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USE OF PUMICE AND SCORIA AGGREGATES FOR CONTROLLING ALKALI SILICA REACTION

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Abstract: Turkey has important potential pumices reserves (68% of the reserve of the world) and 56 % of pumice reserve of Turkey is in the East Anatolia Region. It is important to assess huge pumice reserves in Eastern Turkey for its use in the cement and concrete industry. Use of acidic pumice and basic pumice (scoria) as cement additive or aggregate are gaining popularity because of their proven structural/durability properties. This paper presents the results of an investigation to assess the effectiveness of pumice and scoria aggregates in controlling alkali silica reaction (ASR) of alkali silica reactive aggregate using the following test methods: the accelerated mortar bar test (ASTM C 1260) and the scanning electron microscopy technique (SEM). The morphologies, structures and properties of the samples were determined by XRD, ICP-MS, XRF and thin section study. Mortar cubes were specially prepared according to ASTM standards using 10, 20 and 30% pumice or scoria aggregate as alkali silica reactive aggregate replacement. The results are compared with ASTM requirements to assess the suitability of pumice or scoria for preventing alkali silica reactivity. According to the results of these methods, pumice aggregates control the alkali silica reaction whereas scoria aggregates decrease expansion but is not as effective as pumice in preventing ASR. The results of SEM analysis showed alkali silica gel formation and serious decomposition of aggregate texture due to ASR in scoria added mortar bars.

Keywords: *alkali silica reaction, aggregate, pumice, scoria, SEM*

Introduction

The most important factors that affect the durability of reinforced concrete structures are physical, mechanical, and chemical properties of the materials used for concrete production. Concrete durability may decrease due to internal and external effects (i.e. environmental conditions etc.) and physical/chemical reactions. The most important chemical reaction that affects concrete durability is alkali silica reactivity (ASR) which is a chemical reaction between alkalis (sodium oxide, Na_2O) and potassium oxide (K_2O) found in cement paste and the reactive silica contained in the aggregates.

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This process creates an alkali-silicate gel that absorbs water and increases in volume (Stanton, 1940; Taylor, 1991). The reaction in concrete can develop fast or slow depending on the characteristics of reactive aggregates and water in the pores. There are many minerals that affect alkali silica reactivity. According to earlier studies that have been made on the effect of the ASR, the most active minerals in terms of ASR are found to be volcanic glass, quartz, opal, tridymite, chalcedony, and cristobalite (Ineson, 1990).

Natural materials that are extensively used as mineral admixture in concrete industry found to be effective in decreasing ASR due to aggregate used in concrete (Saglik, 2009; Davraz and Gunduz, 2013). The highly porous structure of natural materials (i.e. perlite, pumice, scoria etc.) were considered to work as an air entrainment agent that holds expanded alkali-silica gels in its structural pores and consequently prevent ASR in concrete (Saglik, 2009).

This study is organized to find the effectiveness of pumice and scoria used as fine aggregate in preventing the ASR in concrete. For this purpose, alkali silica reactive aggregate named ETRA is replaced with 10, 20 and 30% pumice or scoria aggregate and the effect of pumice and scoria in controlling alkali silica reaction is investigated. The accelerated mortar bar test method (ASTM C 1260) which is among widely used tests for evaluating the potential alkali reactivity of aggregates for concrete is used for evaluating ASR of the mixtures. Alkali silica gel formation in each mixture was observed using the SEM analysis.

Materials and methods

Aggregate and cement

Pumice aggregate (PA) and scoria aggregate (SA) were obtained from a quarry in Ercis (Van) and Patnos (Agri). Alkali silica reactive aggregate (ETRA) was collected from Etrusk Volcano located in Ercis, Van, Eastern Turkey. More than 50 kg of pumice and scoria samples were collected from each location. In order to reduce the amount of sample, sampling was done using cone and quartering method and riffles, since sampling must represent the mineralogical, physical and chemical homogeneity. The samples were crushed and ground using laboratory dodge jaw crusher, rod mill and ball mill to reduce their size to -200 mesh (74 μm) for mineralological and chemical analyses. Three hand samples which were chosen from each location were prepared for thin section studies. Cutting, polishing and thinning processes were performed using an oil system. Glue that hardened under UV light was used.

Table 1. Chemical composition of the cement using experimental study

Component (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI	Total alkali
Cement	20.03	4.53	3.50	64.13	1.14	2.65	2.50	0.65

The cement used in the Accelerated Mortar Bar test was an ordinary portland cement – CEM I 42.5 R (Table 1) according to EN 197-1 (equivalent to ASTM C150 Type I).

