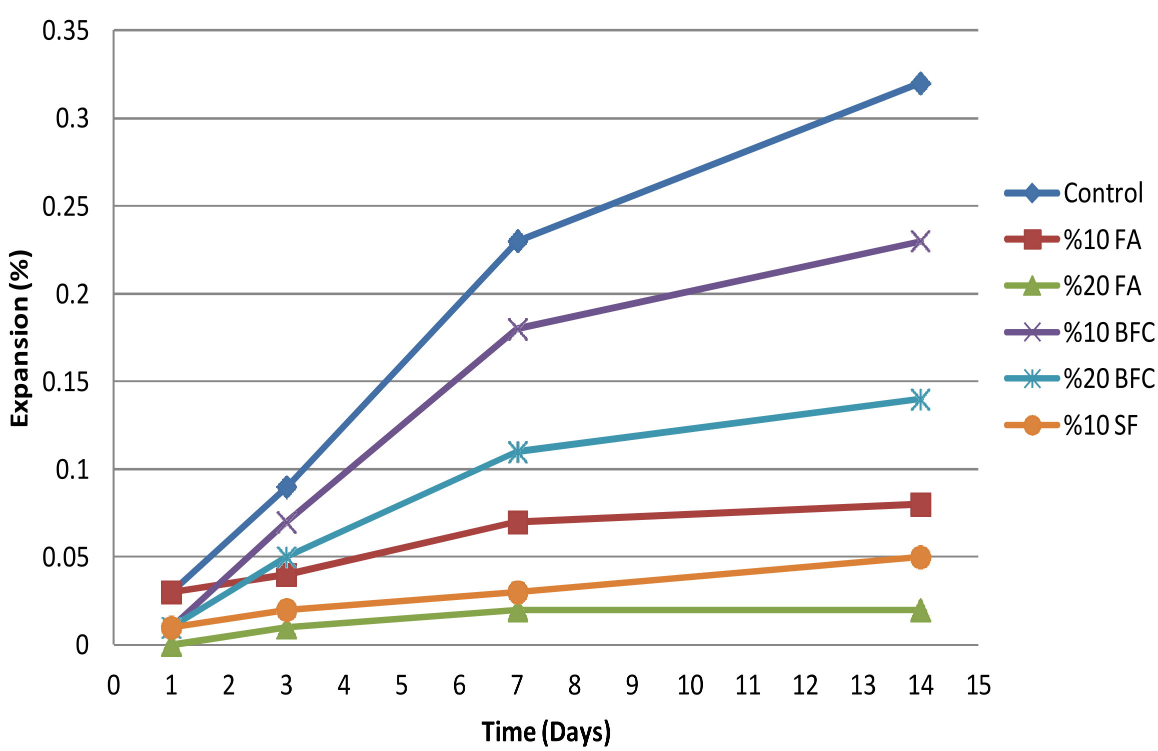

Figure 2. Effect of fly ash, slag, and silica fume on mortar bar expansions containing S2 aggregate with time at various replacement levels.

