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Optimization of four different mineral additive combinations to reduce alkali silica reaction

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ABSTRACT

Presence of alkali silica in aggregates that are used in concrete production causes formation of cracks and decrease of performance over time in concrete.The first damage caused by ASR in Turkey had been observed in certain highway bridges in Izmir locality in 1995. It was found that some aggregates in other regions of Turkey also have a character to cause ASR.The purpose of the study was to minimize potential alkali silica reaction expansion in concrete and mortars produced with the aggregates that are used in constructions in our region.Accelerated mortar bar test method was employed in the study. It was observed in experimental study that that the use of 20-25% fly ash, 25-35% blast furnace slag and 10% silica fume and metakaolin as mineral additive reduced ASR.According to optimization studies, it is appropriate to use 5-10% silica fume, 5% metakaolin, 10-15% blast furnace slag and 10-20% fly ash as mineral additive in optimum mixtures giving ideal expansion value.It was found that the use of 65% of cement together with 35% silica fume, metakaolin, blast furnace slag and fly ash in mineral additive combinations prevents ASR.

Key words: Metakaolin, Expansion, Silica Fume, Fly Ash, Optimization

1. INTRODUCTION

Alkali silica reaction (ASR) refers to the reaction of reactive silica in concrete aggregates and hydroxyl and alkali ions in pore solution of concrete. This reaction causes the formation of alkali silica gel that expands in concrete due to the effect of humidity. Tensile stress resulting from expansion in concrete causes cracks. Damage resulting from ASR in concrete was first proven by Stanton approximately 70 years ago [1].

ASR expansion starts with the formation of gel inside or on the surface of reactive aggregate and absorption of water by the gel. The gel that absorbs water produces approximately 10 MPa compressive stress towards all directions. Number of minimum cracks compensating increase of volume in cement paste that wraps the aggregate due to the compression is three and these cracks generally make a 120^o angle with each other.These cracks propagate by starting from around the aggregate in the form of three or four arm stars. Classical map cracking occurs in unconstrained and unreinforced concrete due to the combination these cracks [2].In structures consisting of constraint, the cracks propagate towards the direction of stress [3]. As the reinforcements are parallel to the tensile, ASR cracks also occur in that direction. However, unlike corrosion cracks, they develop between the reinforcements rather thanon the reinforcement. Map cracking that was formed in a highway barrier due to the effect of ASR is presented in Figure 1-b. Generally rectangular shaped cracks were observed in elements where the reinforcement is equally distributed in two directions like slabs.(Figure 1-a) [4,2,1,5].

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a- Alkali silica reaction cracks and Thomas E. Stanton (Photo extracted from California Department of Transportation)

b-Highway barrier cracks affected by severe map-cracking and ASR (Bolu Mountain,

Figure: 1 Images of Cracks that formed due to Expansion [5]

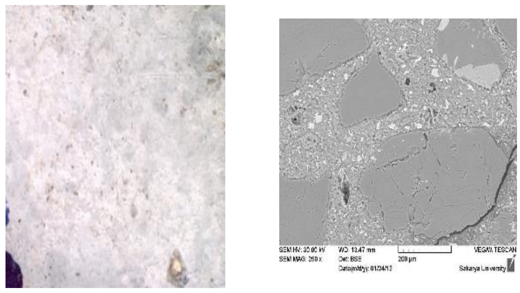
Fly ash (FA), ground granulated blast furnace slag (GGBFS), silica fume (SF) and Metakolin (MK) that are used as a cement component and as a direct concrete additive, affect all properties of concrete in fresh and hardened state.

First studies and researchers on the use of these materials which are four different industrial by-products, in concrete began to be applied in 1800s for BFS, in 1930s for FA, in 1940s for SF and today for Metakaolin [6]. Studies in Turkey began in the late 1950s for the first two materials and in 1980s for the third material.

