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Dynamic characteristics of 100% cold recycled asphalt mixture using asphalt emulsion and cement

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ABSTRACT

This paper aims at investigating the dynamic characteristics of 100% cold recycled asphalt mixture using asphalt emulsion (CRME) and cement. Firstly, dynamic modulus and phase angle of CRME are studied at different curing times. Then, creep and relaxation of CRME are also studied to determine its response at service condition with higher temperature. Lastly, fatigue life of CRME is evaluated in pavement structure and the fracture interface microstructure of CRME is observed by Scanning Electron Microscopy (SEM). The results indicate that CRME is a viscoelastic material and has time-temperature dependence effect both in its early-stage and fully cured stage. The viscoelastic of CRME is significantly weaker than that of HMA. CRME can be depicted by Burgers model and has excellent ability to resist permanent deformation at 60 °C. Fatigue life of CRME is only 1/5-1/10 of ordinary asphalt mixture at high strain, but which still meets the requirement for special heavy traffic (>25,000,000 cycle/track) in road structure. The difference of CRME and HMA in dynamic properties and fatigue life is explained by its internal microstructure. This research may help to better understand the materials property of CRME and benefit to the application of CRME in higher layer of asphalt pavement.

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1. Introduction

More than 60,000,000t of waste asphalt mixtures are produced annually in China. Such a large number of waste asphalt mixtures not only take up a lot of land, but also pollute the environment. On the other hand, the lack of high quality raw aggregates seriously constrains the construction and maintenance in pavement industry, which leads to resource and environmental problems. To resolve this problem, recycling of asphalt pavement has become a hot topic in the past decades (Wang et al., 2016).

There are mainly two methods to reuse recycled asphalt pavement (RAP), hot recycling and cold recycling technologies (Kim et al., 2011). Hot recycling of asphalt mixture has excellent performance similar to that of ordinary asphalt mixture, but it needs reheating RAP and new aggregates. It will surely increase carbon and polluting gas emission. In addition, the ratio of RAP for hot recycling is usually between 20 and 40%, and fine RAP is difficult to be incorporated into recycled mixture due to gradation control (Presti et al., 2016). Cold recycled technology can take advantage of RAP with 80-90 wt% (Stimilli et al., 2013) and has developed dramatically in asphalt pavement rehabilitation in China. Nowadays, cold recycled mixture is usually used in subgrade or under layer (Modarres et al., 2014). It is prone to be used in higher layer with its performance improved, which may bring impressive economical and environmental benefits. However, cold recycled asphalt mixture using asphalt emulsion (CRME) requires a better understanding of its dynamic mechanical properties before being successfully used in upper layers of road.

Currently, pavement design theory is mainly based on Mechanistic-Empirical method and thus properties of pavement materials under dynamic loading are very important. For hot asphalt mixture (HMA), dynamic characteristics including dynamic modulus, phase angel and fatigue life have been comprehensively studied (Nouffou et al., 2014). Dynamic response of CRME has not attracted the same attention because of being used in lower layer in pavement. However, the dynamic properties of CRME are different from HMA due to its composed of asphalt emulsion and cement. In order to further understanding of CRME used in higher layer of

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asphalt pavement structure, dynamic characteristics and fatigue resistance of CRME become a key issue to be studied with the devolvement of cold recycled technology.

Researchers have mainly studied on the static strength (Ji et al., 2016) and strength development of CRME in its curing period (Gómez-Meijide et al., 2016). Nowadays, some researchers have become focused on the dynamic and fatigue characteristics of CRME. Fu and Harvey (2007) considered that the cold mixture with foamed asphalt was a weakly bonded particulate material, but it also had significant stress dependence. Leandri et al (2015) found that CRME are less thermo-sensitive and time-dependent than HMA. Bocci (Bocci et al., 2011) found that CRME had significant temperature sensitivity with low modulus at high temperature and high modulus at low temperature. In addition, CRME could not bear high strain in test and it had a lower fatigue life as compared to HMA. However, Gao (Gao et al., 2016) found that CRME had even longer fatigue life than HMA at a small stress level.

For fatigue life of asphalt pavement used CRME, Kim (Kim et al., 2010) addressed that the pavement using CRME in Iowa state had well durability and long fatigue life. Cox (Cox et al., 2016) indicated that the cold recycled pavement in US-49 sections after 53 months in service were performing satisfactorily and recycled sections were performing slightly better than control section. Xu (Xu et al., 2015) investigated the pavement used CRME in the east of China after 29 months and found that the pavement had a good performance, which indicated that CRME had well fatigue resistance.

