Applications of Autoclave Rapid Test Method in Practical Engineering Projects in China

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ABSTRACT

The alkali reactivities of various kinds of aggregates used or to be used in some large-scale engineering projects in China have been studied by us in recent years. The kinds of rocks involved were andesite, tuff, rhyolite, tuffaceous lava, diorite-porphyrite, sandstone, basalt, diabase, dolomite, granite, granite-gneiss, metamorphic granite, chert and ceramic sand. The alkali reactivities of aggregates were determined by ASTM C227, ASTM C289, petrographic analysis and the autoclave rapid test method suggested by us. The comparison of the experimental results obtained by these methods showed that they were consistent with each other. In a review of the experimental results, it concluded that the autoclave rapid test method can be used to distinguish reactive from non-reactive aggregates.

1. INTRODUCTION

In China there are many factors which make the alkali contents of cements high: (1) A large amount of high alkali clinker is produced by several factories in the northeast and north of China, (2) The factories which use the waste materials e.g. nepheline slurry from the aluminum industry as raw material also produce high alkali clinker, in this case, the alkali content of cement may be as high as 1.1-1.7% eqv. Na_2O (3). In the future, it would be preferable to adopt a dry process instead of the wet process currently used in the cement industry (4). In order to make construction in winter, it is customary to add sodium salts to accelerate the hydration rate of cement (5). In some cases, the kiln dust is added to cement, but in general, the dust contains more alkali than clinker. Indeed, all these factors mean that the probability of deterioration caused by alkali-aggregate reaction increases. Therefore, it is very important to examine alkali reactivities of aggregates to be used in the engineering projects.

In recent years, the alkali reactivities of aggregates used in several large-scale engineering projects were examined by us. They involved: (1) Fengman hydroelectric power station, Jilin Province, (2) Yizheng chemical fibres factory, Jiangsu Province, (3) Shijiu port, Shandong Province, (4) Yantan hydroelectric power station, Guangxi Province, (5) ceramic sands used as aggregates in casting mortar. The experimental results will be described separately in the following paragraphs.

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2. EXPERIMENTAL RESULTS

2.1 Fengman hydroelectric power station, Jilin Province

Fengman hydroelectric power station was built in 1938. Some cases of deterioration were discovered in recent years. In order to clarify whether the deterioration was caused by alkali-aggregate reaction, a large number of concrete cores was taken out and examined by optical microscopy and SEM with EDAX. In addition, the aggregates used in this power station were studied by chemical and petrographic analysis and the alkali reactivities were examined by ASTM C227 (mortar bar test), ASTM C289 (chemical method) and autoclave rapid test method proposed by us (1). The mortar bars results are shown in Table 1.

Table 1 Expansions % of Mortar Bars Made from Aggregates of Fengman Hydroelectric Power Station

No.	Rocks	According to ASTM C227*				According to autoclave rapid method
		3 mon.	½ year	1 year	2 years	
1	Andesite	0.009	0.024	0.016	0.029	0.025
2	Rhyolite	0.010	0.018	0.024	0.032	0.065
3	Tuff	0.005	0.029	0.038	0.040	0.038
4	Diorite-porphyrite	0.003	0.021	0.050	0.077	0.028
5	Tuffaceous lava	0.004	0.035	0.055	0.072	0.029

* Note: Alkali content of cement = 1.2% eqv. Na_2O.

The Experimental results showed that all these aggregates used in Fengman power station were non-reactive as determined either by ASTM or by autoclave rapid test methods. Moreover, except for a few pieces of alkali silicate gel discovered in the concrete cores, no other characteristics of alkali-aggregate reaction were discovered in the concrete. Furthermore, the concrete cores taken from the construction site were cut into two halves, and molded into cylinders with high cement paste and then cured in container with RH 100% at room temperature. After more than 4 years, no alkali-aggregate phenomena were detected. All of these results lead to the conclusion that the cause of deterioration of concrete in this power station could not be confirmed to be caused by alkali-aggregate reaction, even though some aggregates contained cryptocrystalline quartz, volcanic glass, strained quartz, and in a few cases a small amount of opal and agate.

