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The thixotropic behavior of fresh cement asphalt emulsion paste

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HIGHLIGHTS

- A new model is proposed to quantitatively evaluate the thixotropic behavior of CA paste.
- Constant shear rate test is employed in the thixotropy model.
- The de-flocculation and structure rebuilding processes of CA paste are studied.
- The thixotropic behavior of CA paste is clearly different from cement paste.

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ABSTRACT

The workability of grouting cement asphalt emulsion (CA) mortar is governed by the intrinsic thixotropic behavior of CA paste, but limited information is reported about the thixotropic behavior of CA paste. A new thixotropy method of constant shear rate test is proposed to study the thixotropic behavior of CA paste with different asphalt emulsion to cement ratios (AE/C). In the model, the initial structure parameter and the structure rebuilding rate are used to quantitatively describe the structure rebuilding process, the characteristic time of de-flocculation is used to evaluate the de-flocculation process, and the equilibrium shear stress is used to study the irreversible change of CA paste in the thixotropy test. Results show that CA pastes have significantly different thixotropic behavior compared to cement paste. The initial structure parameter and structure rebuilding rate of CA pastes are much smaller than cement paste, and the structure rebuilding rate decreases significantly with AE/C. The characteristic time of de-flocculation of cement paste changes little at different resting time, however, it increases significantly at the first 5 min resting time and then keep stable for CA pastes. The equilibrium shear stress of cement paste does not change in 20 min, but it increases with time for CA pastes due to the demulsification of asphalt emulsion.

1. Introduction

With combined the merits of cement (high strength) and asphalt (good elasticity), cement asphalt emulsion (CA) mortar is well acted as the cushion layer between the track slab and concrete roadbed of non-ballast slab track structures for high-speed railway [1]. CA mortar has been attracted extensive and increasing attention in recent years because its properties directly contribute to the performance of slab tracks during the operation of high-speed railway [2] and affect the service life of the track slab [3]. In placement, CA mortar is grouted into a narrow pre-adjusted chamber with the size of $6450 \times 2550 \times (30 \sim 50)$ mm between the concrete roadbed and the precast track slab. The grouting technology guarantees the smoothness of the track slab and the zero gap bonding between the track slab and concrete roadbed. A good grouting result is the premise of the successful application of CA mortar.

To guarantee the successful placement, fresh CA mortar should possess sufficient flowability to fill the chamber between the track slab and concrete roadbed without vibration, and good segregation resistance to prevent separation of constituents during placement. From a rheological perspective, the flowability is related to the apparent viscosity of CA paste under shear [4,5] and the segregation resistance after placement is dependent on the yield stress of CA paste [6–8]. CA paste is a concentrated suspension composed of cement particles and asphalt droplets suspended in water. The high concentration of particles endows CA paste with an intrinsic thixotropic behavior. The apparent viscosity of paste decreases

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with time under shear stress or rate, and the apparent yield stress increases with time when the shear stress or rate is removed [9,10]. For this thixotropic behavior, CA paste can behave as a good fluid during placement, but builds up an internal structure and have the ability to withstand the sedimentation of the coarsest particles at rest. Therefore, to evaluate the performance of CA mortar in the field, this study will investigate the thixotropic behavior of fresh CA paste.

Many studies focusing on the rheological behavior of CA paste (such as viscosity and yield stress) have been published for the grouting technology [11–16], however, the thixotropic behavior of CA paste is seldom concerned. Thus, fundamental research about the thixotropic behavior of CA paste is urgently needed, including the evaluation method. From a microstructural perspective, the thixotropy of suspension is a result of structural degradation under shear due to the rupturing of flocs of linked particles and flocs structure rebuilding at rest because of Van der Waals' force [17]. The de-flocculation and structure rebuilding processes both reflect the thixotropic behavior. In this paper, a practical thixotropy model is proposed to quantitatively evaluate the de-flocculation and structure rebuilding processes of CA paste. Then, the proposed method is employed to study the thixotropic behavior of CA pastes with different asphalt emulsion to cement ratios (AE/C).

2. Experimental program

2.1. Materials and specimens preparation

A type I cement and a slow-setting anionic asphalt emulsion are used in the experiment, with properties listed in Tables 1 and 2, respectively. For CA paste is a composite suspension combined with cement particles and asphalt droplets, the components differs greatly if AE/C changes. To study the thixotropic behavior of CA paste, the effect of AE/C should be considered. Thus, CA pastes with five AE/C are prepared, which mix proportions are listed in Table 3. All CA pastes include viscosity modified agent (VMA) at a ratio (VMA/W) of 5% to prevent particles sedimentation in test. For the rheology of CA pastes with different AE/C differs greatly at a constant water (including water in asphalt emulsion and additional water) to cement ratio (W/C) [12], it is recommended to study the thixotropic behavior of CA pastes at the same viscosity [12]. The W/C in the five CA pastes was 0.36, 0.35, 0.4, 0.46, and 0.57, respectively. The W/C is chosen to keep the same minimum apparent viscosity of CA paste at 0.15 Pa·s if no viscosity modified agent (VMA) was added, according to previous research [12].

