Pergamon

Cement and Concrete Research, Vol. 27, No. 3, pp. 321-328, 1997

0008-8846/97 $17.00 + .00

PII S0008-8846(97)00011-2

A CASE STUDY OF TWO AIRPORT RUNWAYS AFFECTED BY ALKALI-CARBONATE REACTION. PART ONE: EVIDENCE OF DETERIORATION AND EVALUATION OF AGGREGATES

Tong Liang*, Deng Min, Lan Xianhui** and Tang Mingshu****
*Department of Civil Engineering
Tsinghua University, Beijing 100084, P. R. of China
**Department of Materials Science and Technology
Nanjing University of Chemical Technology,
Nanjing 210009, P. R. of China

(Communicated by Z. Wu)
(Received May 7, 1996; in final form January 17, 1997)

ABSTRACT

Through the inspection of field concrete and detailed petrographic examinations of concrete cores collected from two airport runways, it was found that the main reason of the damages in the concrete structures was alkali-carbonate reaction. The test results of the newly developed autoclave method agreed well with the field performance of the aggregates used. It is suggested that the autoclave method is an effective method to evaluate the reactivity of carbonate aggregates though its general validity should be widely inspected. © *1997 Elsevier Science Ltd*

Introduction

Alkali-silica reaction (ASR) has aroused attention in China since middle 80's. However, it is still lack of knowledge on alkali-carbonate reaction (ACR) among most civil engineers. Although large amounts of high alkali cement and wide variety of carbonate rocks have been used in concrete projects, especially in the north part of China, no systemic survey on existing concrete structures in China had been made before 1990. Up to now the evaluation of alkali reactivity of carbonate aggregates used is usually not conducted in concrete quality control for most concrete structures.

In the late 1980's, inspections on several concrete structures, in which high alkali cement and dolomitic limestone as coarse aggregates were used, were conducted by Prof. Tang's research group in Nanjing University of Chemical Technology (1). The projects covered field survey of concrete piles, railway ties, airport runways and a highway bridge. It was found that runway concrete in two local airports was noticeable damaged after several years in service. The present work deals with the diagnosis of the damage concrete.

Experimental Details

In the present study, the experiments covered inspection of field concrete, petrographic examination of the affected parts and expansion tests of the aggregates containing in concrete and available from local quarries.

For petrographic and microstructural investigation, concrete cores (ϕ20 cm), based on their surface appearances, were drilled from fairly good, damaged, and severely damaged parts of the main runway and the shoulder pavement respectively as shown in FIG. 1. The concrete cores were cut vertically and horizontally for several layers to expose more surfaces. Then polished and thin sections were prepared. As a rapid method to dolomitic limestone particles, acid etching and stained by alizarin red S was applied in the investigation. Besides optical microscope, other techniques such as scanning electronic microscope (SEM-EDXA), X-ray diffraction (XRD), differential thermal analysis (DTA) and infrared spectroscopy (IR) were also utilized in the examination. The findings will be reported in part two of this study.

The reactivity of carbonate aggregates were evaluated mainly by the newly developed methods—autoclave concrete microbar and rock prisms tests (2).

Results and Discussions

Inspection of Deleterious Concrete. WF airport runway was constructed in 1984. The alkali content of the concrete is about 3.9 kg Na_2O equivalent per m^3 concrete. Coarse aggregates (limestone and dolomitic limestone) was supplied from two local quarries. Some slabs showed noticeable cracking after two years of service. The percentage of the damaged slabs was 25.5% in 1990 and increased to 33.3% after another year (3). A typical cracked slab is shown in FIG. 2. In addition, cracks were also found on the walls and the covers of drain. It was noticeable that cracks on the surface of the slabs were not evenly distributed. Some slabs showed severe cracking while the others were perfectly sound.

Similar phenomena were observed in JN airport runway which was constructed in 1989 (4). The main part of the cement used was a high alkali cement with alkali content 1.27%

FIG. 1.
Concrete cores collected from JN airport.

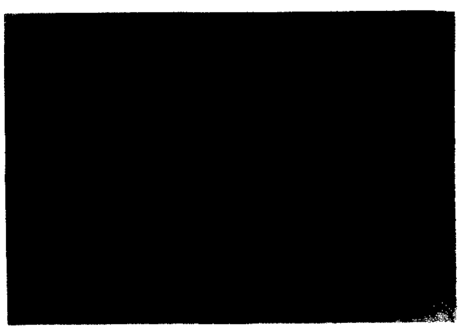

FIG. 2.
Map cracking on the surface of WF airport runway.