2.2 Yizheng chemical fibres factory, Jiangsu Province

This large-scale factory was constructed a few years ago. For the purpose of construction in winter, sodium salts were added in order to accelerate the hydration rate of the cement. Consequently, it was very important to examine the alkali reactivities of the aggregates used in this engineering project. The mortar bars results are shown in Table 2.

According to the results of the mortar bar test, either by ASTM C227 or by the autoclave rapid test method, basalt A and basalt B, diabase and dolomite proved to be non-reactive. In general rocks would be reactive when expansion of mortar bars tested by the autoclave rapid test method exceeds 0.11-0.12%. However, contrary to expectation the values of expansions of the mortar bars made from sandstone which contained a few percent of chalcedony only increased slightly. Through petrographic examinations, it was revealed that the radiative clusters of crystallite chalcedony occurred and were much larger than normal (Fig. 1). As a result, the expansivity of the sandstone is not high even if it is reactive. This result also illustrated that the reactivities of different rocks might be quite different even though they contain the same amount of chalcedony but with different morphologies.

Table 2 Expansions % of Mortar Bars Made from Aggregates of Yizheng Chemical Fibres Factory

No.	Rocks	According to ASTM C227*			According to autoclave rapid method
		3 mon.	½ year	1 year	
1	Sandstone	0.037	0.078	0.077	0.086
2	Basalt (A)	0.014	0.007	0.010	0.069
3	Diabase	0.002	0.003	0.003	0.077
4	Basalt (B)	0.008	0.012	0.013	0.074
5	Dolomite	0.009	0.016	0.008	0.051

* Note: Alkali content of cement = 1.2% eqv. Na_2O.

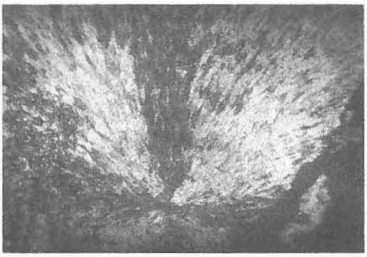

Fig. 2 Radiative cluster of chalcedony crossed Nicols x12

2.3 Shijiu port, Shandong Province

The results of alkali reactivity testing of the aggregates to be used in this port are shown in Table 3. From the results of petrographic analysis it is illustrated that all the minerals of these rocks were non-reactive except for a few coarse quartz crystals showing undulatory extinction. The results of petrographic analysis were consistent with that of the mortar bar tests obtained by autoclave rapid test method which showed that the values of expansions were very small. It led to the conclusion that these aggregates were non-reactive.

Table 3 Expansions % of Mortar Bars Made from Aggregates of Shijiu Port (Autoclave Rapid Test Method)

No.	1	2	3	4	5	6
Rocks	Granite(A)	Granite-gneiss(A)	Granite(B)	Metamorphic granite	Granite-gneiss(B)	Sand
Expansions %	0.014	0.020	0.020	0.030	0.011	0.019

2.4 Yantan hydroelectric power station, Guangxi Province

Limestone was planned to be used as coarse aggregate in this power station, but it was found that it contained a large amount of chert. Therefore, the alkali reactivities of these rocks were examined. The results of mortar bar test are shown in Table 4. The rock samples in these tables were taken from different stone locations.

The values of expansion of mortar bars (Table 4) showed that all samples were reactive. From the results of petrographic analysis it could be seen that the chert in the limestone was composed of microcrystalline quartz and a small amount of chalcedony. The extremely fine crystals of quartz were characterized by intensive undulatory extinction. When they were observed under crossed Nicols, the dark edges of the fine crystals were moving fast along with the rotating of the microscope stage. It illustrated that intensive defects existed in these crystallites. As a result, these cherty limestones were highly alkali reactive as was proved by both petrographic analysis and measurements of the expansions of the mortar bars according to either ASTM C227 or autoclave rapid test method. Furthermore, these rocks also were examined by the ASTM C289 (chemical method). For the purpose of preventing the interference of carbonate, some samples were pretreated by HCl solution. The results showed also that both the pretreated and unpretreated samples were alkali reactive. To sum up, these experimental results identified unanimously that these aggregates were alkali reactive.