Characterization

To investigate the petrographical characteristics of aggregates, thin sections of three aggregate samples were prepared and determined by using LEICA Polorizan Microscope. Major oxide element analyses of the ETRA, PA and SA samples were obtained at the ACME Analytical Laboratories in Vancouver, Canada, using ICP-MS. Compositions of the pumice samples were checked by X-ray Powder Diffraction. By comparing the positions of the diffraction peaks against that of the ICDD cards, the target material could be identified. The XRD data were collected using Rigaku X-ray Diffractometer (Model, RadB-DMAX II) with Cu K_{α} (30 kV, 15 mA, λ = 15.4051 nm) radiation at room temperature. In addition, to confirm the occurrence of alkali–silica gel in mortar bars, LeO EVO 40 scanning electron microscope was used.

Experimental study

A number of tests are available for evaluation of the potential alkali silica reactivity of aggregates. The accelerated mortar bar test (ASTM C 1260) which is one of the widely used tests for evaluating the potential alkali reactivity of aggregates for concrete is used to determine effectiveness of pumice and scoria in controlling ASR. The alkali content of the cement does not affect the expansion in this test method because the specimens are stored in a NaOH solution at 80 ^{o}C. Alkali amount of CEM I 42.5R cement that is used in accelerated mortar bar test is 0.65%. Water/cement ratio of the mortar bars is 0.47 and aggregate grain size is between 4.75 mm and 150 μm as specified in ASTM C 1260. Length changes of samples (original and pumice and scoria added) in the solution are measured on the third, seventh and fourteenth days according to ASTM C 1260 and effectiveness of pumice and scoria aggregate in controlling ASR is determined.

Results and discussion

Characterization of Aggregates

The thin sections, which were randomly selected from the images, are given in Figure 1. PA consists of plagioclase, sanidine, volcanic glass and microphenocrystals of the some mafic minerals such as amphibole and pyroxene. Plagioclase, pyroxene, rare amphibole and volcanic glass form mineralogical assemblage of SA sample. Plagioclase, sanidine, ortho-clinopyroxene, and rare olivine phenocrystals constitute the mineralogical assemblages of the ETRA aggregate. ETRA sample which have intersertale groundmass contains microcrystals of the same mineral assemblage and volcanic glass. Sanidine and plagioclase phenocrystals are partly absorbed, magmatically corroded, displaying sieve texture and they display alteration to clay minerals and serisite (Oyan, 2011; Oyan et al. 2011).

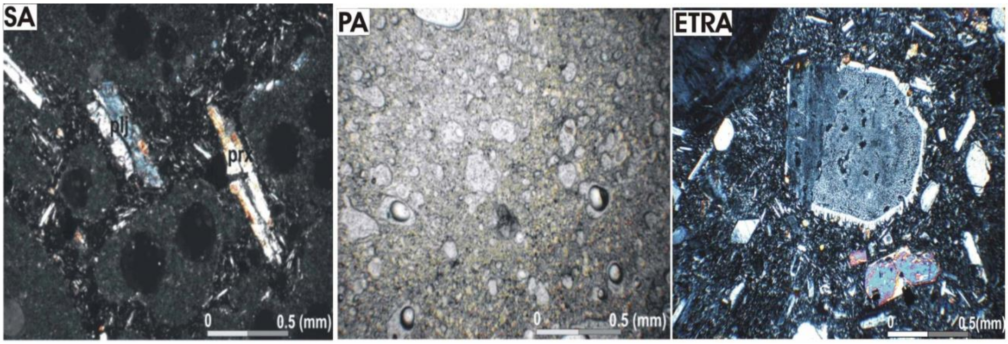

Fig. 1. Thin sections of the aggregates

Major oxide element analyses of the ETRA, PA and SA samples were obtained at the ACME Analytical Laboratories in Vancouver, Canada, using ICP-MS. The major element contents of the samples are given in Table 2. The chemical analysis indicates that SiO_2, Al_2O_3 and Fe_2O_3 constitute major contents of the samples. Pumice aggregates are named pumice and scoria depending on the SiO_2 content. According to chemical analysis, PA and SA can be classified as acidic pumice and basic pumice, respectively. In addition, chemical analysis results show that SiO_2, Al_2O_3 and Fe_2O_3 content is greater than 50%, and CaO content is less than 10%. According to ASTM C 618-08a (2008), the samples having this chemical composition possesses pozzolanic and cementitious properties, which can be used in the concrete industry.

