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ALKALI REACTIVITY OF AGGREGATES AND AAR-AFFECTED CONCRETE STRUCTURES IN BEIJING

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ABSTRACT

The main aim of this study is to gain a better understanding of the alkali reactive characters of the aggregates in Beijing area and nearby. Through site survey and lab tests on the concrete mixed with aggregates from quarries, the results show that the active aggregates in the region of Beijing and rounding Beijing can induce alkali-silica reaction (ASR) and cannot alkali-carbonate reaction (ACR).

Key words: Aggregate, AAR, ASR, ACR, Concrete structures

1 INTRODUCTION

The construction scale in Beijing is getting larger and larger nowadays. The sands and stones produced in Beijing can far from meet the requirement of the concrete structure. Thus sands and stones produced in the regions surrounding Beijing flow into Beijing. The alkali reactivity of the sands and stones is surveyed.

Beijing first set down technical management specification for preventing AAR in the concrete structures in China because the damage of concrete structures due to AAR was found in 1980's in Beijing. This paper also introduces the survey process and results for damaged concrete structures.

2 ALKALI REACTIVITY OF AGGREGATES USED IN BEIJING

The construction scale in Beijing is getting larger and larger nowadays. In 2004, the area only for the construction project part already reaches 100 million square meters. There are still two subway lines and many public facilities such as roads and bridges under construction. The sands and stones produced in Beijing can far from meet the requirement of the concrete buildings. Thus sands and stones produced in the regions surrounding Beijing flow into Beijing. ASTM 1260 method [1] were employed to evaluate alkali reactivity of the sands and stones used in concrete buildings. Results are listed in Table 1. The results indicate that aggregates from the region rounding Beijing are mostly alkali reactive, especially for gravel of Youngding River, Nankou limestone, and Sanhe limestone.

However, according to an official of the Air Service Design and Research Bureau, there occurred alkali carbonate reaction (ACR) in two air service aerodromes in Beijing recently. And the aggregate of concrete all came from the regions surrounding Beijing. Therefore, the experiments of a chemical components analysis, the petrographic method, and

an expansion are used to examine the alkali-reactivity in these limestone aggregates.

2.1 Chemical compositions analysis

The chemical compositions of the limestone aggregates are measured. Table 2 lists the results of chemical constituents of the aggregates.

2.2 Petrographic examination

Optical microscopy is employed in this research. Thin sections of rock specimens are prepared and used to identify petrographic characters of aggregates, including the mineral composites, names, textures, and structures of rocks. The results show in Table 3.

The results from Table 2 and Table 3 demonstrate that three kinds limestone aggregate all contain the some silica dioxide, which could be active silica to induce ASR in concrete. Magnesium oxide content is 18.3%. The results indicate that the limestone aggregate from the regions surrounding Beijing can induce ASR as well as ACR at the same time in concrete.

Table 1 Statistic datum of expansion test results [2]

Location	Youngding River	Chaobai River	Gou River	Guishui River	Nankou	Jumahe River	Sanhe	Jixian
Test group (groups)	55	93	8	5	42	133	72	3
Expansion <0.1% (group)	12	54	7	2	20	39	22	0
Expansion >0.1% (group)	43	39	1	3	22	94	50	3

Table 2 The results of chemical constituents of the limestone aggregates

Location/ aggregate	Chemical composition, /%							
	Loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
Sanhe/limestone	41.99	9.75	0.33	0	28.87	18.30	0.05	0.05
Jixian/limestone (ripple form)	40.94	4.59	0.95	0.43	49.78	2.52	0.29	0
Jixian/limestone (stromatolite form)	41.55	4.59	0.99	0.27	49.60	1.65	0.35	0

Table 3 Petrographic characters of limestone aggregates

Location/ aggregate	Characters
Sanhe/limestone	Powder-crystal and fine-crystal limestone; calcite content > 97%, grain size: 0.03-0.14 mm; cryptocrystalline quartz and microcrystalline quartz content: 2%-3%
Jixian/limestone (ripple form)	Powder-crystal and mud-crystal texture; calcite content > 85%-90%, grain size: 0.02-0.1 mm; dolomite content: < 10%-15%, grain size: 0.06~0.22 mm; quartz content: < 1%, grain size: < 0.04
Jixian/limestone (stromatolite form)	Powder-crystal and mud-crystal texture; calcite content > 97%, grain size: 0.005-0.07 mm; dolomite content: < 5%, grain size: 0.1-0.2 mm

2.3 Expansion experiment

A quick test method for ACR proposed by Professor Tang Mingshu et al [3] and P.E.Grattan-Bellew et at [4] was used to evaluate alkali reactivity. The limestones were crushed into grains with a diameter between 5 mm and 10 mm. The ratio between the cement and aggregate is 1:1 and the ratio of the water to cement is 0.3. The alkali content of cement was boosted to 1.5% by adding Na_2O. The size of the specimens were in 40mm×40mm×160mm. The specimens were demolded after 24 hours and put into hot water at 80°C for 24 hours before being tested. Then it should be put immediately into 1mol/L NaOH solution at 80°C for maintenance 30 days. If the expansion rate is above 0.1% after 30 days, it can be defined as ACR. The results are listed in Table 4.

