ALKALI-AGGREGATE REACTIVITY IN WESTERN TAIWAN

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ABSTRACT

Aggregates selected from areas of four foothills of gravelly deposits and six main rivers in western Taiwan were investigated for alkali-reactivity by different methods. Test results of chemical method (ASTM c-289) showed that 20 of 44 samples were evaluated to be potentially alkali reactive. Further tests for these 20 reactive aggregates by mortar bar method (ASTM C-227) have been evaluated according to the criteria recommended in ASTM C-33. The evaluated results show that all of them were classed as innocuous except the aggregate from Zuo-Sweh river and the cement containing 1.2% of alkali. However, these results may underestimate the expansiveness of the aggregates, when evaluated according to the Bureau of Reclamation criteria. Furthermore, five samples selected from the 20 reactive samples were all classified as alkali reactive when evaluated by the accelerated mortar bar test method using 1 M NaOH solution at temperature of 80 ℃.
Keywords: alkali-aggregate reactivity, expansion, testmethod

INTRODUCTION

Taiwan is an island country with climate of high humidity and temperature. Besides, the geology and geography condition also make this place possible to have alkali-reactive aggregates[1,3,4]. Since 1980, the government[1-2] and academic institutes[3-5] in Taiwan have noticed the problem of alkali aggregate reaction (AAR) in concrete and have gradually devoted resources to do some survey and research work in this field.

In this article, we try to do a more complete study in alkali reactivity for the aggregates located in western Taiwan. The procedures of AAR tests mainly followed the ASTM Specifications. The Accelerated Test[6] Method was also adopted for some samples to check whether it is appropriate for the aggregates in this area or not.

EXPERIMENTS

Surveying and Sampling of Aggregates

The aggregates were selected from 6 river areas and 4 hill areas distributed in western Taiwan. The river areas from north to south include Lan-Yang, Tow-Chain, Dah-An, Dah-Duu, Zuo-Sweh, and Gaw-Pin rivers and the hill areas include San-Yi, Tai-Chung Basin, Bah-Gua Mt., and Dru-San.

The river-area aggregates were obtained from the aggregate plants near the assigned rivers. The hill-area aggregates were collected by digging them directly from gravelly deposit at the assigned hill areas. A total of 44 samples were collected, including 36 river-area samples and 8 hill-area samples. All the samples were washed, crushed and sieved with water before laboratory testing.

Chemical Test Mehod

The 44 aggregate samples were tested following the specification of ASTM C289[7]. After the amount of dissolved silica (Sc) and the reduction in alkali (Rc) were measured, the alkali reactivity of all the samples were classified.

Mortar Bar Test Method

The mortar bar method was adopted to further test the 20 samples which were classified as alkali reactive in the chemical test method. Some mortar bar specimens were made following the specification of ASTM C227[8] for these tests. In these specimens, the total alkali content (Na_2O + 0.658 K_2O) in cement had two levels of 0.82% and 1.20%. Thus, total of 40 sets of specimens were prepared to measure the expansion at different agges. According to these expansion results and the specification of ASTM C33[9] and the Bureau of Redamation criteria[10] the aggregates can be classified as potentially alkali-reactive or otherwise.

Accelerated Test Method

Among these 20 samples of mortar bar tests, we selected three relatively higher alkali-reactive samples coming from Zuo-Sweh, Lan-Yang, and Dah-An river-areas and two slightly alkali-reactive sample coming from Gaw-Pin river-area and Dru-San hill-area to perform accelerated tests also by measuring the bar expansion at different age referring to Shayan, et al. (1988), using 1 M NaOH solution at temperature of 80 °C. In these tests, the total alkali content in cement were two levels of 0.85% and 1.38%. The expansion was measured until 30 days.

