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Comparative study on effects of binders and curing ages on properties of cement emulsified asphalt mixture using gray correlation entropy analysis

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HIGHLIGHTS

- IDT, DS, IDT at low temperature and dry shrinkage, of the mixture were studied.
- Effects of binders and curing ages on the properties of the mixture were compared.
- Zeta potential, SEM, hydration, viscosity and absorption of the binder were analyzed.
- The ranking of the correlation degrees for different property were recommended.

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ABSTRACT

The functions of the binders, cement and emulsified asphalt, in cement emulsified asphalt mixture are quite different from the situation where they are used in cement concrete or asphalt mixture. In addition, reasonable curing ages for the mixture are not well determined, especially in severe weather conditions. It is desirable to recommend the ranking about effects of binder's content and curing age on properties, such as indirect tensile strength (IDT), dynamic stability (DS), IDT at low temperature and dry shrinkage of the mixture to the asphalt pavement engineering. This study was performed to compare effects of binders and curing ages on the properties of the mixture using gray relation entropy analysis. In addition, Zeta potential, viscosity, microstructures, hydration heat of the binders and absorption between cement and emulsified asphalt were also tested to analyze the mechanism. The results indicate that IDT and DS values of the mixture increase remarkably with the increase of cement content. Emulsified asphalt content has a direct relation with IDT at low temperature. The dry shrinkage shows an abrupt increase at the 28-curing day. It is recommended the ranking of the following correlation degrees through the results from the gray correlation degree analyses: cement content > emulsified asphalt content > curing age (IDT); cement content > curing age > emulsified asphalt content (DS); emulsified asphalt content > cement content > curing age (IDT at low temperature) and curing age > cement content > emulsified asphalt content (dry shrinkage).

1. Introduction

Cement emulsified asphalt mixture has environmental, economical and logistical advantages over hot asphalt mixture [1,2]. However, it has attracted little attention as structural layers due to its inadequate performance and susceptibility to early life damage by rainfall. In addition, the internal structure of the mixture is different from that of cement concrete and asphalt concrete [3]. In the mixture, the cement emulsified asphalt composite binders have great influence on the road properties of the mixture [4,5]. On the other hand, sound curing time is required for the mixture to develop acceptable mechanical strength.

Most experiment results indicate that contents of cement and emulsified asphalt significantly affect the properties of the mixture. For example, Oruc et al. [6] implemented laboratory tests on strength, temperature susceptibility, water damage, creep and permanent deformation to evaluate effect of cement on emulsified asphalt mixtures. The test results showed that mechanical properties of emulsified asphalt mixtures were significantly improved with Portland cement addition. Song et al. [7] purposed to evaluate the feasibility on the use of an asphalt emulsion as a polymeric admixture. The study showed that waterproofness, carbonation

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resistance and chloride ion penetration resistance of the asphalt-modified mortars were markedly improved with the increase in the polymer cement ratio. Wang et al. [8] evaluated the effect of the binders on interface adhesion between cement emulsified asphalt mastic and aggregate and recommended rational cement and aggregate types. Evans et al. [9] discussed an investigation of how physical hardening phenomena during isothermal conditioning affected stress relaxation in asphalt cement. Zhang et al. [10] studied the rheological properties of fresh cement asphalt paste and put forward the temperature sensitivity of the rheological properties of the cement asphalt paste depended on the type and content of asphalt emulsion.

In addition, improved understanding and control of curing age is not a new issue. Shuler [11] studied the time to remove traffic control safely on fresh emulsified asphalt chip seals and suggested that moisture content of the chip seal system was related directly to the strength of an asphalt emulsion residue. Kim et al. [12] discussed how curing time and moisture content affected IDT and rutting resistance of the mixtures during the curing process and pointed out the current curing time threshold was not well-founded on sound engineering principles.

Gray correlation theory has been applied in many fields. It can provide solutions for systems in which the model is uncertain, or the information is incomplete. Besides, it provides an efficient solution to uncertain, multi-input, and discrete data problems. In pavement engineering fields, Yang et al. [13] used grey system to study the relationship between composition changes of the aged asphalt and its service performance changes, such as softening point, penetration and viscosity. The result from grey system theory was in accordance with that from the experiential analysis. Wu et al. [14] put forward an acoustical prediction model for asphalt pavements using grey system approach. Du et al. [15] discussed an algorithm of the grey relational-regression analysis (GRRA) for hot mix asphalt. The concept of GRRA based on grey system theory and polynomial regression was introduced and the equation was derived as well. The results showed that the algorithm was very effective. The algorithm of GRRA could be considered as an alternative to HMA design analysis. However, there are few previous studies conducting on influences of binders and curing ages on road properties of the mixture using gray correlation entropy analysis.

In this study, the properties, IDT, DS, IDT at low temperature and dry shrinkage, of the cement emulsified asphalt mixture were studied. Effects of binders and curing ages on the properties of were compared by using gray correlation entropy analysis. The Zeta potential, scanning electron microscope (SEM), hydration heat, viscosity of the composite binders and absorption between cement and emulsified asphalt were tested and analyzed. The ranking of the correlation degrees of binders and curing ages for different property was recommended through gray correlation degree analyses. The primary scope of this study is to determine how cement emulsified asphalt composite binders and curing age affect the properties and to rank influencing factors on the properties of the mixture to improve the quality and durability of cement emulsified asphalt mixture pavement.