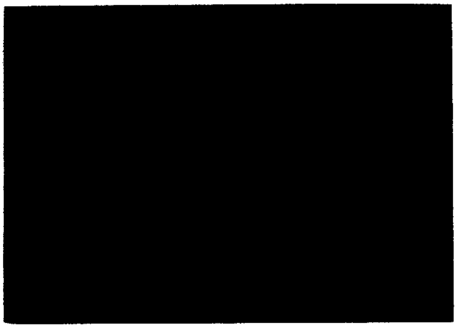

FIG. 3.
Map cracking in a shoulder slab of JN airport runway.

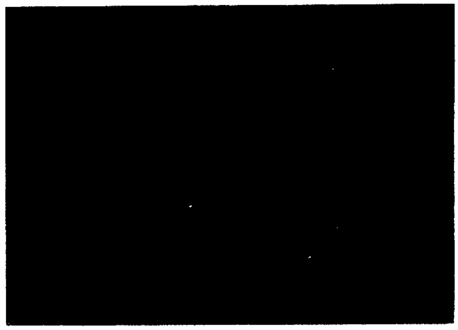

FIG. 4.
Very beginning of the crack development in the airport (JN) runway showing a stain mark.

Na_2O equivalent. A survey made in May, 1991 showed that about 21.7% of the total slabs had cracked. Damage to shoulder slabs on both sides of the runway was relatively severe and comprised 49.5% of the total damaged slabs (FIG. 3). The deterioration processes of the two airport concrete were much alike—the development of water-stains with dark brown center and yellow or gray margin, and then the occurrence of cracks in these spots. The length and width of the cracks and the infected area increased with time. FIG. 4 shows the appearance of the affection at the early age.

Description of Aggregates. Fine-grained limestone or dolomitic limestone used in the two airport runways as coarse aggregates were supplied by the local quarries. Based on their mineral composition and sources, the aggregates were grouped into several classes: WB-1~3 for aggregates used in WF airport and JN-1~3 for JN airport. WB-3 was proved to be reactive and described by Deng (1). WB-2 was dolomitic limestone with partial reactive texture as shown in FIG. 5. The texture of the reactive part was very similar to the typical reactive argillaceous dolomitic limestone found in Kingston, which was described by Gillott (5). The reactive parts are usually band-like distributed, while the surrounding non-reactive parts

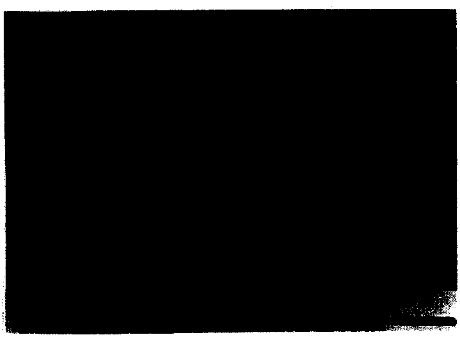

FIG. 5.
Texture of the reactive aggregate (WB-2) (thin section, plane polarized light).

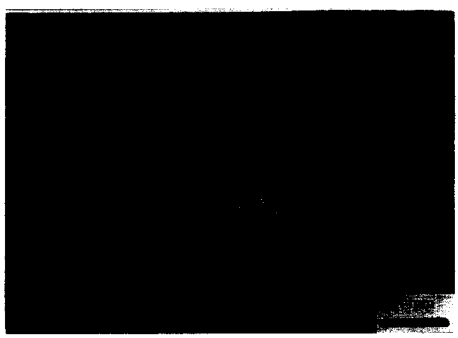

FIG. 6.
Texture of the reactive aggregate (JN-2) (thin section, crossed polarized light).

TABLE 1

Petrographic Characteristics of the Aggregates Used in Field Concrete

Rock types	Sample name	Location of quarries and applied structures	Dolomite Crystals				Matrix		Amount of the total aggregate used (%)
			Amount (%)	Size (μm)	Shape	Distribution	Calcite (%)	Non-carbonate minerals	
Dolomite	NM-0	Nanjing, used as control sample	96	>10^3	A*	Homogeneous for coarse grains with little fine-grained crystals (<5μm) between them	3	Trace (Q)*	
	JE, JM	Tianjing, used in a highway bridge	90-95	<5	A	Homogeneous	5-10	2% (Q, T)	>80
Dolomitic limestone	CK	Kingston, Canada	25	< 50	R	Homogeneous	60	15% (Q, I)	
	WB-2	Shandong, used in WF airport	14	< 70	R	In streaks or veins	66	20% (Q, I)	20
	JN-2	Shandong, used in	45-50	< 80	R	Homogeneous	50~55	4% (Q, I)	20
	JN-3	JN airport	40				60	<2% (Q)	10
	TY-1	Shanxi, used in concrete piles	10-20	< 50	R	In spots	80-90	1-2% (Q, I)	>70
	PD	Shanxi, used in railway ties	10-21	<100	R	In spots	75-85	2-5% (Q, I)	----
	WB-3	Shandong, used in airport WF	7-18	< 80	R	Homogeneous	70-80	7-10% (Q, I)	70
Limestone	JN-1	Shandong, used in JN airport	< 2	< 50	A	Homogeneous	>98	2% (Q, I)	60
	WB-1	Shandong, used in WF airport	< 2	< 50	A		90	5-10 (Q, I)	<10

