DAMAGE TO CONCRETE CAUSED BY MAGNESIUM-RICH AGGREGATE

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A description is given of serious concrete engineering incidents caused by the lack of durability of magnesium-rich aggregate in China. Site investigations and analyses of the microstructure of concrete on the latest BWSC construction incident have been carried out in detail, revealing the symptoms of failure and development rules as well as control measures for the aggregate reactions.

INTRODUCTION

Damage to concrete caused by alkali-aggregate reactions has received great attention but damage caused by aggregate containing high MgO has been neglected and possibly misjudged. In recent years increasing use of artificial aggregate (steel slag, zinc slag etc.) and the presence of magnesia in natural aggregate has brought about several concrete failures.

The first reported such aggregate reaction appeared in Shanming Steelworks, Fujian, China. The project started in 1976 and finished in 1978. After two years' service, large areas of surface layers bulged and peeled off. Afterwards successions of internal cracks appeared. Analysis of the samples showed that the direct cause was the presence of MgO as a major component of the crushed aggregate. Expansion of the MgO through a delayed hydration reaction resulted in the loss of durability of the concrete.

Another incident in which zinc slag was used as concrete aggregate was similar to that occurring with the MgO-rich aggregate which occurred in Zhuzhou, Hunan, China. Cracks and efflorescence appeared in large areas on the outside walls of 23 residential buildings after seven years' service. Investigations showed that the oxidation of Fe^{2+} in zinc slag and the hydration of MgO was the direct cause of the damage to the concrete construction.

This paper reports a study of an MgO-aggregate reaction which occurred in the city of Wuhan, Hubei Province. Because of the presence of the MgO in the aggregate, in less than three years the surface concrete of the construction bulged and peeled off. The reinforcement was exposed and cracks ran through the concrete. The building which cost 8,000 000 yuan had to be abandoned.

These serious failures all showed that as artificial aggregates (mainly industrial waste materials) and natural MgO-rich aggregates (such as magnesia, magnesian limestone, etc.) are gradually put to use in concrete construction account of the possible damage to the concrete caused by the magnesia aggregate reaction must be taken. So far there has been a lack of basic research and systematic reports on the symptoms or on the rules, judgment and appropriate control measures for damage from this reaction.

SITE INVESTIGATION

1. Background:

The BWSC construction covers a floor area of 16,696 m. A cast-in-place reinforced concrete framed structure was adopted. The whole construction was divided into three sections A, B and C among which sections A and C included eight storeys with a height of 38.6 m and Section B contained ten storeys with a height of 44.5 m (See Figure 1).

Construction started in February 1985 and was completed in September 1987. After it was checked and accepted, the building was made available to the users.

2. The symptom and development of the damaged concrete and analysis of the causes.

Signs of damage to the BWSC construction first appeared in January, 1990. The decorative marble cladding on column B-18 in section B was found peeled off. After patching up it peeled off again. Subsequent examination after removing the decorative surface showed partial expansion (See Fig. 2) splitting the concrete and exposure of a reinforcing bar (See Fig.3) to varying degrees in columns B-18, B-17, B-16, B-19 and E16 of section B. The exterior pattern of this concrete damage, as revealed by subsequent examination, was that at a certain humidity, bulging and radiating fine cracking appeared first on the surface of the concrete. Later, partial delamination followed and cracks enlarged continuously. Finally large areas of concrete peeled off, the reinforcing bars were exposed and cracks enlarged and became linked up.

Concrete damage is often attributable to diverse and mixed causes. The site investigation systematically sought and checked these other aspects such as cement quality, construction technique, structure design, service load, foundation subsidence and so on. This proved that all the aspects checked were in accord with relevant state standards. They were not the principal reasons for the damage to the concrete.

During the investigation of the expanded and cracked concrete it was noticed that in the centre of the expanded part and the deepest place of the exposed surface there existed a kind of white or light yellow aggregate which was obviously different from the common aggregate, suggesting that some harmful aggregate might be the direct cause of the damage to the concrete. This suspicious aggregate was tested and identified after separating and sampling.

