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Effect of curing conditions on properties of cement asphalt emulsion mixture

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HIGHLIGHTS

- A RH 90% curing impacts long term mechanical properties of the mixtures.
- The equivalent relationships between different curing regimes are proposed.
- The asphalt aging in CAM with 60 °C curing 72 h can be neglected.
- A 60 °C curing 72 h influences the hydration products and microstructure of CAM.

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ABSTRACT

The properties of cement asphalt emulsion mixture (CAEM) are influenced by curing conditions. In this paper, the strength properties of CAEM are investigated at different curing humidities and periods. Then, the moisture susceptibility test and rutting resistance test are performed to evaluate the effect of typical curing procedures on the emulsion-based mixtures. In order to understand the diversity of different curing procedures, the chemical composition and microstructure of cement asphalt mastic (CAM) are analyzed by Fourier transform infrared (FTIR) spectrometer, X-ray diffraction (XRD) analyzer, and environmental scanning electron microscope (ESEM). The results indicate that the effect of curing humidity on strength development depends on the cement content and curing period. It is recommended to cure all mixtures with lower humidity. The higher temperature accelerated curing for several days can stimulate a normal temperature curing for several months. The equivalent relationships between accelerated curing and normal temperature curing are developed based on the strength and performance analysis. By comparing FTIR results at different curing regimes, it can be found that no obvious asphalt binder aging appears in CAM with the typical accelerated curing procedure. XRD analysis founds that the accelerated curing improves the content of some hydration products content, while leads to the more cement particles encapsulated by asphalt film. Considering results of FTIR and XRD, it is testified that the microstructure characteristics of hydration products in CAM with two curing regimes are obviously different, which can explain the performance variations of CAEM with these curing procedures.

1. Introduction

The environmental benefits of asphalt emulsion mixture (AEM) promote its widespread application as a structural layer material [1–4]. In the mixtures, bitumen droplets are separated from the emulsion system to form a continuous asphalt film on the surface of aggregates [1]. The strength and stiffness of asphalt film gradually increase with asphalt recovery and water evaporation [5]. The change rate of these properties with curing time depends on the environmental conditions and mixture composition [6].

The research results from South Africa, France and other countries indicate the curing period of the emulsion-based mixture takes place over 6 months to 3 years before achieving a final state [7,8]. For quickly obtaining the properties of AEM, the different agencies and researchers have developed some laboratory curing methods [9]. Moreover, some studies have adopted these regimes to study the cement asphalt emulsion mixture (CAEM) [9]. These regimes can be classified into two typical types: ambient temperatures (15–25 °C) curing and higher temperature (35–60 °C) accelerated curing.

The ambient temperature curing is a more convenient and cheaper method than accelerated curing [10,11]. The shortcoming of this method is that the mixture design and evaluation are

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protracted by curing process. The effect of fluctuating ambient temperature (varied 15–25 °C) or relative humidity (varied 6–95%) on the mixtures' performance are neglected by many studies [12–14]. Although some research use the constant ambient temperature to replace fluctuating ambient temperatures [9,10,14,15], the relative humidity (RH) are not controlled. Some studies have found that it is a better choice to accelerate the water evaporation by reducing relative humidity rather than by increasing the temperature [16–18]. The constant ambient temperature [16,19] and/or constant RH [10,12] are often used in some studies, most of these methods are used to obtain early-stage properties of AEM or CAEM in laboratory. Some researches even cured the samples of CAEM at 20 °C and higher RH up to 90% or 95% which was usually used for the curing of cement concrete [14,20]. The possible reason is that the higher humidity at early stage can improve the hydration reaction of cement.

The accelerated curing procedures put the samples at higher temperature draft oven. The bitumen recovery and water evaporation are accelerated. Compared with ambient temperature curing, the mixture spends much shorter time to reach the final state. The different agencies or researchers recommend different accelerated curing procedures. The curing temperatures vary from 35 °C to 60 °C [2,8,17,21,22]. The curing periods vary from 1 d to 28 d. The popular curing procedures are a 40 °C curing 3 d and 60 °C curing 2 d or 3 d after the compacted samples are extruded from the molds with 24 h room temperature curing [9,15,21–27]. An accelerated curing method at 110 °C for 24 h also appears in some literatures [28]. Some researchers worried the accelerated curing probably lead to the early oxidation or aging of asphalt binder [8,10,29,30]. However, there are no enough evidences to support this suspicion.

