Available online at www.sciencedirect.com
ScienceDirect
Procedia Earth and Planetary Science 15 (2015) 725 – 731
Procedia
Earth and Planetary Science

World Multidisciplinary Earth Sciences Symposium, WMESS 2015

The Pessimum Ratio and Aggregate Size Effects on Alkali Silica Reaction

Adil Binal[a]*

[a] *Hacettepe University, Department of Geological Engineering, 06800 Beytepe-Ankara*

Abstract

Alkali aggregate reaction is a chemical reaction that occurs between the reactive component of the aggregate and alkali hydroxide from the cement used in concrete or external source. In this study, the accelerated mortar bar tests were performed and their results were compared with each other in order to investigate the ratio of reactive aggregate which causes maximum expansion in mortar called a pessimum ratio in literature. For this purpose, the pessimum ratios of six different reactive aggregates (opal nodule, chert, chalcedony nodule, andesite, ignimbrite and dolomite) were determined. The effect of the particle size on the development of alkali-silica reaction was determined again by the Accelerated mortar bar tests (AMBT). AMBT were carried out with mortar bars of opal, chalcedony and chert aggregates having 4.76 mm to 0.074 mm grain size (0.074 to 4.76 mm). The experimental results showed that the highest expansion occurred in reactive aggregates, with 150 - 300 m grain size.

Peer-review under responsibilty of the Organizing Commitee of WMESS 2015.

Keywords: Alkali aggregate reaction; grain size; reactive aggregates; opal; dolomite.

1. Introduction

Practical and economical solution has not been found yet for the chemical interaction between alkali solution and reactive aggregate named as alkali-aggregate reaction by Stanton in 1942. In concrete production, it benefits from the silica-free limestone aggregates for preventing the occurrence of alkali-aggregate reaction. However, alternative types of non-reactive aggregates are being explored in areas with fewer limestone quarries or construction site is very far from a site. In Turkey, particularly, the construction of dams in the region of the Eastern Black Sea and Eastern Anatolia has greatly increased. Therefore, natural material requirements have started to increase at a steady

* Corresponding author. Tel.: +90-312-2977185; fax: +90-312-2992034.
E-mail address: adil@hacettepe.edu.tr

Peer-review under responsibilty of the Organizing Commitee of WMESS 2015.
doi:10.1016/j.proeps.2015.08.103

rate in these regions. Alkali aggregate reaction is a chemical reaction that occurs between the reactive component of the aggregate and alkali hydroxide from the cement used in the concrete or external source (Swamy, 1990). There are three known forms of the alkali-aggregate reaction (AAR). These are: alkali carbonate reaction (ACR), alkali-silicate reaction (slowly progressive alkali-silica reaction) and alkali-silica reaction (ASR) (Swamy, 1992). However, in studies conducted in AAR, alkali carbonate reaction only occurs in carbonate aggregates containing silica. Consequently, the alkali-aggregate reaction in concrete may develop depending on silica content of the aggregate. The definition of the alkali carbonate reaction has been removed from the literature (Beyene et al. 2013, Grattan-Bellew and Chan 2013, Katayama 2010, Grattan-Bellew et al., 2010).

1.1 Definition of Pessimum

In the dictionary, the meaningof Pessimum is described by contrast to the word of optimum. Stanton demonstrated in 1940 that a certain proportion of some reactive siliceous aggregate caused the largest expansion of concrete, and that the expansion decreased when the content of the reactive aggregate in the concrete was increased or decreased from that pessimum proportion (Ichikawa 2009, Stanton 1941). He also found that, for a fixed proportion of reactive aggregate, the expansion became maximal at a certain grain size, and that the expansion decreased when the size was increased or decreased from the pessimum size (Ichikawa 2009, Stanton 1940). A typical curve showing the effect of expansion in the concrete due to the Pessimum ratio was given in Figure 1.

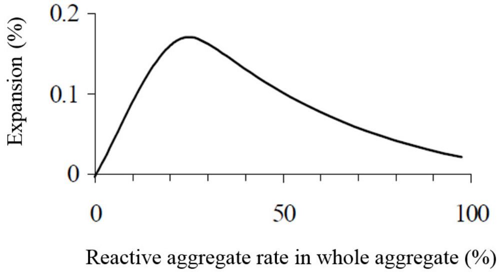


Fig. 1. A typical curve of the Pessimum ratio (French, 1980).

