ALKALI-AGGREGATE REACTION IN BEIJING AREA OF CHINA

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After using comprehensive methods to determine the alkali reactivity of aggregates and to examine the concrete cores in more detail, it was completely confirmed that the deteriorations of concrete structures, over-crossing bridges, industrial building and prestressed concrete railway ties, were caused by alkali-aggregate reaction in Beijing Area of China. The reactive pebble is siliceous limestone or siliceous dolomite. This first discovery will arouse much attention to prevent alkali-aggregate reaction in China.

INTRODUCTION

Although the study of alkali-aggregate reaction was first carried out as early as 1960's in China, until 1988, only a few reactive rocks, such as chert, andesite, rhyolite, tuff, perlite, pichstone, obsidian etc. were discovered, and no evidence of damage caused by alkali-aggregate reaction were proved. However, since 1989, several quarries providing the aggregates for the construction of structures in Beijing have been invistigated in detail. The results showed that the pebble of riverbed and the crushed stone contain a large amount of reactive components such as chalcedony, micro-or crypto-crystalline quartz. Meanwhile, the cases of deterioration caused by alkali-aggregate reaction were confirmed by comprehensive methods. The cases of deterioration involved industrial building, concrete bridge and railway ties. In recent years, in China, there has been considerable changes in the cement industry and construction which might aggravate the damage caused by of alkali-aggregate reaction, the alkali contents of cement clinker was increased and chemical admixtures containing alkali widely used for accelerating construction or preventing damage from freezing and thawing. As a results, if there is no effective preventing measures, the damage caused by alkali-aggregate reaction will rapidly increase. Thus we should pay much attention to the problems of alkali-aggregate reaction in china.

1. Reactivity of Aggregates

The majority of rocks, either pebble or crushed stone used in the Beijing Area is siliceous limestone and some amount of basalt, andesite etc. The siliceous deposits are of Cambrain and Ordovician periods. The dominant reactive mineral are classical chalcedony and micro- or crypto-crystalline quartz (Fig.1). From the view of texture, the crystalline quartz or chalcedony are dispersed in the matrix of calcite or dolomite, but there is also another texture displaying crystals of carbonate dispersed in a quartz matrix.

Fig. 1 A vein of chalcedony and micro- or crypto-crystalline quartz through silicate limestone

The chemical test (ASTM C298) is not suited to determine the reactivity of the above rocks, because they contain a great amount of calcium carbonate. Thus the rapid autoclaved test method (1) was used to determine the alkali reactivity. Recently this rapid method has been proved to be satisfactory to determing the alkali reactivity of silica and silicate rocks by Criaud(2), who made some improvement of this method as dividng the ratio of cement to aggregate from 10:1 to three groups:10:1, 5:1, and 2:1. Increasing the content of aggregate is beneficial to determine the reactivity of aggregate which contains a small amount of reactive component such as phyllite, greywacke, argillite and other rocks. The maxium value of expansion obtained from the three groups of different cement to aggregate ratios was used to evaluate the aggregate used. Table 1 shows the experimental results obtained by autoclave rapid test method. The rocks were taken from the different quarries of Beiji g area.

According to the experimental results of us and Criaud, when the value of expansion is over 0.1%, reactive; 0.8%-0.1%, potential reactive; less than 0.03%, non-reactive. From the expansion values showed in Table 1, it proved that all these aggregates taken from different quarries of Beijing were confirmed to be of high alkali reactivity. Other rocks taken from more than ten quarries in the suburbs of Beijing displayed the similar expansion characteristics, either the pebble or the crushed stone. Of course, their alkali reactivity may be some what different.

2. Cases of Deterioraiion

Since 1989, in the Beijing area of China, several cases of deteriorations caused by alkali-aggregate reaction have been successively discovered, (such as railway ties,

TABLE 1–Expansion of Mortar Bars Tested by Rapid Method

Quarry No.	Average value of expansion (%)	Reactive component
1	0.208	Chalcedony, micro– or crypto–crystalline quartz and a small amount of opal
2	0.185	
3	0.228	
4	0.190	

industrial buildings and bridges). However, there are a number of factors which can cause cracking and deterioration of concrete structure, thus comprehensive study is needed to determine whether the deterioration is caused by alkali–aggregate reaction or by other factors. So far, many samples of deteriorated concrete has been taken from field structures and examined in detail by optic and electronmicroscope, X–ray and EDXA. Consequently, through the comprehensive analysis the above cases of deterioration of concrete structures were confirmed to be caused by alkali–aggregate reaction. This has been the first discovery such case of damage in China, which aroused much attention.

2.1 Railway ties

Fig. 2 shows the cracking of prestressed concrete railway ties which were produced by a prescast concrete factory in Beijin in 1986 and installed in the railway station of Shanghai. It can be seen that obvious map craeks appeared on the end part of tie and cracks were aligned with the direction of major stress in the center part. The size

Fig. 2 Cracking of prestressed concrete railway tie (a) center, (b) end

of tie is $l \times b \times h = 2500 \times 450 \times 155$mm which was made of cement : sand : pebble : water =1:1.249:2.772:0.298, the amount of portland cement, 470kg/m^3; alkali content of cement, 1.10%Na_2O equiv.; besides, 0.6% (by mass of cement) superplasticizer was added. The total amount of alkali in 1M^3 concrete reached about 5.23 kg/m^3. The pebble was taken from a quarry in a suburb of Beijine, which was confirmed to be high alkali reactivity. As described in above, the concrete mix was riched in cement, alkali and reactive component (in aggregate), and provided sufficient conditions to arouse deterioration of alkali-aggregate reaction to cause deterioration of the ties. The damaged concrete blocks were taken from the field. Crack in the blocks contained the white gel of alkali-silica which was clearly obviously visible to the naked eye. When above concrete blocks were cured in steam box at 40℃ for a few months, the white gel dispersed on its whole surface. The reacted rim around the aggregate and alakli enriched on the reacted zone were confirmed.