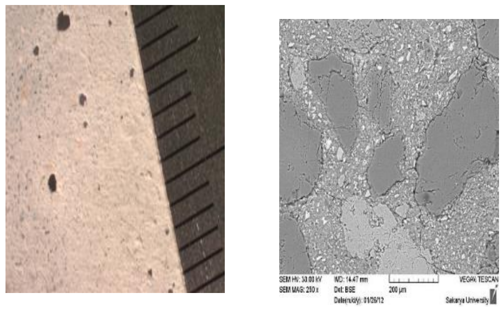
The use of these materials in concrete brings economical, technical and ecological benefits. It can be stated that at first, mineral additives in cement and concrete were mostly used for economic purposes [7]. However, currently conscious use of these additives positively impacts nearly all engineering properties of concretes. Mineral additives are generally known to reduce CO_2 emission by decreasing the amount of Portland cement in bonding material and to bring environmental benefits through recycling of these materials, which are wastes if they remain unused.

When used alone, among the mineral additives that replace cement, 20-25% class F fly ash, 30-35% blast furnace slag, 5-10% metakaolin and silica fume were effective in elimination of ASR. However when they are used in combination with other pozzolans, the use of these mineral additives at a ratio of 5-10% was effective to eliminate ASR [5].

No ASR crack was observed in mortar specimens produced by experimental study when mineral additive was used alone as presented in Figure 2.



Crack and SEM Images in SterioMicroscope in Samples with 30% Fly Ash Additive



Crack and SEM Images in SterioMicroscope in Samples with 30% Blast Furnace Additive

Figure 2.Images of Specimens with 30 % Additive

Our study concentrates on the fact that alkali silica reaction cracks that play an important role in terms of the durability of concrete and concrete elements can be reduced by four different mineral additive combinations.

Four different mineral additives were prepared in different compositions. Experimental study was conducted using accelerated mortar bar method. Statistical Package for the Social Sciences (SPSS) statistical analysis method and regression analysis were used to obtain a relation giving optimum mixture. We aimed to shorten duration of experiment and to make use of waste materials to maintain ASR experiments longer.

2. EXPERIMENTAL STUDY

2.1.Materials Used in the experiment and their properties

The aggregate specimen used in this study was supplied from upper region of Sakarya River. ASR study was carried out on the aggregate according to TS 2517 chemical method and (ASTM C289). According to the relevant standard, 3.zone the specimen aggregate was found to be harmful aggregate (Table 1).

Table 1. ASTM C289 and TSE 2517 ASR Report Chemical

NaOH (Consumed)	350 (mmol/L)
SiO_2 (Solved)	700 (mmol/L)
Result	**III.** Zone (Hazardous aggregate)

Accelerated mortar bar test conducted on the aggregate according to ASTM-C1260 showed that expansion value was around 0.9206 [8,9].

Test results, reference specimen cracks with ASR formation and scanned electron microscope (SEM) images are presented in Figure 3. An evaluation of the results in Table 1 and Figure 1 revealed that the aggregate was extensively harmful in terms of ASR.

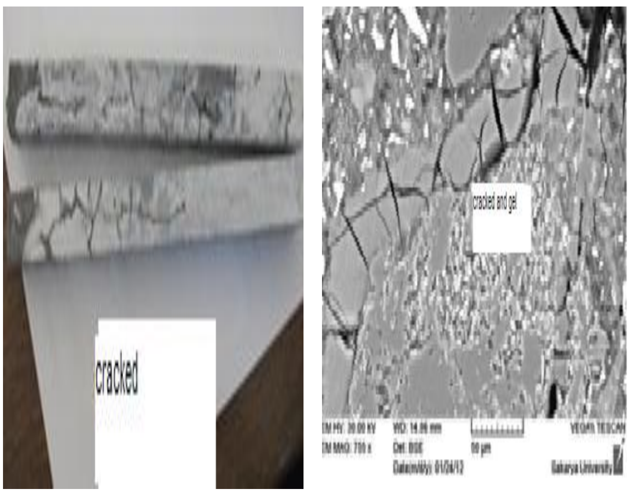


Figure 3. SEM Images and Crack Images of Control Mixture

According to ACI 221, cement equivalent alkali amount (Na_2O+0.658K_2O) should be maximum 0.6% . Ratio of alkali amount of cement used in the test was (Na_2O+0.658(K_2O)) = 0.22*0.658*0.46=0.52 (Na_2O), which is below the value of 0.6%. [10]. Alkali levels of cement and mineral additives are presented in Table2.[5]

