Construction and Building Materials 111 (2016) 164–174

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Stress–strain model of cement asphalt mortar subjected to temperature and loading rate

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HIGHLIGHTS

- The coupled effect of temperature and loading rate on CA mortar are investigated.
- Peak stress and peak strain varies with the temperature and loading rate.
- The shape of the stress–strain curve is related to temperature and loading rate.
- A stress–strain model of CA mortar is proposed and verified.

ARTICLE INFO

Article history:
Received 5 September 2015
Received in revised form 23 December 2015
Accepted 17 February 2016

Keywords:
Cement asphalt mortar
Temperature
Loading rate
Peak stress
Stress–strain model

ABSTRACT

Owing to the importance of cement asphalt mortar (CA mortar) in the service of high-speed lines, an extensive experiment is conducted to investigate the compressive behavior of CA mortar when the temperature and loading rate are changed. The coupled effects of temperature and loading rate on the mechanical properties and stress–strain relationship of CA mortar with high elastic modulus are analyzed. Based on the experimental observations, the empirical equations of peak stress and corresponding axial strain of CA mortar are obtained. Finally, a stress–strain model of CA mortar is proposed in this paper to describe the compressive behavior of CA mortar subjected to the coupled effect of temperature and loading rate.

1. Introduction

Cement asphalt mortar (CA mortar) has gained a wide application in many countries as a key component of non-ballast track in high speed lines. It is an inorganic–organic composite material, which mainly consists of cement, asphalt emulsion, sand and chemical admixtures. In China, two types of CA mortar with a low and high elastic modulus respectively are commonly developed to satisfy the requirements on geometrical adjustment, energy absorption and crack resistance. The performance of CA mortar is crucial to the safety and life of the railway track, therefore, CA mortar has drawn much attention in recent years [1–6].

As a viscoelastic composite material, CA mortar has its unique characteristics in rheology and mechanical properties, which have been extensively studied [3–24]. The loading rate effect and temperature sensitivity of CA mortar were selected among the current research topics due to the fact that CA mortar is normally under the coupled effects of high-frequency loading and temperature variation during the service period. Unlike other cementitious materials, such as concrete or mortar, the incorporation of asphalt makes CA mortar strongly dependent on loading rate and temperature, due to the viscoelastic colloid nature of asphalt [15,17,21–24]. The effect of loading rate on the behavior of CA mortar can be mainly summarized as: (1) The compressive strength was found to increase with the loading rate [5,17]. (2) The dependence of mechanical properties was greater for CA mortar with higher asphalt to cement ratio, which indicated that asphalt is the main reason behind the viscoelastic characteristics of CA mortar [17]. As for the temperature sensitivity of CA mortar, the current studies have showed that the increasing temperature results in the decrease of the mechanical properties such as resilient modulus, compressive strength and flexural strength [15,20,21,23,24]. Similarly, the temperature sensitivity of CA mortar was more prominent when the asphalt to cement ratio is high [24,25]. In terms of rheology, the effect of temperature on CA mortar is also related

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http://dx.doi.org/10.1016/j.conbuildmat.2016.02.080
0950-0618/

Table 1
Basic technical indexes of the dry mix.

Items	Spread flow (mm)		Expansion rate (%)	Compressive strength (MPa)	
	D_5	D_{30}		1 d	7 d
Value	165	154	2.8	14.3	35.1

Table 2
Properties of asphalt emulsion.

Temperature (°C)	Solid content (%)	Storage stability (1 d, 25 °C, %)	Sieve residual (1.18 mm, %)	Evaporation residual (%)
25	63	0.36	0.05	63

Table 3
Mix proportion of CA mortar (kg/m^3).

Asphalt emulsion	Dry mix	Superplasticizer	Deforming agent	Water
265	1490	5.5	0.5	158

to the type of asphalt emulsion [8]. The increase of cationic asphalt emulsion content leads to the strong temperature dependence compared to the anionic asphalt emulsion.

From the previous studies, it is noted that researches for a stress–strain model of CA mortar are limited. Although a stress–strain model of CA mortar under confinement and strain rate has been established, the model is applicable to CA mortar with the low elastic modulus, and the effect of either temperature or loading rate on the compressive behavior of CA mortar with high elastic modulus was not included [16]. Since CA mortar is subject to high frequency loads induced by the wheel/rail interaction and temperature impact by the changing climate, a full understanding of the compressive behavior of CA mortar under coupled effects of loading rate and temperature is urgently needed, and a feasible stress–strain model is necessary for analysis of slab track system in practical applications.

