ALKALI-AGGREGATE REACTIONS IN CHINA

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ABSTRACT

Some of gravel and crushed stones in China were found to be either alkali-silica reactive or alkali-dolomite reactive, or both. They involved igneous, sedimentary and metamorphic rocks. The reactive silica minerals were dominantly microcrystalline to cryptocrystalline quartz and chalcedony. Strained quartz, cristobalite, tridymite and opal also caused some rocks to be reactive. Alkali-aggregate reactions (AAR) have recently diagnosed in numerous buildings, water cooling towers, bridges, railway ties, piles and pavements of airport. To minimize the risk of AAR deterioration in the future structures, standards for evaluation of alkali-reactivity of aggregates and for maximum alkali content in concrete or cement have been proposed.
Keywords: Concrete structure, deterioration, preventing measures, reactive aggregates

INTRODUCTION

The study of alkali-aggregate reactions in China dates back to the early 1960's. Investigations were carried out using ASTM C289 and ASTM C227, and a few of rocks in Yangtse river and some other places were recognized as potentially alkali reactive (Xu et al. 1983 & Chen. 1984). Fly ashes were used to inhibit expansion due to alkali-silica reaction in concrete of dams (Chen. 1984). No case of damage caused by AAR was reported until 1989, when deterioration by AAR was first confirmed in railway ties (Han et al. 1990). In 1991, the first case of deterioration in China due to alkali-dolomite reaction (ADR) was discovered (Deng et al. 1993). Since then, rocks and sands from some quarries have been evaluated in detail. A large amount of rocks in rivers and mountains was found to be alkali reactive. Simultaneously, a number of concrete structures mainly in Northern China were recognized to be damaged by AAR. The reactive aggregates included andesite, siliceous dolostone, metaquartzite and dolomitic limestone etc.

Preventive measures are not generally adopted in construction. With the use of high volume of Portland cement containing high alkali and incorporating chemical admixtures such as antifreezing agent composed of alkali metal salt, some concrete structures in certain regions may be seriously affected by AAR in the near future.

REACTIVE ROCKS

Many types of rocks have proved to be alkali reactive in concrete structures and in laboratory tests. They involved igneous, sedimentary and metamorphic rocks. Table 1 shows alkali-silica reactive rocks found in Beijing, Jixian, Shuizhong, Jingzhou, Changchun, Pingdingshan, Linru, Shijiugang, Hangzhou, Guizhou, Chengdu, Hai river in Hebei, Hongshui river in Guangxi, Yangtse river, Han river and Tuo river (Han et al. 1990, Tamura & Huzikou. 1988, Zhen and Tang. 1982, Xu & Chen. 1983). The dominant reactive minerals in rocks were microcrystalline to cryptocrystalline quartz and chalcedony. The chalcedony made the rocks highly reactive. Cristobalite was a minor component of some andesitic rocks. Tridymite was found in one of perlites. Strained quartz was responsible for the reactivity of meta-granite and meta-quartzite, which may be classified as cataclastic rocks developed by dynamic metamorphism. The typical microstructures of these rocks are demonstrated in Fig. 1.

Table 1 Alkali-silica reactive rock found in China

Types	Reactive rocks	Reactive minerals
Igneous rock	Basalt, diorite porphyrite, quartz diorite-porphyrite, andesite, andesite porphyry, felsite, trachyte, rhyolite, obsidian, perlite, tuff, volcaniclastic rock	Microcrystalline to cryptocrystalline quartz, chalcedony, cristobalite, tridymite
Sedimentary rock	Chert, siliceous dolostone, siliceous limestone, mudstone	Microcrystalline to cryptocrystalline quartz, chalcedony
Metamorphic rock	Argillite, phyllite, meta-granite, meta-granite porphyry, mata-quartzite	Strained quartz, microcrystalline quartz, chalcedony