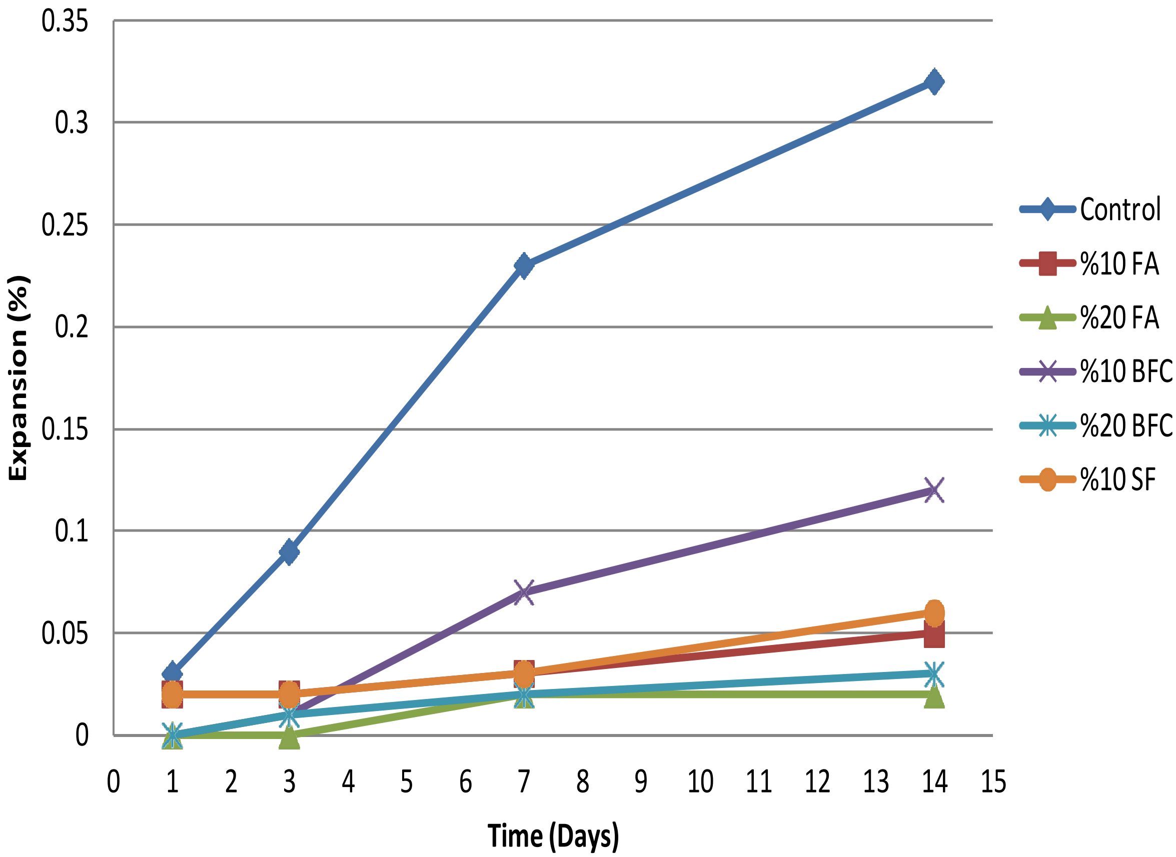

Figure 3. Effect of fly ash, slag, and silica fume on mortar bar expansions containing S3 aggregate with time at various replacement levels.

Table 9. Expansion results of mortars containing natural zeolite.

Time (Days)	Control bar	10% low reactive zeolite	20% low reactive zeolite	10 % high reactive zeolite	20% high reactive zeolite
S1 aggregate					
1	0.73	0.02	0.0	0.0	0.0
3	0.95	0.20	0.02	0.15	0.01
7	1.22	0.48	0.11	0.33	0.03
14	1.27	0.56	0.15	0.37	0.08
S2 Aggregate					
1	0.03	0.0	0.0	0.0	0.0
3	0.09	0.06	0.01	0.04	0.01
7	0.23	0.15	0.05	0.14	0.02
14	0.32	0.26	0.10	0.23	0.04
S3 aggregate					
1	0.00	0.0	0.0	0.0	0.0
3	0.01	0.01	0.02	0.02	0.01
7	0.16	0.12	0.06	0.10	0.03
14	0.24	0.18	0.10	0.16	0.05

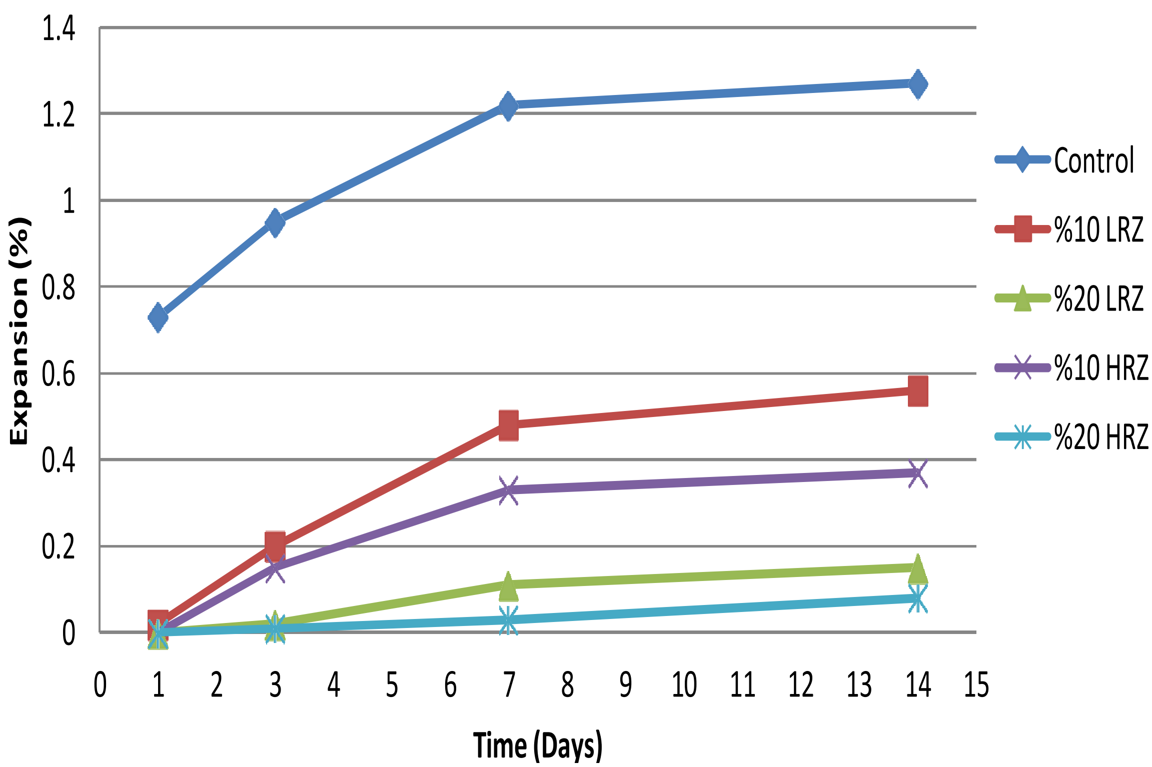

Figure 4. Effect of zeolite addition on mortar bar expansions containing S1 aggregate with time at various replacement levels.

