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Short communication

The thaumasite form of sulfate attack in concrete of Yongan Dam

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Abstract

According to microanalytical investigations, it is shown that the concrete of Yongan Dam is deteriorated due to the thaumasite form of sulfate attack (TSA). Analysis results of scanning electron microscopy (SEM), Energy Disperse X-ray (EDX) and X-ray Diffraction (XRD) are supported by the analysis of the concrete composition and the geographical conditions of the dam.

Keywords: Thaumasite; Sulfate attack; Concrete

1. Introduction

Many hydraulic concrete structures, such as Yongan Dam, in Xingjiang, China have been reported to be deeply deteriorated for over 6 years, which has been perplexing the engineers. An establishment claimed that the attack was a typical ettringite form of sulfate attack (ESA) and suggested that the sulfate resisting cement be used to prevent concrete from this attack [1].

In August 2004, the investigations on the concrete of Yongan Dam were made by the authors, which shows that the attack was caused by TSA.

China has a vast territory, and in many regions concrete is conducive to thaumasite formation. However, the harm of TSA and the measures of prevention of TSA in concrete structures have not been well known. Therefore, the work of investigation and research on TSA should be taken as quickly as possible.

2. The composition of the concrete and the description of degradation

According to [1], the concrete slabs of Yongan Dam have the thickness about 50 mm, they are in downstream of the dam, and in most of the time were underwater. The concrete contains 300 kg/m^3 of cement, its water/cement ratio is 0.5, and the designed strength is C20. Their raw materials are as follows.

(1) Cement: Ordinary Portland cement of grade 32.5 with about 9% powdered limestone.
(2) Aggregates: natural sand and gravel. The sand has the fineness modular of 2.59, the gravel has the size of 5 mm–40 mm diameters, and their major chemical component is calcite.
(3) Mixing water: the water in trunk canal with 653 mg/l SO_4^{2-}.

Yongan Dam is in Keshi, Xinjiang where the land is arid and rich in various kinds of salt especially sulfate salts. Moreover, this is an area where the temperature is very different between day and night. In summer, the highest temperature is up to 37 °C and at night it is only 15 °C–20 °C and in March to April and September to October it is even lower than 15 °C at night. The construction of the dam was finished in August–October 2003; stored water in November 2003; and dried again in winter. Next year in 2004, it stored water again in March, and in April, it was found that the slabs had became gray and mushy throughout the thickness where they contacted with groundwater. There were no visual signs of degradation when the slabs had no contact with groundwater. Fig. 1 shows attacked concrete.

3. The research on the attack

3.1. The analysis of scanning electron microscopy

Fig. 2 is an SEM micrograph of the concrete, in which there are a large amount of needle-like crystals. According to the

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Fig. 1. The photo of the attacked concrete.

traditional theory of sulfate attack in cementitious materials, the needle-like crystals should be ettringite. However if the crystals are ettringite, they should contain Al^{3+} in it, but when EDX analysis (Fig. 3) was taken, it showed that the crystal includes Ca, S and Si, but no Al. Therefore, the crystals are not expected to be ettringite.

3.2. The analysis of X-ray diffraction

Although the structure of thaumasite is similar to ettringite's, there are still some differences between their XRD patterns [2–4]. Fig. 4 is the XRD pattern of the attacked concrete, from which it shows that the concrete does contain thaumasite but no ettringite; and besides the thaumasite, a certain amount of gypsum and calcium carbonate is present. The XRD analysis confirms the EDX results which leads to the conclusion that the needle-like crystals in SEM micrograph (Fig. 2) are not ettringite, but thaumasite.

3.3. Comprehensive analysis

According to geographical conditions of the Yongan Dam, and the raw materials from which the concrete was made [1], all of the factors required for the thaumasite formation are provided. The mixing water and the groundwater contain a large amount of

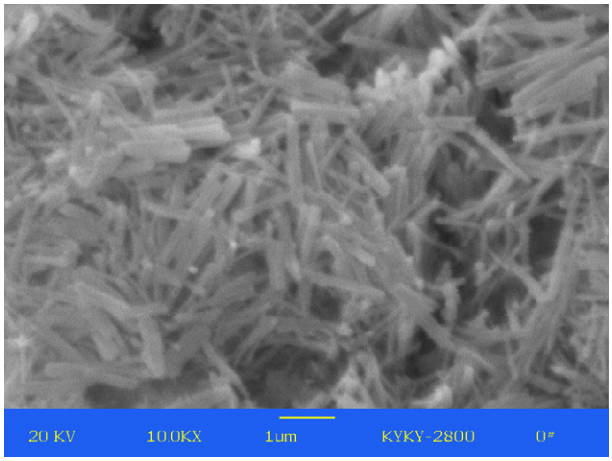

Fig. 2. The SEM micrograph of the sample.

