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STUDY ON EXPANSION PROPERTIES OF ALKALI REACTIVE AGGREGATE BY CONCRETE

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1. INTRODUCTION

In 1983, damages to concrete structure caused by alkali reactive agregates were first reported in the Hanshin district, Japan. From subsequent survey it was found that damages caused by alkali reactive aggregates had occurred quite widely throughout Japan.

From recent damages and from reports of past damages, it was found that damages caused by alkali reactive aggregates are mostly due to alkali-silica reaction, which is influenced by the alkali content in cement, total alkali content in concrete, type of reactive aggregate including fineness and particle size, and furthermore mix proportion of reactive aggregate. These factors will also change expansive properties.

This paper summarizes the study on expansive properties of different aggregates when mix proportion of reactive aggregates, alkali content in cement, and alkali cement content in concrete were changed. This study was conducted with six typical alkali-silica reactive coarse aggregates (5 types of andesite and 1 type of chert) found in Japan.

2. EXPERIMENTAL METHOD

2.1 Procedure

The experiment as shown in Table 1, was conducted with 6 types of alkali reactive coarse aggregates, (5 types of andesite, 1 type of chert) and 3 types of cement with different alkali content 0.36%, 0.93% and 1 type with 1.50% Na_2O equivalent, prepared by adding alkali to 0.93% alkali content cement. The respective cement content in concrete was 300, 450 and 600 kg/m^3. Test specimens prepared under 189 different conditions were measured for alkali-silica expansion under a 40 degree humid atmosphere.

Table 1. Causes and conditions

	Causes	Conditions
1	Type of reactive aggregate	6 types (andesite-A, B, C, D, E, chert-F)
2	Mix proportion of ractive aggregate	3 levels (30, 60, 100%)
3	Alkali content of cement	3 levels (0.36, 0.93, 1.50%)
4	Cement content in concrete	3 levels (300, 450, 600 kg/m^3)
5	Total alkali in concrete	9 levels (1.08, 1.62, 2.16, 2.79, 4.18, 4.50, 5.58, 6.75, 9.00 kg/m^3)

2.2. Materials

2.2.1 Cement

The chemical composition of the 2 types of cement used in the experiment is shown in Table 2. The cement with alkali content of 1.50% Na_2O equivalent was prepared by adding analytical grade reagent NaOH and KOH while keeping the Na_2O/K_2O ratio in 0.93 alkali content cement constant.

Table 2. Chemical composition of cement

(%)

Type of cement	ig. loss	insol.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	R_2O*
L	0.7	0.2	22.3	5.5	2.9	62.6	2.7	1.8	0.17	0.29	0.36
M	0.5	0.1	21.8	5.0	3.2	64.0	1.6	2.1	0.59	0.51	0.93

Note: $*R_2O = Na_2O + 0.658\ xK_2O$

2.2.2 Aggregates

Fine aggregates verified to be innocuous by chemical method was used. Coarse aggregates were a standard aggregate, verified to be innocuous and 6 types of alkali reactive aggregates, verified to be deleterious. The physical properties of the aggregates are shown in Table 3 and their potential alkali reactivity, determined according to chemical method, are shown in Table 4 and Figure 1.

Table 3. Physical properties of aggregate

Classification		Type	Specific gravity		Unit weight	Solid volume percentage	Percentage of solid volume for particle evaluation	Absorption	Materials finer than 0.074 mm sieve	Clay lumps	Weight loss in solundness test	Weigh loss abrasion of coarse aggregate	Particles less than 1.95 specific gravity	Organic impurities in fine aggregate	Content of soft particle particle	Crushing
			Surface	oven	(kg/ℓ)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)
Coarse aggregate	Reactive	A	2.65	2.60	1.45	55.8	55.8	1.97	1.0	0.0	2.4	18.4	0.0	–	7.9	20.1
		B	2.73	2.70	1.55	57.5	57.5	2.20	0.8	0.0	2.8	16.5	0.0	–	1.5	16.5
		C	2.68	2.63	1.56	59.1	59.1	1.72	0.1	0.0	6.8	20.0	0.0	–	1.2	19.7
		D	2.54	2.49	1.44	57.5	57.5	1.94	0.8	0.0	3.4	11.7	0.0	–	0.0	15.5
		E	2.63	2.57	1.56	60.6	60.6	2.03	0.8	0.0	2.8	16.5	0.0	–	1.0	19.6
		F	2.67	2.65	1.57	59.2	59.2	0.86	0.3	0.0	4.0	17.4	0.0	–	11.7	19.8
	Standard	N	2.65	2.62	1.58	59.8	59.8	0.51	0.2	0.0	3.3	14.1	0.0	–	2.1	14.7
Fine aggregate		–	2.65	2.62	1.62	61.7	55.6	1.18	2.7	0.8	6.4	–	0.1	Good	–	–

