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Case study

Physical sulfate attack on concrete lining–A field case analysis

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ABSTRACT

In the tunnels of the Cheng-Kun Railway in China, concrete failure can usually be observed from the effect of sulfates. A field investigation was conducted to analyze the concrete damage mechanism by means of XRD, IC, AAS and EPMA. The results showed that (1) large amounts of Na_2SO_4 were generated on the surface layer of the concrete lining, causing concrete detachment layer by layer; (2) the concrete lining in contact with air had been neutralized to more than 50 mm in depth, and the cement hydration products had been converted into $CaCO_3$; (3) ettringite and gypsum, the products of chemical sulfate attack, were also detected in the neutralized concrete lining. This analysis of a field case concluded that Na_2SO_4 crystallization caused the detachment of the surface layer of the concrete lining, and the chemical sulfate attack occurred in the inner part of the concrete lining.

1. Introduction

Salt weathering is one of the most important degradation mechanisms that porous materials, such as stone and masonry, undergo at and near the surface of the earth [1]. When the porous material is in contact with the soil, salt (especially sulfates) containing ground water can enter the pores through capillary sorption. Evaporation, occurring in the part that is in contact with relatively dry air near the surface of the earth (evaporation zone), will lead to an increase in the salt concentration of the pore liquid in the evaporation zone and, ultimately, in supersaturation formation. Then, salt crystallization in pores causes the failure of the porous material in the evaporation zone, but with the sound part buried in the salt environment. A similar phenomenon can be found in Portland cement (PC) concrete elements partially exposed to sulfate environments. Researchers attribute the failure of concrete to sulfate salt weathering, sulfate salt crystallization or physical sulfate attack [2,3]. However, this viewpoint was questioned in the review paper [4] in detail because the indoor and field test results were opposed to the classic theories of salt weathering of porous materials: (1) Concrete cylinders partially exposed to a Na_2SO_4 solution under a high relative humidity (RH) condition show a larger damage area; (2) the sulfate salt crystallization does not occur at the portion of the sample cylinders where the SO_3 content is the highest;(3) the change of pore structure of concrete due to air entraining agent did not show significant effect on concrete damage; (4) concrete with a higher water/cement (W/C) ratio is more resistant to sulfate attack, which is in contrast to one of the basic principles of salt crystallization: i.e., finer pores in porous materials cause more significant deterioration. According to the discussion on the theory of crystallization based on the relationship between interfacial tension and growth pressure [5,6], a conclusion was deduced that the physical sulfate attack could not occur in the Portland cement concrete due to the chemical reactions between sulfates and cement hydration products, and the chemical sulfate attack may still be the main mechanism of concrete damage.