RESULTS AND DISCUSSIONS

Test Results

(1) Chemical Test Method

The results of 44 samples tested by chemical method were listed in Table 1. They showed that 17 of the 44 samples were harmless aggregates; 7 samples were potentially harmful; the rest 20 samples were harmful aggregates which are mainly distributed over Zuo-Sweh, Lan-Yang, and Dah-An river-areas.

(2) Mortar Bar Test Method

We further used mortar bar method to test the 20 harmful samples classified by chemical method tests. The test results of 3-month, 6-month and 1 year expansion are shown in Table 2. Among them the expansion characteristics of four selected mortar bars are sketched in *Fig. 1*. Apparently, the expansion of the samples with 1.20% of total alkali content in cement are greater than those of the samples with 0.82% of total alkali content in cement for any mortar bar ages. By checking the level of expansion, we find that the expansion of the aggregates with 0.82% total alkali content in cement never exceeds the upper limit of the specification of ASTM C33 and the Bureau of Reclamation criteria. However, when the total alkali content in cement is 1.20%, according to the Bureau of Reclamation criteria (> 0.05% @ 6 month and > 0.1% @ 1 year)[11], most of the aggregate samples (13 of 16) coming from Lan-Yang river, Dah-An river and Zuo-Sweh river would be classed as deleterious. These results of evaluations are different from those based on ASTM C33, in which almost all the aggregates were classed as innocuous except one sample coming from Zuo-sweh river-area. So, following the criteria recommended in ASTM C33 for the evaluation of the results from mortar bar expansion test may have some short-comings.

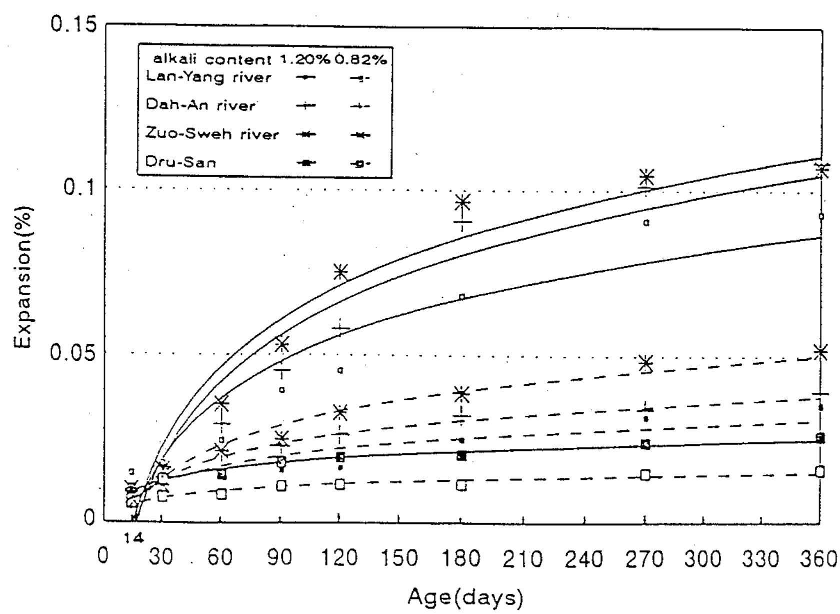

Fig. 1 Expansion characteristics of mortar bar made with various aggregates

Table 1 Potential alkali reactivity test result of aggregates (chemical method)

