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Degradation mechanism of CA mortar in CRTS I slab ballastless railway track in the Southwest acid rain region of China – Materials analysis

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HIGHLIGHTS

- A new quantitative method was carried out to calculate asphalt content in CA mortar.
- A new rapid qualitative method was put forward to explain the mechanical properties degradation of CA mortar.
- The decrease of asphaltenes and asphalt is the main reason resulting in the material degradation.
- The discoveries and methods in this study are applicable to CRTS I track structure in different regions.

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ABSTRACT

Cement-emulsified asphalt mortar (CA mortar) is a key component of ballastless high-speed rail systems. Previous research illustrates acidic substances can provoke an intense deterioration on CA mortar. In order to investigate the relationship between acid rain environment and degradation mechanism of CA mortar in practical engineering, microstructure and organic-inorganic compositions of CA mortar collected from Chongqing and Chengdu were observed respectively. The degree of acid rain corrosion and thaumasite sulfate attack (TSA) were identified by analyzing the quantity and distribution of hydration products with XRD, SEM-EDAX, FTIR. The data of $Ca(OH)_2$ X-ray diffraction intensity and weight loss of CA mortar in specific temperature range was used to calculate asphalt content. The asphalt components were examined using TG-DTA. Results showed that the loss of asphalt and asphaltenes under the coupling effects of loads and rain was one of the main reasons for the material degradation, instead of salt crystallization erosion or TSA caused by acid rain, neither the oxidation aging of asphalt. The results of this research will promote the microstructure optimization of CA mortar, and the development of the repairing material or technology to improve the maintenance system for high speed railways in different regions.

1. Introduction

Currently, ballastless slab track is widely used in high-speed railways in many countries such as Japan, Germany, France and China [1]. In China Railway Track System I (CRTS I) track structure (Fig. 1), CA mortar is casted between the track slab and concrete roadbed, playing the roles of leveling, supporting and vibration isolation [3]. It is a key part in ballastless slab railway track system in high speed railways [4].

In practical engineering, the damage or deterioration of CA mortar layer are recognized as one of the most critical issues after a short-time operation, as shown in Fig. 2. Such damage modes not only increase the cost of railway operation, but also significantly weaken the structural integrity of the slab track system, and contribute to the potential failure of the slab tracks [5]. However, at present, there is no specific repairing method except a complex expensive solution, the overall replacement.

Most of studies on damage mechanisms of CA mortar focus on the effects of loads or the mechanical properties of the track structure [2,5] and overlook the material quality in the localization process of CA mortar. However, without a systematic analysis of material properties, we cannot precisely locate the weak areas in this composite where should be improved and optimized. Also, it will be nonsense to discuss which material or technology can be

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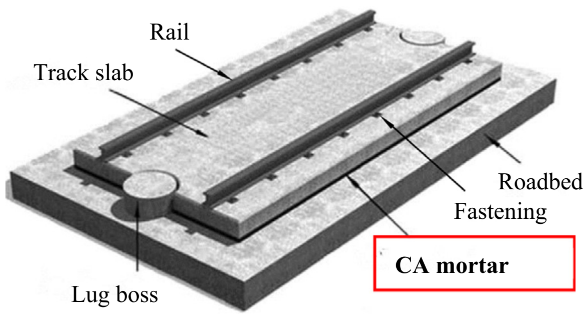

Fig. 1. Structure of CRTS I track system [2].

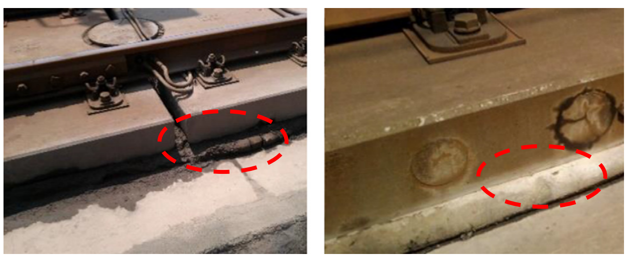

Fig. 2. Typical damages of CA mortar in CRTS I track structure in the Southwest acid rain region of China.

applied to repair the track structure. Analysis of the deterioration mechanism of CA mortar from the materials aspect is urgently necessary and indispensable to establish a thorough maintenance system for high-speed railways in China.

The objective of this study is to analyze the deterioration mechanism of CA mortar in the Southwest acid rain region from the aspect of materials. Typical degradation principles of concrete and bitumen materials, including acid erosion, salt crystallization attack, photo-oxidation aging and the loss of components, et al. are going to be discussed respectively.