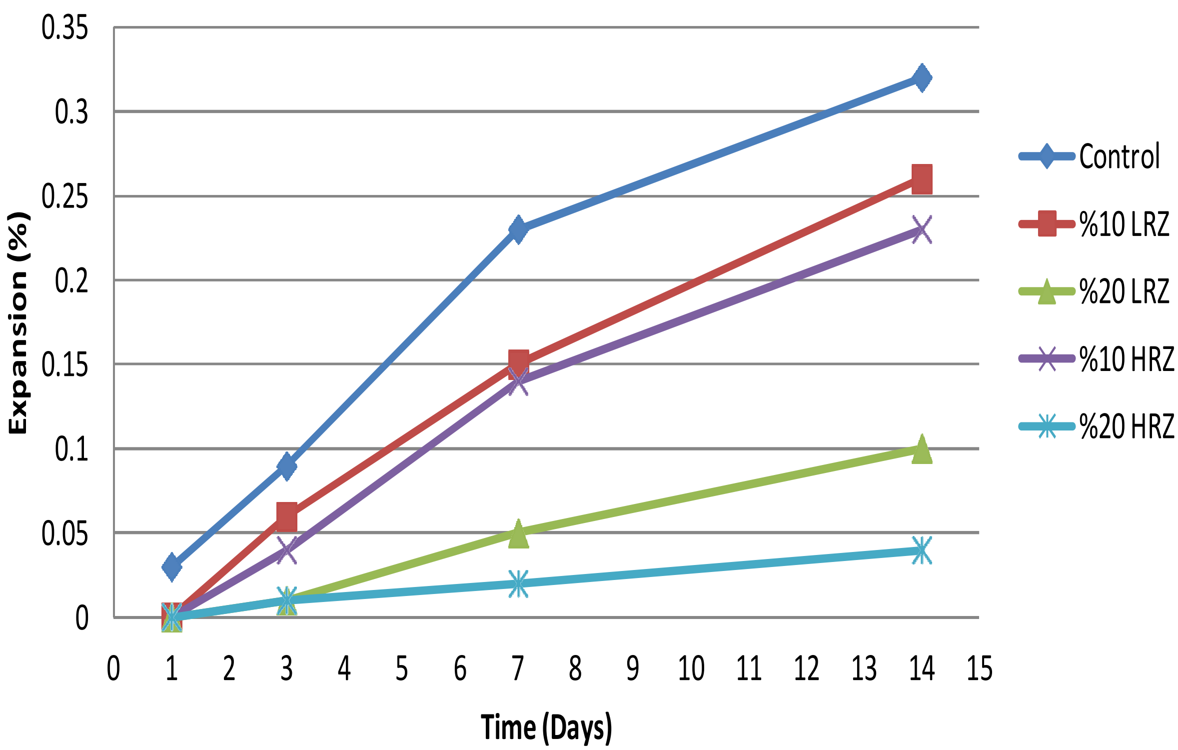

Figure 5. Effect of zeolite addition on mortar bar expansions containing S2 aggregate with time at various replacement levels.

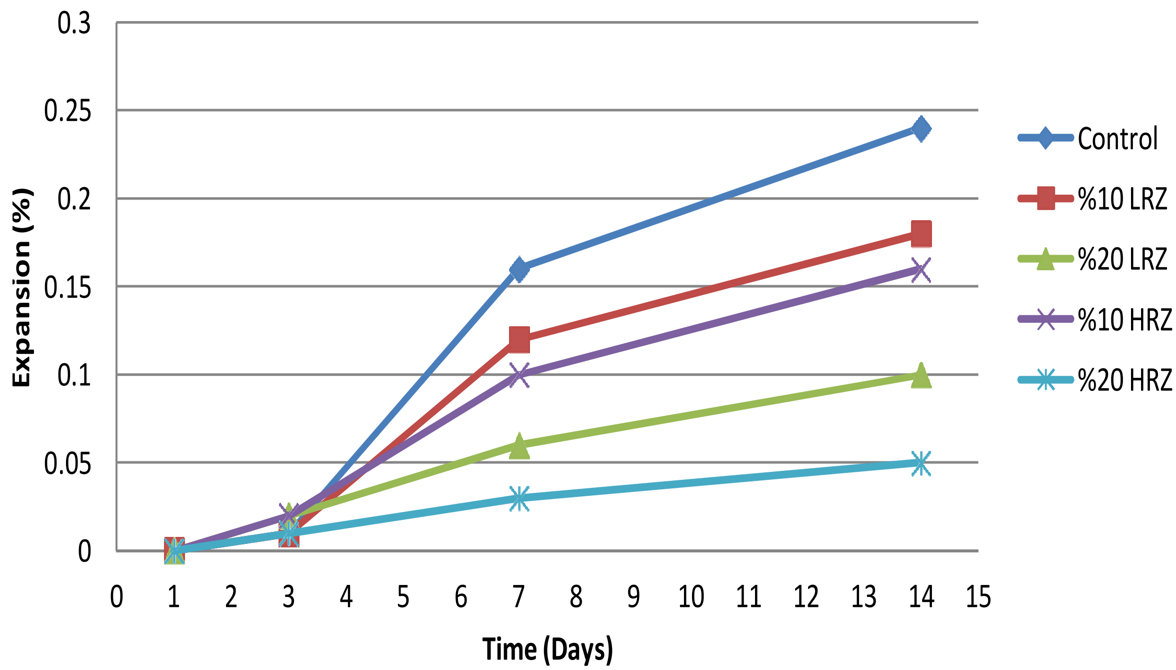

Figure 6. Effect of zeolite addition on mortar bar expansions containing S3 aggregate with time at various replacement levels.