2. Materials

2.1 Cement

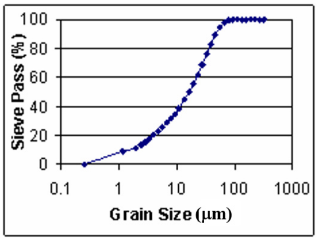
Type I Portland cement supplied from Lafarge Co. (OPC 42.5) that complies with the features of ASTM C 150 [19] was used in this study. It has a low total alkali (Na_2O_{eq}) level of 0.79%. Its chemical composition and relevant physical properties, as obtained from manufacturers and the geochemical laboratory of Hacettepe University, are presented in Table 1.

2.2. Reactive Aggregates

Six different reactive aggregates and one non-reactive aggregate were used in the mortar bar tests. The Reactive aggregates were opal nodules including opal-Ct and quartz minerals, chert, chalcedony nodules including bands of well-developed quartz crystals, andesite, non-welded ignimbrite including pumice at high proportions, limestone and dolostone which were collected from Kutahya, Ankara, and Mersin vicinities. Opal nodules, chert, chalcedony nodules, andesite, dolostone and ignimbrite as the reactive aggregates and limestone as the innocuous aggregates were used in the mortar bar tests. Mineral contents of them were determined by "CuKα" X-Ray source at °2ϑ in 5°-35° intervals and polarized microscopy studies; furthermore, the percentage of mineral in aggregate was calculated from a characteristic peak of mineral (Table 2).

Table 1. Chemical compounds and physicomechanical properties of cement (OPC 42.5).

Chemical Compound,(%)*		**Physical and Strength Properties**	
SiO_2	20.45	Fineness (Blaine), m²/kg**	3400
Al_2O_3	5.20	Specific Gravity	3.3
Fe_2O_3	3.41	*Compressive Strength, (MPa)*	
CaO	63.30	2 days (ASTM C 109)	22.3
MgO	1.25	7 days	37.6
SO_3	2.95	28 days	44.7
Ignition loss	1.50	*Tensile Strength, (MPa)*	
Relict material	0.30	7 days	2.05
Others	0.26	28 days	2.31
Na_2O	0.42	**Grain Size (µm)*****	
K_2O	0.56		
Total Alkali ($Na_2O+0.658*K_2O$)	0.79		
Cement Compounds, (%)			
C_3S	54.2		
C_2S	17.8		
C_3A	8.0		
C_4AF	10.4		



* Chemical compound was determined at Hacettepe University Geochemical Laboratory.
** The fineness of cement was obtained at Hacettepe University Department of Mining Engineering.
*** The grain size of it was determined by using Sympa Technology Laser Grain Size Analyses System at Hacettepe University Department of Mining Engineering.

Table 2. Mineral contents of aggregates tested.

Type of Aggregate	***Semi-Quantities Mineral Contents**	**Water Absorption By Volume (%)**	**Source Area**
Opal	Opal-Ct 87% Quartz 13%	2.55	Kutahya City, Turkey
Chert	Quartz 93% Calcite 7%	4.68	Guvenc Village, Ankara City, Turkey
Chalcedony	≈100% Quartz	3.07	Cubuk Village, Ankara City, Turkey
Andesite	Feldspar 28% Quartz 18% Clay 24% (Smectite, Kaolin) Calcite 29%	6.62	Papazderesi locality, Etlik, Ankara City
Ignimbrite	Clay 52% Feldspar 34% Mica 11% Quartz 7%	23.9	Cebeci, Ankara City
Dolostone	Dolomite, auxiliary minerals are Quartz, Clay, Limonite	2.0	Yavca, Mersin City
Limestone	≈100% Calcite	4.22	Beytepe Village, Ankara City, Turkey

3. Method

In literature, opal is defined as the most reactive mineral type and harmful aggregate for concrete. Volcanic glass, micro and crypto-crystalline quartz, chalcedony, tridymite and cristobalite were defined as moderately reactive minerals (Diamond, 1976; Ineson, 1990; Al-Dabbagh, 1986; Michel et al., 2000). Andesite includes volcanic glass that has reactive functionality (McConnell, et al., 1947; Mizumoto et al., 1986; French, 1992). Chlorite and clay minerals in weathered basalt are transformed into a silica gel as well as crack growths occur in concrete having basalt aggregate (Batic et al., 1994). Experiments were performed according to ASTM C 1260 standard accelerated mortar bar test (AMBT). The weight percentage of aggregates used in mortar bar test is given in Table 3. The aggregates used in AMBT were defined as deleterious because of more than 0.1% expansion in length. In the Pessimum ratio determination tests, the rates of the reactive aggregate in the total aggregate ranged from 5% to 100%. In order to determine the effect of particle size on expansion, reactive aggregates having grain sizes between 4.76 and 0.074 mm were mixed into the mortar.

