Construction and Building Materials 137 (2017) 153–159

Contents lists available at ScienceDirect

Construction and Building Materials

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

Early-age strength and long-term performance of asphalt emulsion cold recycled mixes with various cement contents

Jinhai Yan [a], Zhen Leng [b,*], Feng Li [a], Haoran Zhu [a], Shihui Bao [a]

[a] National Engineering Laboratory for Advanced Road Materials, Jiangsu Transportation Institute Group, 2200 Chenxin Street, Nanjing 211112, China
[b] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

HIGHLIGHTS

- Early-age strength and long-term performance of the asphalt emulsion cold recycled mixes were investigated.
- Correlation models between early-age strength and long-term performance were developed.
- Adding cement plays positive effects on both earl-age strength and long-term performance.
- Strong correlation exists between early-age strength and long-term performance of asphalt emulsion recycled mixes.

ARTICLE INFO

Article history:
Received 19 September 2016
Received in revised form 27 December 2016
Accepted 26 January 2017

Keywords:
Reclaimed asphalt pavement
Cold recycling
Asphalt emulsion
Cohesive force
Raveling loss rate
Failure strain

ABSTRACT

Cold recycling with asphalt emulsion is an economical and environment-friendly technology for asphalt pavement maintenance and rehabilitation. This study aims to investigate the early-age strength and long-term performance of the asphalt emulsion cold recycled mixes with various cement contents, as well as the correlation between the early-strength and long-term performance. To achieve this objective, three research tasks were conducted, including: 1) quantifying the early-age strength of four types of asphalt emulsion cold recycled mixes by measuring their cohesive forces and raveling loss rates through the Hveem cohesion test and raveling test, respectively; 2) characterizing their long-term performance properties, including moisture stability, high-temperature stability, and low-temperature cracking resistance; and 3) developing the correlation models between the early-age strength and long-term performance of asphalt emulsion cold recycled mixes through regression analysis. It was concluded that adding cement in cold recycled mixes played positive effects on both its early-age strength and long-term performance. In addition, strong linear correlation was found between the early-age strength and long-term performance of asphalt emulsion cold recycled mixes.

1. Introduction

Cold recycling of reclaimed asphalt pavement (RAP) is a cost-effective and environment-friendly technology, which has been widely applied for asphalt pavement maintenance, rehabilitation and reinforcement [1]. Asphalt emulsion, and foamed asphalt have been commonly added to RAP to produce cold recycled mixes, while cement has been often added to enhance the mechanical properties of the asphalt emulsion cold recycled mixes due to the accelerated emulsion coalescence after compaction, cement hydration, and improvement of binder viscosity [2–6]. Due to the curing effects of asphalt emulsion, cold recycled mixes with asphalt emulsion show different performance characteristics, especially at the early stage, compared with hot-mix asphalt (HMA). Correspondingly, various research studies have been conducted on the mix design, long-term performance, performance evaluation and prediction, and economic and environmental analysis of cold recycling [7–16]. In general, asphalt emulsion cold recycled mixes have been reported to provide satisfactory performance in terms of moisture damage resistance, rutting resistance, and low-temperature cracking resistance compared with HMA [17–20]. However, very few studies have systematically looked into the early-age strength, long-term performance, and their correlation of asphalt emulsion cold recycled mixes with and without cement. As a result, this study aims to investigate the early-age strength and long-term performance of asphalt emulsion cold recycled mixes with different cement contents, as well as their correlation. The early-age strength of the cold mixes was evaluated through the Hveem

* Corresponding author.
E-mail addresses: jason.yan1@gmail.com (J. Yan), zhen.leng@polyu.edu.hk (Z. Leng), lf78@jsti.com (F. Li), zhr75@jsti.com (H. Zhu), bsh359@jsti.com (S. Bao).

http://dx.doi.org/10.1016/j.conbuildmat.2017.01.114
0950-0618/

cohesion test and raveling test, while the long-term performance was characterized through tests on their moisture stability, high-temperature stability, and low-temperature cracking resistance

2. Experimental program

2.1. Materials

The RAP samples used to produce the cold recycled mixes in this study were collected from the surface and binder courses of the Ning-Xuan highway in Nanjing, China. The binder extraction and recovery tests indicated that the asphalt content of RAP was 4.3%. The 25 °C penetration, softening point, and 15 °C ductility of the extracted RAP binder were 24 (0.1 mm), 65 °C, and 14 cm, respectively. Virgin coarse limestone aggregates (16 mm–31.5 mm) were added to the cold recycled mixes to improve interface friction between aggregate. The asphalt emulsion used in this study is a cationic slow-setting asphalt emulsion (CSS-1 h), and ordinary Portland cement with a 28-day compressive strength of 42.5 MPa (labelled as PO 42.5 according to the Chinese specification standards, JTJ 034-2000) was used. Pre-mix water was added to cold recycled mixes to improve the coating of the RAP and virgin aggregates, lubricate the mix during compaction, and accelerate the cement hydration reaction.