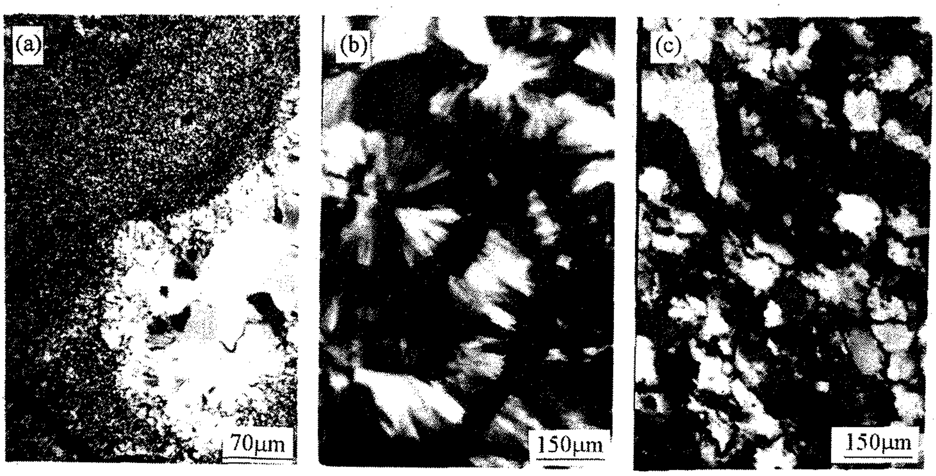
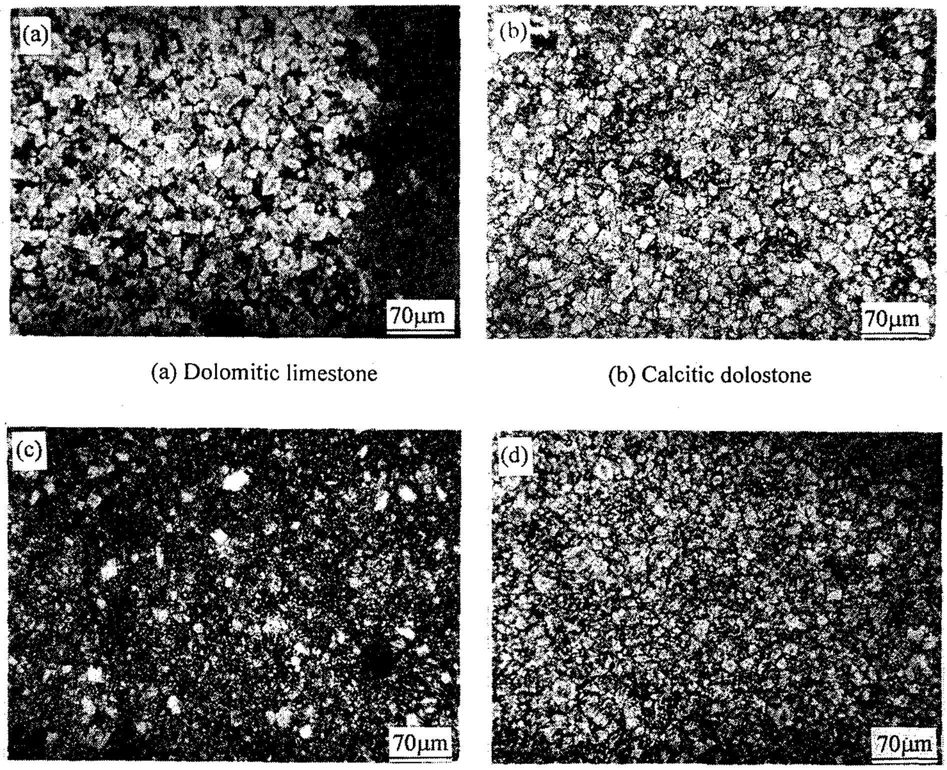


Fig. 1 The microstructures of alkali-silica reactive rocks

The alkali-dolomite reactive rocks included dolomitic limestone, calcitic dolostone, siliceous dolostone and dolostone from Taiyuan, Jixian, Huailou, Huailai, Nankou, Changchun, Pingdingshan, Lintong, Jinan and Weifang. Many of dolomitic limestones showed a texture of fine-grained (10-60 μm) dolomite rhombs scattered in matrix of calcite and a small amount of acid insoluble residue (less than 5%). The residue was composed of crystalline quartz, feldspar and clays. Dolomite in these rocks was distributed either in veins or homogeneously. These rocks showed intermediate expandability. Some dolomitic limestones with more impurities were highly expansive. The calcitic dolostones contained rhombhedral dolomite in 2-20 μm distributed in matrix of calcite, quartz and clays and were very expansive. Fine-grained dolomite and microcrystalline quartz or even chalcedony were involved in the siliceous dolostones. These rocks were founded being both alkali-dolomite reactive and alkali-silica reactive. When silica was homogeneously scattered in the fine dolomite crystals, rocks in concrete might cause a larger expansion. Argillaceous dolostones with fine dolomite were highly reactive. The pure fine-grained dolostones showed a mosaic texture and were expansive although the magnitude of expansion was slightly small. The representative microstructures of these rocks are shown in Fig. 2.



