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Effect of emulsifier on cement hydration in cement asphalt mortar

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HIGHLIGHTS

- We study hardening mechanism of cement asphalt paste when fixing asphalt emulsion to cement ratio.
- Type of emulsifier and its dosage both affect the hardening process of cement.
- Significant differences in hydration parameters are detected utilizing different emulsifier.
- Emulsifier with less retarding effect can develop a high early strength CA mortar.

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ABSTRACT

Cement asphalt mortar (CA mortar) is a key material of non-ballasted track structure. In order to solve the problem that cement hardens slowly in CA mortar, the retarding effect of emulsifier on cement hydration was studied by measurement of cement setting time, hydration heat and X-ray diffraction analysis. Results show that emulsifier has significant retarding effect on cement hydration, which is relevant to the types of emulsifier and its dosages. The retarding effect increases with the increment of the mass ratio of emulsifier to cement. Significant differences in the setting time, cement hydration rate, hydration heat and the content of $Ca(OH)_2$ are detected utilizing different types of emulsifier. Emulsifier with excessive retarding effect on cement not only abort cement hydration in early age, but also cause a loss in the later hydration heat and content of cement hydrates. Therefore, suitable emulsifier with little retarding effect on cement hydration and its appropriate dosage are recommended when producing asphalt emulsion for CA mortar.

1. Introduction

The non-ballast slab track is an advanced track form that has been used widely in high-speed railway in countries, such as Japan, Germany and China, due to its manifold advantages of reduction in structure height, lower maintenance requirements and increased service life [1]. The non-ballast slab track is being widely used in high speed railways in many countries like Japan, Germany and China. Cement asphalt mortar (hereinafter abbreviated CA mortar) is the key component in the structure of slab track, which mainly consists of cement, asphalt emulsion, fine aggregate and several chemical admixtures. There are two kinds of CA mortar in the world. One with high elastic modulus and strength is called high strength CA mortar serviced in Bögl slab track, in which anionic asphalt emulsion is utilized. The other with low elastic modulus and strength is called low strength CA mortar which use cationic asphalt emulsion as a raw material and was previously employed in the shinkansen slab track. Both CA mortars are introduced into China and employed in the construction of high-speed railway. Research has been done in China during the past few years [2–6]. These results indicate that the mass ratio of asphalt emulsion to cement (hereinafter abbreviated to m(A)/m(C)) is the dominant factor determining the performance of CA mortar. In high strength CA mortar, the m(A)/m(C) is between 0.35 and 0.45, while in low strength CA mortar, it is between 1.4 and 1.6.

Limitations arise when m(A)/m(C) is fixed. The prepared CA mortar hardens very slowly. When the CA mortar pours into the mezzanine, it is easy to cause the phenomenon of bleeding, segregation, shrinkage, and so on. The phenomenon can make CA mortar unable to bond well with track slab and even lead to disengage, which seriously affects the service life of slab track. To solve this problem, researchers have done some studies on cement asphalt emulsion materials. Previous results showed that the early-age properties of cement asphalt emulsion materials are relevant to curing temperatures and the mass ratio of asphalt to cement [7–9]. With higher curing temperature and lower m(A)/m(C), the critical early-age life properties improved more and faster. It was reported that asphalt emulsion retarded the early hydration of cement in cement asphalt emulsion pastes, and the retarding effect

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increased with the increment of m(A)/m(C) [12–16]. By now, the only reported solution of early-age hydration of cement asphalt emulsion pastes is utilizing sulfoaluminate cement instead of some part of ordinary Portland cement in CA mortar when fixing m(A)/m(C) [10,11]. However, it may take a risk of shortening the working time of CA mortar for grouting.

In this paper, the problem that cement can harden at proper speed when fixing the m(A)/m(C) is solved. As is known that asphalt emulsion is composed of asphalt, water and emulsifier. When asphalt emulsion is mixed with cement, the effect of water and asphalt on cement is inevitable in cement hydration. However, the type of emulsifier and its proportion can be chosen when producing asphalt emulsion. In fact, they are the primary reasons why asphalt emulsion can retard cement hydration.

2. Experiments

2.1. Materials and sample preparation

Cement pastes were prepared with an ordinary Portland cement P.O.42.5, which physical properties are listed in Table 1. Two anionic emulsifiers and two cationic emulsifiers were employed in the preparation of the cement pastes, which were called as ER anionic emulsifier, JY anionic emulsifier, PC cationic emulsifier, and JY cationic emulsifier, respectively.

Cement–emulsifier pastes were prepared according to the formulations in Table 2. When solid content is 60% in asphalt emulsion, m(A)/m(C) is about 0.4 in high strength CA mortar and about 1.4 in low strength CA mortar [2,5]. As was reported, the mass radio of emulsifier to asphalt emulsion is about 3–4% if the asphalt emulsion can be used in CA mortar [18]. Therefore when the mass ratios of anionic emulsifier to anionic asphalt emulsion vary from 1.5% to 4%, the mass ratio of anionic emulsifier to cement varies from 0.6% to 1.5%. When the mass ratio of cationic emulsifier to cationic asphalt emulsion varies from 1.5% to 4%, the mass ratio of cationic emulsifier to cement varies from 2% to 5.6%. All mixtures were prepared at water requirement of normal consistency for cement.