The steady state flow behavior of the five CA pastes in Table 3 is tested by a rheology test shown in Fig. 1. The data of the viscosity and yield stress conform well to Bingham model, and the plastic viscosities of the five CA pastes show little difference. Thus, the five CA pastes is typical CA pastes which can be used to study the thixotropic behavior of CA pastes with different AE/C.

All CA pastes are prepared by hand-stirring. For each cement paste, cement, superplasticizer, VMA, and water are stirred for four minutes. For CA pastes, cement, superplasticizer, VMA, and water are stirred first for two minutes, and asphalt emulsion is added and continually stirred for two minutes. This mix protocol is performed to form an initial water film surrounding cement surface which can diminish the effect of cement on the stability of asphalt emulsion. All pastes are prepared twice for rheology testing.

2.2. Test methods

2.2.1. Steady flow curve test

The steady flow curve test is to obtain the yield stress and plastic viscosity of CA paste under steady flow because the yield stress can be as a quantitative index to evaluate the thixotropic behavior of CA paste. A higher yield stress means that CA paste is more thixotropic. Therefore, the yield stress can be used to judge whether the thixotropy evaluation method is suitable for CA paste or not. It should be stated that the yield stress is only an indirect index to evaluate the thixotropic behavior, it cannot reflect structural degradation under shear and flocs structure rebuilding at rest.

Table 2
Properties of anionic asphalt emulsion.

Test on emulsion	Value	Test on residue from distillation	Value
Engler viscosity (25 °C, Pa·s)	7.1	Solid content (%)	60.0
Mean particle diameter (μm)	2.620	Penetration (25 °C, 100 g, 5 s, 0.1 mm)	66.3
Sieve test (1.18 mm, %)	0.01	Softening point (R&B, °C)	46.5
Storage stability (1d, 25 °C, %)	0.4	Ductility (25 °C, cm)	127
Storage stability (5d, 25 °C, %)	1.5		

The steady flow curve of CA paste are tested by a temperature-controlled rheometer with a coaxial cylinder geometry. The constant temperature of test system is 23 ± 0.001 °C. The rheometer and rotor are shown in Fig. 1. The radius of the rotor is 10 mm. The gap between rotor and cylinder is 0.85 mm. After mixing, the sample is immediately loaded to the cylinder for testing, a process that takes one minute. Then, the shear protocol shown in Fig. 2 is performed to get the flow curve of CA paste. First, a 2 min pre-shear at 300 s^{-1} and 1 min rest is intended to create uniform condition before testing. Then, 9 steps which shear rate is decreased from 100 s^{-1} to 1 s^{-1} are performed to get the flow curve of CA paste at steady state. This test is performed twice for each sample.

2.2.2. Thixotropy test

The rheological test for the thixotropic behavior of CA paste is shown in Fig. 3. First, a 2 min pre-shear at 300 s^{-1} is intended to create uniform condition for samples before testing. Then, samples are rest for certain time (1 min, 5 min, 10 min, 15 min, 20 min). Finally, samples are sheared by a constant shear rate at 50 s^{-1} for 30 s. The third step data are used to analyze the thixotropic behavior of CA paste. 50 s^{-1} is chosen in the third step because the flocculation structure of CA paste can be broken down in this shear rate. Meanwhile, the authors' previous study indicates that the apparent viscosity of CA paste decreases firstly and then increases slightly with the increasing shear rate [12,16] due to the dilatancy effect [18]. All CA pastes do not have a pronounced dilatancy effect at 50 s^{-1}.

3. Thixotropy model for CA paste

3.1. A simple thixotropy model

In study of the thixotropy of cement paste, several methods are proposed, such as hysteresis loop method, specific rebuilding energy method deduced by hysteresis loop [19], shear rate decay method [20]. These methods are simple and easily operated for qualitatively and quantitatively comparing the thixotropy of different cement pastes, however, they cannot evaluate both the de-flocculation and structure rebuilding process of cement paste. By now, a good quantitative thixotropy method with strict mathematical form is the flocculation structure parameter method.

The apparent viscosity of a thixotropic material is dependent on the current state of flocculation, and the flocculation state is related to the shear history of the thixotropic material. To describe this thixotropic behavior, a general mathematical form of the equation about the flocculation state of a thixotropic material is proposed by Cheng and Evans [21], which is written as:

$$\tau = \eta(\lambda, \dot{\gamma})\dot{\gamma} \tag{1}$$

$$\frac{d\lambda}{dt} = f(\lambda, \dot{\gamma}) \tag{2}$$

where λ is a structural parameter related to the extent of structure within the material, τ is the shear stress (Pa), $\dot{\gamma}$ is the shear strain rate (1/s), η is the apparent viscosity (Pa·s). For the change rate of

Table 1
Chemical composition of type I cement.

Materials	SiO_2	Al_2O_3	Fe_2O_3	SO_3	CaO	MgO	Na_2O	K_2O	LOI	Total
Percentage	20.2	4.7	3.3	3.3	62.9	2.7	/	/	1.1	98.2