Table 2 . Results of chemical analyses of the ETRA, pumice and scoria samples

Samples	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	LOI	Sum
ETRA	59.21	16.53	6.01	2.57	4.99	4.37	3.06	1.02	0.38	0.11	1.45	99.7
PA	71.29	12.67	1.50	0.09	0.52	3.66	4.60	0.09	0.02	0.07	5.4	99.93
SA	48.58	16.19	14.10	4.41	7.21	3.64	1.10	2.40	0.66	0.22	1.2	99.70

The XRD patterns of the samples are given in Figure 2. PA is an amorphous volcanic rock. X-ray diffraction data indicates that PA has not a crystalline structure and very broad reflection (peak) between 20° and 30° (2θ) confirming the presence of amorphous quartz as the characteristic properties of the acidic pumice. The XRD patterns of others show little crystalline mineral phases. Anorthite (JCPDS Card File No. 73-1435), hornblend (JCPDS Card File No. 71-1062) and crystalline quartz (JCPDS Card File No. 76-0823) are also observed in the XRD pattern.

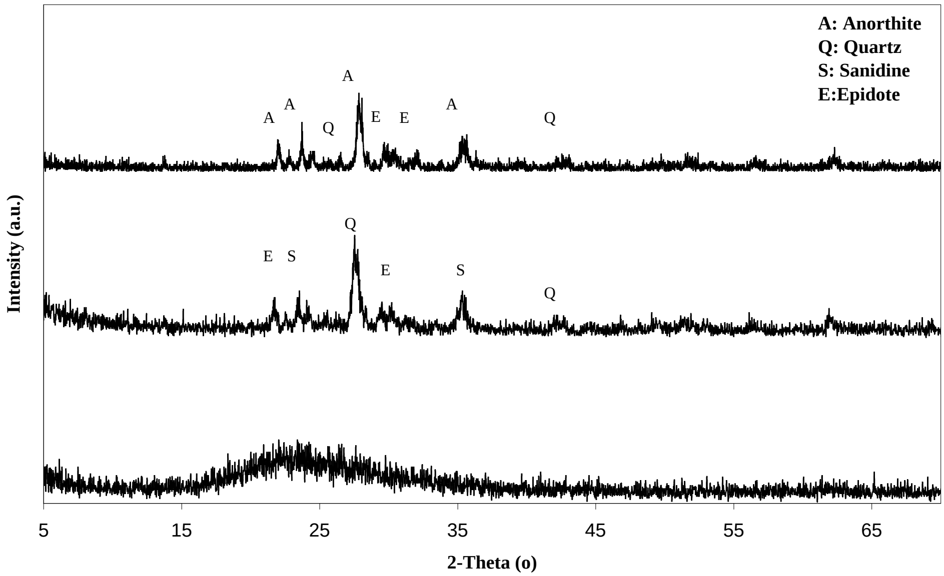

Fig. 2. XRD patterns of the samples

Accelerated mortar-bar test and determination of alkali–silica gel

Mortar bars were prepared using the ETRA aggregate and pumice and scoria added (10, 20 and 30% pumice or scoria replacement) ETRA aggregate. All samples were tested according to the ASTM C1260 Standard "Test method for Potential Reactivity of Aggregates (Mortar-Bar- Test)" and the results are given in Table 3.

Table 3. Average values of mortar-bar of ETRA and pumice and scoria added (30% pumice or scoria replacement) ETRA. P-pumice, S-scoria

Sample	3 day	7 day	14 day	ASTM C 1260	
ETRA	0.070	0.165	0.407	0.407 > 0.2	Deleterious
ETRA+%10 P	0.040	0.046	0.052	0.05 < 0.1	Innocuous
ETRA+%20 P	0.032	0.036	0.042	0.04 < 0.1	Innocuous
ETRA+%30 P	0.024	0.028	0.03	0.03 < 0.1	Innocuous
ETRA+%10 S	0.028	0.03	0.291	0.291 > 0.2	Deleterious
ETRA+%20 S	0.02	0.02	0.224	0.22 > 0.2	Deleterious
ETRA+%30 S	0.013	0.013	0.118	0.10 < 0.118 < 0.2	Potentially Deleterious

According to the results of accelerated mortar bar method test, expansions of the ETRA sample were found to be higher than 0.20 % as shown in Table 3. The 14-day expansions were respectively decreased to 0.05, 0.04 and 0.03% for 10, 20 and 30% pumice replacement. Ten and 20% replacement of scoria aggregate decreased the alkali silica gel formation but the aggregate mixture still found to be deleterious. Use of 30% scoria aggregate decreased the 14-day expansion to 0.118%. These results show that pumice used as fine aggregate substantially decreases ASR of deleterious aggregates whereas scoria used as fine aggregate prevent ASR of deleterious aggregate but is not as effective as pumice (Fig. 3).