(a) Dolomitic limestone

(b) Calcitic dolostone

(c) Argillaceous dolostone

(d) Fine-grained dolostone

Fig. 2 The textures of alkali-dolomite reactive rocks

CASES OF DETERIORATION

To date it has been confirmed that buildings, water-cooling towers, bridges railway ties, piles and pavements of airport have cracked due to alkali-aggregate reactions. The affected structures by AAR may be more than the discovered cases because many deteriorated structures have not been subjected to investigation.

The west wall of the heat station in Beijing Internal Combustion Engine Plant was constructed with slag Portland cement in 1960. After suffered 40-50℃ and high humidity, the wall showed seriously random cracking. Petrographic examination revealed that the coarse aggregates in 5-30 mm contained microcrystalline quartz and typical chalcedony. Some aggregates were attacked and alkali-silica gel was formed (Han et al. 1990).

The concrete water-cooling towers in Tongliao Power Station, Inner Mongolia and Tiechangou Power Station, Xinjiang cracked after being in service for years. Reactive coarse aggregates with chalcedony and microcrystalline quartz were used. SEM/EDAX observation showed that some coarse aggregates were eroded and there was alkali-silica gel in the interface between aggregates and mortars. Little ettringite was found.

Bridges in Beijing and in railways in Jiangxi, Shandong and Hebei provinces were distressed by alkali-aggregate reaction. The bridges of Beijing were constructed during 1978-1986 and demonstrated map cracking on slabs, beams or piers in 1990. Investigations carried by Zhao et al (1993) and the authors established that cracking of the bridges was mainly caused by alkali-silica reaction between alkali in pore solutions and chalcedony as well as microcrystalline to cryptocrystalline quartz involved in the coarse aggregates basalt, andesite, siliceous dolostone etc. The railway bridges were precast and prestressed. The content of cement was 470-550 kg/m^3 concrete. The bridge beams were showing longitudinal cracking in the belly and bottom flange and random cracking in other parts. Field surveys taken during 1991-1992 revealed that, of 450 spans of bridges 8-15 year old, 405 spans were cracked. The cracked bridges were made with high alkali Portland cements and reactive coarse aggregates contained microcrystalline to cryptocrystalline quartz and/or chalcedony.

The prestressed railway ties manufactured in Beijing and Pingdingshan were showing map cracking beyond the rail seats and longitudinal cracking between the rail seat. The cracked on-line and spare (set beside) ties from Beijing were found in Guiyang, Shanghai, Beijing, Taiyuan and Northeast China. Alkali content of the ties was about 5 kg/m^3. The reactive aggregates were same as that used in the railway bridges from Beijing. Petrographic and SEM/EDAX examinations showed that the concrete was damaged by alkali-silica reaction. The railway ties from Pingdingshan contained reactive dolomitic limestone, calcitic dolostone and metaquartzite. They were made with a local high alkali (1.19% Na_2Oequiv.) Portland cement. The content of alkali was approximately 6.0 kg/m^3. These ties were confirmed to be affected by both alkali-dolomite reaction and alkali-silica reaction brought about by strained quartz.

Prestressed piles made in Taiyuan were longitudinally cracked after 1 year in service. The aggregates were derived from a river gravel source consisting of dolomitic limestone and dolostone. Coarse dolomitic limestone was found to be responsible for the distress. Piles in a concrete product plant and an internal combustion engine plant in Beijing were also showing longitudinal cracking. The piles were precast and prestressed. The materials used were same as that in the railway bridges or the wall mentioned above. Alkali-silica reaction was the main cause for cracking.