Table 10. Expansion results of mortars containing micronized calcite.

Time (Days)	Control bar	10% micronized calcite	20% micronized calcite
S1 aggregate			
1	0.73	0.08	0.03
3	0.95	0.20	0.21
7	1.22	0.40	0.37
14	1.27	0.55	0.40
S2 aggregate			
1	0.03	0.04	0.0
3	0.09	0.08	0.01
7	0.23	0.26	0.12
14	0.32	0.30	0.17
S3 aggregate			
1	0.00	0.01	0.02
3	0.01	0.03	0.03
7	0.16	0.14	0.10
14	0.24	0.19	0.13

aggregate is seen in Figure 10. As seen from Figure 6, when the cement type changes final expansions differs from each other. It is can be seen from Figure 10 that ASR expansions can be affected by Na_2O_{-eq} amount in cements. Mortar bars prepared with S1 aggregate and cement type B have 14 days expansions of 0.82% while cement type D have 14 days expansions of 0.54%. Even so the average expansions of aggregates were different in the usage of different cements and the final decision about the reactivity of aggregate was unchanged.

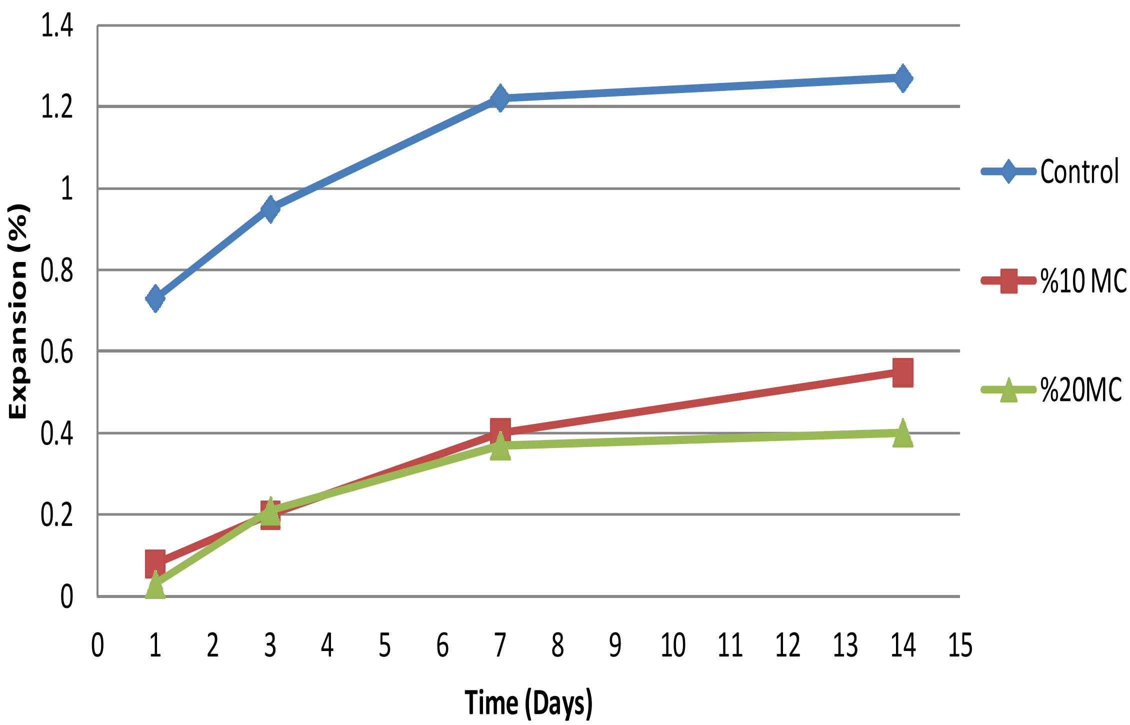

Figure 7. Effect of calcite addition on mortar bar expansions containing S1 aggregate with time at various replacement levels.