2.2. Test methods

2.2.1. Cement setting time

According to ISO 9597:1989, all specimens in Table 2 were mixed to measure initial setting and final setting time of cement. The test temperature is 20 °C ± 2 °C.

2.2.2. Determination of hydration heat

The hydration heat of cement emulsifier pastes was measured by isothermal calorimetry. The sample mass was 2.0 ± 0.1 g. After the temperature balance of specimen and instrument was reached, the test started. The constant temperature of test system was 25 °C ± 0.02 °C. The testing time lasted about 160 h.

2.2.3. X-ray diffraction (XRD) analysis

Specimens with about 5 g in mass were made from 5$\varphi \times$ 5 cm test-piece and taken out at 1 day, 3 days and 7 days after mixing. The specimens' curing temperature was 20 °C ± 2 °C. The specimens were put into bottles filled with pure ethanol immediately in order to stop their hydration when they were at the desired hydration time. Then the specimens were dried in 60 °C drying oven. At last the specimens were ground into fine powder and analyzed by XRD.

Table 2
Mix proportions of samples.

m(E)/m(C)[a] (%)		m(W)/m(C)
Anionic emulsifier (JY and ER)	Cationic emulsifier (JY and PC)	
0	0	0.28
0.6	2	0.28
1.1	4.2	0.28
1.3	4.9	0.28
1.5	5.6	0.28

[a] The mass ratio of emulsifier to cement.

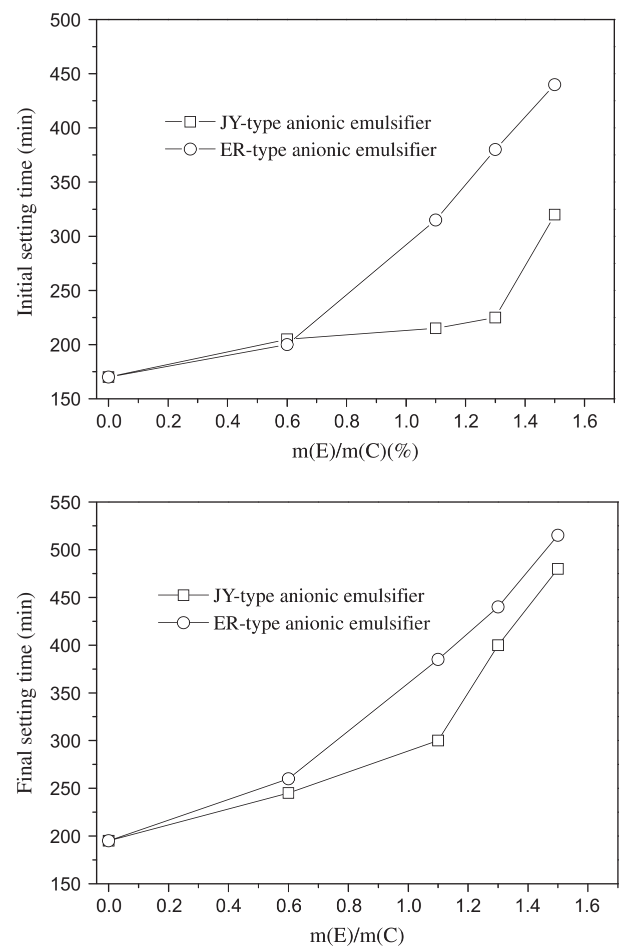

Fig. 1. Initial and final setting time of cement containing anionic emulsifier.

3. Results and discussion

3.1. Effect of emulsifier dosage and type on cement setting time

The initial and final setting time of cement pastes with anionic emulsifier are shown in Fig. 1. It can be seen clearly that the initial and final setting time increase with the increase of m(E)/m(C), and their growth are different with the types of anionic emulsifier. The final setting time of plain cement paste is 195 min, but it is prolonged to 515 min with ER anionic emulsifier and 480 min with JY anionic emulsifier at an m(E)/m(C) of 1.6%. Compared with the types of anionic emulsifier, the emulsifier dosages have greater impact on cement hydration. The m(E)/m(C) adds each 0.2%, the final setting time of cement increases about 60 min ~100 min. The initial and final setting time of cement pastes with cationic emulsifier are shown in Fig. 2. Compared to anionic emulsifier, the cationic emulsifier have greater impact on cement hydration, especially JY cationic emulsifier. At an m(E)/m(C) of 5.6%, the final setting time of cement paste is prolonged to 4000 min with JY cationic emulsifier, which is only 860 min with ER cationic emulsifier.

Table 1
Physical properties of cement.

Density (g/cm^3)	Water requirement of normal consistency	Setting time (min)		Compressive strength (MPa)		Flexural strength (MPa)	
		Initial set	Final set	3d	28d	3d	28d
3.13	0.28	170	195	5.9	9.0	23.6	47.6