Table 3. Sieves used in AMBT.

Sieve opening (mm)		
Top	**Bottom**	**% by weight**
4.76 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

4. Results

4.1. The Pessimum Ratio

Pessimum ratios vary depending on the reactive silica content of the aggregates. In the mortar bar tests, the maximum length expansions were determined in the samples, including 20% of opal (Fig. 2a). In the literature, pessimum ratios of opal range between 5% and 20%. The reason of this wide range is the presence of an amorphous silica type. Opal aggregates, including opal-A can show more length expansion values than aggregates comprising opal-CT (Binal, 2004). In this study, opal aggregates used in the tests include opal-CT and quartz type minerals. The maximum expansion in the mortar bar, including chert aggregates was determined to be 40% (Fig. 2b). The Pessimum ratio of chert aggregates varies depending on the amorphous silica content, cracks and calcite filling.

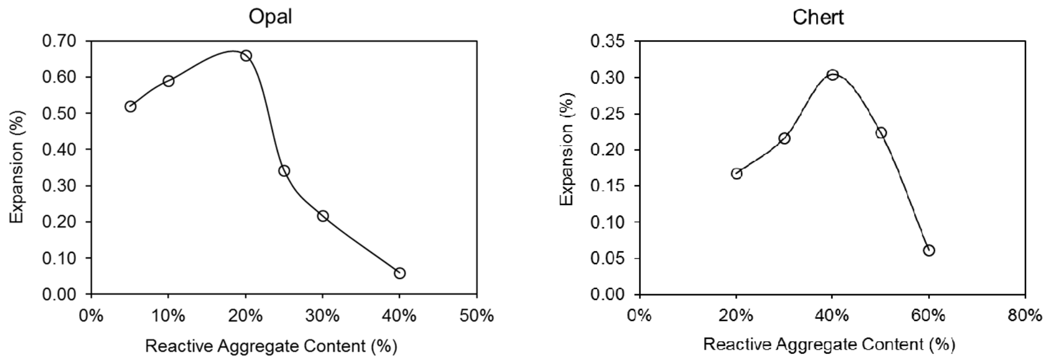


Fig. 2 a). The graph of the Pessimum ratio of opal aggregates, b) Chert.

Chalcedony aggregates include quartz veins. Therefore, the pessimum ratios of chalcedony aggregates are very high (50%) when compared to other types of aggregates (Fig. 3a). The reason of the alkali aggregate reaction in concrete including the andesite aggregate is volcanic glass contained in the matrix of andesite. Therefore, in case of highly andesite aggregate usage in concrete mix, pessimum behaviour can be observed (80%) (Fig. 3b).

Ignimbrite aggregates used for the mortar bar test have shown the pessimum ratio at the 50%. However, ignimbrite aggregates are classified as harmless due to the length of expansion not exceeding 0.1% (Fig. 4a). Dolostone aggregates show too low expansion in experiments (Fig. 4b) because of low silica content. Therefore, dolostone was classified as the innocuous aggregate.

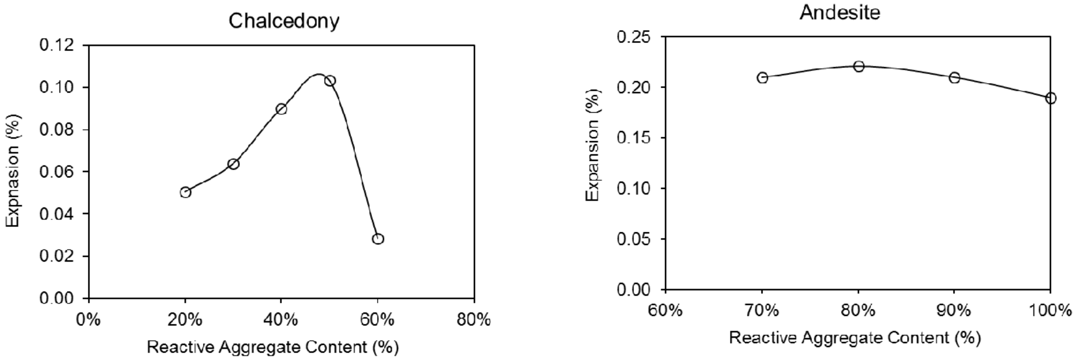


Fig. 3. a) The graph of the Pessimum ratio of chalcedony aggregates, b) Andesite.