RESULTS AND DISCUSSION

In order to identify the composition, structure and type of reaction of this harmful aggregate, it has been subjected to chemical analysis, X-ray diffraction and SEM analysis. A laboratory experiment was conducted to simulate and accelerate the damage.

Table 1 shows the composition of the aggregate. Both white and yellowish aggregates were composed mainly of MgO, the content of which was as high as 80%. This is typical of the material causing damage to concrete.

TABLE 1 - CHEMICAL ANALYSIS OF SUSPICIOUS AGGREGATE

Sample composition	Result (%)			
	MgO	SiO_2	CaO	LOI
White aggregate	79.9	2.1	1.5	16.5
Yellowish aggregate........	80.1	1.1	1.0	17.9

Figure 4 represents the result of X-ray diffraction. The major mineral component in the aggregate is periclase followed by $Mg(OH)_2$ which is brucite, the hydrated product of MgO. This result is in keeping with the chemical analysis.

Figure 5 is an SEM photograph of the aggregate. It clearly shows the expanded state of the aggregate which has hydrated for two years It can also be seen that the slow hydration of this material leads to increase of volume and the development of swelling stresses and cracks. It can be inferred that, in the concrete structure, once the swelling stress is sufficient, damage to the concrete will occur. We can conclude that the BWSL failure was caused by the addition of this harmful aggregate which reacted slowly with water at normal temperature

$$MgO + H_2O = Mg(OH)_2.$$

The speed of this reaction is usually very slow lasting 2 - 5 years or more with an increase of volume of about 2.2 times. This swelling of the aggregate brought about the partial swelling and cracking in the hardened concrete. As the concrete surface and edges are usually the weakest sites and easiest to observe, we can see the particle swelling and cracking and the spalling of the decorative cover in these locations some two years after the completion of the project.

It is worth noting that the speed of reaction and the degree of the damage of aggregate are related not only to the content of MgO temperature and moisture, but also to the distribution and grain size of the reactive aggregate in the concrete. In order to prove this relationship and to confirm that the damage to the BWSC project was caused by this reaction, a simulating laboratory test accelerating the damage was conducted. Standard cement paste samples were prepared in the standard way in 4 x 4 x 16 cm moulds using either one piece of about 1.5 cm grain, 3 pieces of about 0.5 cm grains or an equivalent quantity of the powdered form of the suspect aggregate taken from the damaged building. After curing for 28 days, the samples were put in water at 100°C for four hours. The result showed that the samples with about 1.5 cm and 0.5 cm grains split up in the cross section whereas the sample mixed with MgO powder remained intact. This further confirmed that the failure of the BWSC project was indeed caused by magnesia and indicated that the larger the size of the grain the more concentrated are the inner stresses, and the more serious the damage to the concrete construction.

DISCUSSION

Because industrial wastes are used as artificial aggregates and natural aggregates which contain MgO and magnesian limestone are increasingly used in concretes, damage due to the magnesium reaction in concrete projects is becoming more serious. Several failures of such projects showed that on the reaction with MgO-rich aggregate has several characteristics. It has a long latent period, bears great dangers and is hard to judge and repair. Therefore, when industrial wastes and natural aggregates which contain magnesia are used in concrete projects, the following points should be considered so as to avoid these aggregate reactions.

1. When the aggregate which contains MgO is to be used, the level of MgO must be measured and at the same time the aggregate must be tested under steam or autoclave curing in order to evaluate the degree of damage and the limitations of use. In structural projects magnesium-rich aggregate should be avoided if possible. In the process of construction contamination with magnesium-rich aggregate should also be avoided.

2. The potential damage can be decreased by prehydration. If some industrial wastes which contain magnesia are used as aggregate in concrete, they should be stored for a sufficiently long time, or be steamed or autoclaved before use.