In total, four cold recycled mixes as shown in Table 1 were prepared and evaluated. Among the four mixes, Mix III was the design mix for cold recycling adopted in Ning-Xuan highway, and the other three mixes, which have various percentages of cement, were selected to evaluate the effect of cement content. The gradation of the combined RAP and virgin aggregate was designed to meet the requirement of the Chinese specification for cold recycling (JTG F41-2008), as shown in Fig. 1.

2.2. Early-age strength characterization

The early-age strength of the cold recycled mixes was quantified by the Hveem cohesive test and raveling test. The test specimens for these two tests were 150 mm in dimeter and 80 ± 3.0 mm in height, and 150 mm in diameter and 70 ± 5.0 mm in height, respectively. 20 gyrations of compaction were applied to each specimen using a Superpave gyratory compactor. The vertical pressure and the angle of the Superpave gyratory compactor were 600 ± 18 kPa and 1.25 ± 0.02°, respectively. Three replicates were prepared for each mix, and all specimens were cured at a temperature of 25 °C and a humidity of 70% for 4 h. All samples were demolded right after compaction.

2.2.1. Cohesion test

The cohesion test was performed in accordance with ASTM D1560-81. Fig. 2 shows the Hveem cohesiometer used in this study and a failed specimen after testing. During this test, steel balls keep falling into the bucket at the end of the cantilever beam at a constant speed. The test will stop when the specimen cracks or the vertical deformation is more than 13 mm. The cohesion force value, C (g/cm^2), is calculated based on the weight of steel balls in the bucket using the following equation

$$C = \frac{L}{W \times (0.031H + 0.00269H^2)} \quad (1)$$

where L, W, and H represent the ball weight (g), the specimen diameter (cm), and the specimen height (cm), respectively.

2.2.2. Raveling test

The raveling test was performed in accordance with ASTM D7196-06. Fig. 3 shows the raveling tester used in this study and the specimen before and after testing. This test measures the raveling resistance of asphalt emulsion cold recycled mixes by simulating the abrasion caused by early-age traffic. The test is continued for 15 min or until a major part of the specimen is broken. When the test is completed, the specimen will be carefully removed from the base and its surface will be gently brushed with a paint brush to remove any loose material. Then, its weight will be measured and the raveling loss rate, L (%), can be calculated using the following equation:

Table 1
Material compositions of cold recycled mixes.

Mix	RAP (%)	Virgin Coarse Aggregate (%)	Asphalt Emulsion (%)	Portland Cement (%)	Pre-mix Water (%)
I	85	15	4.3	0	2.6
II	85	15	4.3	1.0	2.6
III	85	15	4.3	1.5	2.6
IV	85	15	4.3	2.0	2.6

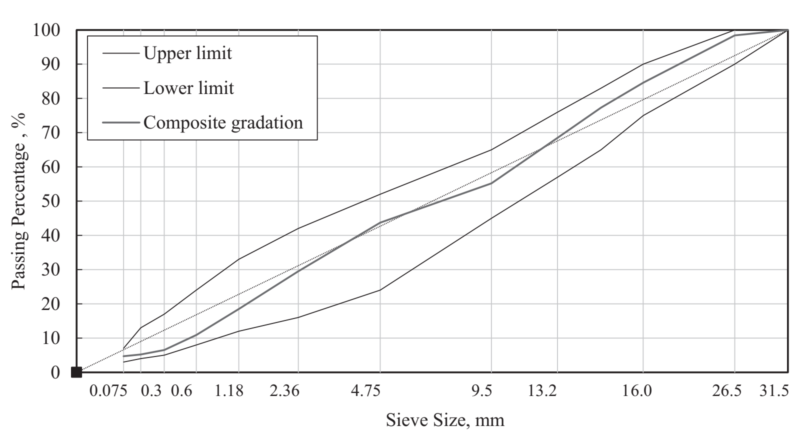

Fig. 1. Cold recycled mix gradation.