Table 4. Potential alkali reactivity test of aggregate (chemical method)

Classification		Type	Mineral	Potential alkali reactivity test	
				Rc (m mol/ℓ)	Sc (m mol/ℓ)
Coarse aggregate	Reactive	A	Augite・Hypersthene・Andesite	139.0	492.0
		B	Augite・Hypersthene・Andesite	124.6	541.0
		C	Olivine・Augite・Hypersthene・Andesite	105.6	596.0
		D	Andesite	181.5	703.8
		E	Hypersthene・Augite・Andesite	99.5	630.6
		F	State (50%), Chert (45%), Sandstone (5%)	51.7	99.5
	Standard	N	Sandstone	47.8	38.2
Fine aggregate		--	Sandstone	27.2	13.3

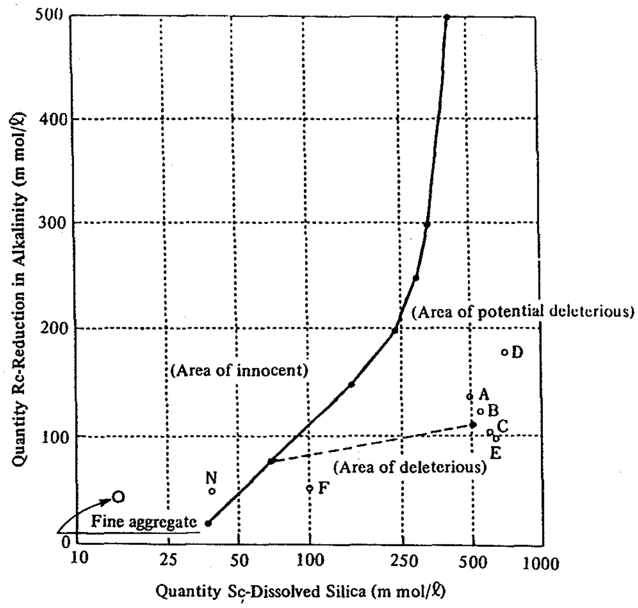

Fig. 1 Result of evaluation in accordance with ASTM evaluation method

2.3 Mix Proportion of Concrete

Mix proportion of concrete were 3 types shown in Table 5. The mixes were determined according to absolute volume in order to equalize the influence of reactive aggregates by keeping the unit absolute volume of reactive aggregates in the mix constant.

Table 5. Mix proportion of concrete

Water cement ratio	Fine aggregate percentage	Cement content	Water content	Fine aggregate	Coarse aggregate
	(%)	kg/m^3		Absolute volume (ℓ/m^3)	
0.70	44	300	210	295	
0.47	39	450	210	247	380
0.37	33	600	220	190	

2.4 Testing Method

Expansion was measured on a 10x9.5x9.5 cm specimen. The initial length was determined by measuring the specimen demolded at age of 2 days and cured for 1 week under sealed condition. The specimen was next exposed to 40 degree humid environment then was measured for expansion once every 2 weeks up to age of 2 month age and after this age was measured once a month.

3. RESULT AND DISCUSSION

The expansion test for all concrete prepared with the 6 types of reactive aggregate showed that expansion increased in proportion to the increase of total alkali content, but development of expansion showed a tendency to saturate at age of 12 month. Therefore, the main factors causing expansion were studied based on measurements conducted at age of 18 month when expansion had sufficiently saturated.

3.1 Total Alkali Content

According to the results of this experiment, alkali content of cement and cement content in concrete was found to influence alkali-silica reaction, which was influenced by cement content when total alkali content of cement was fixed and by alkali content of cement when cement content in concrete was fixed. In order to provide a general interpretation of expansion, it was reported [1] [2] that the total alkali content in concrete conducted from these factors was characteristic factor in order to provide a general interpretation of alkali-silica expansion, therefore we also disscussed the expansion properties by the total alkali content in concrete.