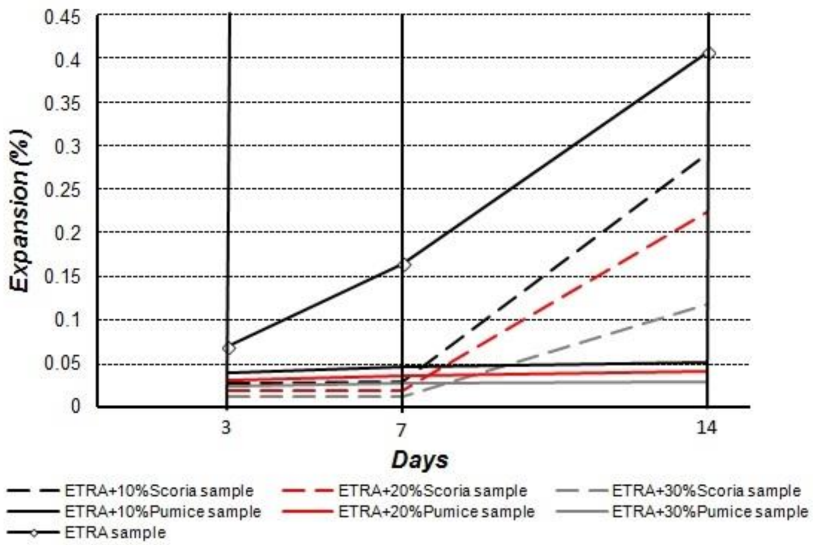

Fig. 3. Mortar-Bar test results showing the effect of percentage of pumice and scoria aggregate on expansion and time

The SEM observations of mortar bars tested according to ASTM C 1260 confirm the occurrence of alkali–silica gel in the samples in Figure 4 and Figure 5. Figure 4 (a) shows ASR gel formation in ETRA sample displaying the characteristic expansion cracks in the concrete. ASR gel formation are rarely observed in tested mortar bars produced with pumice added ETRA aggregate (Figs 4b and 5b). The 10% pumice aggregate replacement prevented ASR gel formation but could not prevent expansion cracks. 20% replacement was as effective as 30% pumice replacement in decreasing ASR gel formation. In contrary, the SEM observations of tested mortar bars prepared using scoria and ETRA aggregates confirm the occurrence of alkali–silica gel. Figures 4c, 4d, 5c, and 5d show alkali silica gel formation in ETRA+Scoria samples exhibiting the characteristic expansion cracks on the aggregate surface inside the mortar bars. 10 and 20% scoria added aggregates were found to be deleterious in terms of the 14-day expansion percentages whereas 30% scoria added aggregate was found to be potentially deleterious.

