ALKALI-AGGREGATE REACTIONS IN THE CEMENT CONCRETE PAVEMENTS OF AIRPORT

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ABSTRACT

The concrete of many airport pavements in north China has been deteriorated since 1970's. The causes of deterioration were investigated. Results show that the concrete was mainly damaged by alkali-aggregate reactions. Measures to prevent newly constructed concrete from being destroyed were evaluated.
Key words: Airport, alkali-aggregate reaction, concrete, preventing measures

INTRODUCTION

The pavements of airport in China were constructed almost with cement concrete. The designed life span of them was 20-30 years or more. This life was based on the strength of concrete structures rather than the service life of concrete itself, which may practically be more than 40 years under the conditions of safe loads and use in scheduled circumstances. However, some pavements constructed during the past 25 years showed deterioration of concrete in 3-5 years. Field surveys show that pavements of 16 airport on the north of Yangtze river were damaged by physical or chemical factors. In some airport, 30% pavements were cracked, scaled or even loosened. While the pavements in some other airport were slightly affected.

To evaluate the causes of deterioration, concrete cores in 10-15 cm diameter were drilled from the pavements of 6 airport. Carbonation proceeded only 1.0-1.5 cm from surface to interior, and was not considered as a major cause of the deterioration. The aggregates did not contain gypsum and ferro sulphides, and mortars were not attacked by sulphate except that in the some pavements of one airport, as indicated by x-ray diffraction analysis (XRD), differential thermodynamic analysis (DTA) as well as petrographic examinations (Shu et al. 1993). The airport localized in the North of China where the average temperature ranged from -16 ℃ to 0 ℃ in the coolest month. However, the deterioration of concrete did not reveal the characteristics of freezing and thawing. The concrete was not reinforced and might not be affected by corrosion of steel.

Thus, it was suspected that the damage of concrete pavements was mainly due to alkali-aggregate reactions — another factor that lowered durability of concrete. This paper describes the evaluation of alkali-reactivity of aggregates, petrographic examinations of concrete cores and prevention of alkali-carbonate reaction.

ALKALI-AGGREGATE REACTION IN PAVEMENTS OF AIRPORT

The aggregates used in one of the damaged airport were collected, and were submitted to tests of alkali-reactivity. The concrete cores derived from the airport were petrographically examined.

Components and microstructures of aggregates

The fine aggregate was river sands composed of well-crystallized quartz and feldspar. These minerals do not bring about concrete to be damaged by alkali-aggregate reaction.

The coarse aggregates come from two local quarries in the east of Shandong and were designated as JD and CL in this paper, respectively. They both were crushed slightly dolomitic limestones. Their chemical compositions are shown in Table 1. The aggregates consisted of calcite, dolomite and a very small amount of quartz according to x-ray diffraction analysis (XRD). The contents of dolomite and calcite listed in Table 1 were calculated by assuming that CaO and MgO were completely combined with CO_2 to form calcite and dolomite. Petrographic and SEM-EPMA examinations revealed that the dolomite was localized in strips that composed of 10-40 μm dolomite, 4-8 μm calcite and 4-20 μm quartz and feldspar.

Table 1 The chemical and mineral compositions of coarse aggregates

Sample	Chemical composition (%)							Mineral (%)			
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I	Dolomite	Calcite	Residue	Total
JD	4.56	1.21	0.48	50.49	1.70	0.30	41.24	7.77	86.03	6.25	99.98
CL	4.19	1.14	0.45	51.39	0.89	0.40	41.48	4.07	89.64	5.79	99.50

Alkali-reactivity of aggregates

The fine and coarse aggregates were subjected to micromortar bar test (CECS 48-93) to evaluate their alkali-silica reactivity. The aggregate JD was separated into JD1 and JD2 according to the difference in color. Similarly, the aggregate CL was separated into CL1, CL2 and CL3. Results are shown in Table 2. Expansions of sand and rocks JD1, JD2, CL1 and CL2 are far below the limit 0.10%. Therefore, they were not alkali-silica reactive. The rock CL3 contained more acid insoluble residue in which quartz was in several to 20 μm, and was alkali-reactive. The reactive rock CL3 occupied a small portion in coarse aggregates.