* A: Anhedral R: Rhombohedral Q: microcrystalline quartz I: illite T: talc

around consist of fine-grained calcite with very little impurities. FIG. 6 shows the petrographic characteristics of JN-2 aggregate. Fine-grained dolomite crystals embedded in even finer calcite matrix with very small amount of impurities. It was noted that this is a common feature of reactive aggregates found in China.

The characteristics of these aggregates are listed in TABLE 1. The fine aggregates used in the two airports were supplied by local natural sand and were evaluated as non-reactive by autoclave microbar test (3,4).

Petrographic Examination. In WF airport concrete, microcracks can be observed across WB-2 or WB-3 aggregate particles and surrounding paste in all concrete cores examined. Such cracks were found even in the sounded core as shown in FIG. 7. This is usually known as a typical character of alkali-aggregate reaction. It was also noted that cracks tended to stretch out of dolomite-rich areas of the reactive aggregates. FIG. 8 shows a microcrack generated in the surrounding paste of a WB-3 dolomitic limestone particle where dolomite crystals were gathered. For aggregate WB-1, no microcracks were found around and within the aggregate in all samples examined. Besides surface cracks, a predominant difference among good, damaged and severely damaged concrete cores was the debond feature i.e., crack between aggregates and cement paste which are more pronounced at the bottom. For the two airport concrete, the more severe the surface cracks, the more noticeable the debond

FIG. 7.
A crack crossing an aggregate WB-2 particle and stretched to the surrounding paste in the fairly good concrete core of WF airport.

FIG. 8.
A crack tended to begin at dolomite-rich area (WB-3) in the airport WB concrete (thin section, plane polarized light).

between the aggregate and cement paste. The reason for such a damage is not well understood.

For cores of the runway in JN airport, the typical feature of the reactive aggregate, i.e., cracks began within the aggregate particles and stretched out into the surrounding paste, was observed for the aggregate JN-2 and JN-3. FIG. 9 shows a crack around aggregate JN3. It was also noted that these aggregates JN-2 and JN-3 containing very little amount of clay. For aggregate JN-1, no visible cracks were recognized. However, surrounding cracks or debonding between the aggregate particle and paste were observed. This feature also presented for JN-2 and JN-3.

Based on the previous investigation, it could be concluded that deleterious alkali-carbonate reaction (dedolomitization) occurred in the two airport concrete. The aggregates (JN2, JN3 WB-2 and WB-3) were the main reactive aggregates. Additional test results (3,4) suggested that other deleterious processes such as ASR was ruled out in JN concrete and

FIG. 9.
Cracks around an aggregate JN-3 particle in the heavily damaged concrete core of JN airport (thin section, plane polarized light).

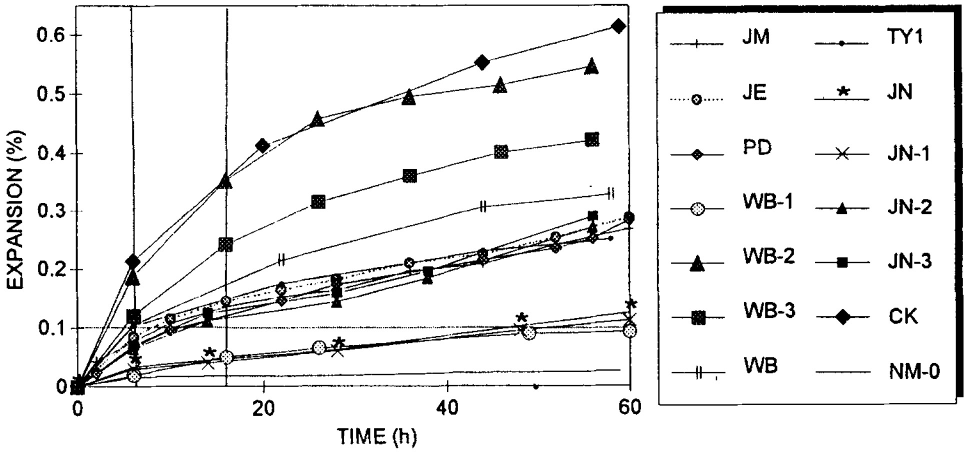

FIG. 10.
Expansion of concrete microbars of the aggregates of known performance in field concrete autoclaved at 150°C in 10% KOH solution.

considered to be a minor factor in WB airport. The local weather conditions and the characteristics of the damage showed that the frost attack was not, at least, the main reason of the deterioration. Therefore, it is understood that the reason for damage of the two airport concrete was the deleterious alkali-carbonate reaction.