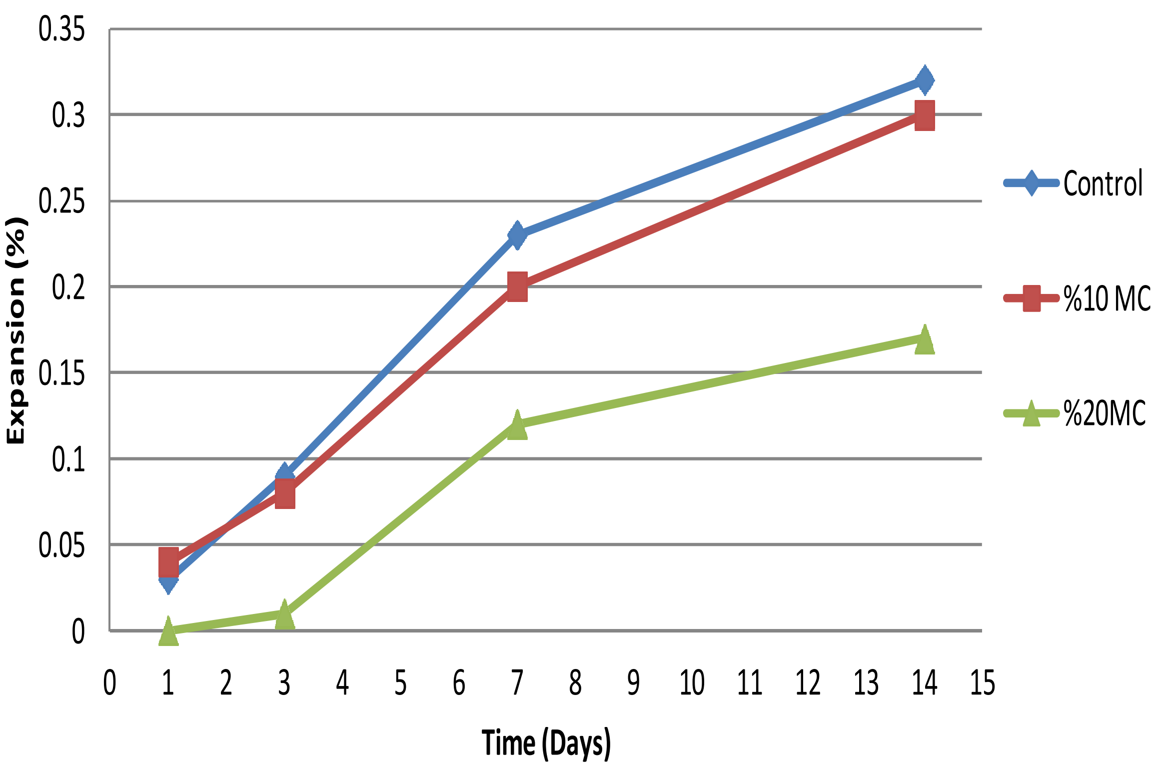

Figure 8. Effect of micronized calcite addition on mortar bar expansions containing S2 aggregate with time at various replacement levels.

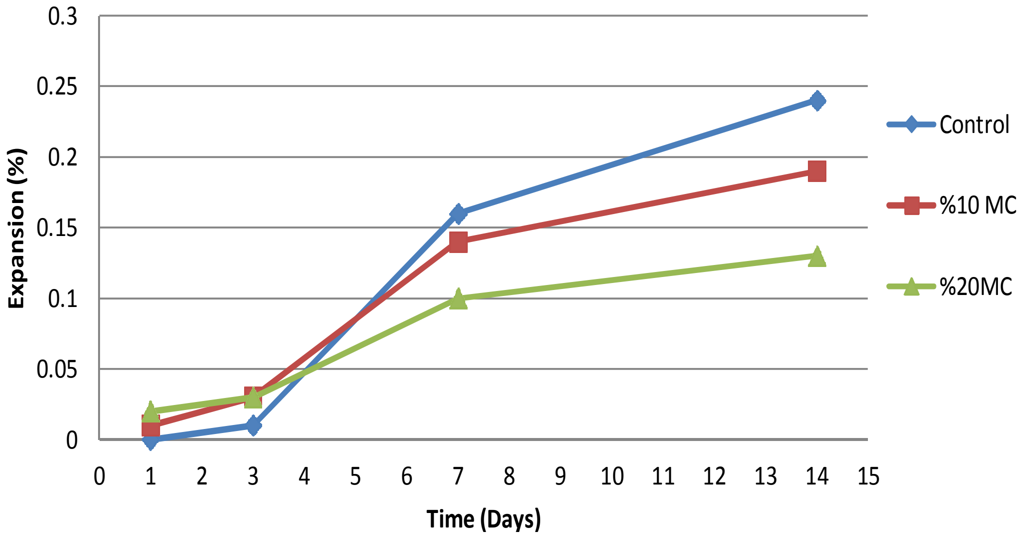

Figure 9. Effect of micronized calcite addition on mortar bar expansions containing S3 aggregate with time at various replacement levels.

Table 11. Expansion results of mortars regarding to cement type.

Time (Days)	S1	S2	S3	S4-1	S4-2	S5
Cement B						
1	0.02	0.01	0.0	0.09	0.09	0.0
3	0.53	0.14	0.01	0.12	0.15	0.02
7	0.66	0.24	0.08	0.34	0.22	0.08
14	0.82	0.47	0.16	0.42	0.29	0.16
Cement C						
1	0.01	0.03	0.0	0.08	0.08	0.0
3	0.37	0.12	0.02	0.10	0.12	0.02
7	0.49	0.24	0.09	0.29	0.17	0.06
14	0.63	0.51	0.18	0.36	0.22	0.15
Cement D						
1	0.03	0.02	0.0	0.07	0.04	0.0
3	0.32	0.14	0.03	0.11	0.12	0.02
7	0.44	0.37	0.10	0.31	0.21	0.07
14	0.54	0.46	0.20	0.40	0.27	0.16

Cements used in this study have generally high alkali content. Considering the results, it is better to use cements with 0.6% Na_2O_{-eq} value and below (Stanton, 1940).

