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Research on development mechanism of early-stage strength for cold recycled asphalt mixture using emulsion asphalt

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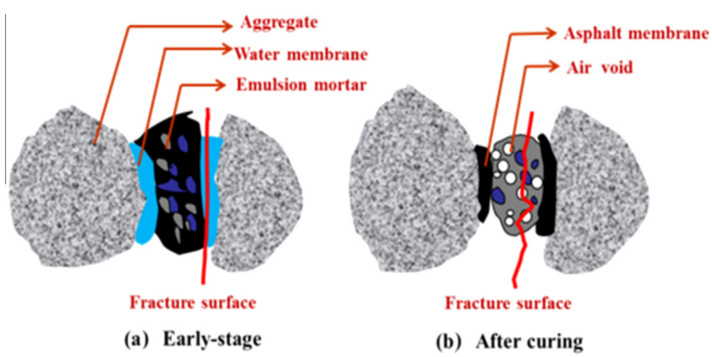
HIGHLIGHTS

- Cement hydration plays the predominant role in strength of CRME in 0–5 days.
- The failure fracture of CRME in early-stage is mainly adhesion failure in interface.
- The failure fracture of CRME after curing is mostly due to cohesive fracture.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper aims at investigating the development mechanism of early-stage strength for cold recycled asphalt mixture using emulsion asphalt. The influence parameters of early-stage strength development for cold recycled mixture by emulsion and cement (CRME) is firstly studied, and then the direct tensile test is used to determine the early-stage strength development law of emulsion asphalt–cement mortar. Lastly, the image analysis is used to identify the fracture morphology of cross-section of cold recycled mixture, and the development mechanism of cold recycled mixture is revealed. The results indicate that the cement plays the predominant role in strength of CRME in first 3 days, while emulsion asphalt plays the predominant role in both early-stage and final strength. Moreover, the adhesion between mortar and aggregate provide the strength for CRME in earth-stage, while the cohesion in emulsion–cement mortar provides the strength for CRME after curing. The findings in the paper provide new approaches to improve the early-stage strength of CRME.

1. Introduction

Asphalt pavement tends to deteriorate during its service life due to traffic and environmental effect. After the reconstruction and major maintenance of pavement, nearly 6000 million waste asphalt mixtures are produced annually in China. Nowadays, recycling of waste asphalt mixture attracts more attention in these years due to the lacking of natural aggregate and budget [1–3].

Generally, recycling of waste asphalt mixture can divide into cold recycled and hot recycled [4,5]. Cold recycled technology can take up 70–90% of recycled asphalt pavement (RAP), and it is develop dramatically in China for pavement rehabilitation and used as subgrade or in asphalt pavement structure. Cold recycled of RAP also comprises two methods including emulsified asphalt

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and foamed asphalt. Cold recycled of RAP by emulsion asphalt and cement (CRME) is a promising method to be used in expressway with high-vehicle and widely used in asphalt pavement rehabilitating [6,7]. Although cold recycled by emulsion asphalt and cement has been successfully applied, there are still some critical problems existing in this technology, which restricted its further application. Among these problems, it needs 3–7 days for curing in summer and much longer in winter due to the low early strength of CRME, which prolongs the construction period and increase the difficulty for traffic organization.

Many researchers focus on the strength of CRME in both laboratory and field pavement. Extensive research indicated that the cement accelerate the breaking of bitumen emulsion and setting of the mix, which increase the early strength of CRME [8,9]. Kim confirmed that the amount of moisture and length of the curing period significantly affect the properties of the CIR mixtures by emulsion asphalt [10]. Bocci found that the curing process was slower at low temperatures, while higher temperatures resulted in higher rates of strength increase [11]. Brown found that cement influenced the initial curing process of CRME and increased the early strength of CRME [12]. In addition, Rita conducted a study and conclude that the addition of cemented materials increase the strength of CRME, while make CRME to be prone to shrinkage cracking [13]. Harvey found that the interface between asphalt and aggregate was important for cold recycled mixture by foamed asphalt, and concluded that foamed asphalt mixtures were weakly bonded granular materials [14,15]. Thomas also found that CRME behaved similar to granular materials at early-stage and similar to conventional asphalt mixture materials after curing [16].

Based on the literatures above, the strength development of early-stage and its mechanism has not been comprehensively studied. However, early-stage strength has become a critical problem for application of CRME both in China and other countries [17]. The limited knowledge on early-stage strength of CRME cannot make recommendation for the curing process and improve the early-stage strength of CRME, which provides the motivation to undertake this research.

The objective of this paper is to investigate the devolvement mechanism of early-stage strength for CRME, and to determine the critical parameters influencing the early-stage strength of CRME. The early-stage strengths of CRME at different curing conditions are investigated, and then the role of emulsion and cement content is studied. Lastly, the image process is conducted to investigate the fracture mechanism of CRME. The research will help to know the devolvement mechanism of early-stage strength for CRME and to improve the early-stage strength of CRME.