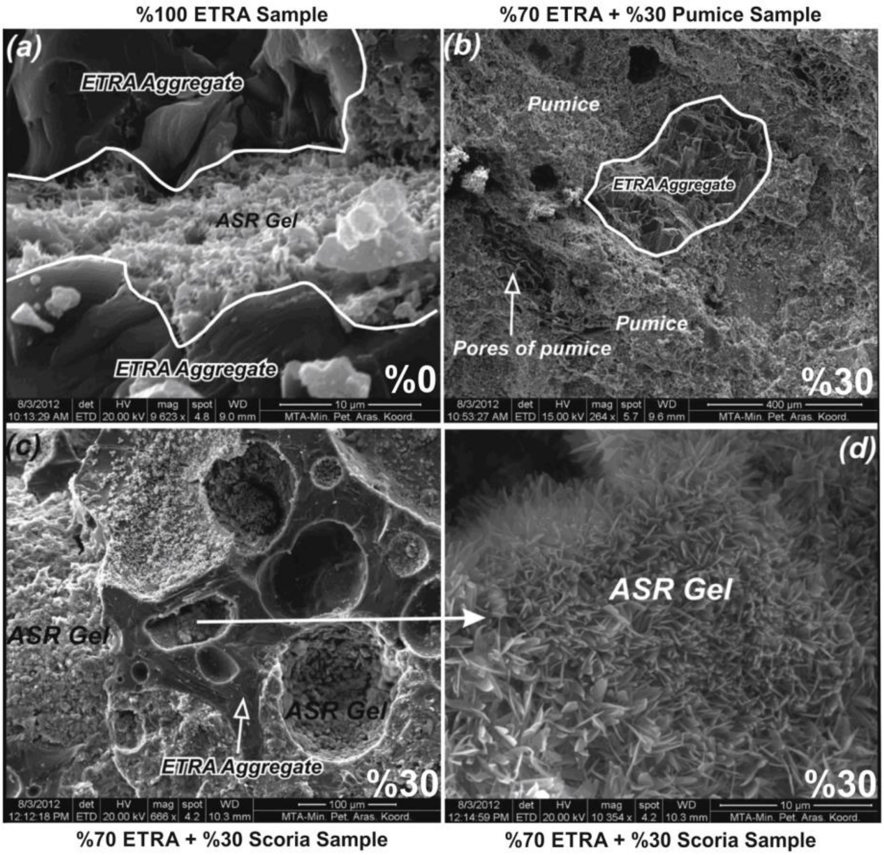

Fig. 4. SEM photomicrographs of the original and 30% pumice and scoria added samples

Conclusion

This study is organized to find the effectiveness of pumice and scoria used as fine aggregate in preventing the ASR in concrete. According to the results of this study, pumice used as fine aggregate substantially decreases ASR of deleterious aggregate. 10% pumice aggregate replacement prevented ASR gel formation but could not prevent expansion cracks. 20% replacement was as effective as 30% pumice replacement in decreasing ASR gel formation. It was also found that scoria used as fine aggregate prevent ASR of deleterious aggregate but is not as effective as pumice in preventing ASR. 10 and 20% scoria added aggregates were found to be deleterious in terms of the 14-day expansion percentages whereas 30% scoria added aggregate was found to be potentially deleterious. Future studies should be organized to find the effect of chemical composition of pumice and scoria aggregate in controlling ASR. Such studies are important for sustainable construction.

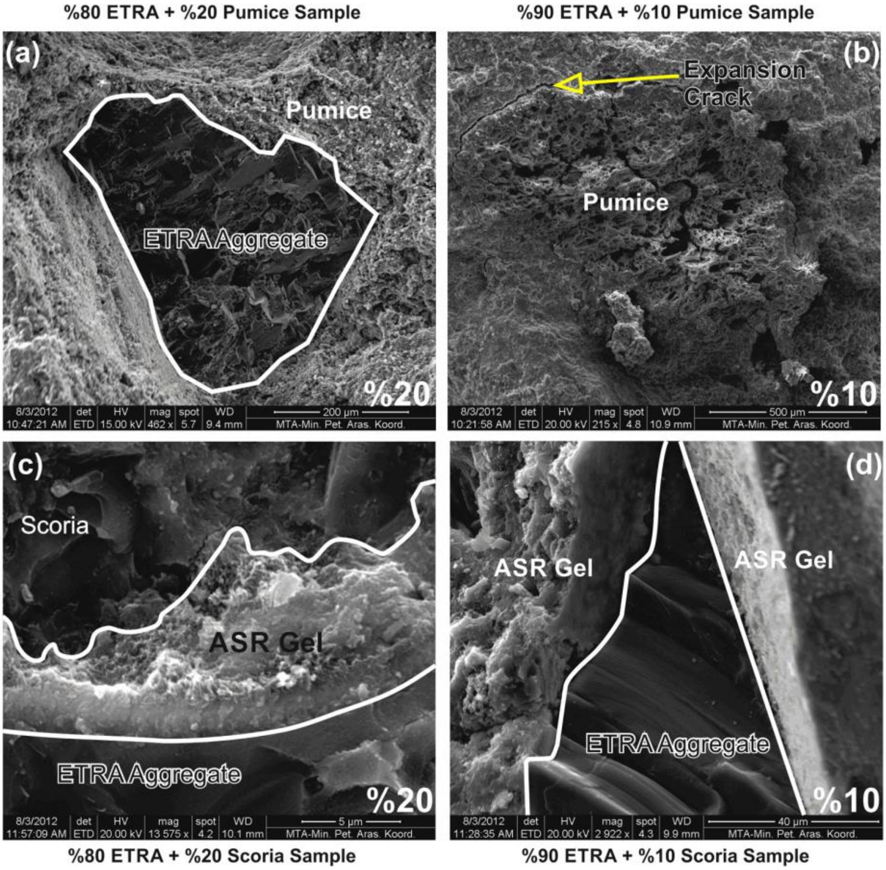

Fig. 5. SEM photomicrographs of the 10 and 20% pumice and scoria added samples

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