3. The size of particle and the distribution of magnesia-bearing aggregate should be controlled in the process of construction. The result of our experiments indicates that $Mg(OH)_2$ can be effectively turned into magnesium silicates by adding materials with pozzolanic activity such as silica fume and perlite waste,

thus greatly reducing the expansive stresses and the consequent damage.

4. Projects in which the aggregate reaction may occur can be treated with water repellent material to delay or reduce the degree of damage.

CONCLUSION

1. The failure of the BWSC is due to MgO-rich aggregate becoming hydrated in the concrete.

2. The exterior characteristics of the Mg-rich aggregate reaction is somewhat similar to those of alkali aggregate reaction, such as the occurrence of expansion producing cracks in the concrete surface with ultimately large areas of concrete surface peeling off and cracks extending and linking up.

3. The interior cause of the problem is that MgO is hydrated slowly to $Mg(OH)_2$ and this results in a volume increase and expanding stresses.

4. The damage due to magnesia-bearing aggregate can be reduced by prehydration or the addition of materials with high pozzolanic activity.

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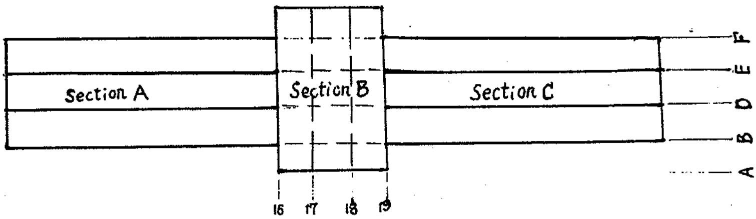

Fig. 1 Schematic Diagram of BWSC Preject

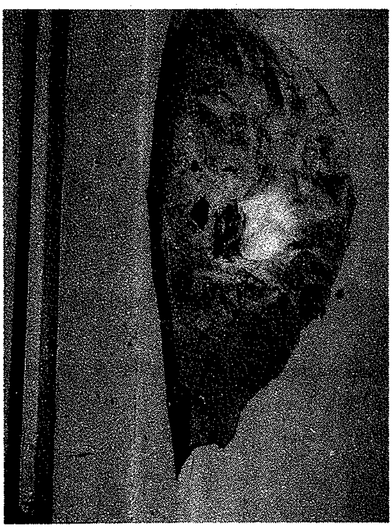

Fig. 2 Photo of Swelling Area in Concrete

Fig. 3 Exposure of Steel Bar in Concrete

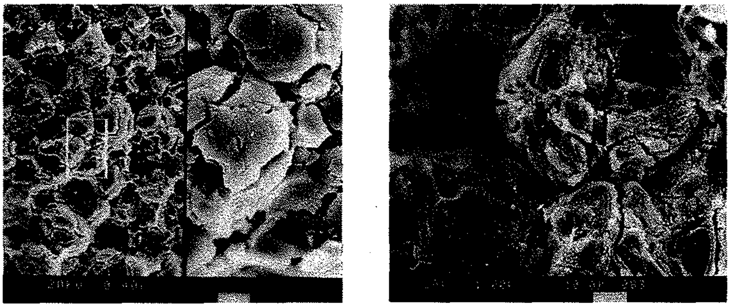

Fig.5 Observation of SEM Micrographs on Swelling Aggregate

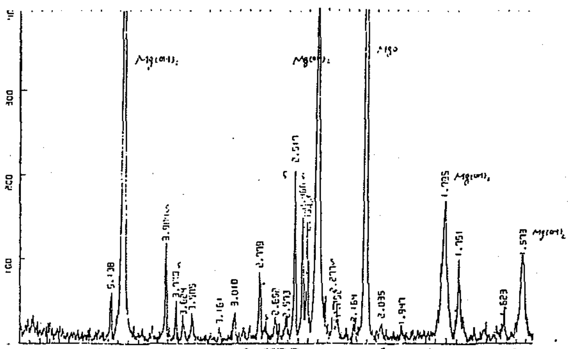

Fig.4 The Result of XRD on the aggregate