According to the expansion experimental results (Table 4), aggregates in the regions of Beijing and surrounding Beijing induce AAR expansion to can be describes as following:

- The expansion ratio of concrete sample made from Sanhen limestone is 0.119%, and more than 0.1% at 15 days. However, when 30% fly ash replaces cement by weight, the expansion ratio is –0.005%, which indicates that replacing cement of 30% fly ash prevent effectively AAR. Therefore 0.119% expansion ratio of concrete sample is due to ASR and not ACR.
- The expansion ratio of concrete samples made from three kind aggregates are more than 0.1% at 30 days, which indicate that AAR have occurred. When 30% fly ash replace cement by weight, the expansion nearly is zero, AAR is prevented. The results indicate that the above expansion of samples is due to ASR and not ACR.
- The reactive-aggregates in region of Beijing and rounding Beijing belong to the active aggregate of ASR and not active aggregate of ACR.

3 SURVEY AND ANALYSIS OF DETERIORATED STRUCTURES

3.1 Cloverleaf junctions

3.1.1 Site survey

In the winter of Beijing city, freezing and thawing of salt solution is used for thawing snow and ice that should not be neglected. Site observation shows that secondary beams and transversal beams are most vulnerable to damage because rainwater streams down from the bridge surface and leave these beams in a moist state for a good part of the time. In winter, the temperature in Beijing often drops below freezing. Obviously, freezing and thawing contributes to the deterioration of these often wet concrete members.

Table 4 The results of expansion experiment

Location/aggregate	FA* /%	Expansion, /%			
		3d	9d	15d	30d
Sanhe/limestone	0	0.014	0.045	0.119	0.243
	30	0.002	-0.002	-0.005	-0.013
Jixian/imestone (ripple form)	0	0.012	0.035	0.060	0.108
	30	0.002	-0.001	0.002	0.028
Jixian/limestone (stromatolite form)	0	0.017	0.031	0.047	0.124
	30	0.003	0.004	0.002	0.031

* Fly ash replace cement by weight.

Chaoyangmen cloverleaf junction

Chaoyangmen cloverleaf junction is located on the second ring road of Beijing, which were precast at site from August 30 to October 18, 1978. Yungding River aggregate was used as coarse and fine aggregate of the concrete. A lot of cracks were found in the lower part of some double-column piers (Figure 1). These cracks have developed in the shape of network and the gap of cracks along the reinforcement direction is relatively wide. Dotted rusts of reinforcement in some cracks show that the reinforcement is corroded.

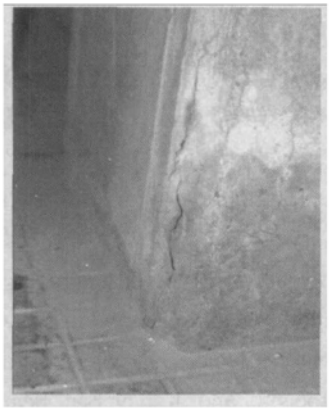

Fig. 1 Chaoyangmen cloverleaf junction

Sanyuan cloverleaf junction

Sanyuan cloverleaf junction is a large-scale junction built in the middle of 1980's. According to the report, since concreting of the secondary beams was carried out in the last ten days of March, when the outdoor temperature was low, 5% (by weight of cement content) of $NaNO_2$ was added in the mixing. Yongding River aggregate was used as coarse aggregate of the concrete. Serious cracks occurred on part of the secondary beams and main beams and part of the concrete are loosened. Dotted rusts of reinforcement are found in the cracks (figure 2).