Expansion Tests. Newly developed autoclave micro-concrete bar method can distinguish reactive carbonate rock from the non-reactive (2). However, the criteria of the suitable autoclave time and corresponding expansion are not well defined. Beside the aggregates WB-1~3 and JN-1~3, some selected reactive carbonate aggregates used in other field concrete (1) were also enrolled in the investigation. The full descriptions of these aggregates are also listed in TABLE 1.

The expansions of concrete microbars containing the aggregates used in field concrete at different autoclave time are shown in FIG. 10. The expansions of all reactive carbonate aggregate were noticeably greater than those of non-reactive rocks, while the control sample (NM-0) showed only very slight expansion. For most dolomitic limestone, the expansive rates were lower than the highly expansive aggregates (WB-2 and CK). When adopting 0.1% after 6 and 16 hours' autoclave as the criteria for deleterious expansion, it is feasible to distinguish the reactive and non-reactive aggregates, and also to categorize the expansive characteristics of reactive rocks. If the expansion exceeds 0.1% at 16 hours, the aggregate in the concrete microbars can be considered as potentially reactive. If the expansion reaches 0.1% at 6 hours, the aggregate is understood as highly reactive.

These criteria can also be applied to understand the results of rock prism test. At least six rock prisms of different directions were prepared for several rock samples. The average expansions of the rock samples at different autoclave times are illustrated in FIG. 11. Similar expansion trends were observed. It is noted that the reactive and non-reactive aggregates can also be distinguished by the rock prism method. It is known that the expansion values may be different for different orientations of the prisms and even different from place to place in a rock sample. Thus, more than six prisms are preferred for the evaluation. The expansions of the rock prisms are usually greater than those of the according concrete microbars. It is

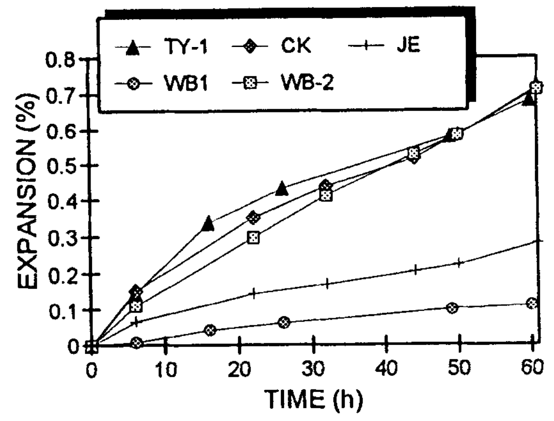

FIG. 11.
Expansion of rock prisms of several selected aggregates used in field concrete autoclaved at 150°C in 10% KOH solution.

considered that this method is more sensitive than concrete microbar method and especially valuable in the investigation of the expansive mechanism.

In fact, a good linear correlation between the expansion of concrete microbars and the rock prisms was recognized (6). This made it possible for the evaluation of the reactivity of an aggregate using either the concrete microbar method or the rock prism test. Due to the elimination of the directional effect and the homogenous sampling, the concrete microbar method is preferred to be used as a standard method. The rock prism method can be used as an additional test.

Although the reactivity of the carbonate aggregates is correctly predicted by the autoclave methods, more work is needed involving comparison of the test results with detailed inspection of aggregate performances in various concrete structures, and with the results of the standard concrete tests. This is very significant for all other rapid test methods as well.

Conclusions

The deterioration of the two airport runway concrete was mainly due to alkali-carbonate reaction. Dolomitic limestone WB-2, WB-3, JN-2 and JN-3 are the main reactive aggregates.

By comparison with the field performance of aggregates and the autoclave testing results, it was proved that autoclave concrete microbar test is an effective method to distinguish reactive and non-reactive aggregates. When the expansion of concrete microbar exceeds 0.1% after 16 hours' autoclave, the aggregate involved is considered as potentially reactive. The rock prism test is also useful in the evaluation although more rock prisms of various orientations and from different parts of a rock sample are necessary to get a suitable prediction.

The procedures of diagnosing a field concrete whether it is affected by deleterious ACR or not should involve detailed petrographic examination of the concrete by proper sampling and the evaluation of aggregates involved.

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