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Effectiveness of Natural Zeolite in Mitigating Alkali Silica Reaction Expansions

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Abstract**—**This paper investigates the effectiveness of two natural zeolites in reducing expansion of concrete due to alkali-silica reaction. These natural zeolites have different reactive silica content. Three aggregates; two natural sands and one crushed stone aggregate were used while preparing mortar bars in accordance with accelerated mortar bar test method, ASTM C1260. Performances of natural zeolites are compared by examining the expansions due to alkali silica reaction. Natural zeolites added to the mixtures at 10% and 20% replacement levels by weight of cement. Natural zeolite with high reactive silica content had better performance on reducing expansions due to ASR. In this research, using high reactive zeolite at 20% replacement levels was effective in mitigating expansions.

Keywords**—**Alkali silica reaction, natural zeolite, durability, expansion.

I. Introduction

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 cement by supplementary materials. The third option has attracted much more attention by researchers because plentiful supplementary material resources are available for use in concrete and also in mortars [1]. Today, it is well known fact that supplementary materials known as mineral admixtures such as fly ash, silica fume, blast furnace slag, metakaolin, and zeolite are successfully used to control ASR expansions [2]. 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 silica fume and fly ash [3].

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 [4]. NZ may be used not just like a pozzolan but additionally like micro filler within the cement for general densification of microstructure. Incorporation of 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-cement paste is zoned by the combination of filler and pozzolanic reaction [3], [5].

In this study, tests were carried to determine effectiveness of two different natural zeolites on controlling ASR expansions. Both natural zeolites were used at %10 and %20 replacement levels by weight of cement and were compared because of their different reactive silica content and origin. The study tested a variety of aggregates from different quarries. For instance, aggregates which were found reactive due to ASTM C1260 method were used in the tests [6].

II. Materials and Methods

A. Cement, Aggregates and Natural Zeolite

The binder was normal Portland cement CEM I 42.5R, specified by European Standard EN 197-1 (EN 197-1, 2000) [7]. Table I shows their chemical composition and alkali equivalent (Na_2O equivalent) contents, and Table II shows its physical properties. In this study, three aggregates from varied quarries were used. The aggregates have different origin and mineral composition. Mineral compositions of aggregates were taken from petrographic examinations conducted in accordance with ASTM C295 (ASTM C295, 2011) [8]. Chemical composition was derived from the tests conducted in geochemistry laboratory. First aggregate is natural sand obtained from Sakarya River and named as S1 aggregate. Second aggregate is a crushed aggregate stone obtained from Istanbul region and named as S2 aggregate. Third aggregate is natural sand obtained from Istanbul region and named as S3 aggregate. Mineralogical compositions of all aggregates were shown in Table III and chemical compositions of aggregates were shown in Table IV.

In this experiment, supplementary materials consist of two NZ with different reactive silica content. Chemical composition and physical properties of supplementary materials are shown in Tables I and II, respectively. NZ used in this study are labeled as zeolite with high reactive silica content (HRZ) and low reactive silica content (LRZ).

B. Methods

The efficiency of two natural zeolites in controlling ASR expansion was 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 natural zeolite by weight of cement. Based on the test method, mortar bars were prepared by using 1 part of cement to 2.25 parts of aggregates. Additionally, the water to total

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cementations materials (w/c) was kept at 0.47. Two mortar bars (25 × 25 × 225 mm) were cast for each mortar mixture. After 24 hours, mortar bars were removed from the molds and stored in a water bath with tap water at 80°C for a period of 24 hours. After this preconditioning, the length of mortar bars were measured (initial reading). Then they are placed into storage containers filled with 1 normality (1N) of NaOH solution at 80°C for the duration of the test. Subsequent length readings were made using comparator seen in Fig. 1 on 1[th] 3[th] 7[th] 14[th] days. Expansions were measured as changes in mortar bar length. The same procedure was followed for the entire test.

Fig. 1 Comparator

TABLE I
CHEMICAL COMPOSITION

Oxide (wt%)	Cement	Low Reactive Zeolite (LRZ)	High Reactive Zeolite (HRZ)
SiO_2	17.70	66.18	66,06
Reactive SiO_2	-	38.18	57,10
Al_2O_3	3.95	12.92	11,32
Fe_2O_3	3.76	2.33	1,26
CaO	62.45	1.35	1,35
MgO	1.05	2.61	3,14
SO_3	4.12	-	-
LOI	4.82	-	-
$(Na_2O)_{eq}$	1.03	3.55	3,11

TABLE II
PHYSICAL PROPERTIES

Physical Properties		Cement	Low Reactive Zeolite (LRZ)	High reactive Zeolite (HRZ)
Specific Gravity (gr/cm^3)		3,14	2,21	2,38
Setting Time	*Initial (min)*	129	-	-
	Final (min)	191	-	-
Soundness(mm)		1,0	-	-
Specific Surface (cm^2/g)		3950	23890	20660

TABLE III
MINERALOGICAL COMPOSITION OF AGGREGATES

Mineral (Modal %)	S1	S2	S3
Quartz	78-82	30-95	84-86
Feldspar	5-6	10-15	2-3
Mica	1	15-20	-
Clay + Carbonate	-	30-35	-
Opaque	-	3-4	-
Turmaline	0.5	-	-
Garnet	1	-	-
Chlorite+ Epidote	1	-	-
Ferric Oxide	1-2	-	<0.5
Calcite	2-3	-	1-2
Rock Particles	-	-	10-12