The relation between total alkali content in concrete and expansion of concrete containing reactive aggregates is shown in Figure 2 for different reactive aggregate content. From the relation between total alkali content in concrete and expansion, it was observed that regardless of mix proportion of reactive aggregates the expansion was not observed until total alkali content of 2.79 kg/m^3, therefore there is a threshold. A high increase of expansion is influenced by the type of aggregate and the mix proportion of reactive aggregate, but when total alkali content exceeds 4 kg/m^3, increase of expansion was especially high with the increase of total alkali content.

The maximum expansion was observed when total alkali content was highest at 9.00 kg/m^3 for almost all aggregates. However, the degree of expansion differed considerably with the type of aggregates, also expansion showed a tendency to become higher with increasing the mix proportion of reactive aggregate in concrete. For example, the expansion of aggregates D and E is highly influenced by the mix proportion of these aggregate in concrete when total alkali content is 4 – 5 kg/m^3 developing the expansion. The relation among types of aggregate, maximum expansion and mix proportion of reactive aggregate is summarized in Table 6.

Table 6. Influence of maximum expansion and aggregate mix proportion (Age of 18 months)

Type of aggregate	Maximum expansion (%)		Influence of mix proportion of reactive aggregate	
A, C	Expansion, medium:	0.25 ~ 0.35	Influence medium:	When mix proportion is 100%, the total alkali, which causes expansion, is higher (large threshold) than that of other mix proportion.
B	Expansion, large:	0.35 or more		
D, E	Expansion, medium:	0.25 ~ 0.35	Influence large;	Tendency is larger than above. Threshould for 100% mix proportion is around 5 kg/m^3.
F	Expansion, small:	0.25 or less	Influence small:	Influence of mix proportion is small.