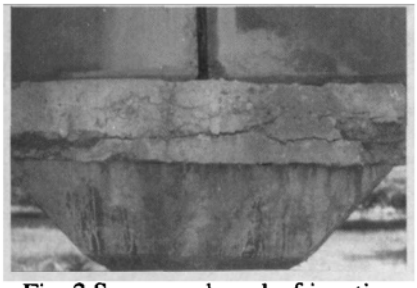

Fig. 2 Sanyuan cloverleaf junction

Beiyao cloverleaf junction

Beiyao cloverleaf junction initially built in June 1986 and completed in November of the same year. The bridge is supported by precast R.C. T-beams with a wide web, under the T-beam are the secondary beams. To date, network-shaped cracks have developed on part of secondary beams (Figure 3). Longitudinal cracks are also observed on individual T-beams and dotted rusts of reinforcement can be seen in cracks.

Fig. 3 Secondary beams of Beiyao cloverleaf junction

3.1.2 Tests on concrete core samples

In order to analyze further the damaging, the following test is carried out: Cores from members seriously damaged by ASR are bored and then cut into cylindric specimens. Stainless steel probes were stuck to the surface of these specimens and placed in the middle along the longitudinal direction of the cylindrical specimens for measuring the expansion. The specimen was immersed in water at 20°C for 2 days, and the lengths of the specimens are then measured for reference. Furthermore, the specimens are cured under 40°C with a relative humidity of greater than 95%. Core expansion tests (Fig. 4 and 5) [5] all show that ASR occurs in the four cloverleaf junctions investigated and is a main factor responsible for the poor durability of the concrete. Samples from secondary beams of Sanyuan. The sizes of concrete core specimens in Fig. 4 are 4cm×4cm×10cm (curve 1), 4cm×4cm×10cm (curve 2), 4cm×4cm×11cm (curve 3), and 4cm×4cm×16cm

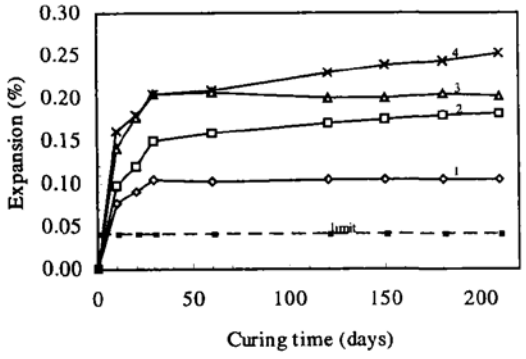

Fig. 4 Expansion of concrete cores from secondary beams of Sanyuan cloverleaf juction

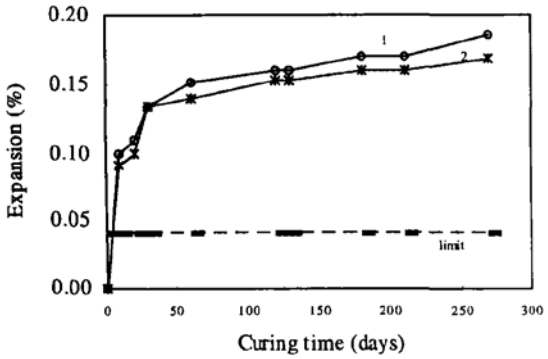

Fig. 5 Expansion of concrete cores from T-beam of Beiyao cloverleaf junction. The specimens were in 4cm×4cm×16cm

(curve 4) respectively. The samples are stored in conditions at 40°C and 100% R.H.

3.2 AAR in Beijing Neimeng Hotel and Restoration

3.2.1 Site survey

Beijing Neimeng Hotel was established in 1984, composed of floor under the ground and 12 floors above the ground amoung, which 2th to 12th floors are standard floors. The underground part is box foundation, and the parts above the ground are frame and shear wall structure all in precast units, The beam and board is covered with overlapped instant cast concrete layers. The compressive strength of concrete is 25MPa in original design requirement, and 40MPa for structural columns, 20MPa for beams, 25MPa is used for instant cast. Redecoration took place in the winter of 1998 and all original decoration was dismantled.

After dismantlement of the original decoration, longitudinal cracks were discovered on columns from 1st to 11th floor. It was interesting that no cracks were found at either end of the columns. In addition, all cracks on the columns were positioned at 40cm to 2m above the floor (Figure 6).

3.2.2 Core samples tests

Core of column shows that the aggregate has a thin reactive edge. Thus an EDXA analysis is made to a thin section under the microscope. Data of the analysis is shown in Table 5.