Concrete pavements of airport in China were also damaged by AAR. Table 2 lists some details about the pavements. The pavements showed map cracking. Dolomitic limestones were suggested as mainly detrimental component. Dolomite in these rocks was in 10-60 μm and was dispersed in matrix of calcite and acid insoluble residue. Laboratory tests indicated that the dolomitic limestones were alkali-dolomite reactive. Cracks in concrete were partially stretched out of dolomite-rich zones of the aggregates and extenuated to the surrounding mortars. The results of DTA and SEM/EDAX showed that the dolomitic limestone in JN airport was attacked and brucite was formed. The siliceous dolostones in TX airport were both alkali-silica reactive and alkali-dolomite reactive. Microcrystalline quartz and chalcedony involved in these rocks were responsible for their alkali-silica reactivity. Tuff in CC airport contained reactive microcrystalline quartz and caused deleterious expansion.

Table 2 Some details of the deteriorated airport pavements

Airport	Cement (kg/m^3)	Reactive aggregates	Date of construction	Damaged area (%)	Date of field survey
CC	330-350	Dolomitic limestone, tuff	1985-1986	20	1992
TX	310-320	Siliceous dolostone	1986	1.1	1992
LT	290-300	Dolomitic limestone	1975	6.0	1991
JN	310	Dolomitic limestone	1989	21.7	1991
WF	310	Dolomitic limestone	1983-1984	33.3	1991
XJ	300	Dolomitic limestone	1976	18	1989

PREVENTING MEASURES

ASTM C295, C227, C289 and C586 were incorporated to a standard (SD 105. 1982) of the Hydraulic and Power Ministry of China in 1982. They were employed to evaluate alkali-reactivity of aggregates. The standard formulated that low alkali cements (Na_2Oequiv. being not more than 0.60%) should be used or mineral admixtures should be applied to effectively inhibit the deleterious expansion when aggregates were alkali-silica reactive in hydraulic power stations. The alkali-carbonate reactive aggregates should not be selected as aggregates. Fly ashes have been used to prevent dams from being damaged by alkali-silica reaction (Chen. 1984). These measures have effectively made the hydraulic concrete structures not to be affected AAR. These ASTM standards were then transplanted to a standard (JGJ 53. 1993) on sand and rock of the Ministry by Construction in 1992. This standard claimed that only aggregates used by important concrete structures should be submitted to evaluate alkali-reactivity, and preventive measures mentioned above should only be applied to important structures. Practically, the part on AAR of this standard is rarely implemented.

Furthermore, a standard (CECS 48. 1993) was proposed by the authors, which concerned rapid determining of alkali reactivity of sands and rocks. This method was based on the Chinese autoclave method and was only suited to evaluate alkali-silica reactivity. This standard is extensively used by Chinese engineers and researchers.

High alkali Portland cements are now used in some concrete structures. The content of alkali is sometimes as high as 1.20% Na_2Oequiv. Chemical admixtures are universally used in China to improve workability, strength development or other properties of concrete. The commercial admixtures available in China often contain alkali metal salts such as Na_2SO_4 and $NaNO_2$. These salts may carry 0.8-13 kg/m^3 Na_2Oequiv. into concrete. Their combination tends to raise the alkali content of concrete being far higher than 3.0 kg/m^3. To avoid or minimize the risk of deterioration due to AAR, a standard (CECS 53. 1993) for maximum alkali content in concrete was proposed. When alkali-silica reactive aggregates are involved, the limit of alkali content in concrete or other measures shown in Table 3 are proposed. Many factors restrain the application of these measures.

Table 3 The limit of alkali in concrete with alkali-silica reactive aggregates and measures

Conditions of	Maximum alkali content (kg/m^3) in concrete and measure		
circumstances	Ordinary structure	Important structure	Special structure
Dry	no limit	no limit	3.0
Wet	3.5	3.0	2.1
With alkali	3.0*	unreactive aggregate	unreactive aggregate

* *The structures should be effectively painted, otherwise unreactive aggregates should be used.*

Based on the absences of low alkali Portland cements and nonreactive aggregates in North China, we are planing to use sulfoaluminate and ferroaluminate cements to counteract deterioration due to alkali-dolomite reactive aggregates. In addition, we are trying to produce a series of special cements to meet the demands for producing durable concrete with high strength.

CONCLUSION

Reactive aggregates are presented in many regions of China. Some concrete structures have been distressed by either alkali-silica reaction or alkali-dolomite reaction, or both. Many efforts will be made to minimize the risk of alkali-aggregate reactions in concrete. Deterioration due to AAR will be expected to be a continuing problem in China in the next ten years or more.

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