Note) Maximum expansion of N aggregate: 0.15% or less

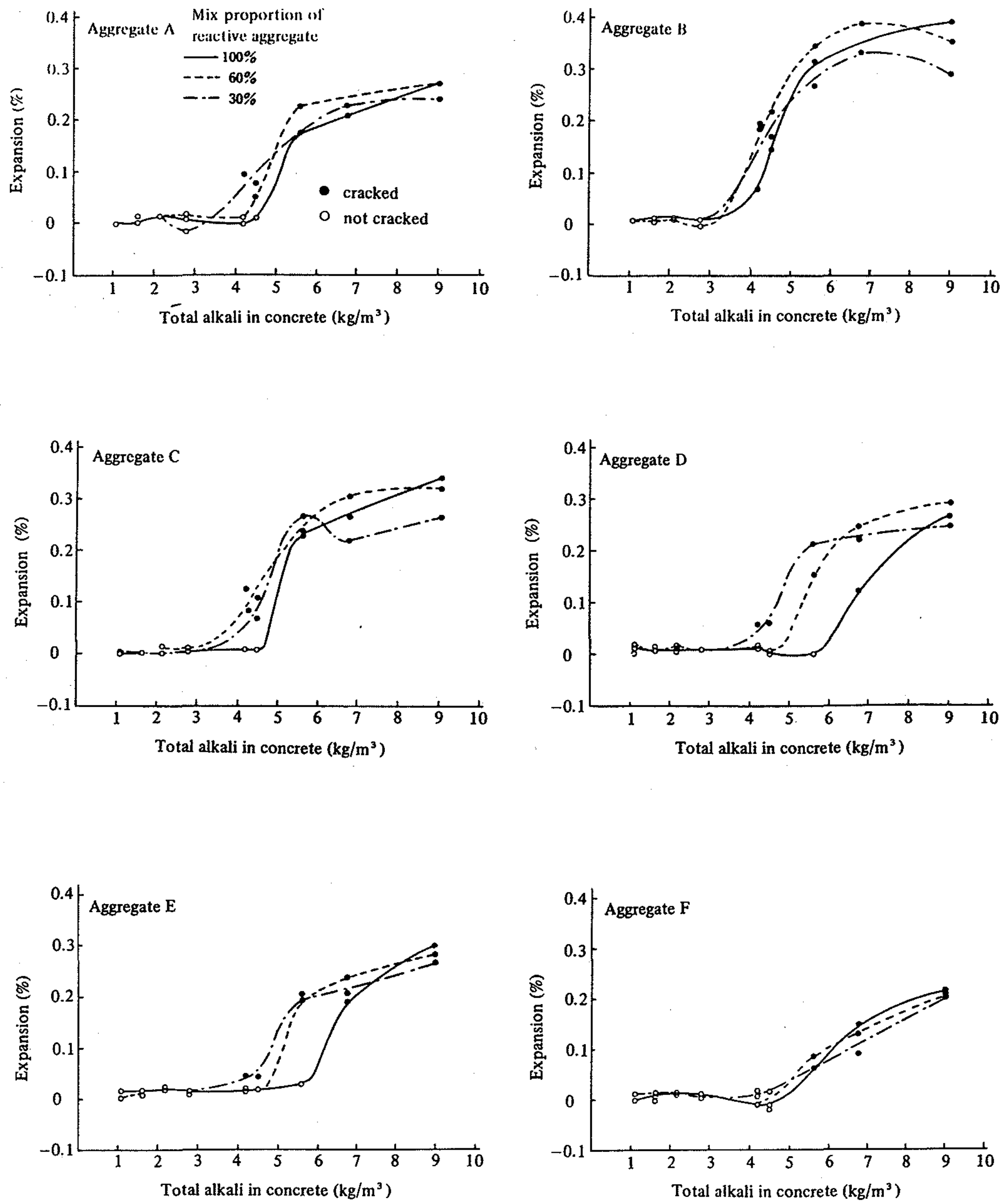

Fig. 2 Relation between total alkali in concrete and expansion

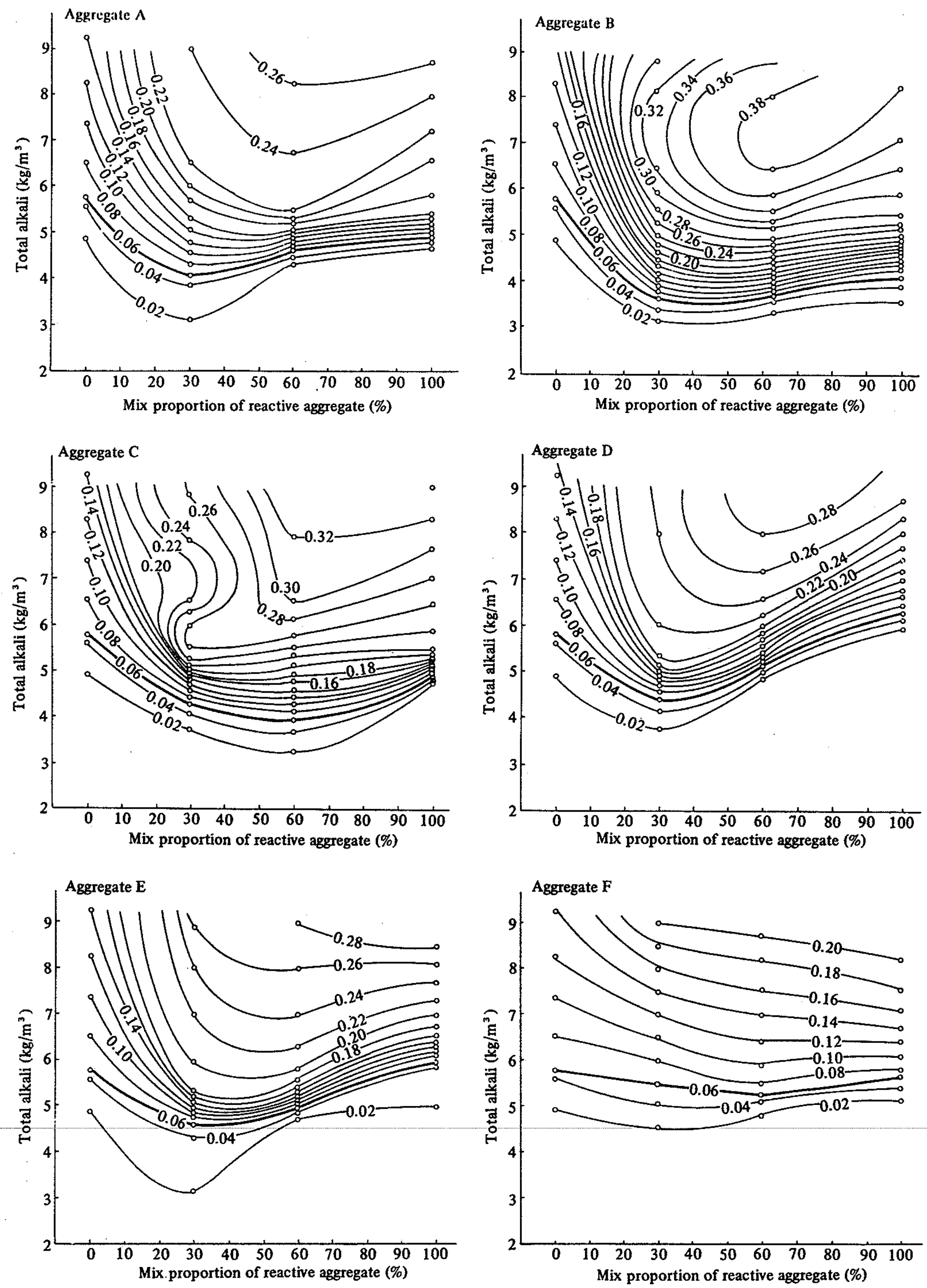

Fig. 3 Expansion contour line for reactive aggregate

3.2 Expansion Contour Line

From the preceeding description, it is clear that regardless of the type of reactive aggregate, alkali-silica expansion is mostly determined by the total alkali content and mix proportion of reactive aggregate. Also it was observed that a pessimum of mix proportion of reactive aggregate existed for maximum expansion and in some aggregates pessimum of alkali content was also observed.

Expansion contour lines, which summarize the expansion properties of respective aggregate, were developed using the above two factors as parameters, and are shown in Figure 3. The contour line of average expansion of 0.06%, when cracks are first observed, is shown in bold line to indicate the lower expansion limit when concrete is damaged. These contour lines show that the pessimum of mix proportion exist for andesite type aggregates A, B, C, D, and E, also pessimum of alkali content exist for aggregate B.

Pessimum of mix proportion was observed to move toward higher mix proportion with increasing total alkali content. On the other hand, the expansion properties of chert type aggregate F was observed to be quite different from andesite type aggregates and neither pessimum of mix proportion nor pessimum of alkali content was observed, and expansion became higher as mix proportion of reactive aggregate and total alkali content became higher.