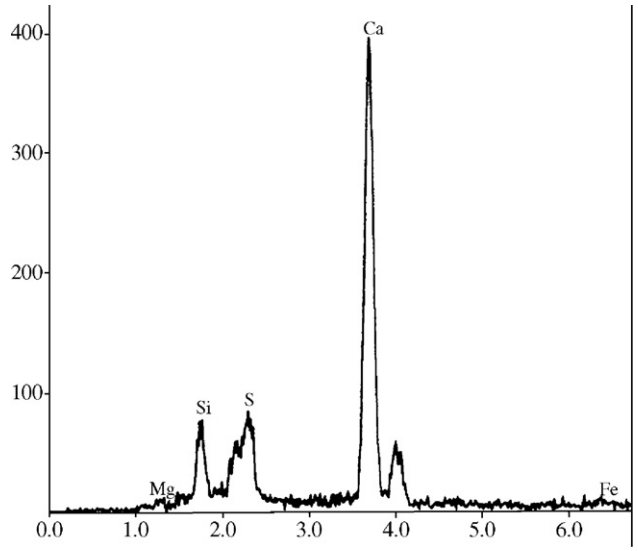

Fig. 3. EDX pattern.

sulfate. In cement paste, the Si^{4+} is present, principally from CSH, C_3S, and C_2S. In the concrete, a large amount of CO_3^{2-} is present from fine and coarse carbonate aggregates, and powdered limestone in the cement. In addition, Yongan Dam is in the condition of low temperature at most times of the year. All these are conducive to thaumasite formation in concrete. XRD, SEM and EDX analyses have shown that thaumasite does exist in the degraded concrete. Therefore, it is concluded that the attack that the concrete of the Yongan Dam encountered is caused by TSA.

Based on the existing cases, the time for concrete degradation by TSA is typically ranging from 5 to 10 years [5–8]. While the Yongan Dam deteriorated in less than 1 year after its construction, which is rare for such a rapid deteriorating speed. It indicates that concrete can be deteriorated rapidly due to TSA in some adverse conditions.

4. Tentative exploration of the mechanism of the thaumasite formation

It has already been reported [6] that there are two mechanisms of thaumasite formation, i.e., the mechanism of ettringite conversion and the mechanism of solution reaction.

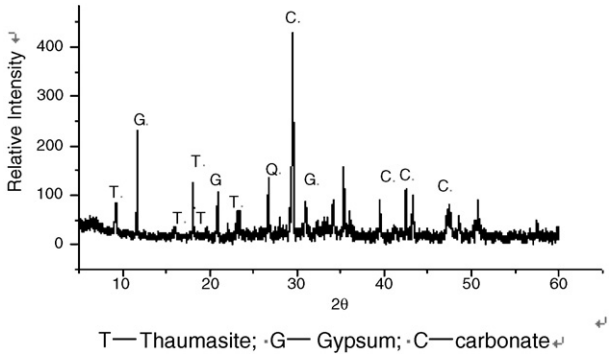

Fig. 4. The X-ray pattern of the sample.

According to the results of microanalytical investigations and examination of the deteriorating feature, it is possible that the thaumasite in Yongan Dam concrete may be formed both by the routes of solution reaction and ettringite conversion. On the one hand, the $Ca(OH)_2$ in concrete reacts with SO_4^{2-} to produce gypsum which reacts with $CaCO_3$ and CSH to form thaumasite. On the other hand, due to the C_3A-content of the Portland cement, formation of secondary ettringite was possible. This could be yielded in expansions and deterioration of the concrete structure. Thus, SO_4^{2-} could ingress more deeply. Furthermore, the ettringite could be transformed to thaumasite by the "indirect" route. Together, this could result in a very fast and substantial softening of the concrete structure.

5. Conclusion

According to microanalytical investigations, it is shown that the concrete of Yongan Dam is deteriorated due to TSA. Analysis results of SEM, EDX and XRD are supported by the analysis of the concrete composition and the geographical conditions of the dam.

TSA occurred after only 1 year, which is unusually short.

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