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Influence of the properties of filler on high and medium temperature performances of asphalt mastic

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HIGHLIGHTS

- Four fillers including limestone, hydrated lime, fly-ash and diatomite are studied.
- Five tests are conducted on fillers and four tests are conducted on asphalt mastics.
- The high/medium temperature performances of DAM are better than that of LAM, HLAM and FAM.
- Correlation degrees between properties of filler and performances of mastic are studied.
- SSA is expected to be the most influential property on performances of asphalt mastic.

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ABSTRACT

Filler is the main component of asphalt mastic and its properties are closely associated with the performances of asphalt mastic. To investigate the relationship between properties of fillers and performances of asphalt mastic, four fillers including limestone, hydrated lime, fly-ash and diatomite were selected to prepare corresponding asphalt mastics. The density, specific surface area, particle size distribution, mineralogy component and hydrophilic coefficient of fillers and softening point, viscosity, force ductility and dynamic rheological property of asphalt mastics with different fillers were tested. Grey relational analysis (GRA) method was employed to determine the correlation degree between properties of fillers and high/medium temperature performances of asphalt mastics. Results showed that four fillers presented differences in density, specific surface area, mineralogy component and hydrophilic coefficient. Besides, softening point, viscosity, deformation energy and complex modulus of diatomite asphalt mastic were higher than that of other three filler-asphalt systems. Furthermore, specific surface area was suggested to be the most influential property on the high and medium temperature performances of asphalt mastic in comparison with other properties based on the results of GRA.

1. Introduction

Asphalt mixture is the most widely used material in pavement due to its superior in-service performance. In practice, pavement performance is related to the cohesion and adhesion properties of asphalt mastic [1,2]. Asphalt mastic is generally made by mixing asphalt binder with certain percentages of fillers which is a fundamental dispersed system in asphalt mixture [3]. The filler provides necessary cohesion between components to form asphalt mastic and increase stiffness of asphalt mixture [4,5]. Therefore, filler is an important component which affects the properties of asphalt mastic and furtherly influence the performance of asphalt mixture. It is necessary to investigate the relationship between properties of filler and performances of asphalt mastic.

There are many kinds of fillers used for construction of asphalt pavement, such as limestone filler, basaltic filler, hydraulic lime, Portland cement, hydrated lime, fly-ash, diatomite, etc. [1,4–10]. Results from these literatures indicated that using fillers like hydrated lime, fly-ash and diatomite, etc. instead of the most commonly used limestone are beneficial to improve the properties of filler-asphalt system and corresponding asphalt mixtures.

In order to analyze the influence of filler on properties of asphalt mastic, a number of researches have been carried out. Yiqiu et al. [3] studied the effects of filler/asphalt ratios on high-temperature and low-temperature properties of different asphalt-mineral filler mastics and found that the rheological behavior of

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asphalt-mineral filler mastics were nonlinear, and followed an exponent function model. Hesami et al. [11] also investigated the relationship between the filler concentration and the viscosity of asphalt mastic. They developed a new empirical framework which consisted of Einstein equation and Frankel equation based on the theory of suspensions. The model indicated that viscosity of asphalt mastic nonlinearly increased with the increasing of filler concentration. Lackner et al. [12] studied the effect of filler on the low-temperature creep of asphalt mastic with the Mori–Tanaka scheme. They found that only the volume fraction of filler had an effect on the creep properties of asphalt mastic while the shape and the chemical composition of the filler particles did not influence low-temperature creep. These researches demonstrated that the rheological behaviors of asphalt mastic at high and low temperatures are significantly influenced by the filler concentration.

Furthermore, Antunes et al. [1,13] studied the effect of geometrical properties, physical properties and chemical composition of fillers in filler-bitumen interaction. They found that specific surface, fractional voids and bitumen number were inter-correlated. Hydrated lime had very high stiffening power which was explained by their geometric characteristics. Besides, their findings showed that chemical composition of filler was not directly related to stiffening effect in mastic. Nevertheless, Movilla-Quesada et al. [4] studied the effect of mineralogy, size and shape of filler particles on stiffness of filler-asphalt system. They suggested that filler particle size and mineralogical characteristics would influence the stiffening effect and adhesion in filler-asphalt system. Robati et al. [14] carried out an interesting work on filler stiffening effect on asphalt mastic of microsurfacing. They proposed a new conceptual model which described mastic stiffness (G^*) as a function of filler concentration with only one parameter. Besides, a quantitative relationship between model parameter and properties (Rigden voids, effective filler size, PH and methylene blue value) of filler was developed, which enabled that the optimum filler amount could be conveniently obtained without testing the properties of mastic or asphalt mixture at different filler concentrations.