It is worth mentioning that a lot of chert or flint from different provinces of China proved to be non-reactive. Alkali reactivity as great as that of this cherty limestone is rare.

Table 4 Expansions % of Mortar Bars Made from Chert Limestones

No.	According to ASTM C227*			According to autoclave rapid method
	3 mon.	½ year	1 year	
1	0.164	0.226	0.259	0.145
2	0.144	0.224	0.259	0.141
3	0.080	0.149	0.168	0.222
4	0.129	0.192	0.221	0.165

* Note: Alkali content of cement = 1.0% eqv. Na_2O.

2.5 The alkali reactivity of ceramic sand

In electric porcelain factories, ceramic sands are customarily used as aggregates for casting cement mortar. Superplasticizers are used in some factories for the purpose of increasing the strength of casting cement mortar. However, in the laboratory we have found that using ceramic sand (Table 5, No. 2) as aggregate and adding superplasticizer, the mortar bars expanded up to 0.247-0.302% after two years curing in water or in a 100% RH container, and cracked severely (2). Petrographic analysis showed that there was a small amount of cristobalite in this ceramic sand. Although the mortar bars were made from low alkali cement (0.4% eqv. Na_2O), since the mixture was made from cement:sand =3:1, the relative amount of alkali to the sand was very high. Consequently, severe deterioration caused by alkali-aggregate reaction took place. Afterwards, we investigated several kinds of ceramic sands from different factories. Their alkali reactivities were determined through petrographic analysis and by our autoclave rapid test method. The results are shown in Table 5. It could be seen that both methods were consistent with each other. When petrographic analysis discovered that certain ceramic sand samples contained the reactive mineral - cristobalite, the expansions of mortar bars made from them as determined by autoclave rapid test method were very high. It confirmed again that the rapid test method can be used to distinguish the reactive from non-reactive aggregates.

The alkali reactivities, of a hundred glass samples, made in the laboratory, were determined by our autoclave rapid test method. The correlations between the alkali reactivities and chemical compositions of glass were established.

Table 5 Comparison of the Results of Petrographic Analysis with Autoclave Rapid Test Method for Ceramic Sands

No.	Minerals of ceramic sands	Expansions % of mortar bars
1	Quartz, mullite, glass	0.056
2	Quartz, mullite, glass, a small amount of cristobalite	0.166
3	Quartz, mullite, glass	0.075
4	Quartz, mullite, glass, a large amount of cristobalite	0.366
5	Mullite, corundum. glass	0.021

3. DISCUSSION

A review of the above described experimental results, leads to the conclusion that the results obtained by autoclave rapid test method are consistent with those of ASTM C227 and C289. Furthermore, the rapid test method can display the alkali reactivity of rock which contains reactive minerals discovered by the petrographic analysis (e.g. cristobalite). At the same time, the rapid method can distinguish the degree of reactivity. For example, the ceramic sand (No. 4 Table 5) which contained more cristobalite showed higher value of expansion (0.366%) than that (0.166%) of No. 2 in Table 5. Additionally, this rapid method is characterized by a lot of advantages: the mortar bars are very small, strenuous labour can be reduced, and the results can be obtained in a short time (two days). For this reason, we have given the information of the test results to Yantan hydroelectric power station at the right time.

Of course, alkali-aggregate reaction is very complex, and there are many factors which effect on it. We hope to get more comparative results if we can obtain different types of aggregates from various parts of the world. Currently we propose an expansion limit of 0.11-0.12% for non-reactive aggregates, but this limit needs to be confirmed by additional testing.

Finally, it should be noted that the aggregates identified by the autoclave rapid test method by us are limited to the alkali-silica type.

4. CONCLUSION

Several test results for practical engineering projects described above, show that the results obtained by the autoclave rapid test method are consistent with those of ASTM C227 and C289 and of petrographic analysis. It is concluded that this method can be used to identify the alkali reactivities of aggregates. It is particularly suitable for a primary test when there are a large number of aggregates to be identified.

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