Table 5 Column core sample EDXA analysis results

Position	no	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O
Agg.	1	1.34	1.66	0.78	50.9	36.3	6.30
	2	91.08	0.75	0.62	5.32	2.04	0.16
	3	89.76	0.76	1.82	4.88	1.99	0.72
Agg. edge	4	58.90	17.6	0.21	6.61	2.30	13.4
	5	56.28	13.8	4.18	10.6	1.94	12.5
	6	42.33	16.1	3.24	2.07	22.2	12.6
Cem Mor.	7	27.03	8.77	7.37	40.7	9.85	5.59
	8	38.62	10.3	5.80	27.9	8.61	7.66
	9	34.	8.22	3.86	46.8	2.30	3.92

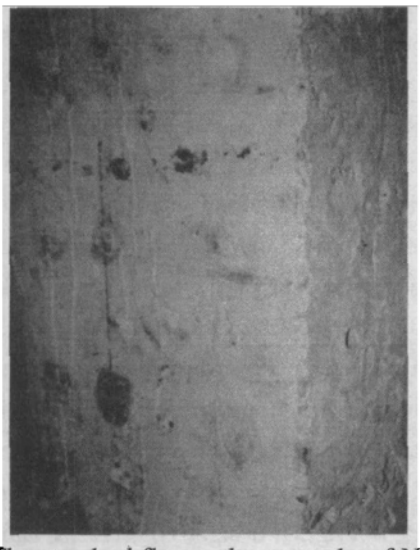

Fig. 6 The standard floor column cracks of Neimeng Hotel

EDXA analysis results indicate that as reactive edge is thin, the reactive edge of aggregate not only contain the gel to consist of potassium, sodium and silica but also mix with a C-S-H gel. With respect to the composition of cement part 7, 8 and 9 quite a quantity of alkali is involved. A preliminary conclusion can be drawn, based on data from EDXA, that an alkali and aggregate reaction has taken place in the cracked columns.

Then both ends of the core were set up test heads and dipped into water of normal state (20±2°C). The dilatability ratio was read at 0.055%, which is liberated expansions ratio from columns structure binding force. Then the test sample was cured under condition of 40°C and 100%PH, which have lasted for 5 months. The test sample further expansion to 0.341%, obviously in excess of the harmful limitation of 0.04% and 0.075%. In addition to the experimental data, the following factors can neither been neglected [6].

- In 1980's, all cement used in North China was high alkali cement. The prepared concrete strength 40 Mpa was applied in large amount (approximately 500kg/m^3). However siliceous-limestone produced in Youngding River, as confirmed by the surcey and test conducted in 1991-1993, is highly reactive of ASR. This explains why the concrete contains potential factor for alkali aggregate reaction.
- It is illustrated in the blueprint that on a standard floor, between axes B and C is designed as corridor, while the part between A and B as well as that between C and D are reserved as bathrooms of guestrooms flank of all the cracked columns. Moisture is required for expansion from alkali aggregate reaction. Wall columns were most found at 40cm to 2m above the floor, roughly equivalent to stature of a man in bath. The moisture was extended up and down a little. Moreover both ends of columns are thickly bound with wires. Alkali aggregate reaction was not as severe up to that extent and the dilation was not strong enough to break either end of the columns.

To judge from the above, it is concluded that the longitudinal cracks on framework columns on 1st to 11th floor of Neimeng hotel were dilated cracks caused by ASR. Therefore the following measures are recommended to reinforce the columns:

- All the cracks should be sealed by filling epoxy resin.
- All cracked columns should be reinforced by sticking steel after the filling, and coat to proof surface of the columns to prevent water from pervading into columns.
- According to the original design, two rooms are contained between two columns on a standard floor and the bathrooms are placed beside the columns, doors and passages of the guestrooms beside the partition between two columns. For keeping draining of the column, it is suggested that the bathrooms should be placed beside the partition between the columns, and the doors and inner passages of the guestrooms are re-arranged beside the columns instead.

3.3 AAR in railroad bridges

The railroad bridge was built in 1980's. Yongding River aggregate was used as coarse and fine aggregate of the concrete. Datong Portland cement

was used. An alkali content was more than 1% Na_2O_{eq}. The railroad bridges from Beijing to Chengde found the many cracks due to ASR.

4 CONCLUSIONS

Through site survey and lab tests on the concrete mixed with aggregates from quarries of the region of Beijing and rounding Beijing, the following conclusions can be drawn:

1. The four junctions are mainly caused by ASR expansion.
2. The longitudinal cracks on framework columns on 1st to 11th floor of Neimeng hotel are caused by ASR.
3. Revealed by the damage in site structure as well the obvious expansion of the lab specimens due to ASR, it is certain that ASR in concrete is quite dangerous and will reduce the lifespan of concrete considerably.
4. Results of tests show that the active aggregates in the region of Beijing and rounding Beijing can induce ASR and cannot ACR.

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