According to current researches, properties of asphalt mastic are related to the concentration and physical, geometrical and chemical properties of filler. Rheological properties of asphalt mastic at high and low temperature are nonlinearly changed with the increasing of filler concentration [3,11,12,14]. The adhesion and stiffening effect in filler-asphalt system are more or less influenced by the physical, geometrical and chemical properties of filler [1,4,13,14]. However, relationships between properties of filler and performances of asphalt mastic are not clear and the property which mostly influences the performance of asphalt mastic has not been definitely suggested. It is meaningful to make clear that the effect of properties of filler on performance of asphalt mastic in order to improve the in-service performance of asphalt pavement. This can also provide a reference for evaluation of filler in the construction of asphalt pavement.

Grey relational analysis (GRA) is part of grey system theory which proposed by Professor Deng in 1982 [15]. It was widely used in many fields to analyze the optimum selection or evaluate the influential degree of factors in uncertain systems [16–20]. Du et al. [20] and Shen et al. [21] applied the GRA in the design of asphalt mixture. Jiang et al. [22] analyzed the influential factors on pavement performance of conductive asphalt concrete with the use of GRA. Shen et al. [23] also evaluated performances of HMA with reclaimed building materials by the application of GRA. And Feng [24] employed the GRA to analyze the influential factors on anti-rutting factor and fatigue factors of asphalt mastic based on the results of DSR. These researches demonstrated that it was helpful and effective to evaluate the influential factors and optimize the design of materials by the application of GRA. Hence, it is employed in this paper to find out the most influential properties of fillers on performances of asphalt mastic.

Therefore, the relationships between properties of filler and performances of asphalt mastic were investigated by the application of GRA in this paper. Four fillers including limestone, hydrated lime, fly-ash and diatomite were selected. The density, specific surface area (SSA), particle size distribution and hydrophilic coefficient (HC) of four fillers were tested. The Limestone asphalt mastic (LAM), hydrated lime asphalt mastic (HLAM), fly-ash asphalt mastic (FAM) and diatomite asphalt mastic (DAM) were prepared using high-shear homogenizer. The high (higher than 40 °C) and medium (from 5 to 40 °C) temperature performances of four mastics including softening point, viscosity and force ductility were tested. Considering that the geometry and the chemical composition of filler particles does not influence low-temperature (lower than 5 °C) creep of asphalt mastic, which was demonstrated by Lackner et al. [12], herein the low temperature performance of asphalt mastic was not investigated. Relationships between properties of fillers and performances of asphalt mastics were investigated based on grey relational analysis (GRA).

2. Materials and methods

2.1. Asphalt

The asphalt AH-90 (penetration grade 80/100) used in this paper came from Panjin Petrochemical Industry, Liaoning Province of China. The main physical properties of neat asphalt are given in Table 1.

2.2. Filler

Limestone, hydrated lime, fly-ash and diatomite are selected to prepare the asphalt mastics in this paper. The selected limestone is traditional filler used in the construction of asphalt pavement, which is obtained from local stone factory in Jilin Province. Hydrated lime is selected because it is the most widely used anti-stripping agent of asphalt mixture [5], which is a commercial production with more than 95% of $Ca(OH)_2$ and produced in Tianjin Municipality. Fly-ash is the main solid waste produced from coal-fired thermal power plant, which has been widely applied for construction materials. Not only the performance of asphalt mixture could be improved by the addition of fly-ash, but also the costs and environmental impact are reduced [6]. The selected fly-ash is from Henan Province. Diatomite is a sedimentary rock composed of fossilized skeletons of diatoms, which is a potentially excellent filler applied in construction of asphalt pavement [8–10,25]. Selected diatomite is calcined product from the Changbai area of Jilin Province. The morphology of four fillers is shown in Fig. 1.

2.2.1. Density

The density of filler is tested according to LNEC E 64-1979 [26]. Firstly, pyknometer is filled with kerosene to appropriate mark and the pyknometer is immersed in 20 °C water bath. The first reading of liquid volume is recorded when constant temperature in the flask has been achieved. Then, fillers are added into pyknometer till liquid level close to the maximum reading and the mass of filler tipped in the pyknometer is recorded. The stopper is placed and pyknometer is rolled to remove all adhering air. Finally, the pyknometer is immersed in the water bath till the temperature variations in excess of 1 °C and the final reading is got.

2.2.2. Specific surface area (SSA)

Specific surface area (SSA) is a basic physical property of filler, which directly affect the adsorption capacity in mixing with asphalt [1]. BET method is employed to test the specific surface area of fillers based on Brunauer-Emmett-Teller (BET) theory [27,28]. The BET SSA of selected filler is determined using N_2 as adsorbate.

Table 1
Physical properties of neat asphalt.

Property	Result
Penetration (25 °C, 0.1 mm)	90
Softening point $T_{R\&B}$ (°C)	42.6
Ductility (15 °C, cm)	>100
Density (g/cm^3)	1.014
After TFOT	
Mass loss (%)	0.37
Penetration ratio of 25 °C (%)	59