DISCUSSION

Reduction of expansion versus supplementary materials

Fly ash, blast furnace slag, and silica fume

Different mineral admixtures were used in this study to compare their effectiveness in controlling ASR expansions. All the samples with admixtures show less expansion than the control mortar bar. FA reduces concrete permeability (Ellis, 1992) and the replacement amounts which is around 25% have been shown to significantly mitigate ASR, even in marine environments for concretes whose w/c ratio are below 0.5 (Berube et al., 2000). SF has also been proved to mitigate ASR, for example in 10% SF replacement of cement reduces expansions to a level close to 20% FA replacement (Touma et al., 2000). BFC was found effective in reducing ASR expansion; for example mortar bars containing slag showed lower expansions at 14 days as

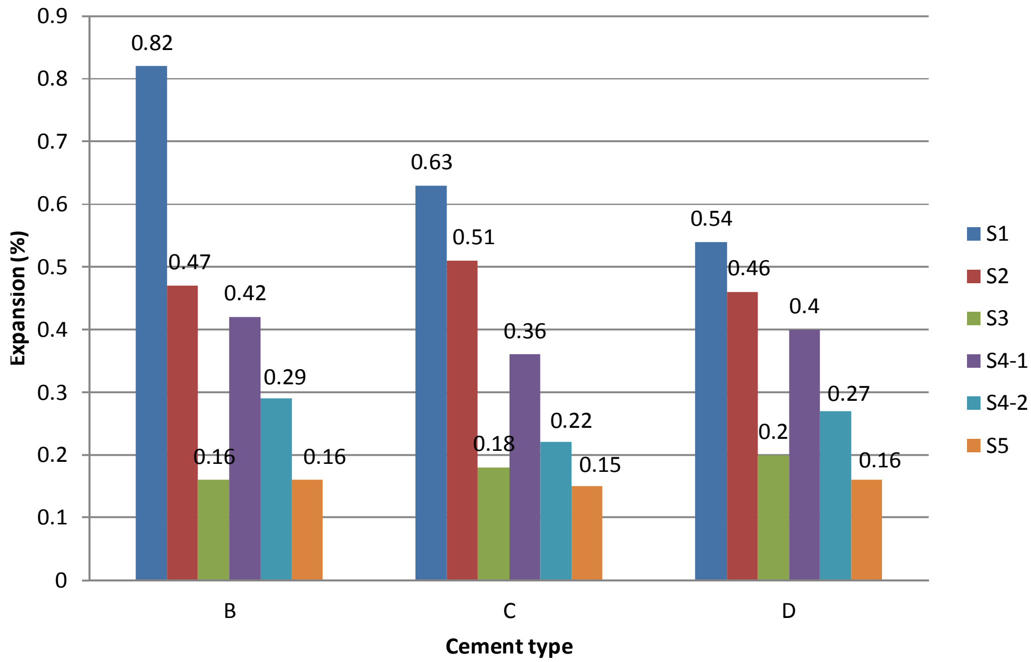

Figure 10. Effect of different cement usage on mortar bar expansions.

compared to control specimens (Rangaraju et al., 2009). Mortar bars containing FA, slag at 20% of replacement always appears to be effective to control ASR expansions. SF was very effective at 10% replacement level. These findings confirm the evidence obtained from the length change measurements. Of all the mixtures tested, SF is the most effective material mitigating ASR expansion, although the SiO_2 content is much higher than other mineral admixtures. Further, the use of other supplementary materials and replacement levels to be, when they are used together would be researched through ASR.

Natural zeolite

A number of research studies have been confirmed that NZ effectively prevents the deleterious expansion of concrete due to ASR (Feng et al., 1998). In general, it was observed that the degree of expansion decreases as the level of NZ addition increases. It is also obtained from the results that NZ with high silica content had better performance than that with low silica content on suppression of ASR. Based on the results of accelerated mortar bar tests, in samples prepared with S1,S2, and S3 aggregates, 10% replacement level of both NZ have the expansions lower than the control samples. 20% replacement level of both NZ is successfully lower down the expansions under the acceptable limits. Samples with 20% replacement of both zeolites always showed lower expansions under code defined acceptable limits. It can be concluded that using high reactive zeolite at 20% cement replacement is effective in mitigating ASR expansions whereas using low reactive zeolite and high reactive zeolite at 10% cement replacement was not enough to suppress them.

Micronized calcite

MC as a filler was added to the investigation for the reason of difference in chemical composition in S4 aggregates. Their calcite contents were different and researchers claimed that expansions are affected by calcite content of aggregates. The influence of MC addition on ASR expansion is shown in Figures 8, 9, and 10. In general, it was observed that the degree of expansion decreases as the level of MC addition increases. It was also observed from the results, that MC is effective on suppression of ASR. MC lowers the expansions in control samples prepared with S1 aggregate; however, 20% replacement of MC was highly effective mitigating ASR expansions. Samples prepared with S2 and S3 aggregate with 20 replacement of MC showed lower expansions under acceptable limits. It can be concluded that using MC with 20% replacement level of cement seems effective in mitigating ASR expansions whereas using it at 10% replacement level of cement was not enough to suppress them. To show the relative effectiveness of all admixtures, expansion results are presented together and shown in Figures 11, 12, and 13.