The aim of this study is to develop a stress–strain model of CA mortar with high elastic modulus subjected to the coupled effects of loading rate and temperature. The experiments to study the compressive behavior of CA mortar under three temperatures and seven loading rates were conducted. The effects of loading rate and temperature on experimental stress–strain relationship were examined, and the equations to determine the peak stress and corresponding axial strain of CA mortar were proposed. Based on the experimental results, a stress–strain model applicable to CA mortar with high elastic modulus was established. Through the comparison between experimental and predicted stress–strain curves, the proposed model was verified.

2. Experimental program

2.1. Raw materials

A commercial dry mix, which mainly consists of sand and cement, was used for cement asphalt mortar in this study. The mass ratio of cement in the binder is 34%. The basic technical indexes of the dry mix are shown in Table 1. An anionic asphalt emulsion with a solid content of 63% was used and the properties of the emulsion can be found in Table 2. A high-range polycarboxylate-based superplasticizer and an antifoaming agent were incorporated in the mix to increase the flowability and dumping capacity. The mix proportion of CA mortar is listed in Table 3, and the basic properties are shown in Table 4.

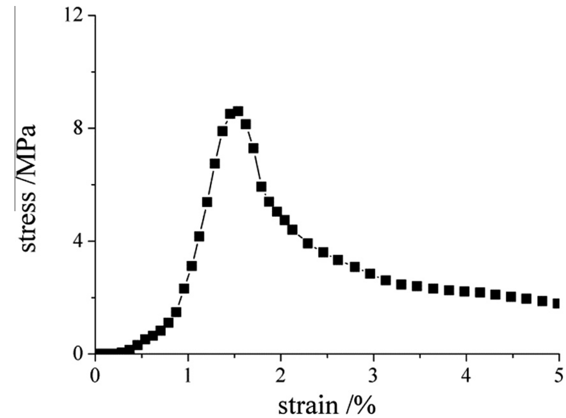

Fig. 1. Typical stress–strain curve of CA mortar.

2.2. Specimen preparation

A mechanical mixer was used to ensure consistency in the samples. During the mixing, the asphalt emulsion was first poured into a stirring pot, and the superplasticizer together with antifoaming agent and water were added and quickly stirred for 30 s. Then the dry powder was added into the mixture within one minute. The stirring rate was raised to 260 r/min for another 120 s before casting. The fresh mortar was finally poured into a Φ 45 $\times$ 90 mm cylindrical mould for compressive tests. The specimen size was chosen to satisfy the load requirements of testing machine and avoid the eccentricity caused by a high slenderness ratio. After demoulded, the specimens were transferred into the standard curing room until the target curing ages of 14 and 28 days was reached. Before the test, the specimens were polished for the smooth and parallel upper and lower surfaces.

2.3. Experimental method

Following the time–strength relation of cement, it is considered that cement in 14 days after mixing may have achieved a similar degree of hydration as cement in 28 days after mixing [26]. Therefore, the compressive test was conducted at the curing age of 14 and 28 days, at which days the strength of CA mortar is believed to be approximately developed to the same magnitude. In order to simulate the real-time behavior of CA mortar layer, seven loading rates of 1 mm/min, 5 mm/min, 10 mm/min, 20 mm/min, 30 mm/min, 40 mm/min and 50 mm/min were selected based on the estimation of strain rate by Fu et al. [27]. The loading rate of 1 mm/min was set as the static loading rate for the reference. Meanwhile, three different temperatures of 5 °C, 20 °C and 35 °C were chosen in this test under the current experimental condition. Before the test, the specimens were kept in a temperature-controlling chamber until the temperature of the specimen was the same to the targeted temperature. Three specimens were tested for each loading condition. A total of 126 specimens were tested.

The compressive test of CA mortar was conducted on a universal testing machine, by which the loading rate control can be specified. The applied load and strain response of the specimen can be automatically captured by the acquisition system and used to determine the peak stress and the corresponding axial strain.

3. Results and discussion

3.1. Stress–strain curves of CA mortar

All stress–strain curves of CA mortar were derived from experimental data. A typical stress–strain curve of CA mortar is shown in Fig. 1. The similar shape of stress–strain curve of CA mortar was

Table 4
Technical indexes of CA mortar.

Items	Density (kg/m^3)	Spread flow	Flowability (s)	Air content (%)	Expansion rate (%)	Separation rate (%)
Value	1948	D_5 = 310 mm, t_{280} = 10 s D_{30} = 290 mm, t_{280} = 18 s	86	3.9	1.6	0.5