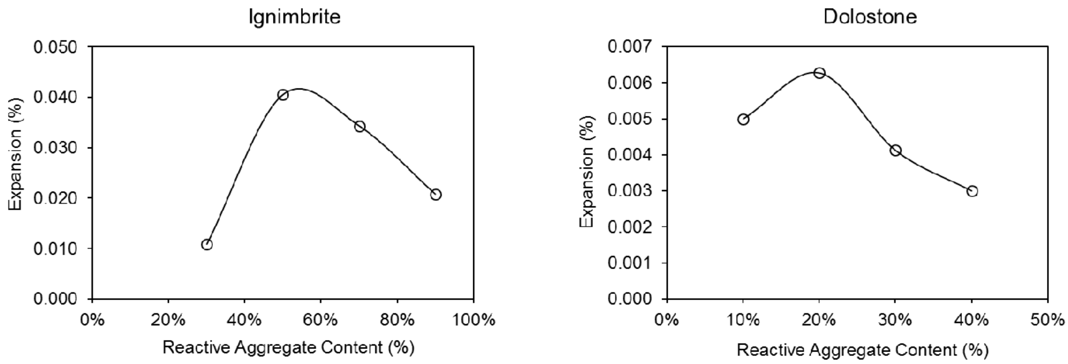


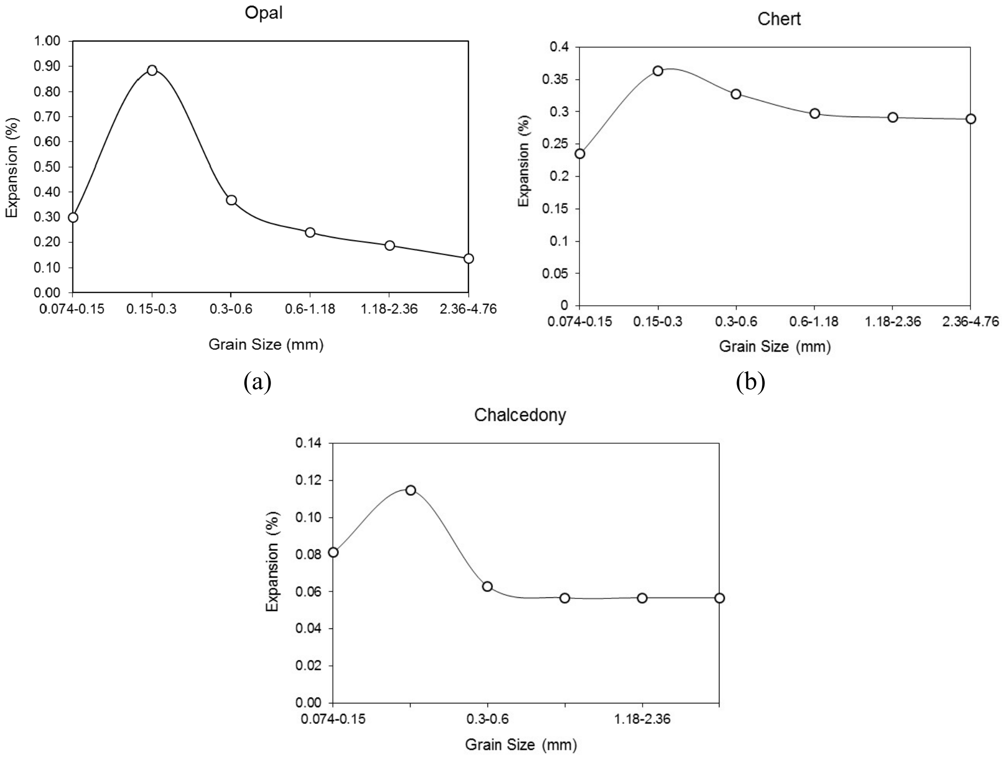
Fig. 4. a) The graph of the Pessimum ratio of ignimbrite aggregates, b) Dolostone.

4.2 Grain Size Effect

Mortar bar tests were carried out to determine reactive aggregate grain size effect on the expansion. The reactive aggregates (opal, chert and chalcedony) in the Pessimum ratio were added into the mortar bar mix. At the end of all tests, the highest amounts of expansion in length were determined in the mortar bars having the grain size of 0.15 to 0.3 mm (Fig. 5a-c). The expansion value of opal aggregates with the grain size between 0.15 and 0.3 mm (0.88%) was higher than the value of the pessimum ratio determination test (0.66%).

5. Conclusion

The mixes for the mortar bar tests must be prepared according to the Pessimum ratio when river aggregate is used in a concrete mix. In particular, producers must pay attention to the grain size of the reactive aggregate when using crushed stone in a ready mix.