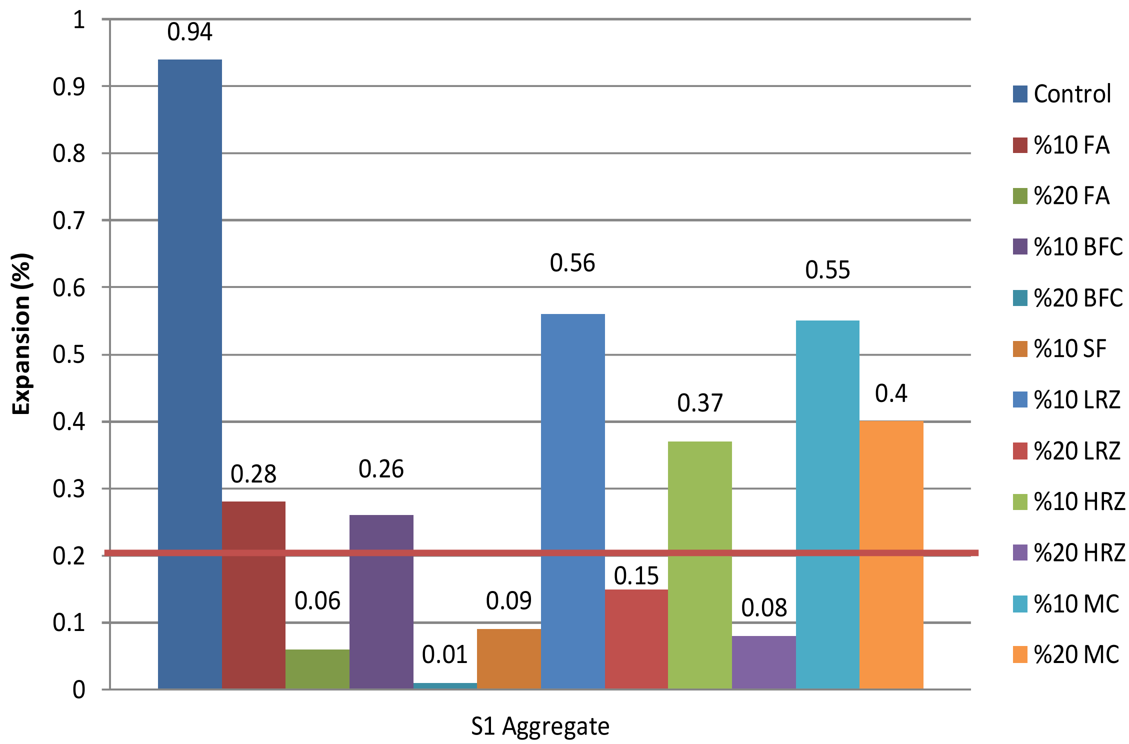

Figure 11. Effect of mineral admixture addition on mortar bar expansions containing S1 aggregate with time at various replacement levels.

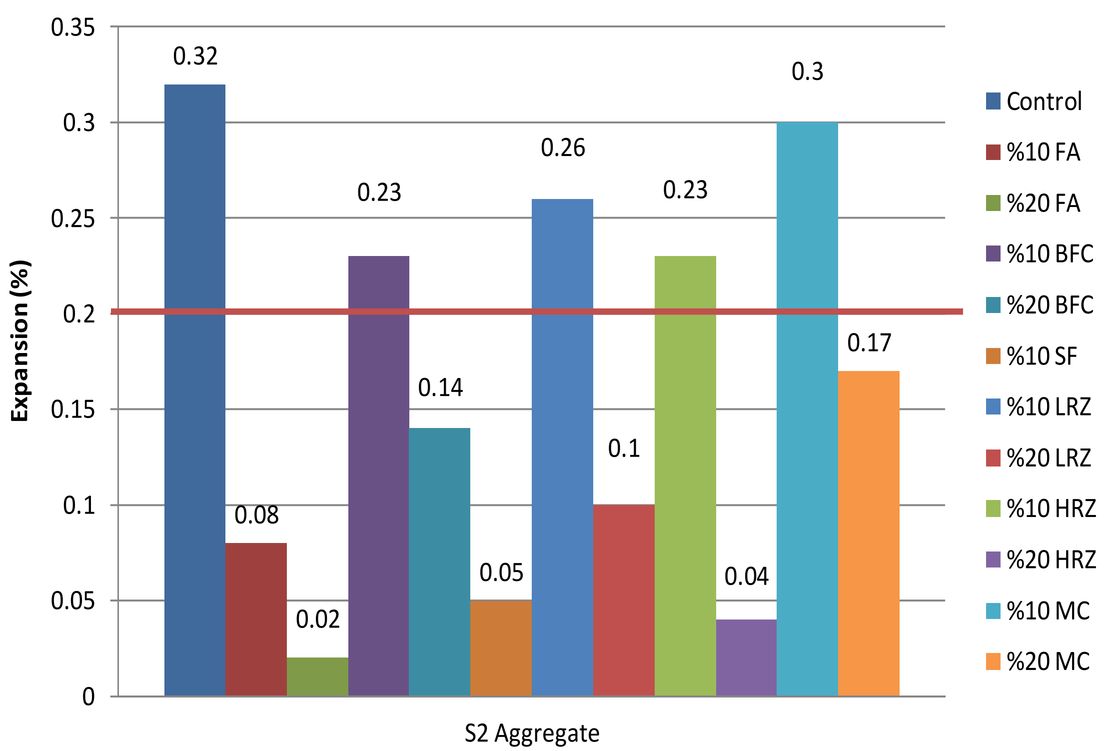

Figure 12. Effect of mineral admixture addition on mortar bar expansions containing S2 aggregate at various replacement levels.

