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Development of microstructure and early-stage strength for 100% cold recycled asphalt mixture treated with emulsion and cement

Juntao Lin [a,*], Lin Huo [a], Fang Xu [a], Yue Xiao [b,*], Jinxiang Hong [c]

[a] Faculty of Engineering, China University of Geosciences (Wuhan), Wuhan 430074, China
[b] State Key Laboratory of Silicate Materials for Architectures, Wuhan University of Technology, Wuhan 430070, China
[c] State Key Laboratory of High Performance Civil Engineering Materials, Jiangsu Research Institute of Building Science, Nanjing 210008, China

HIGHLIGHTS

- Early-stage strength of CRME is influenced by cement and moisture content.
- Microstructure formation of CRME is controlled by integration of emulsion particles.
- Additives and surfactant can effectively improve the early-stage strength of CRME.

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ABSTRACT

This paper aims at investigating the microstructure and early-stage (<14 days) strength formation for 100% Cold Recycled Asphalt Mixture treated with Asphalt Emulsion and Cement (CRME). First, the factors influence on early-stage strength of CRME are carefully discussed. The microstructure formation of CRME in early-stage are identified by means of Environmental Scanning Electron Microscope (ESEM) and SEM. Moreover, two approaches including accelerating the hydration of cement and accelerating the integration of asphalt emulsion are proposed to improve the early-stage strength of CRME. The results indicate that the early-stage strength formation depends mainly on integration between emulsion particles in CRME. The early-stage strength of CRME can be improved by both accelerating the hydration of cement by additives and accelerating the demulsification of asphalt emulsion by surfactant, and the addition of surfactant in CRME has better effect in improving the early-stage strength. The method of accelerating the demulsification of asphalt emulsion by surfactant is recommended in practical application, which will help to enlarge the application range of CRME in winter or cold regions.

1. Introduction

Cold recycling of asphalt pavement is an effective way to reduce construction materials and cost as well as carbon emission in pavement rehabilitation [1,2]. Nearly 70 million tons of Reclaimed Asphalt Pavement (RAP) are produced every year in China, which causes resource waste and environmental pollution. As a result, cold recycling of asphalt pavement has developed dramatically in China. Cold Recycled Mixture by Asphalt Emulsion (CRME) is usually used in base course or lower layer in road structure in China [3], and more than 4000 km of roads using cold recycled technology were built in the past decade. It is reported that cold recycled mixtures is usually used in low-traffic road in USA and South Africa [4–6]. However, cold recycling of RAP by asphalt emulsion and cement has been applied in expressway with high traffic volumes in China [7]. As a result, cold recycled asphalt mixture using asphalt emulsion and cement (CRME) requires better mechanical properties in China. Moreover, practical experience found that CRME used in winter or cold regions in China may appear early-stage (<14 days) deterioration because of low early-stage strength.

The early-stage (<14 days) strength of CRME is of great significance for saving construction time and decreasing the early damage of road [8], which becomes the critical concern for using CRME in cold regions or winter [9,10]. The early-stage strength of CRME is obviously lower than that of conventional hot asphalt mixture (HMA) [11–13], which leads to long curing time before opening traffic or constructing HMA layer. Strength development of CRME in both laboratory and field has been widely studied. Researchers found that curing temperature was a factor significantly influencing the early-stage strength of CRME, and early-stage strength of CRME increased with the increases of

* Corresponding authors.
E-mail addresses: linjt@cug.edu.cn (J. Lin), xiaoy@whut.edu.cn (Y. Xiao).

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curing temperature [14]. Portland cement could also significantly increase the early-stage strength of CRME [15,16]. In addition, the microstructure of CRME is found to has a given correlation with its mechanical properties. Nassar [17] found that the microstructure of CRME was continuously evolved by SEM. Early hydration product ettringite (AFt) was converted into calcium sulfoaluminate (AFm), which may cause damage in CRME. Dulaimi [18] studied the microstructure of CRME with active mineral powders at 3-day curing and 28-day curing. The results showed that active mineral powders produced more hydration products at 28-day curing, which resulting in higher modulus of CRME. However, the microstructure formation process of CRME in early-stage has not yet been studied under water environment by ESEM, and which may directly reveal the essence of early-stage strength formation of CRME.