(a) (b)

(c)

Fig. 5. a) The grain size effect on expansion for opal aggregate, b) Chert and c) Chalcedony.

References

1. Al-Dabbagh, I., 1986. Flint characteristics and alkali silica reactivity, Proceedings of the 7th International Conference on Alkali-Aggregate Reaction in Concrete, Grattan-Bellew, P.E. (ed.), Ottawa, Canada, 413-417.
2. ASTM C-1260-94, 1997, (American Society for Testing and Materials), Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar Bar Method), Annual Book of ASTM Standards; Section Concrete and Mineral Aggregates, Philadelphia, 04.08, 650-653.
3. Batic, O., Maiza, P., Sota, J., 1994. Alkali silica reaction in basaltic rocks NBRI method, Cement and Concrete Research, 24(7), 1317-1326.
4. Beyene, M., Snyder, A., Lee, R.J., Blaszkiewicz, M., 2013. Alkali Silica Reaction (ASR) as a root cause of distress in a concrete made from Alkali Carbonate Reaction (ACR) potentially susceptible aggregates, Cement and Concrete Research, 51, 85-95.
5. Binal, A., 2004. Pesimum reaktif agrega içeriğinin alkali-silika reaksiyonuna etkisinin deneysel yöntemlerle araştırılması, Istanbul Universitesi Yerbilimleri Dergisi, 17(2), 119-128.
6. Diamond, S., 1976. A review of alkali-silica reaction and expansion mechanisms, Reactive aggregates, Cement and Concrete Research, 6, 549-560.
7. French, W.J., 1980. Reactions between aggregates and cement paste-an interpretation of the pessimum, Quarterly Journal of Engineering Geology, 13(4), 231-247.
8. French, W.J., 1992. The characterization of potentially reactive aggregates, Proceedings of the 9th International Conference on Alkali-Aggregate Reaction in Concrete, 338-346.
9. Grattan-Bellew, P.E., Chan, G., 2013. Comparison of the morphology of alkali–silica gel formed in limestones in concrete affected by the so-called alkali–carbonate reaction (ACR) and alkali–silica reaction (ASR), Cement and Concrete Research, 47, 51-54.
10. Grattan-Bellew, P.E., Mitchell, L.D., James Margeson, J., Min, D., 2010. Is alkali–carbonate reaction just a variant of alkali–silica reaction ACR=ASR?, Cement and Concrete Research, 40(4), 556-562.
11. Ichikawa, T., 2009. Alkali–silica reaction, pessimum effects and pozzolanic, Cem. Concr. Res. 39, 716-726.
12. Ineson, P.R., 1990. Siliceous components in aggregates, Cement and Concrete Composites, 12(3), 185-190.
13. Katayama, T., 2010. The so-called alkali-carbonate reaction (ACR)-Its mineralogical and geochemical details, with special reference to ASR, Cement and Concrete Research, 40(4), 643-675.
14. McConnel, D., Mielenz, R.C., Holland, W.Y., Greene, K.T., 1947. Cement-aggregate reaction in concrete, Proceedings American Society for Testing Materials, 44, 93-128.

15. Michel, B., Gnagne, C., Thiebaut, J., Wackenheim, C., Maurin, B., 2000, Flint reactivity, 11th International Conference on Alkali-Aggregate Reaction, Bérubé, M.A., Fournier, B., Durand, B. (eds.), Ottawa, Canada, 71-80.
16. Stanton, T.E., 1941. Expansion of concrete through reaction between cement and aggregate. Am. Soc. Civil Eng. Trans. Paper 2129, 54–126.
17. Stanton, T.E., 1940. Expansion of Concrete through Reaction between Cement and Aggregate, Proceedings, American Society of Civil Engineers, New York vol. 66, 1940, 1781–1811.
18. Stanton, T.E., Portep, O.J., Meder, L.C., Nicol A., 1942. California experience with the expansion of concrete through reaction between cement and aggregates, ACI Journal, 38(3), 209-235.
19. Mizumoto, Y., Kosa, K., Ono, K., Nakano, K., 1986. Study on cracking damage of a concrete structure due to alkali-silica reaction, Proceedings of the 7th International Conference on Alkali-Aggregate Reaction, P.E., Grattan-Bellew (ed.), Ottawa, Canada, 204-209.
20. Swamy, R.N., 1990. The Alkali-Silica Reaction in Concrete, Thomson Litho. Ltd., Scotland, UK.
21. Swamy, R.N., 1992. Alkali-Aggregate Reactions in Concrete: Material and Structural Implications, Sciences in Concrete Technology, Malhotra, V.M. (eds.), Ottawa, Canada, 533-581.