Construction and Building Materials 107 (2016) 109–116

Contents lists available at ScienceDirect

Construction and Building Materials

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

Evaluation of anti-icing performance for crumb rubber and diatomite compound modified asphalt mixture

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HIGHLIGHTS

- Crumb rubber and diatomite compound modified asphalt mixture was prepared.
- Mechanical properties of compound modified mixture were improved.
- Evaluation of ice breaking rate by image processing technology was satisfactory.
- Correlations of different factors with ice breaking rate were investigated.

ARTICLE INFO

Article history:
Received 10 October 2015
Received in revised form 24 December 2015
Accepted 5 January 2016
Available online 9 January 2016

Keywords:
Crumb rubber
Diatomite
Anti-icing
Image processing
Correlation analysis

ABSTRACT

In this paper, anti-icing performance of crumb rubber and diatomite compound modified asphalt mixture was evaluated. Firstly, compound modified mixture was prepared in laboratory. Corresponding volumetric parameters and mechanical properties were compared and verified. Secondly, anti-icing test specimens were produced and measured by self-designed apparatus. Ice breaking rate calculated from image processing technology was adopted to assess the anti-icing effect, and correlation analysis was used to evaluate the influence of factors including rolling time, ice thickness, testing temperature and load frequency. Finally, the effects of these factors on anti-icing performance of modified mixture were investigated. Results indicate that the mechanical properties of control asphalt mixture have been improved by crumb rubber and diatomite. The correlation of rolling time for ice breaking rate is strong positive, while it is strong negative of ice thickness and very strong positive of test temperature. Weak correlation between load frequency and ice breaking rate is also observed. The results can provide a reference for anti-icing pavement design using crumb rubber and diatomite compound modified asphalt mixture.

1. Introduction

Bituminous materials have been widely used in highway pavement, and got satisfactory application effects [1]. As for conventional hot asphalt mixture, it should possess favorable properties to resist the influence of heavy traffic and environmental factors. However, the effect on durability of hot asphalt mixture is profound because of its viscoelastic property. The consequences are rutting or permanent deformation at high temperature, cracking at low temperature and fatigue at moderate temperature [2,3]. In order to overcome these deficiencies, various methods have been used to modify the asphalt by improving its viscoelastic behavior.

Diatomite is a widely used mineral with low cost and considerable storage, which has high absorptive capacity and stability [4–6]. It has been used to improve the performance of asphalt. Cong et al. [7] investigated the effects of diatomite on properties of asphalt. The results indicated that no chemical reaction was found between diatomite and asphalt. Both viscosity and complex modulus increased after modification at high temperature. However, the complex modulus decreased below 5 °C, which would result in low temperature cracking of asphalt mixture. Song et al. [8] studied the absorption rule of diatomite and asphalt. The results suggested that diatomite could effectively absorb lower molecular group and form anchorage structure, which improved the property of asphalt. Cheng et al. [9] investigated the effects of diatomite on aging properties of asphalt. The results indicated that diatomite could improve the high temperature stability and antiaging property. However, it had adverse effects on ductility and low temperature property.

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http://dx.doi.org/10.1016/j.conbuildmat.2016.01.003
0950-0618/

As shown from above results, diatomite-modified asphalt mixture has better high temperature performance and thermal physical property. However, its low temperature performance is negatively affected. Therefore, the pavement using diatomite-modified asphalt mixture is more easily to emerge low temperature cracking. This phenomenon will seriously influence the application of diatomite-modified asphalt mixture in low temperature areas such as seasonal frozen regions [3].

Crumb rubber is another bitumen modifier, which is produced from end-of-life tyres (ELTs). The increasing number of vehicles in worldwide generates millions of used tyres each year. The amount of ELTs is 290 million in 2003 in US, 355 million each year in Europe, and 200 million in 2010 in China. Moreover, the annual growth rate of used tyres is over 10% [10–13]. Millions of used tyres have been illegally disposed, which may pose great threat to human health and cause serious environmental risks. In recent years, crumb rubber obtained from ELTs is used in asphalt mixture, which can improve its low temperature, high temperature and fatigue performances [14–16]. Moreno et al. [17] analyzed the effect of crumb rubber modifier on asphalt. The results showed that crumb rubber modifier increased the stiffness modulus and creep modulus and improved the resistance to plastic deformation of bitumen. Xiang et al. [18] investigated the properties of crumb rubber on performance of modified asphalt. The results indicated that the crumb rubber modified asphalt have better performance than matrix asphalt. Dias et al. [19] evaluated the mechanical response of gap-graded asphalt rubber mixture produced through dry process. Comparative analysis with reference mixture indicated that asphalt rubber mixture not only is less sensitive to high temperature but also improves fatigue cracking performance. Palit et al. [20] compared the performances of crumb rubber modified asphalt mix with control one. It was found that the modified mix has better fatigue and permanent deformation properties, lower temperature susceptibility and greater resistance to moisture damage.