2. Experimental programs

2.1. Raw materials

Properties of emulsified asphalt were tested according to *Standard Test Methods of Asphalt and Asphalt Mixtures for Highway Engineering (JTJ E20-2011)* [16], a Chinese specification for asphalt materials. The crushed limestone aggregate and limestone filler were used in this study, whose properties were tested according to *Test Methods of Aggregate for Highway Engineering (JTG E42-2005)* [17], a Chinese specification for highway engineering aggregate and fillers. Ordinary Portland cement (P·O 42.5R) was adopted. The test results of raw materials were shown in Table 1.

2.2. Experiment setups

The aggregate gradation was shown in Fig. 1. The content of the emulsified asphalt and the cement were 6.5%, 7.5%, 8.5% and 2.0%, 3.0%, 4.0% in aggregate mass, respectively. The solid portion of the mineral filler was used as 6.0% in aggregate mass. The additional water (not including the water from emulsified asphalt) was added for preparing Marshall specimens and the dry density was measured to determine the water dosage. Reasonable water content was the additional water dosage in the mixture with the highest dry density. The additional water dosages were shown in Table 2. Specimens were cured for 7 days and 28 days in a curing room with 20 °C temperature and 90% relative humidity. In accordance with the *Standard Test Methods of Asphalt and Asphalt Mixtures for Highway Engineering (JTJ E20-2011)* [16], IDT, DS and IDT at low temperature of the mixture were tested.

The cylindrical specimens with 101.6 mm × 63.5 mm were prepared for IDT test by using static compression method. The test temperature was 20 °C and the load rate was 50 mm/min. In IDT test, the cylindrical specimens were subjected to compressive loads between two loading strips, which created tensile stress along the vertical diametric plane causing a splitting failure. The IDT was also tested at a lower temperature, −15 °C, which was calculated according to Eq. (1).

$$\mathrm{IDT} = \frac{2\times 10^{-6} P_{\max}}{\pi d t} \tag{1}$$

where IDT is the indirect tensile strength, MPa; *P* the peak load, *N*; *d* the diameter of the specimen, mm and *t* is the height of the specimen, mm.

The specimen size for dynamic stability test was 300 mm × 300 mm × 50 mm. The test temperature was kept at 60 °C. The touch stress between solid rubber wheel (200 mm in diameter and 50 mm in width) and specimens was 0.7 MPa and the load applied to specimen was about 780 N. The solid rubber wheel ran on the surface of the specimen for 60 min. The DS value was calculated by the Eq. (2).

$$\mathrm{DS} = \frac{(t_2 - t_1)\times N}{d_2 - d_1} \tag{2}$$

where DS is the dynamic stability, n/mm; d_1 the displacement at t_1 (45 min), mm; d_2 the displacement at t_2 (60 min), mm; *N*-back and forth movement cycles per minute for solid rubber wheel on the surface of the specimen, 42 n/min.

According to *Testing Methods of Cement and Concrete for Highway Engineering (JTG E30-2005)* [18], three numbers of beam specimens with dimensions of 100 mm × 100 mm × 515 mm were prepared for a shrinkage test. Studs with diameter of 6 mm were attached to all specimens by their faces on all sides. The specimens were then air cured in an atmospheric temperature of 25 °C and relative humidity of 60%. At the initiation of air curing, the initial length was read. Changes in the length of the specimens were measured during air curing at 7 and 28 days. According to the Eq. (3), the dry shrinkage ratio was calculated.

$$\varepsilon_t = \frac{L_0 - L_t}{L}\times 100 \tag{3}$$

where ε_t is the dry shrinkage ratio, %; *L* the length of reference beam, 515 mm; L_0 the initial length, mm; L_t the length at different curing ages, mm and *t* is the curing age, 7 and 28 days.

In addition, Zeta potential, viscosity, microstructures and hydration heat of the composite binders were also tested. The testing temperature was 25 °C. Zeta potential was measured using a Malwern Zetasizer Nano. AR2000ex Rheometer made by TA Company USA was used to analyze viscosity of the binders with the different shear rates. The microstructures of the binders were analyzed by S4800 SEM. The binders were gold-plated for the examination. TAM Air hydration heat tester was used to test hydration heat of the binders. Images of fresh emulsified asphalt without and with cement were obtain with LWT150PT optical microscope.

3. Gray relation entropy analysis

3.1. Determine the standard classification sequence

The actual values gotten from the experiments of the properties, such as IDT, DS, IDT at low temperature and dry shrinkage were selected as reference sequence, $X_0(k)$. Values of each influencing factor, binder contents and curing ages, were determined as comparative sequence, $X_i(k)$; where $k = 1, 2, \ldots n$ and $i = 1, 2, \ldots$ m. For convenient calculation, values are transferred from an original sequence to a comparable sequence shown in Eq. (4).

$$\begin{aligned} X_0 &= X_0(1), X_0(2), \ldots X_0(n) \\ X_1 &= X_1(1), X_1(2), \ldots X_1(n) \\ &\cdots\cdots\cdots \\ X_m &= X_m(1), X_m(2), X_m(n) \end{aligned} \tag{4}$$