aggregate			composition	alkali reactivitv test		classication*)
				Rc(m·mol/l)	Sc(m·mol/l)	
Lan-Yang river	up-stream	coarse	Quartz. Feldspar	58.80	100.29	×
		fine	Sandstone. Shale	88.36	115.37	△
	mid-stream	coarse	Quartz. Feldspar	73.49	103.33	×
		fine	Shale. Sandstone	86.86	118.33	△
	down-stream	coarse	Quartz. Feldspar	44.27	99.29	×
		fine	Slate. Shale. Sandstone	87.86	115.65	△
Tow-Chain river	up-stream	coarse	Quartz	88.86	69.63	○
		fine	Shale. Sandstone	79.51	61.97	○
	mid-stream	coarse	Quartz. Feldspar	83.52	56.07	○
		fine	Shale. Sandstone. Quartz	79.33	70.14	×
	down-stream	coarse	Quartz. Feldspar	74.33	61.96	○
		fine	Shale. Sandstone	97.05	48.95	○
Dah-An river	up-stream	coarse	Quartz. Sandstone	58.59	78.72	×
		fine	Shale. Sandstone. Quartz	57.76	67.72	×
	mid-stream	coarse	Quartz. Feldspar	53.64	77.85	×
		fine	Shale. Sandstone	56.11	63.62	×
	down-stream	coarse	Quartz. Sandstone	28.06	60.72	×
		fine	Quartz. Sandstone	32.68	64.48	×
Dah-Duu river	up-stream	coarse		51.16	59.35	×
		fine	Shale. Sandstone	60.74	49.59	○
	mid-stream	coarse		38.30	50.35	×
		fine	Sandstone. Shale	56.51	50.12	○
	down-stream	coarse		36.31	46.98	×
		fine	Sandstone. Shale. Quartz	55.68	52.07	○
Zuo-Sweh river	up-stream	coarse	Quartz. Feldspar	88.59	100.91	△
		fine	Sandstone. Shale	108.53	139.95	△
	mid-stream	coarse	Quartz. Feldspar	72.13	82.78	×
		fine	Sandstone. Shale. Quartz	64.49	120.04	×
	down-stream	coarse	Quartz. Feldspar. Mica	55.51	67.01	×
		fine	Sandstone. Shale. Quartz	63.48	132.28	×
Gaw-Pin river	up-stream	coarse	Quartz. Sandstone	92.24	69.34	○
		fine	Shale. Sandstone	102.05	75.74	○
	mid-stream	coarse	Quartz. Feldspar. Calcite	62.49	44.46	○
		fine	Shale. Sandstone	97.06	100.49	△
	down-stream	coarse	Quartz. Calcite. Sandstone	64.98	54.48	○
		fine	Shale. Sandstone	92.24	109.71	△
San-Yi	1	coarse	Quartz. Sandstone	39.59	49.66	×
	2	coarse	Feldspar. Mica	44.27	48.02	×
Tai-Chung	1	coarse	Quartz. Sandstone	41.92	38.79	○
	2	coarse	Feldspar. Mica	38.92	48.50	×
Bah-Gua	1	coarse	Quartz. Sandstone	79.01	37.57	○
	2	coarse	Feldspar. Mica	74.33	35.02	○
Dru-San	1	coarse	Quartz. Feldspar	57.90	46.10	○
	2	coarse	Sandstone	59.30	25.18	○