The coarse aggregates were also subjected to rock prism and microconcrete bar tests to determine their alkali-carbonate reactivity. The rock prisms were in 10mm ×

Table 2 Results of micromortar bar test on the aggregates

Ratio of cement to aggregate	Expansion (%)					
	Sand	JD1	JD2	CL1	CL2	CL3
10	0.040	0.032	0.055	0.038	0.051	0.065
5	0.048	0.046	0.046	0.047	0.066	0.070
2	0.051	0.063	0.063	0.057	0.068	0.121

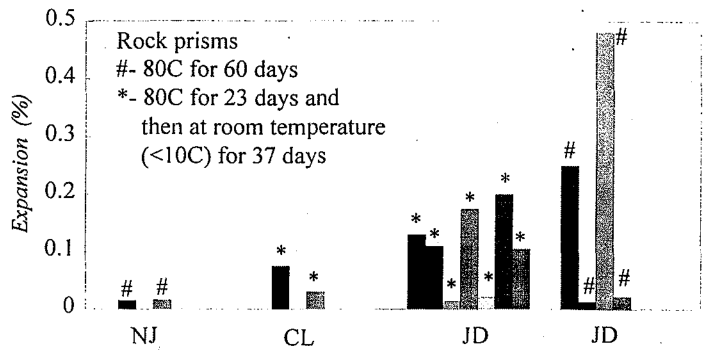

Fig. 1 Expansions of rock prisms cut from the coarse aggregates

10mm × 32mm and were stored in 1mol/L KOH solutions at 80 ℃. Expansions of prisms cured for 60 days are demonstrated in Fig. 1. The rock NJ was nonreactive dolostone from Nanjing used for control sample. It is obvious that the coarse aggregates were expansive. Some prisms cracked in the region richened in dolomite. This seems to indicate that the coarse aggregates were alkali-carbonate (dolomite) reactive.

The relationships between expansion of 20mm × 20mm × 60mm microconcrete bars (Tang et al. 1994) and autoclave time are shown in Fig. 2. Size of aggregate in the specimens was 5-10mm. Ratio of cement to aggregate was 1. W/C was equal to 0.30. The alkali content of Portland cement was boosted from 0.43% to 1.50% Na_2Oequiv. by adding KOH into the mix water. The bars demolded after 24 hours were precured in 100 ℃ steam for 4 hours, and then autoclaved in 10% KOH solution at 150 ℃. The aggregate NJ is nonreactive dolostone from Nanjing used for control sample. The concrete with NJ expanded very small. However, the aggregates CL and JD both caused a large expansion in concrete. The bars were cracked after autoclaving for 6 hours. Examination of polished samples shows that the cracks either originated the coarse aggregate particles or extended from interior of aggregate particles to mortar. These manifest that the aggregates were alkali-carbonate (dolomite) reactive.

Petrographic examinations of concrete cores

The concrete cores drilled from the pavements of airport were cut and polished. Many cracks occurred in the whole 180mm thick concrete pavements. It is observed on the polished plates and thin sections that the cracks originate from the coarse aggregates and a few of coarse aggregate particles suffered cracking. The cracked portion of the aggregate particles was rich in dolomite. This appears to indicate that the cracks

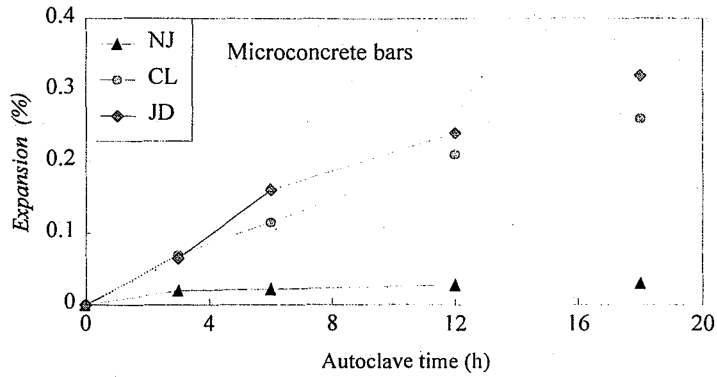

Fig. 2 Expansion of microconcrete bars vs. autoclave time

was caused by expanding of the aggregate particles due to alkali-carbonate reaction. The fine aggregate, crystals of quartz and feldspar, was not attacked and did not cause distress.