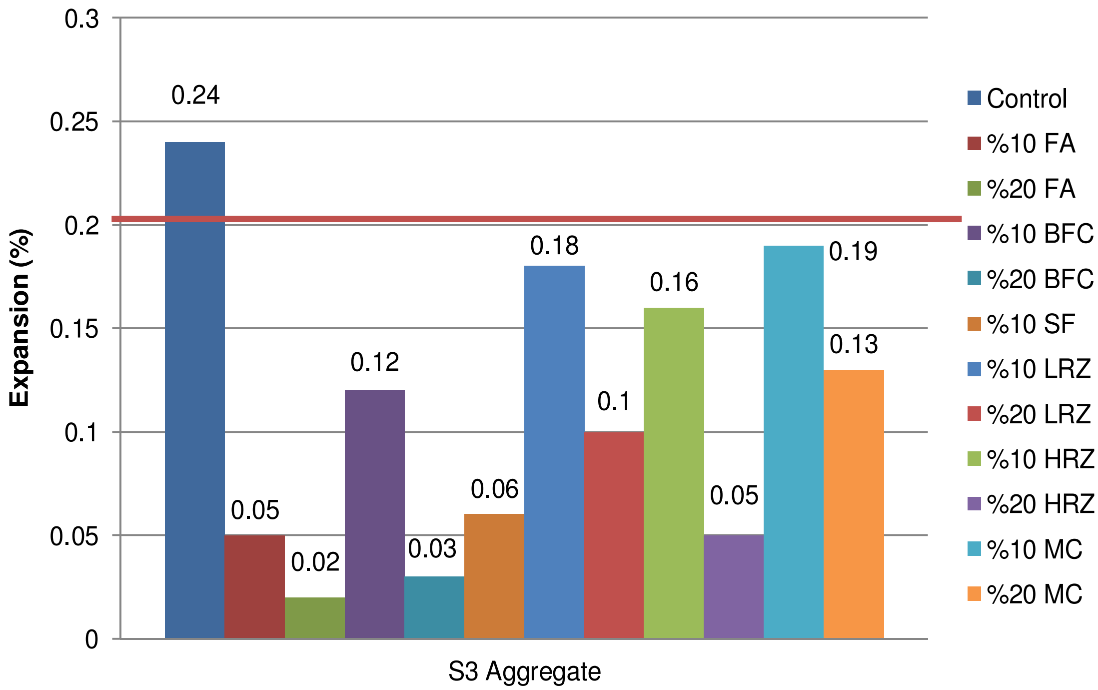

Figure 13. Effect of mineral admixture addition on mortar bar expansions containing S3 aggregate at various replacement levels.

Different cement usage

In related standard (ASTM C1260, 2007), it is stated that, because the specimens are exposed to a NaOH solution, the alkali content of the cement is not a significant factor in affecting expansions. Again, in the same standard, it is stated that the alkali content of the cement had been found to have negligible (Davies and Oberholster, 1987) or minor (Hooton, 1990) effects on expansion in this test. Researchers investigated that the change of cement caused different expansions at the end of 14 days. To investigate this effect, three different cements with different Na_2O_{-eq} content and five aggregates were used in this part of the study. Mortar bars cast with same aggregate but different cements have different expansions but they did not show distinct expansion results from each other. As a result, different cement usage makes a difference between the expansions but cannot change the final decision about the reactivity of the aggregates.

Conclusion

In this study, effectiveness of two zeolites with different reactive silica content, FA, BFC, SF, and MC in reducing expansions due to ASR was investigated. Test results reveal that the control mixtures used in the study showed considerable ASR expansion. Most of the batches tested were able to mitigate ASR expansions to below 0.10% and therefore according to ASTM C1260, very few of them were not within the permissible limits.

Using NZ gives positive results due to ASR. If NZ content increases, expansion due to the reaction decreases. NZ with high silica content has better performance than with low silica content on suppression of ASR. It can be concluded that using high reactive zeolite at 20% replacement of cement is effective in mitigating ASR expansions.

FA and BFC at certain replacement levels showed positive performance in reducing ASR expansions. At levels of replacement up to 10% failed to control ASR expansions of highly reactive aggregate with 0.60% length change. FA and slag were effective at 20% replacement level. Using SF has a significant effect on expansions at 10% replacement for potentially and highly reactive aggregates with 0.24, 0.32 and 0.60% length change. The use of 20% of high reactive zeolite or 10% of SF was similarly efficient in controlling deleterious expansions of mortar bars containing reactive aggregates. They lowered the expansions almost to the same levels. Also MC at 20% replacement of cement seems to be effective in mitigating ASR expansions; whereas, using it at 10% was insufficient to suppress them. Different cement usage showed a minor difference between the expansions; however, the final decision about the reactivity of aggregate was indecisive. In further studies, this research needs to determine the effectiveness of supplementary materials by using prolonged tests in worldwide standards.

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