When the minimum total alkali content for different aggregates which expands concrete to 0.06% the point when concrete is damaged, was investigated, the results for different aggregates were A 4.3 kg/m^3, B 3.5 kg/m^3, C 3.9 kg/m^3, D 4.3 kg/m^3, E 4.5 kg/m^3 and F 5.2 kg/m^3. The total alkali content for B aggregate which gives the highest expansion exceeds the total alkali content of 3.0 kg/m^3 [3] which is considered to be the upper limit inhibit alkali-silica expansion. Therefore, it was confirmed that expansion can be inhibited if total alkali content is under 3.0 kg/m^3.

4. CONCLUSION

Since concrete damages caused by alkali silica reaction is reported over a wide area in our country, alkali-silica expansion properties were studied on 6 typical alkali reactive aggregates by testing condition of 40 degree humid environment. The main results from the experiment were listed as follow.

1. Alkali-silica expansion is mostly determined total alkali content and mix proportion of reactive aggregate in concrete.

2. Andesire type aggregates all showed the existence of pessimum of mix proportion of aggregate and some showed the existence of pessimum of alkali content.

3. A threshould of alkali content was found to exist.

4. From the expansion contour line, it was confirmed that the minimum total alkali content which damages concrete is 3.0 kg/m^3 even for aggregates with the highest alkali-silica expansion.

REFERENCE

[1] Oberholster, R.E.: Alkali Reactivity of siliceous Rock Aggregate: Disgnosis of the Reaction, Testing of Cement and Aggregate and Prescription of Preventive Measures. 6th International conference Alkalis in Concrete. 1983.

[2] Palmer, D.: Alkali-Aggregate Reaction in Great Britain – The Present Position, Cement and Concrete Association Reprint, 1981.

[3] Cement and Concrete Association: Minising the Risk of Alkali-Silica Reaction – Guidance Notes, Report of a Working Party, 1983.