PREVENTING OF ALKALI-CARBONATE (DOLOMITE) REACTION

For the highly reactive dolomitic limestone from Kingston, Canada, low alkali Portland cement and mineral admixtures such as slag and fly ash are ineffective in suppressing expansion due to alkali-carbonate (dolomite) reaction (Deng et al. 1993 & Rogers. 1992). Compared with the Kingston reactive rock, the rocks used as coarse aggregates in the airport are moderately reactive. In this part, the effectiveness of mineral admixtures and low alkali cements in minimizing expansion due to these moderately reactive rocks was investigated

Materials and procedure

The low alkali cements used were Portland cement (OPC), sulfo-aluminate cement (SAC) and ferroaluminate cement (FAC). Their alkali contents were 0.51%, 0.32% and 0.18% Na_2Oequiv., respectively. Pulverized fly ash (PFA) and granulated blast furnace slag (BFS) were used, which both were commercially available. Their chemical compositions and specific surface area are shown in Table 3. The reactive rocks were

Table 3 The chemical compositions and specific surface area of materials

Material	Chemical composition (%)										Blaine
	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	L.O.I	Total	(m^2/kg)
OPC	20.72	4.91	4.23	61.39	1.23	2.30	0.29	0.33	4.08	99.48	313
SAC	8.92	1.72	31.32	38.54	1.83	11.49	0.10	0.33	4.09	98.34	400
FAC	9.89	4.99	23.97	41.18	1.39	12.12	0.08	0.15	5.61	99.38	412
PFA	48.12	4.60	32.10	3.77	1.15	1.36	0.62	1.05	6.50	99.27	433
BFS	35.52	3.24	11.08	38.82	9.07	0.40	0.34	0.55	-	99.02	443

the coarse aggregates used in the airport. Nonreactive dolostone from Nanjing, China was used for control sample. Sand was nonreactive.

Concrete specimens were cost in 20mm × 20mm × 60mm. Each set composed of 6 concrete prisms. The coarse aggregate was in 5-10 mm. Cementitious materials: rock: sand: water=1:1.5:1:0.35. The specimens were cured in 20℃ moist room for 24 hours. Then, they were demolded and cured at 40℃ & 100% RH.

Results

To assess the effectiveness of low alkali cements, PFA and BFS on minimizing the expansion due to alkali-dolomite reaction, the difference between length changes of concrete prisms with reactive aggregate and with nonreactive aggregate was calculated. In question, this difference may approximately be considered as the expansion caused by the reactive aggregate.

Table 4 shows the expansion brought about by the reactive aggregate in the three low alkali cements and one high alkali cement HPC. The sample HPC was derived from the low alkali Portland cement by boosting its alkali content to 1.50% Na_2Oequiv. The moderately reactive rocks in concrete made with the high alkali Portland cement caused a large expansion and cracked the concrete prisms. When incorporated in concrete made with low alkali cements OPC, SAC and FAC, they caused almost no expansion. On other word, low alkali cements OPC, SAC and FAC may effectively contract the expansion of moderately reactive rocks in concrete at least in the test duration.

The effectiveness of PFA and BFS on inhibiting alkali-dolomite reaction of the moderately reactive rocks is demonstrated in Table 5. PP30 and PP50 were low alkali

Table 4 The influence of cements on expansion of moderately reactive rocks in concrete

Cement	Expansion (%)							
	30d	60d	120d	180d	270d	360d	550d	720d
HPC	0.028	0.022		0.033		0.099		
OPC	0.004	0.005	0.008	0.005	0.007		0.004	0.016
SAC	0.003	0.002	0.002	0.000	-0.021		-0.018	-0.024
FAC	0.007	0.010	0.008	0.007	0.006		0.000	0.002

Table 5 Influence of PFA and BFS on expansion of alkali-dolomite reaction

Cement	Expansion (%)							
	30d	60d	120d	180d	270d	360d	550d	720d
HPC	0.028	0.022		0.033		0.099		
OPC	0.004	0.005	0.008	0.005	0.007		0.004	0.016
PP30	0.000	0.000	0.000	-0.005	-0.005		0.005	0.007
PP50	0.004	0.006	0.008	0.006	0.000		-0.005	-0.015
PB30	0.003	0.003	0.001	0.004				
PB50	0.002	0.000	0.001	-0.001	-0.001		0.012	0.016

Portland cement (OPC) with 30% and 50% PFA, respectively. PB30 and PB50 were OPC with 30% and 50% BFS, respectively. The results seem to show that low alkali Portland cements with 30-50% PFA or BFS may effectively minimize the expansion due to alkali-dolomite reaction of moderately reactive rocks during the test period.

The deterioration of alkali-aggregate reaction usually occurs in a long time, especially for those moderately and weakly reactive aggregates. The effectiveness of the low alkali cements and mineral admixtures needs to be observed further.

CONCLUSION

The concrete pavements of airport in China have suffered deterioration of alkali-carbonate (dolomite) reaction. The small amount of alkali-silica reactive aggregate might distress the concrete. Low alkali sulfoaluminate cement, ferro-aluminate cement, Portland cement and Portland cement with 30-50% PFA or BFS may significantly restrain the expansion due to alkali-carbonate (dolomite) reaction of the moderately reactive rocks.

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