Table2. Alkali Level Table of Cement and Mineral Additives

	Alkali level (%Na_2O equivalent)	Equation and alkali level necessary to find alkali level in used cement and mineral additives	
		(%Na_2O + 0.658 (%K_2O))	(% Na_2O Equivalent)
Cement (CEM I R 42.5)	should be <%0.6	0.22+0.658*0.46	0.52
Fly Ash	should be <%3.0	0.00+0.658*2.53	1.66
Blast Furnace Slag	should be <%1.0	0.50+0.658*0.87	1.27
Metakaolin		0.00+0.658*0.68	0.45
Silica Fume	should be <%1.0	0.29+0.658*0.87	0.86

3. EXPERIMENT PROCESS

3.1Accelerated mortar bar test (ASTM C 1260)

This test method is conducted by keeping mortar bars that are produced using the aggregates, whose alkali reactivity will be determined, in high solution, keeping the bars at a high temperature and measuring length changes. All specimens were prepared according to ASTM-C227 standard. Following the first length and 2.expansion measurement, 3-7-14 and 28-day values were identified for the specimens that were placed in solution with high alkalinity as required by the standard[11,12]. Mineral additive and cement ratios used in the prepared mortar bar specimens and the first expansion values are presented in Table 3. Silica fume, fly ash, blast furnace slag and metakaolin were used as mineral additive combinations.

Table 3. Mineral additive and Cement Mixture ratios and Expansion values

Specimen Group	Expansion Results	Metakaolin MK	Fly Ash FA	Blast Furnace Slag (BFS)	Silica Fume SF	Cement
Reference Specimen	0.921	0	0	0	0	1
Mk 1	0.171	0.05	0	0	0	0.95
Mk 2	0.076	0.1	0	0	0	0.9
Mk 3	0.064	0.15	0	0	0	0.85
Mk 4	0.275	0	0.0	0.05	0.05	0.85
Mk 5	0,053	0.2	0	0	0	0.8
Mk 6	0.068	0.15	0.2	0	0	0.65
Mk 7	0.075	0.15	0	0.2	0	0.65
Mk 8	0.081	0.1	0.1	0.12	0	0.65
Mk 9	0.079	0	0.2	0.15	0	0.65
Mk10	0.096	0	0.1	0.2	0	0.65
Mk11	0.0619	0	0.1	0.1	0.1	0.7
Mk12	0.0659	0	0.15	0.15	0.15	0.55
Mk 13	0.0593	0	0	0.2	0.2	0.6
Mk 14	0.0491	0	0.2	0	0.2	0.6
Mk 15	0.0527	0	0	0.25	0.15	0.6
Mk 16	0.0566	0	0.25	0	0.15	0.6
Mk 17	0.0560	0	0	0.3	0.1	0.6
Mk 18	0.0610	0	0.3	0	0.1	0.6
Mk 19	0.0790	0	0.2	0.15	0	0.65
Mk 20	0.0967	0	0.15	0.2	0	0.65
Mk 21	0.4308	0	0.05	0.15	0	0.8
Mk 22	0.2350	0	0.1	0.15	0	0.75
Mk 23	0.1818	0	0.15	0.15	0	0.7
Mk 24	0.2674	0	0.15	0.05	0	0.8

Accelerated Mortar Bar Test 28 day expansion results are given in Table 3, and the graph is given at Figure 4.

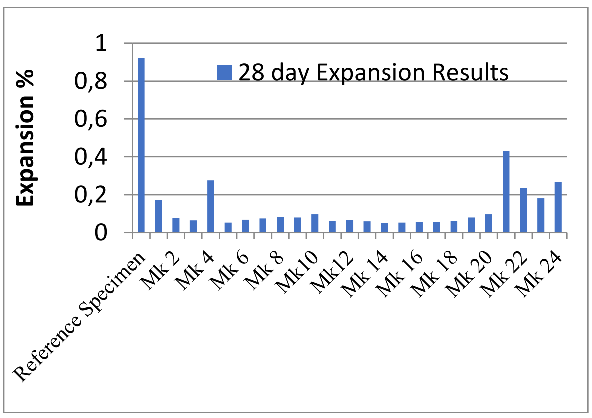


Figure 4. Accelerated mortar bar test expansion results graph

4. OPTIMIZATION STUDIES WITH MINERAL ADDITIVE COMBINATIONS

Statistical Package for the Social Sciences (SPSS-18) statistical analysis program was used for optimization studies[13].The following operations were performed on experiment results. Expansion values were taken as dependent, while cement, metakaolin, silica fume, fly ash and blast furnace mixture ratios were taken as the affecting factors while selecting method enter (Table 4).

