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# Creep properties of cement and asphalt mortar

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## HIGHLIGHTS

- The creep process of type I, II CA mortar was analyzed.
- The relationship between the creep volume and load level was expressed by equation.
- The microscopic response mechanism of creep properties of CA mortar was analyzed.
- The long-term strength of CA mortar was determined to be $0.4\sigma_p$.
- The established creep model can effectively predict the creep deformation of CA mortar.

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## ABSTRACT

In order to study the long-term deformation properties of cement and asphalt mortar (CA mortar), the creep properties of CA mortar on different load levels were studied by independently designed creep testing apparatus. The experimental results show that the creep deformation of CA mortar can be divided into the attenuation creep stage in which the deformation rate decreases gradually and the steady creep stage in which the creep rate is relatively stable. The greater the load is, the bigger the deformation rate and the creep deformation in every stage are. The specific creep of type I CA mortar is bigger than that of type II CA mortar. The long-term strength of two kinds of CA mortar is $0.4\sigma_p$ which is calculated by the method of isochronous stress–strain curves. A creep model of CA mortar based on the thermodynamic theory is established, and the correlation coefficients between fitting results of model and experimental results are all greater than 0.98. The study results can improve the structural design theory of ballastless slab track.



## 1. Introduction

With the rapid development of high-speed railway, cement and asphalt mortar (CA mortar) which is the material of the cushion layer of ballastless slab track is widely used, and it consists of cement, emulsified asphalt, fine aggregates, water, admixtures and is an organic–inorganic composite material formed by mechanical mixing, whose main functions are supporting and adjustment, buffer and coordination, blocking cracking, providing elasticity and resistance for track structure. CA mortar has an important influence on the stability, ride comfort and durability of high-speed railway [1–5].

As a viscoelastic composite material, and in order to meet its service environment and construction conditions, the physical and chemical properties of CA mortar (rheology, water absorption, freezing resistance and expansibility) and mechanical properties (compressive strength, Young's modulus, strain rate effect) have been studied extensively [6–12], the corresponding results also play a good guiding role in actual projects. According to survey, after the high-speed railway has been operated for 3–5 years, the cushion layer of CA mortar will have unrecoverable deformation, which results in a large area of void, gap, so that the working condition of track structure has continuous deterioration and the safe, high-speed, smooth and comfortable operation of trains will be seriously influenced. Therefore, the study on the long-term deformation properties of CA mortar, especially the creep properties, is very necessary.

Creep is that the deformation of material increases with the growth of time at constant load. For concrete, creep will not only result in prestress losing of prestressed reinforced concrete, but also has an impact on the creep, deflection and stress distribution of structure. The study on creep properties of concrete is relatively mature, and many researchers have put forward various creep theories and calculation methods, which provide the effective prediction of creep behavior of ordinary concrete and high performance

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concrete [13–20]. Among them, the most typical creep prediction models of concrete are CEB/FIP (1970, 1978, 1990), ACI (1978), AASHTO, GL2000, GZ (1993), etc. [21], which consider the influence of mix, the relative humidity of environment, loading age, loading time and member size, and are ideal creep prediction models. Though CA mortar is also cement-based material, due to the difference in composition and internal structure, the physical and chemical properties have large difference between CA mortar and concrete. So, the creep properties of CA mortar cannot be explained and predicted by the creep theories and calculation models of concrete, but at present, the study on the creep properties of CA mortar has not been reported around the world.

In this work, the independently designed creep testing apparatus was used to study the creep properties of CRTS (China Railway Track System) type I, II CA mortar respectively on 5 load levels (I1 = $0.1\sigma_p$, I2 = $0.2\sigma_p$, I3 = $0.3\sigma_p$, I4 = $0.4\sigma_p$, I5 = $0.5\sigma_p$. II1 = $0.1\sigma_p$, II2 = $0.2\sigma_p$, II3 = $0.3\sigma_p$, II4 = $0.4\sigma_p$, II5 = $0.5\sigma_p$, $\sigma_p$ is the peak strength of CA mortar). The internal micro mechanism of creep properties of CA mortar is analyzed and the long-term strength of CA mortar is determined. Based on thermodynamic theory, a creep model of CA mortar is established. The results can provide a reference for perfecting the design theory of ballastless slab track.

## 2. Experimental

### 2.1. Raw materials

The following materials were used to make the CA mortar specimens: special dry powder for CRTS type I, II CA mortar provided by Anhui Engineering Material Technology Ltd., which is composed of Portland cement, pelletized sand, aluminum powder, expansive agent and other additives. 24 h Volume expansion rates of the two kinds of dry powder are 2.1% and 1.25%, respectively, cement contents are about 33% and 36% (by mass), respectively, and 1d compressive strengths are 6.89 MPa and 13.15 MPa according to Chinese standard, respectively. The asphalt contents of SBS modified cationic emulsified asphalt for type I CA mortar and common anionic emulsified asphalt for type II CA mortar are respectively 58% and 60% (by mass), whose physical properties are shown in Table 1. The mixing water is clean tap water. The mass ratios of asphalt and cement in type I, II CA mortar are respectively 0.85 and 0.3. Experimental results show that the fluidities of fresh mortar are respectively 24.15 s and 96.15 s, gas contents are respectively 8.42% and 6.23%, which meet the Chinese regulation [22,23] put in references. The physical properties of Portland cement, pelletized sand and aluminum powder are shown in Tables 2–4.