2. Materials and experiments

2.1. Materials

Cationic slow-setting emulsion asphalt (CSS) was prepared with base asphalt binder and emulsifier in the laboratory. The base asphalt used in this study was obtained from market. The basic properties of the emulsion asphalt are shown in Table 1.

Table 1
Properties of emulsion asphalt.

Type	CSS
Residue by distillation (%)	63
Emulsifier content (%)	3
Storage stability at 1 day (%)	0.2
Storage stability at 5 days (%)	1.1
Penetration of residue, 25 °C	69.5
Ductility of residue, 15 °C	66.5

The recycled asphalt pavement (RAP) was obtained from one expressway in Jiangxi Province, China, and the aggregates gradation of CRME is shown in Fig. 1. CRME used in this paper with RAP of 89% was designed by modified Marshall Methods, Firstly, the optimum adding moisture content was determined as 2.3% by weight of aggregates, and then the optimum emulsion asphalt content was determined as 3.8% by weight of aggregates through Marshall Test. It was noted that the cement used in this study was designed as 2% for conventional CRME samples.

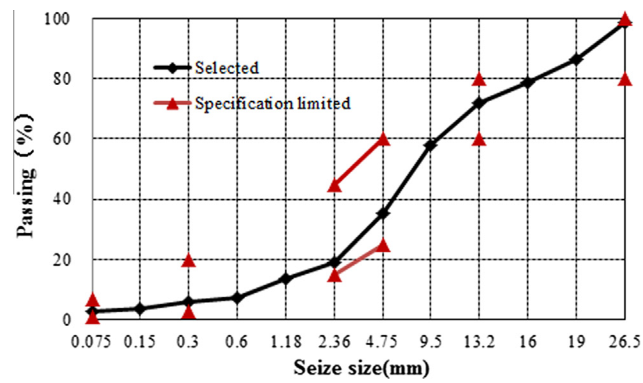

Fig. 1. Grading curves of aggregates.

Normally, after CRME specimens were prepared, the specimens were placed in oven at a temperature of 60 °C for 168 h to stimulation the long-term curing process [18,19]. During the curing, CRME specimens were covered with a plastic film except the tops to allow water to evaporate through the top surface only. In this paper, CRME specimens were placed at the room with temperature of 20 °C and humidity of 60% or 90% for 24 h, 48 h, 72 h and 120 h to simulate the early-stage curing of CRME.

2.2. Experiments

2.2.1. Indirect tension strength test

The CRME samples of 150 mm in diameter and 100 mm in height were prepared with SGC (Superpave Gyratory Compactor). The indirect tension strengths of specimens with different curing conditions were tested at a temperature of 15 °C with a loading rate of 50 mm/min.

2.2.2. Moisture content test

The moisture in CRME composed of the water added in mixing and the water in emulsion asphalt and aggregate. The moisture content is defined as the moisture weight in CRME divided by the weight of dry aggregate and asphalt in CRME. During the test, the CRME samples were placed at room temperature of 20 °C and 30 °C with the humidity of 60%, and the weight of samples is monitored for 1–7 days, and the moisture content of CRME is calculated each day.

2.2.3. Direct tensile test

The direct tensile test was used to characterize the adhesion strength of emulsion–cement mortar. Firstly, cement and mineral filler were mixed with water according to the designed value in cold recycled mixtures, and then mixed with emulsion asphalt to form the emulsion–cement mortar in order to simulate the mortar in CRME.

After the emulsion–cement mortar was prepared, it was placed on the surfaces of two asphalt mixture slices (5 cm * 5 cm) and two aluminum plates (4 cm * 4 cm) to simulate the adhesion of mortar with RAP. The image of samples can be seen in Fig. 2. The samples with different curing time were tested at a constant displacement rate (5 mm/min) until failure. The maximum failure stress and displacement were obtained.

2.2.4. Image analysis

The image analysis was performed to get insight into the fracture mechanism of CRME in early-stage. Firstly, the full fracture section images of CRME samples (10 * 15 cm) at different curing time were obtained, and then Matlab13.0 with self-defined program was employed to analysis the fracture surface images of CRME. The fracture surface area between aggregate and emulsion mortar was calculated based on image analysis. The specific procedure is firstly conducting the planarization the 3D cross section, and then switching into grey-level after digitization, finally calculating the FASA ratio after identifying the bonding failure in the interface from the threshold of one color in the grey-level. Fig. 3 shows the image analysis process of CRME, and the fracture aggregate ratio of surface area (FASA) was identified and calculated as critical parameter to reflect the fracture mechanism of CRME in early-stage.