Table 4. Program Inputs and Method

Model	Variable Inputs	Method
1. Solution	Cement, Silica Fume (SF), Fly Ash (FA), Blast Furnace Slag (BFS), Metakaolin (MK)	Enter

The program was run between critical values of 005 and 0.1 under sub-title of Anova statistics program. Regression coefficient and estimated error of model were found (Table5).

Table 5.Regression Coefficient and Estimated Error of the Model

Summary of the Model				
Model	Correlation coefficient R	Regression coefficient R^2	Adjusted R^2	Estimated Error of the Model
2. Solution	0.867	0.752	0.692	0.12994

Objective function coefficients of the mineral additive amounts and significance level of the test performed were obtained from the results of model solution. (Table 6)

Table 6.Objective Function Coefficients obtained by Linear Regression Results and Significance Level

Factors	Non-standardized coefficients		Standardized coefficients		
	B Objective Function Coefficients	Standart Error	Beta	t	Significance Level P≥,05
Metakaolin (MK)	-1.789	0.471	-0.540	-3.798	0.001
Silica Fume (SF)	-0.585	0.271	-0.342	-2.154	0.043
Fly Ash (FA)	-0.504	0.272	-0.294	-1.85	0.078
Blast Furnace Slag (BFS)	-0.752	0.378	-0.267	-1.991	0.060
Cement	0.504	0.074	1.555	6.83	0.000

It was observed that reliable test results were obtained according to significance level. An equation giving expansion values was developed using objective function coefficients. Model expansion was studied using the objective function coefficients obtained from analysis results (Table 7).

Table7. Model Expansion Study with Objective Function Coefficients

	MK	SF	FA	BFS	Cement	
Objective function coefficients	-1.789	-0.585	-0.504	-0.752	0.504	
Limit Ratios	≤0.05	≤0.20	≤0.20	≤0.05	≥0.65	
Decision Variable Ratios at the end of the Operation	%5	%20	%5	%5	%65	Total 1
Model Expansion Value	Z = 0.058349 Optimum expansion was found by the program					

Model expansion study was designed to use max 35% mineral additives and over 50% cement. In addition, the optimum mixture giving the most appropriate mixture and expansion value was found by limiting silica fume to ≤0,05, fly ash to ≤0.20, blast furnace slag to ≤0.20 and metakaolin to ≤0.05 with an upper limit (0.35) for four mineral additives and limiting cement to ≥0.65 (Table 8).

Table8. Optimum Mixture and Expansion Value found by Model Expansion

MK	FA	BFS	SF	Cement	Model Expansion Value
%5	%20	%5	%5	%65	0.058349

The equation giving optimum mixture found by the modelling study is presented below. (Equation 1). MEV : Model Expansion Value

MEV={(-1.789*MK) + (-0.585*FA)+(-0.504*BF) + (-0.752*SF)+(0.504*Cement)} Equation. 1

Expansion values obtained by this equation formula are presented in Table 9. Graphs of these values are presented in Figure 5.

Table 9.Model Expansion and Experiment Results found by Optimum Mixture Equation

Specimen Group	Model Expansion Results	Expansion Results	Specimen Group	Model Expansion Results	Expansion Results
Referans	0.504	0.921	Mk 14	0.035	0.049152
Mk 1	0.3893	0.171	Mk 15	0.0636	0.052768
Mk 2	0.2747	0.076	Mk 16	0.0433	0.0566
Mk 3	0.1600	0.064	Mk 17	0.076	0.0560
Mk 4	0.3363	0.2755	Mk 18	0.0517	0.0610
Mk 5	0.0454	0,053	Mk 19	0.135	0.0790
Mk 6	0.0577	0.0681	Mk 20	0.1390	0.0967
Mk 7	0.0415	0.0758	Mk 21	0.2983	0.4308
Mk 8	0.0121	0.0812	Mk 22	0.2439	0.2350
Mk 9	0.135	0.0790	Mk 23	0.1894	0.1818
Mk 10	0.1390	0.0967	Mk 24	0.2902	0.2674
Mk 11	0.1687	0.0619			
Mk 12	0.0010	0.0659			
Mk 13	0.0512	0.0593			