At the beginning, the deterioration of tie was suspected to be caused by cycle of wetting and drying or freezing and thawing. Nevertheless, concrete cubes($15 \times 15 \times 15$cm) made from a similar concrete put in laboratory(20℃,high humidity) were also seriously deteriorated so that the reacted products were escaped and empty space was remained around the particles of aggregate (Fig.3,a). Thus it was impossible to suspect cycle of wetting and drying or freezing and thawing to be the reason causing damage. Similarly, the form of alkali-silica gel was confirmed by EDXA (Fig. 3, b). The expansion of concrete cube reached nearly 3.67% during about 8 years curing which was over 36 times the value of 0.1% limit ASTM C227. The concrete cube made in laboratory was damaged seriously and was sufficient evidence of damage caused by alkali-aggregate reaction.

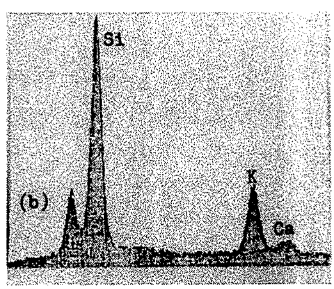

Fig. 3 (a) reacted aggregate, (b)composition of alkali-silica gel in reacted rim determined by EDXA

2.2 Industrial building

A steam dome continuously suffering high temperature (40-50℃) was built in 1960 in Beijing General Factory of Internal Combustion Engine. The concrete wall made from slag portland cement, W/C=0.39, cement:sand:pebble=1:1.099:3.58, was seriously damaged. A concrete core, $d \times l = 7 \times 12$cm, was taken from the wall. Map cracks and reaction rims around aggregates were fully displayed on the whole surface. Examining the thin section of core under polarization microscope, the amount of reactive pebble containing chalcedony was estimated to be 15–40%. Fig.4 shows the chalcedony, cracks and composition of reacted rim determined by EDAX.

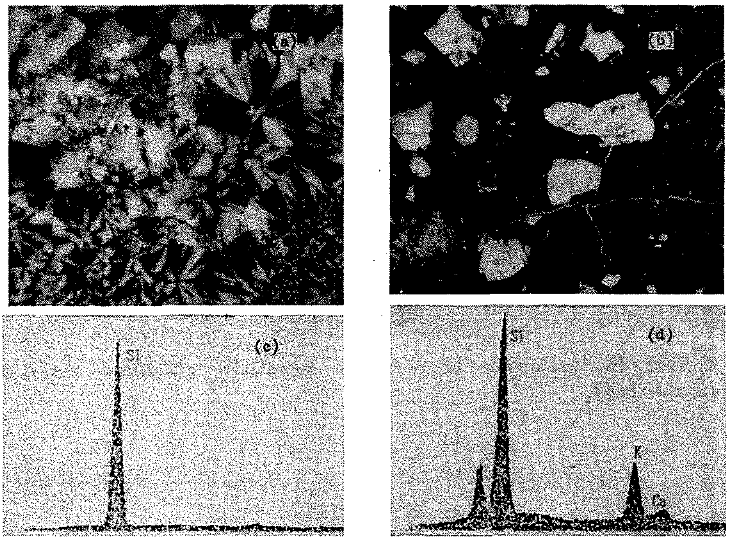

Fig.4 (a) chalcedony, (b)cracks, (c)Si–center of particle (by EDAX), (d)Si, K–reacted rim (by EDAX).

It is worthy of note, this is an example which proves that the concrete structure made from slag cement might also be damaged by alkali–aggregate reaction under special rigorous enviroment such as continous high temperture and high humidity. Unforturnately there is lack of data about the alkali content of cement ant the content of slag in the cement.

2.3.Over–crossing Concrete Bridges

Upto now, more than seventy over–crossing concrete bridges has been built in Beijing, some of which show signs of distress. Several concrete cores were taken from these bridges. It was proven that the pebble contained in the concrete cores was of high alkali reactivity, and either reaction rim or gel enriched with alkali was also observed on it. Especially the damage was aggravated where the beams were subjected to flowing rain water.

3. Discussion and Conclusion

In recent years, several factors may have aggravated the damage caused by alkali–aggrgate reaction in China. (1) In the north part of China, millions of tons of high alkali cement are produced, because the alkali content of raw materials, especial clay, was very high. Sometimes, the alkali content of clinker may reach as high as 1.2–1.4% Na_2O equiv. (2) In some factories, the high alkali dust was added to cement as additive. (3) In order to accelerate the construction, accelerators, such as Na_2SO_4,

Na_2CO_3, were widely adopted. (4) In winter, in order to prevent freezing and thawing, and allow the construction to be carried out even in −10℃—−20℃, $NaNO_2$ and NaCl etc. were added. (5) In most cases, the aggregates were not examined with respect to their alkali reactivity.

So far, the first incidence of damaged concrete structures, caused by alkali-aggregate reaction, has aroused much attention. It can be expected that many measures must be taken in near future in China.

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