Many published researches of CA mortar discussed its fluidity properties [6], interactions between components [7], mechanical properties [8], production and construction methods [9], et al. In contrast, no much attention has been given to its durability and weather resistance. According to limited research results, loading conditions and natural environments including rainfall, freezing-thawing cycles, dry-wet cycles, et al. are the main influential factors leading to materials deterioration of CA mortar. At present, it is widely accepted that the dynamic water under the action of trainload is one of the major environmental factors.

Hydrogen bonds in water molecules can reduce the interfacial bonding force between asphalt-hydrates and asphalt-sands by penetrating into the organic-inorganic interfaces. Combined with the softening of the asphalt membrane, CA mortar will be eventually "soften". Additionally, under the action of high pressure impulse loads, the water in the pores will generate super-pore water pressure, which will produce a shear effect on the surrounding pore walls, causing splitting failure on the surface. Moreover, previous experiments illustrate that acid rain can cause serious erosion on CA mortar. In a simulated acid rain environment, C-S-H gels are dissolved while a large amount of $CaSO_4{\cdot}2H_2O$ and ettringite (AFt) crystallization are produced. In addition, biological corrosion accelerates the degradation process. As a consequence, compressive strength and elasticity modulus of the specimens decrease sharply [10].

Compared with self-compacting concrete (SCC), the filling layer material in CRTS III track structure, CA mortar is more vulnerable to acid rain. The reasons are shown below,

(1). The cement content of CA mortar is lower than that of SCC, which leads to less alkali. It means that $Ca(OH)_2$ can be easily completely neutralized, resulting in the decomposition of C-S-H gels and the decrease of cementitious capability.
(2). CA mortar is a porous material with low strength. Crystallization expansion pressure of $CaSO_4{\cdot}2H_2O$ and AFt, the reaction products of acid rain and $Ca(OH)_2$, will exceed the allowable stress of the parent material and cause cracks.
(3). CA mortar is an organic-inorganic composite, in which polar organic compounds reduce the surface tension of cement hydrates, greatly accelerating the acid rain erosion.

To investigate the materials degradation mechanism in practical engineering located in Southwest acid rain region, the deterioration degree is acquired firstly. Inorganic cement hydrates and organic asphalt are discussed separately based on typical degradation principles of cement-based materials and bituminous materials in acid rain environments.

2. Experiments details

2.1. Materials

The specimens were collected from two different high-speed railway operating lines (Sui-Yu line in Chongqing and Cheng-Mian-Le passenger transport line in Chengdu). The ones from Sui-Yu line was obtained from Beibei district which was one of the most serious acid rain areas in Chongqing province – the most serious acid rain region in China from the 1980s to the 1990s. Chongqing has abundant average annual rainfall between 1000 mm and 1350 mm with 80% relative humidity, making it become one of the highest humidity areas in China [11].

The other CA mortar specimens were made with exclusively dry material (contents cement, sand, aluminum powder and other admixtures), emulsified asphalt, organic silicone defoamer, styrene acrylic emulsion and tap water. Properties of the emulsified asphalt are shown in Table 1. Table 2 presents the mix proportions and properties of CA mortar, which are similar to those used in the construction of the Cheng-Mian-Le and Sui-Yu line. All of these data satisfy the provisional technical specifications [12]. Besides, the cement mortar specimens were made with ISO standard sand and Lafarge P.O 42.5 Portland cement, based on the mix proportions in Table 5. The compositions and the physical properties of the cement are shown in Table 3 and Table 4 respectively.

2.2. Methods

Table 6 shows the group numbers, specimens' sources, curing or service conditions and the ages of the specimens. Specimens in Group I–III were drilled from the filling layer of ballastless slab track structures and made into cylinders, with Φ 50 mm × 50 mm.

Also, the specimens in group IV–VI were made into cylinders with the same size, based on the mix ratio in Table 2. After pouring and curing in models at 25 °C for 24 h, they were demolded and exposed in indoor natural environment for 28 days (group IV) or 3 years (group V) before other tests. The acid solution used for immersion for group VI pieces was made with a molar concentration ratio of 6:1 of H_2SO_4 and HNO_3. The pH was kept at 3.0 by adding acid solution for the first 3 months. Then, the containers were sealed until 18 months.

The specimens in group VII were cement mortar cubes, with the size of 40 mm × 40 mm × 160 mm, which were made based on the mix ratio in Table 5. After curing indoor for 1 day, they were demolded and placed in a water-bath box at 55 °C for 3 days.

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