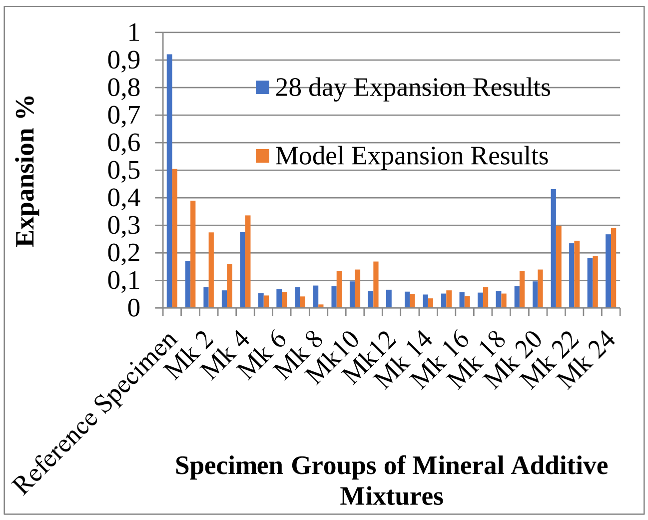


Figure5. Comparison of Model Expansion Values and Experiment Results

Studies giving optimum expansion values and mixtures were continued by limiting objective function coefficients obtained from analysis results.

Optimum model expansion value and optimum mixture amounts were obtained by keeping the upper limit for total mineral additive mixture at 0.35% and cement at 0.65%≥ (Table 10). A new experimental study was carried out using the optimum mixture values. Expansion values are presented in Table 10.

Table10. Optimum Mixture Amounts giving Optimum Expansion Value

Model Solution No	MK %	SF %	FA (%)	BFS (%)	Cement (%)	Model Expansion Value	Experimental Study Expansion Value
MS 1	5	5	20	5	65	0.058	0,060
MS 2	5	-	15	15	65	0.101	0,116
MS 3	5	-	20	10	65	0.099	0,104
MS 4	10	-	12.5	12.5	65	0,086	0,090
MS 5	5	5	12.5	12.5	65	0,092	0,096

According to these results it is adequate to use 5% metakaolin, 5~10% silica fume, 15~25% class F fly ash and 5~15% blast furnace slag as mineral additive combinations. It was observed that formation of alkali silica reaction cracks was eliminated when around 35% four mineral additive combinations and 65% cement was used.

Results of optimization study revealed that model expansion and experimental study expansion values showed consistency at the level of 97-98%. 2-3% deviation was observed between model expansion and expansion results found by experimental study. This deviation is believed to result from experimental setting. Model expansion values and experimental study expansion values graph is presented in Figure 5.

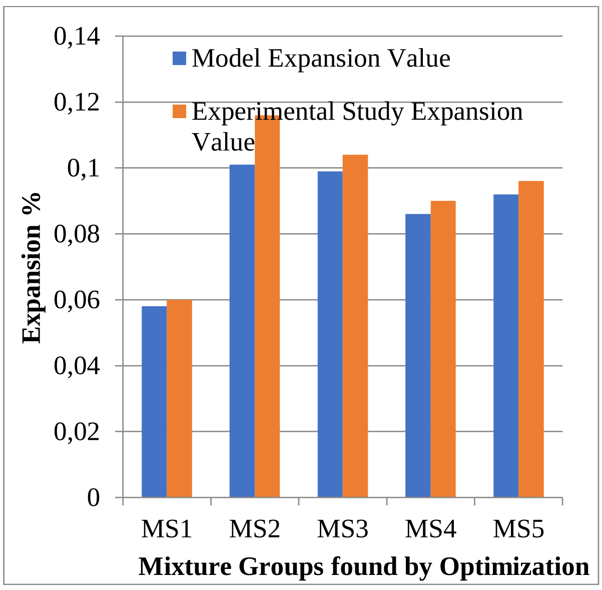


Figure6. Model Expansion and Experimental Study Expansion Values Graph

Model expansion values that gave optimum mixtures were found based on reducing alkali silica values below the standards. As it can be understood from the scope of the study, concrete damage caused by ASR will be eliminated for long years.