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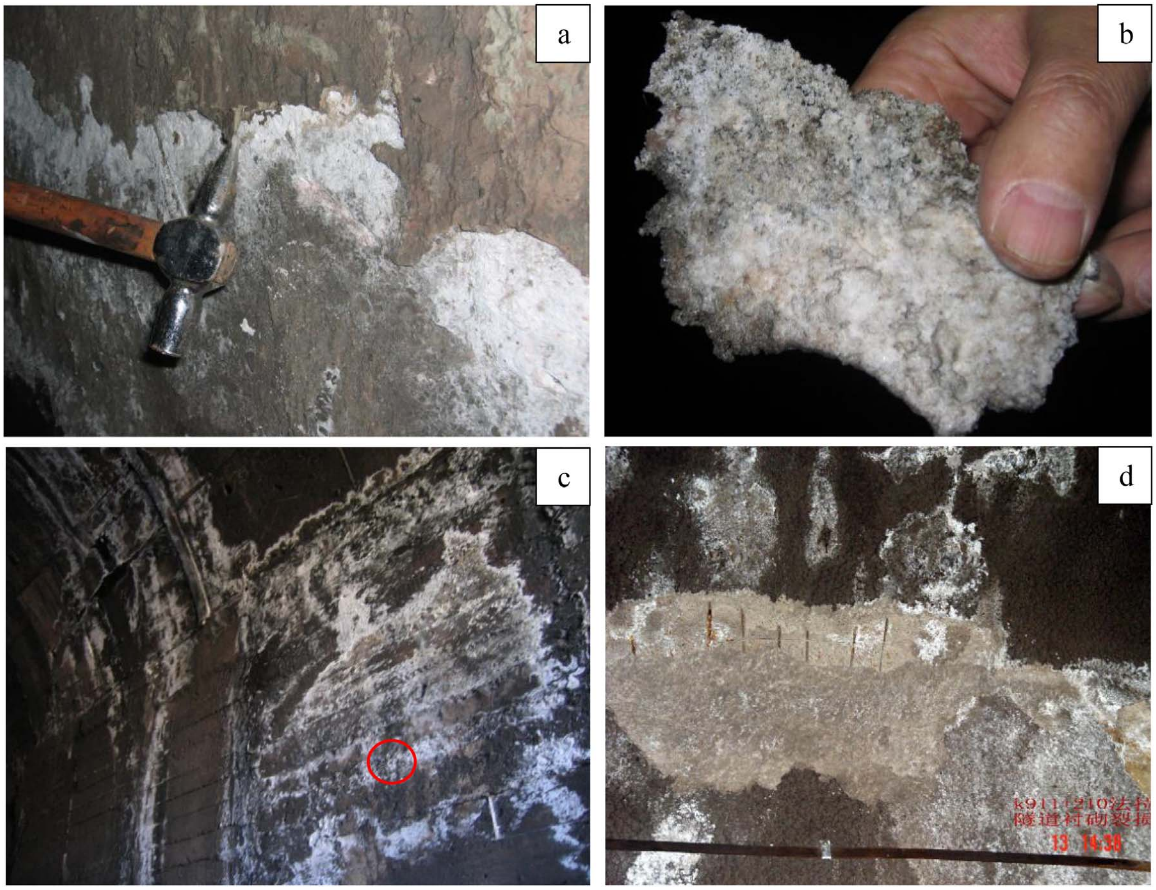

Fig. 1. Damaged concrete in the tunnels.

However, a large amount of white sulfate crystals on the surface of concrete is also a real observation in the field cases [3]. This phenomenon cannot reasonably be explained by the chemical sulfate attack. Therefore, what is the real fact of the concrete deterioration in the field cases?

A field investigation is quite significant and necessary to disclose the damage mechanism. In the southwestern regions of China, the groundwater contains a large amount of SO_4^{2-} [7]. The concrete lining in many tunnels of Cheng-Kun Railway built in 1950s was found to be severely damaged due to the effect of sulfates (shown in Fig. 1). According to the guidance of Kunming Railway Administration, a field investigation was carried out and different micro tests were performed in the Repair Engineering Institute of SHO-BOND Corp., Japan to analyze the damage mechanism. The question will be discussed and answered according to the test results.

2. Field investigation

Fig. 1 presents several typical pictures of damaged concrete in several tunnels.Based on the visual observations shown in Fig. 1, the concrete damage process could be described as follows:

- A surface layer of concrete approximately 5 mm thickness was detached from the concrete lining due to the sub-efflorescence of a large amount of white crystals (shown in Fig. 1(a) (b)).
- The aggregates of the concrete could be observed after detachment of the surface layer, and a large amount of white crystals appeared on the concrete surface (shown in Fig. 1(c));
- Due to the continuous detachment of concrete layers the steel bars were exposed to air and rusted (shown in Fig. 1(d));
- It could be reasonably induced that the concrete lining would detach layer by layer on the surface and finally break down.

In order to identify the damage mechanism, two concrete cores (ϕ30) were drilled with water from the lining of Yangjiuhe Tunnel and Bagele Tunnel (the red line circle shown in Fig. 1(c)), respectively, and detached concrete pieces from the two tunnels were also collected. Another sample of air-contacting concrete pieces was broken from the outer part of the core of Bagele Tunnel and Yangjiuhe Tunnel. The samples were analyzed by means of a Carbonation Depth (CD) test, Electron Probe Micro-Analysis (EPMA), X-