*) ○ : non-reactive
△ : potentially reactive
× : reactive

Table 2 Mortar bar test result

aggregate			alkali level	expansion (%) at 3 month	expansion (%) at 6 month	expansion (%) 1 year	alkali level	expansion (%) at 3 month	expansion (%) at 6 month	expansion (%) 1 year
Lan-Yang river	up-stream	coarse		0.02977	0.05228	0.06429		0.01600	0.02800	0.03875
		fine		0.02151	0.03277	0.03753		0.00976	0.01876	0.02451
	mid-stream	coarse		0.03925	0.06800	0.09301		0.01500	0.02449	0.03524
		fine		0.02624	0.05098	0.06646		0.01350	0.02299	0.03474
	down-stream	coarse		0.02576	0.05201	0.06226		0.01475	0.01875	0.02275
		fine		0.01927	0.03503	0.04204		0.01200	0.01525	0.02676
Tow-Chain river	up-stream	coarse		0.01276	0.01702	0.03053		0.00875	0.01050	0.02225
		fine		0.01375	0.01976	0.03201		0.01199	0.01399	0.02498
	mid-stream	coarse		0.01501	0.01877	0.03127		0.01075	0.01200	0.02225
		fine		0.01549	0.01949	0.02974		0.01375	0.01725	0.02826
	down-stream	coarse		0.01526	0.02101	0.03252		0.01277	0.01477	0.02578
		fine		0.01800	0.02475	0.03585		0.01475	0.01801	0.02927
Dah-An river	up-stream	coarse		0.04530	0.09060	0.10862		0.02228	0.03203	0.03928
		fine		0.03249	0.06747	0.08421		0.02303	0.02628	0.03554
	mid-stream	coarse		0.03877	0.06480	0.07605		0.01875	0.02299	0.02749
		fine		0.03605	0.05934	0.06986		0.01850	0.02325	0.03024
	down-stream	coarse		0.04783	0.07761	0.08613		0.02128	0.02679	0.03229
		fine		0.03780	0.05733	0.06559		0.01908	0.02159	0.02560
Dah-Duu river	up-stream	coarse		0.02924	0.04823	0.05773		0.01875	0.02250	0.02750
		fine		0.02525	0.03950	0.04799		0.02099	0.02448	0.02548
	mid-stream	coarse		0.02998	0.04747	0.05571		0.01849	0.02274	0.02574
		fine	1.2%	0.02670	0.04670	0.05495	0.82%	0.01673	0.02147	0.02297
	down-stream	coarse		0.02402	0.03978	0.04529		0.01874	0.02099	0.02249
		fine		0.02049	0.02174	0.02824		0.01552	0.02128	0.02303
Zuo-Sweh river	up-stream	coarse		0.05306	0.09660	0.10711		0.02454	0.03856	0.05185
		fine		0.05194	0.09314	0.10664		0.02354	0.03632	0.04559
	mid-stream	coarse		0.02526	0.03627	0.04352		0.01727	0.02053	0.02503
		fine		0.02878	0.04730	0.05405		0.01701	0.02202	0.02677
	down-stream	coarse		0.03280	0.04682	0.06560		0.01427	0.01777	0.02353
		fine		0.03578	0.06305	0.08107		0.02279	0.02280	0.03006
Gaw-Pin river	up-stream	coarse		0.02302	0.03153	0.04204		0.01750	0.01875	0.02325
		fine		0.02478	0.02628	0.03629		0.01980	0.02079	0.02681
	mid-stream	coarse		0.02723	0.03272	0.04421		0.01956	0.02031	0.02407
		fine		0.02570	0.03550	0.05024		0.01852	0.01977	0.02553
	down-stream	coarse		0.02277	0.03028	0.04704		0.01276	0.01451	0.02302
		fine		0.02426	0.03476	0.04151		0.01476	0.01677	0.02402
San-Yi	1	coarse		0.01676	0.02652	0.03453		0.01151	0.01451	0.02126
	2	coarse		0.01725	0.02625	0.03651		0.00926	0.01301	0.01926
Tai-Chung	1	coarse		0.01751	0.02126	0.02751		0.01200	0.01279	0.01876
	2	coarse		0.02352	0.02977	0.04428		0.01301	0.01401	0.01901
Bah-Gua Mt.	1	coarse		0.01500	0.01775	0.02175		0.00825	0.00975	0.01525
	2	coarse		0.01476	0.01651	0.02127		0.01000	0.01100	0.01424
Dru-San	1	coarse		0.01750	0.02001	0.02576		0.01025	0.01100	0.01575
	2	coarse		0.01575	0.01750	0.02350		0.01226	0.01301	0.01926

(3) Accelerated Test Method

The test results for the 4 selected aggregate samples are shown in *Fig. 2*. Based on these data, the expansion of all the 10-day-age samples are over 0.1%. Not only three samples which were relatively higher alkali-reactive in mortar bar method tests but also the other two which were slightly alkali-reactive are all classified as reactive. These test results are very different from those of mortar bar tests. Whether this method is suitable for detecting the alkali-reactive of the aggregates in western Taiwan or not is worth a further study.