The accelerated curing reaches the similar state of in-situ condition curing or ambient temperature curing with extraordinarily short time. The Asphalt Academy recommends curing the specimens at 40 °C for 3 d to simulate 6 months of conditioning in situ [23]. Serfass et al. found that 14 d of curing at 35 °C and RH 20% corresponded to approximately 1–3 years in the field under temperate climate [8]. A research from Ireland claimed that curing at 40 °C for 28 d could be an equivalent of 1 year of field curing [31]. Du found that the ITS of AEM after 60 °C curing for 72 h was higher than that of AEM curing at 25 °C for 28 d [32]. Therefore, the equivalent relationships between accelerated curing and normal temperature curing are still no clear consensus.

In addition, a lot of studies have demonstrated that the higher temperature curing condition affects the hydration reaction of cement paste [33]. The compressive strength of cement paste was decreased after the certain curing period with curing temperature higher than 40 °C [34]. Similar conclusions at other curing temperatures have been found in cement concrete by many studies [35]. The strength characteristic at different temperature is derived from the microstructure and hydration products characteristics of cement pastes [36]. The hydration reaction of cement in asphalt emulsion is much complicated than in isolated paste [37]. It is essential to study the effect of accelerated curing on cement hydration in bitumen emulsion.

The objective of this research is to investigate the effect of curing conditions on performance of CAEM. The ambient temperature curing and high temperature accelerated curing methods were both considered. The strength parameters, moisture susceptibility and rutting resistance of CAEM were evaluated by several laboratory tests. Furthermore, the samples of cement asphalt mastic (CAM) with different curing procedures were tested by X-ray diffraction and Fourier-transform infrared (FTIR) spectroscopy, and environmental scanning electron microscopy (ESEM).

2. Materials and methods

2.1. Raw materials

The raw materials in this study included aggregates, asphalt emulsion and cement. A limestone aggregate was used in this study. The crushing value, sediment percentage, needle and sheet percentage of the limestone aggregates were at 18%, 0.6% and 11% of the total aggregates weight, respectively. The moisture content and water absorption of aggregates was 0.8% and 1.5% of dry aggregates weight. The designed gradation meets the limits range of dense graded hot-mix asphalt (HMA) for base course [38]. The gradation and its limits are provided in Fig. 1. The selected binder was a cationic bitumen emulsion. The basic properties of the emulsion are presented in Table 1. A type II composite Portland cement (CPC) was used to replace partial weigh of filler. The properties of CPC and limestone filler are both given in Table 2. The test methods of aggregates, bitumen emulsion and CPC were discussed in Chi-

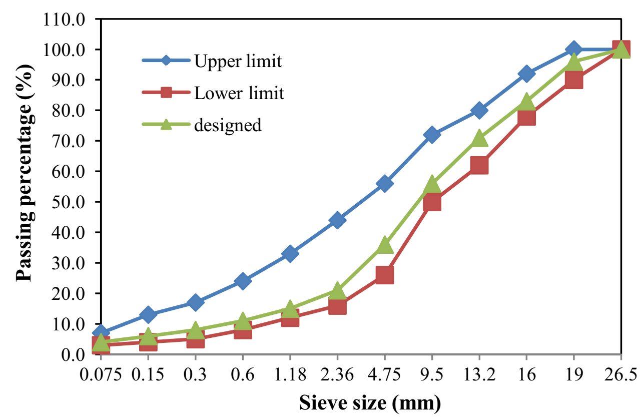

Fig. 1. Gradation of the mixture.

Table 1
Test results of cationic asphalt emulsion.

Properties	Specification	Value
Residue by distillation/%	≥55	62
1.18 sieve test/%	≤0.1	0.05
5 d storage stability/%	≤5	1.9
PH	–	2.7
Residue test		
Penetration (25 °C, 100 g, 5 s)/0.1 mm	45–150	62
15 °C ductility/cm	≥40	69
Soft pointing (R&B)/°C	–	47

Table 2
The basic properties of filler and CPC.

Properties	Filler	CPC
Physical properties		
Density (g/cm^3)	2.703	2.878
Passing percentage at 0.075 mm (%)	97.80	96.50
BET Surface area (m^2/g)	3.326	4.501
Initial setting time (min)	–	270
Final setting time (min)	–	410
7 d compressive strength (MPa)	–	28.9
28 d compressive strength (MPa)	–	41.3
Oxide properties		
CaO (%)	41.2	15.5
SiO_2 (%)	3.9	51.7
Al_3O_2 (%)	–	6.9