TABLE IV
CHEMICAL COMPOSITION OF AGGREGATES

Mineral (Modal %)	S1	S2	S3
SiO_2	56.55	60.64	50.30
Al_2O_3	10.46	4.74	19.27
Fe_2O_3	3.80	2.19	9.52
CaO	12.54	16.97	3.71
MgO	2.31	0.70	4.40
TiO_2	0.50	0.14	1.10
P_2O_5	0.14	0.07	0.19
MnO	0.12	0.12	0.14
Cr_2O_3	0.03	0.01	0.02
$(Na_2O)_{eq}$	3.44	2.23	3.88
LOI	9.16	11.21	5.99

III. RESULTS

Expansions of mortar bars prepared with two natural zeolites and their control bars are shown in Table V. Figs. 2-4 represent the expansion results up to 14 days. Mortar bars cast with 10% and 20% replacements of high and low reactive zeolite and S1, S2 and S3 aggregates. Aggregates have higher expansion than 0.2% at the end of 14 days are defined as highly reactive aggregate by researchers [9]. Considering the average of 14 days expansions, S1, S2 and S3 aggregates can be classified as highly reactive aggregate.

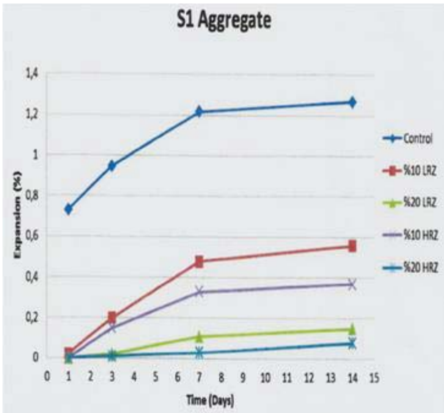

Fig. 2 Expansions of mortar bars cast with S1 aggregate

Fig. 3 Expansions of mortar bars cast with S2 aggregate

TABLE V
EXPANSIONS OF MORTAR BARS

Aggregate	Time (Days)	Control Bar	%10 LRZ	%20 LRZ	%10 HRZ	%20 HRZ
S1	1	0.73	0.02	0.00	0.00	0.00
	3	0.95	0.20	0.02	0.15	0.01
	7	1.22	0.48	0.11	0.33	0.13
	14	**1.27**	**0.56**	**0.15**	**0.37**	**0.08**
S2	1	0.03	0.00	0.00	0.00	0.00
	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	1	0.00	0.00	0.00	0.00	0.00
	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**

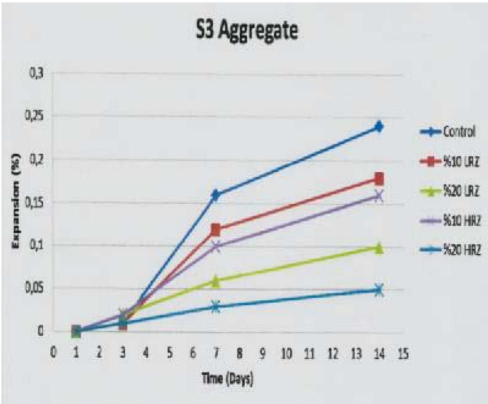

Fig. 4 Expansions of mortar bars cast with S3 aggregate

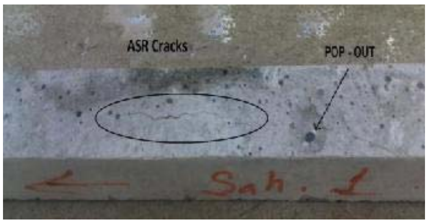

Fig. 5 Expansion cracking due to ASR and Pop-out of aggregate

IV. Discussion

A number of research studies have been confirmed that NZ effectively prevents the deleterious expansion of concrete due to ASR [10]. In general, it was observed that the degree of expansion decreases as the level of NZ addition increases [11]. 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. Using high reactive zeolite at 20% cement replacement was effective in mitigating ASR expansions whereas using low reactive zeolite and high reactive zeolite at 10% cement replacement was not enough to suppress them. Cracks and pop-outs observed on samples due to ASR are seen in Fig. 5.

V. Conclusion

1. Mortar bars prepared with S1 aggregate showed very high final expansion, 1.27%, at the end of 14 days and was found highly reactive due to ASR.
2. Samples prepared with S2 aggregate showed medium final expansion, 0.32%, at the end of 14 days and was found highly reactive due to ASR
3. Mortar bars cast with S3 aggregate showed low final expansions, 0.24%, at the end of 14 days and was found highly reactive due to ASR.
4. It was observed that the degree of expansion decreases as the level of NZ addition increases.
5. Based on the results of accelerated mortar bar tests, %10 replacement level of both NZ lowered the expansions under code defined limits in samples prepared with S2, and S3 aggregates but couldn't lower it in highly reactive S1 aggregate.
6. 20% replacement level of both NZ successfully lowered down the expansions under the acceptable limits in all samples of three aggregates.
7. Samples with 20% replacement of both zeolites always showed lower expansions under code defined acceptable limits.
8. HRZ has better performance than LRZ on suppression of ASR. It can be concluded that using high reactive zeolite at 20% replacement of cement is effective in mitigating ASR expansions.

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