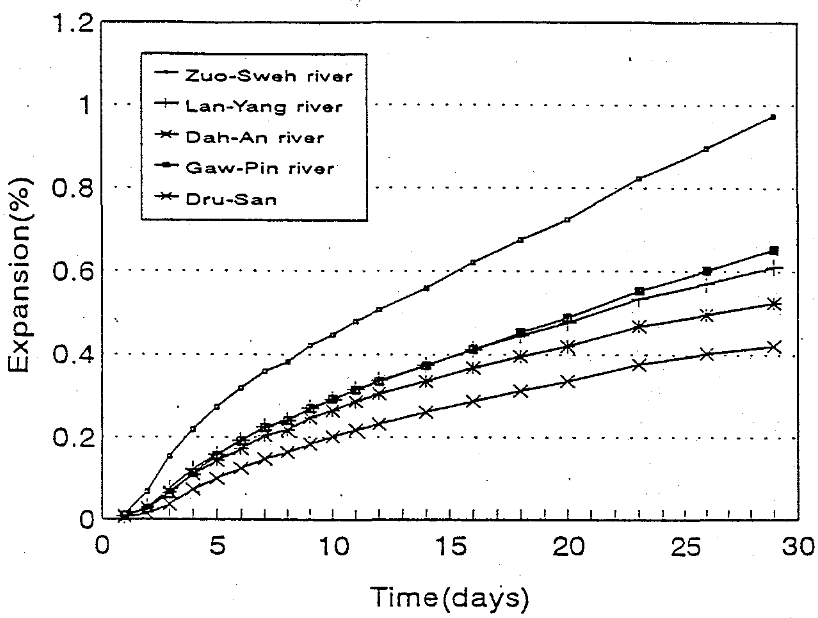

Fig.2 Expansion v. time of mortar bar subjected to the accelerated test

A combined Evaluation for Alkali-Reactivity of Aggregates in Western Taian

According to the test results of chemical method, 20 of 44 samples were tested to be harmful aggregate. When these 20 harmful samples were further tested by mortar bar method, it was found that the evaluation following the criteria recommended in ASTM C33 may underestimate the expansiveness of the aggregates. And when evaluated according to the Bureau of Reclamation criteria, only the aggregates from Lan-Yang river, Dah-An river and Zuo-Sweh river were classed as deleterious. It is therefore evident that the mortar bar method (ASTM C227) is inadequate for exactly identifying the reactivities of slowly reactive aggregates. These aggregates need to be tested according to more advanced methods[6].

The test results of accelerated method show that the 10-day expansion values of all samples are much greater than this method's upper limit, 0.1%. Accordingly, these aggregates will be suggested to be reactive.

Since the traditional mortar bar methods are no longer considered satisfactory for evaluating the potential reactivities of aggregates, there is a need to refine the existing standard tests and to develop new methods. Maybe the accelerated method is a better method, however, it needs further investigations before using this method as the AAR tests for the aggregates distributed in western Taiwan.

CONCLUSIONS

After the chemical method, the mortar bar method, and the accelerated method were investigated for the alkali reactivities of aggregates in western Taiwan, the following conclusions can be made :

(1) Twenty out of 44 samples were classified as alkali reactive aggregates by the mechanical method of ASTM C289.

(2) These 20 alkali reactive samples were further tested according to the mortar bar method of ASTM C227. The test results were evaluated by both the criteria of ASTM C33 and the Bureau Reclamation. The conclusions came to that the former one apparently underestimates the expansiveness of the aggregates. This method therefore needs to be refined.

(3) Five samples were selected from the 20 samples of mortar bar tests and tested by the accelerated method. The results show that all the 10-day expansions are much greater than the suggested upper limit, 0.10%, and should be classified as reactive.

(4) It is suggested that using the accelerated method as the AAR test method for the aggregates distributed in western Taiwan needs further investigations.

ACKNOWLEDGMENTS

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