Based on these previous studies, the dynamic characteristics of CRME have not been comprehensively studied and some conclusions are mutually contradictory between laboratory and field. In addition, the dynamic characteristics of CRME in different curing times is not focused. The limited information on dynamic response and fatigue life of CRME restrict the road structure design and cannot make recommendation for further using CRME in upper layer in road structure. These problems of CRME provide the motivation to undertake this research.

The objective of this paper is to investigate the dynamic characteristics of CRME, and viscoelastic, creep and fatigue resistance of CRME is researched and compared to conventional HMA. The novelty of this paper is studied the dynamic modulus and fatigue life of CRME in different curing times and the microstructures of CRME is used to explain the changes of dynamic characteristics. The research will be meaningful to further understand the performance of CRME and help to determine the application range for CRME in asphalt pavement.

2. Materials and experiments

2.1. Materials

2.1.1. Asphalt emulsion

Cationic slow-setting asphalt emulsion (CSS) was prepared by colloidal mill with base asphalt binder and cationic emulsifier in laboratory. The specified cationic emulsifier for cold recycled pavement was obtained from Jiangsu province, which was the critical component in CRME and needed to be cared during the mix design process. The basic properties of the asphalt emulsion were shown in Table 1.

Table 1
Properties of asphalt emulsion.

Type	CSS
Residue by distillation (%)	63.2%
Emulsifier content (%)	3.0%
Storage stability at 1d (%)	0.7%
Storage stability at 5ds (%)	1.7%
Penetration of residue, 25 °C	65.5
Ductility of residue, 15 °C	71.2

2.1.2. RAP and gradation

The recycled asphalt pavement (RAP) was obtained from Taigan expressway in Jiangxi Province, China. RAP materials were tested and sieved to determine the gradation curve of cold recycled mixture. The milling RAP in the pavement was divided into 0–5 mm, 5–10 mm and 10–30 mm. The properties of asphalt binder extracted from RAP were shown in Table 2. It was seen that the penetration of asphalt binder was 21.2 (0.1 mm) and the ductility was only 26.2 cm, which indicated that the binder was serious aged after 10 years in service.

Table 2
Properties of the reclaimed Asphalt from RAP.

Type	Results
Penetration (25 °C)/0.1 mm	21.2
Ductility(15 °C, 5 cm/min)/cm	26.2
Soft point/°C	48.1

The gradation of RAP and CRME was shown in Table 3. The gradation of CRME with 100% RAP was determined based on the proportion of RAP milled from the pavement. It was noted that the content of cement obtained from Anhui province was determined as 2% by weight of RAP aggregates, and cement was the important component to improve the early-stage performance of CRME (Nassar et al., 2016).

2.1.3. Design and preparation of CRME

CRME with 100% RAP was designed by modified Marshall Methods in China. This method including three processes. Firstly, the optimum water content of CRME was determined by the density of samples prepared by heavy hammer while the asphalt emulsion content was determined as 4.0%. Then, the optimum asphalt emulsion content was determined by indirect tensile strength of samples prepared by Marshall test under the optimum water content. Lastly, the performance of CRME was examined by indirect tensile strength and moisture damage resistance. During the mix design process, the optimum asphalt emulsion content and water content was determined as 3.5% and 3.8% by weight of aggregates, respectively. One kind of conventional HMA with the gradation of AC-25 was used as comparison. For the HMA, the optimum asphalt content was determined as 3.9% by weight of raw aggregates.

Cylinder CRME specimens were prepared by SGC (Superpave Gyratory Compactor) with 60 cycles, the specimen with 170±3 mm in height and 150 mm in diameter were prepared. Then, the CRME specimens were covered with a plastic film except the surface to allow water to evaporate through the top surface only. One group of CRME specimens were placed at the room with temperature of 20 °C and humidity of 60% for 7d (day), 14d and 28d to simulate curing in environment, while the other group of specimens were placed in oven with the temperature of 65 °C for 21-d to simulate fully cured.

2.2. Experiments

2.2.1. Dynamic modulus test

Dynamic modulus and phase angle was tested according to specification for asphalt mixture according to AASHTO T342 and JTJ E20-2011. Five temperature including −10 °C, 5 °C, 20 °C, 35 °C and 50 °C were chosen and the frequency range was determined as 0.01–25Hz. The test picture is shown in Fig. 1.

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