5. RESULTS AND DISCUSSION

The use of pozzolanic or mineral additives is known to have advantages in terms of enhancing the durability of concrete and resistance against ASR. The use of mineral additives at appropriate amounts inevitably has positive effects on concrete properties.

Experimental study showed that ASR can be reduced below the standard value when 20-25% fly ash, 25-35% blast furnace slag, 10% silica fume and 10% metakaolin are used as mineral additives.

It was observed in the study that alkali silica reaction cracks that play a vital role in terms of the durability of concrete and concrete elements were reduced by the use of four mineral additive combinations at appropriate ratios.

According to the results of experimental study, it is adequate to use 5% metakaolin, 5~10% silica fume, 15~25% class F fly ash and 5~15% blast furnace slag as mineral additive combinations. Thus, ASR is completely eliminated by using 35% mineral additive and around 65% cement.

The results of optimization study revealed that model expansion and experimental study expansion values were 97-98% consistent.

2-3% deviation was found to results from experimental setting.

Reactivity level of the aggregate that will be used affects these results. Therefore, no matter where, firstly it is advised to determine alkali level in cement and alkalinity level of the aggregate.

The long experimental process was completely shortened with this study. It will be appropriateto use mineral additives extensively in terms of the durability of concrete and make use of these additives which are otherwise considered as waste.

REFERENCES

[1] Stanton, D,E., "The expansion of concrete through reaction between cement and aggregate," Proc. Amerikan Society of Civil Engineers, 66:1781-1881, 1940.

[2] Figg, J., "ASR-Inside Phenomena and Outside Effects (Crack Origin and Pattern)," pp.152-156,P.E.Grattan-Bellew (Ed.), Concrete Aggregate Reaction Noyes Publications, NewJersey, 509p, 1987.

[3] Poole, A.B., "Introduction to Alkali-Aggregate Reaction in Concrete," pp.30-53 The Alkali Silica Reaction ,n Concrete, R.N. Swamy (editör) Van Nostrand Reinhold, Newyork, 1992.

[4] Swamy, R.N., "Testing for Alkali Silica Reaction," pp.54-95, The Alkali-Silica Reaction in Concrete, R. N. Swamy (editor), Van Nostrand Reinhold, New York, 1992.

[5] Yıldırım, K., Sümer, M., Uysal, M., " The Optimization of Mineral Admixture Compositions in Reducing Concrete Alkali Silica Reactions" Unpublished PhD Thesis, 2013.

[6] Lewis, R., Sear, L., Wainwright, P. and Ryle, R., " Cementitious Additions," Advanced Concrete Technology Set, V.3, Butterworth&Heinemann, 2003.

[7] Tokyay, M., "Betonda UK, GYFC ve SD'nin Rolü," Beton 2013 HazırBeton Kongresi, pp. 201-238, 2013

[8] ASTM C-289-94, "Standard Test Method for Potential Reactivity of Aggregates (Chemical Method)", Annual Book of ASTM Standards, Annual Book of ASTM Standards, Concrete and Aggregates, Philadelphia, PA, USA, American Society for Testing and Materials, 4 (2): 157-163, 1994.

[9] TS 2517, ''Chemical Test for Potential Reactivity of Alkali Aggregates'', Turkish Standards Institute, Ankara, 1977.

[10] Yıldırım K, Sumer M., ''Comparative Analysis of Fly Ash Effect with three Different Method in Mortars that are Exposed to Alkali Silica Reaction'', Composites: Part B, 2013.

[11] ASTM C-227-97,"Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)", Annual Book of ASTM Standards, Concrete and MineralAggregates, Philadelphia, PA, USA, American Society for Testing and Materials, 4 (2): 126-130, 1994.

[12] ASTM C-1260-94,"Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)", Annual Book of ASTM Standards, Concrete and Aggregates, Philadelphia, PA, USA, American Society for Testing and Materials, 4 (2): 650-653, 1994.

[13] Statistical Package for the Social Sciences (SPSS) SPSS 18