Lots of studies have been conducted on the properties of diatomite-modified asphalt and crumb rubber-modified asphalt. However, the study on crumb rubber and diatomite compound modified asphalt is still limited. A more favorable pavement material can be obtained if the compound modified asphalt possesses the advantages of both diatomite and crumb rubber modified ones.

Moreover, ice on pavement surface in cold winter is a great threat to traffic safety. Investigation data indicates that 15–30% of the traffic accidents are caused by snow and ice [12,21]. Therefore, anti-icing pavement is important and widely used in the world [21–24]. According to research results by Zhou and Tan [25], pavement using crumb rubber modified asphalt has better anti-icing performance than conventional one.

In this paper, diatomite and crumb rubber compound modified asphalt mixture was prepared. Changes of volumetric parameters and mechanical properties of asphalt mixture before and after modification were investigated. Using image processing technology and correlation analysis method, the effects of rolling time, ice thickness, testing temperature and load frequency on anti-icing performance of modified mixture were discussed and analyzed.

2. Materials

2.1. Raw materials

Physical properties of AH-90 neat asphalt were tested and given in Table 1. Andesite mineral aggregate was chosen for its excellent adhesion with asphalt, and the physical properties of which were listed in Table 2. The mineral filler used was limestone powder. Physical properties of filler were shown in Table 3. Physical properties and particle distribution for diatomite were listed in Tables 4 and 5. Crumb rubber particle was obtained from the waste tire rubber, whose properties were shown in Table 6.

2.2. Mixture preparation

Stone Mastic Asphalt (SMA) was widely applied in asphalt road construction for its good performance. Thus, the SMA-13 gradation was used in this investigation. The Course Aggregate Void Filling (CAVF) method was employed in the mixture design procedure for SMA-13 [25]. The design gradation was shown in Fig. 1. The diatomite content 15% by weight of asphalt was validated through experiment. And the crumb rubber content 3% by weight of aggregate was determined by volumetric parameters and Marshall stability of mixtures. In this research, the optimum asphalt aggregate ratio for the crumb rubber and diatomite compound modified mixtures was 6.3% according to Marshall design method.

In order to make the crumb rubber and diatomite dispersed homogeneous in the mixture, the blend process was optimized. Firstly, aggregates and crumb rubbers are mixed in mixing pot for 90s in order to make crumb rubber fully dispersed in aggregate. That is because the density of crumb rubber is lower than aggregate, which is easy to agglomerate in the process of mixing, and lead to the reduction of workability for mixture. Then, asphalt is added into aggregate and crumb rubber for mixing 90s, crumb rubber modified asphalt mixture is obtained. According to our

Table 1
Physical properties of neat asphalt.

Property	Value	Technical criterion [a] (%)
Penetration(25 °C, 0.1 mm)	93	80–100
Penetration index (PI)	−0.83	−1.5 to +1.0
Softening point $T_{R\&B}$ (°C)	44.0	⩾42
Ductility (15 °C, cm)	165.1	⩾100
Flash point (°C)	277	⩾245
Specific gravity (15 °C, g/cm^3)	1.090	–
After TFOT		
Mass loss (%)	−0.2	⩽±0.8
Penetration ratio (25 °C, %)	62.4	⩾57
Age ductility (10 °C, cm)	10	⩾8

[a] The technical criterion was based on Standard JTG F40-2004 [3].

Table 3
Physical properties of mineral powder.

Property	Hydrophilic coefficient	Apparent density (g/cm^3)	Gradation	
			Sieve size (mm)	Passing (%)
Value	0.80	2.741	0.6	100
			0.15	95.4
			0.075	86.3

Table 2
Properties of aggregate.

Sieve size (mm)	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Apparent density (g/cm^3)	2.866	2.867	2.894	2.705	2.640	2.697	2.637	2.502	2.529
Bulk density (g/cm^3)	2.795	2.785	2.783	–	–	–	–	–	–