Normally, increasing the dosage of cement seems to be an effective method to increase the strength of CRME. However, the addition of cemented materials increases the strength of CRME, while make CRME prone to shrinkage cracking [19–21], and the dosage of cement is usually limited to 2.0% wt in CRME in China. For improving the performance of CRME, Wang [22] used a recycling agent and an acrylic copolymer emulsion to improve the engineering performance of control CRME, and it was concluded that the method provided significantly better overall performance than the conventional method. Martinez-Arguelles [23] found fiber can enforce the strength and crack-resistance ability. Stimilli [24] proposed a new mixing method by using water vapour instead of water to add moisture in the mixing plant to improve the strength of CRME. It was reported that the method decreased the air void and improved the permanent deformation resistance of CRME. The author [25] studied the development mechanism of early-stage strength for CRME, and it was concluded that cement played the predominant role in first 3-day of early-stage strength, while emulsified asphalt played the predominant role in both early-stage and final strength. Moreover, the moisture content in interface between asphalt emulsion and RAP had important impact on early-stage strength of CRME. The mechanism of early-stage strength evolution helps to explore the early-stage strength improvement methods in this paper.

Based on the previous studies, the limited information on microstructure formation and improving early-stage strength of CRME cannot make recommendations for using cold recycling technology in road at cold regions or winter with heavy-traffic, even leading to the early-stage damage of cold recycled pavement. The urgent demand of improving early-stage strength for CRME provides the motivation to undertake this research.

The objective of this paper is to investigate the microstructure and early-stage strength formation for CRME. Firstly, the relationship between materials composition and early-stage strength of CRME is detailly discussed. Then, early-stage microstructure formation process is studied by means of ESEM observation and SEM analysis. Lastly, two methods of improving the early-stage strength for CRME based on the relationship between materials composition and microstructure formation are proposed and investigated. The research is meaningful to propose an effective method to improve the early-stage strength and promote the application of CRME.

2. Materials and experiments

2.1. Materials

2.1.1. Asphalt emulsion

Cationic slow-setting asphalt emulsion (CSS) for CRME was prepared by colloidal mill with base asphalt binder and cationic emulsifier. The cationic emulsifier was synthetized in laboratory, and the basic properties of the asphalt emulsion were shown in Table 1.

2.1.2. Portland cement

The Portland cement (PO 42.5) from Anhui province was used in CRME, which was obtained from market and widely used in China. The basic properties of the cement were shown in Table 2.

2.1.3. Additives

Three kinds of early-strength additives for cement were adopted in this paper. Among these additives, one organic addictive with triethanolmine (T, $C_6H_{15}O_3N$) and two inorganic additives with sodium sulfate (S, Na_2SO_4) and aluminium chloride (cl, $AlCl_3$) were obtained from market. The dosage of additives was the percentage proportion by weight of filler (<0.075 mm), and the optimum dosage of each additives was discussed later. One typical anionic surfactant named polycarboxylate superplasticizer with main chain grafted polyether was used to improve the mixing process of CRME, which could improve the dispersion performance of cement, filler and RAP aggregates as well as asphalt emulsion. The optimal dosage of surfactant was determined as 0.025% by weight of aggregate based on compaction test.

2.2. Experimental programme

2.2.1. Mixtures design

The RAP was obtained from Taigan expressway in Jiangxi Province, China. CRME used in this paper with RAP of 100% was designed by modified Marshall Methods according to the specification of China [26]. It is noted that the mould with 152.4 mm in diameter and 95.3 mm in height is used in Marshall method for CRME with nominal maximum aggregate size of 26.5 mm. The aggregates gradation of CRME is shown in Fig. 1. The optimum adding moisture content was determined as 1.7% by weight of aggregates using heavy compaction method through maximum density [27]. Then, the optimum asphalt emulsion content was determined as 3.8% (2.4% residual asphalt) by weight of aggregates through maximum indirect tensile strength. The content of cement in CRME was designed as 2% by weight of aggregates according to the engineering experience in China. Table 3 shows the composite of control CRME mixtures designed in this section.

Table 1
Properties of emulsion asphalt.

Property	Value	Specification
Residue by distillation (%)	63.5	EN 1428
Emulsifier content (%)	3.0	–
PH	3.1	–
Mixing stability with cement (%)	1.5	EN 12848/T0657
Storage stability at 1 day (%)	0.2	ASTM D244
Storage stability at 5 days (%)	1.4	ASTM D244
Penetration of residue, 25 °C (0.1 mm)	69.5	EN 1426
Ductility of residue, 15 °C (cm)	78.5	ASTM D113

Table 2
Basic properties of the cement.

Property	Value	Specification
Initial setting time (min)	142	ASTM C191
Final setting time (min)	278	ASTM C191
Compressive strength at 3d (MPa)	18.2	BS EN 12390
Compressive strength at 7d (MPa)	44.5	BS EN 12390
0.075 mm passing rate (%)	93	–