**Table 4**
Main composition of aluminum powder.

| Component | Al | Fe | Si | Cu | $H_2O$ | Other |
|---|---|---|---|---|---|---|
| Content (%) | 99.80 | 0.076 | 0.046 | 0.0019 | 0.015 | 0.0611 |

### 2.2. Experimental method

According to Kanil's study results of the rheological properties of asphalt mixture and such viscoelastic materials, the influence of size of specimens on the mechanical properties of material is minimum when the ratio of height to diameter of specimens is greater than 1.5 [24]. So in this paper, in order to carry out creep experiment easier, the size of creep specimens of CA mortar is Ø100 mm × 150 mm.

CA mortar specimens were prepared by the following procedures: first, the emulsified asphalt and water were poured into the stirring pot and slowly stirred (140 r/min) for 1 min, and proper amount (0.05 g/L) of defoamer was added to eliminate the bigger bubble. In the stirring process, the dry powder was slowly added into the stirring pot, which took less than 30 s. After adding the dry powder, the mixer was turned off for 10 s, the dry powder on the wall of stirring pot was mixed into mortar. Finally, the mixture was slowly stirred for 1 min continually, then quickly stirred (285 r/min) for 2 min and slowly stirred for 30 s to eliminate bigger bubble in the mortar. After mixing, the fluidity and gas content of fresh mortar were tested according to Refs. [22,23], and then the mortar was poured into mold with the dimension of Ø100 mm × 150 mm which was demolded after 24 h. At last, the mortar specimens were kept at 20 ± 3 °C, 65 ± 5% RH to the defined age.

In order to ensure the stress direction is perpendicular to the loading plane, before the experiment, the end faces of CA mortar specimens were polished by double-end face automatic polishing machine, the horizontal error of double end faces was less than 0.05 mm. Then, the peak strengths of CA mortar at standard loading rate (1 mm/min) were tested by electronic universal testing machine, and the results are respectively 1.988 MPa and 15.26 MPa. Finally, by independently designed creep testing apparatus, the creep experiment was carried out at 5 load levels which were respectively 10%, 20%, 30%, 40% and 50% of peak strengths. The creep loads were exerted by jacks and stabilized by compressing springs at the bottom of apparatus, the load was displayed on the force measuring ring. When the load reached the preset load level, the adjusting nuts on creep testing apparatus were locked. In order to keep loads constant, the loads should be added in a timely manner when the load variation was greater than 2% of initial load level. The creep deformation of CA mortar was measured by dial gauge, whose plugs were pre embedded in specimens through the sockets in the both sides of mold when fabricating specimens. There were 3 specimens in each group, and the final result was the average deformation of 3 specimens. While the creep experiment was carried out, the shrinkage deformation of CA mortar under the same environmental condition was tested, the environmental temperature and humidity of were 23 ± 2 °C, 65 ± 5% RH. After reaching the preset load level, the instantaneous elastic deformation of CA mortar was recorded immediately, in the initial 1 h, the experimental

**Table 1**
Physical properties of emulsified asphalt.

| Type | Solid content (%) | Engler viscosity (25 °C) | Sieve residue (1.18 mm) (%) | Storage stability (25 °C) (%) | | Evaporation residues penetration (25 °C)/0.1 mm | Evaporation residues ductility (25 °C) (cm) |
|---|---|---|---|---|---|---|---|
| | | | | 1d | 5d | | |
| Cationic | 58 | 5.8 | 0.005 | 0.35 | 1.86 | 82 | 102 |
| Anionic | 60 | 5.6 | 0.005 | 0.32 | 1.94 | 81 | 104 |

**Table 2**
Physical properties of cement.

| Specific surface area ($m^2\ kg^{-1}$) | Water content of standard consistency (%) | Loss on ignition (%) | Compressive strength on 3d and 28d (MPa) | Volume stability | Flexural strength on 3d and 28d (MPa) |
|---|---|---|---|---|---|
| 339.3 | 27.3 | 2.2 | 29.1 and 60.2 | Up to standard | 5.6 and 9.3 |

**Table 3**
Physical properties of pelletized sand.

| Apparent density ($g/cm^3$) | Moisture content (%) | Water absorption rate (%) | Clay content (%) | Mud content (%) | Ruggedness (%) | Organic matter (colorimetric method) | Chloride content (%) |
|---|---|---|---|---|---|---|---|
| 2.64 | 0.04 | 0.4 | 0 | 0 | 2.0 | Up to standard | 0 |