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Multiscale test research on interfacial adhesion property of cold mix asphalt

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HIGHLIGHTS

- Cold-mix diluents and additives can increase surface free energy of pure asphalt.
- Limestone has the largest SFE and adhesion work to asphalt in dry condition.
- Cohesion and adhesion failure usually occurs in dry and damp condition respectively.
- A good correlation exists between macro mechanical indicators and energy indices.
- Limestone is generally better at resisting moisture damage than granite and basalt.

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ABSTRACT

In order to establish proper evaluation methods and indicators for cold mix asphalt (CMA), various scales test methods were used to study the interfacial behavior between asphalt binder and aggregate. The surface free energy of asphalt binder was tested using sessile drop method, and the surface free energy of aggregate was measured using column wicking method. The adhesion work between asphalt and aggregate, moisture damage resistance indices were calculated using the basic surface free energy components. Macro mechanical adhesion property between asphalt binder and aggregate in two conditions (dry and damp) were obtained through the pull-off test. A freeze–thaw splitting test was conducted to verify the effectiveness of energy indices. The results show that diluents and additives used in cold mix asphalt can increase surface free energy of pure asphalt. Limestone has the largest surface free energy, and the largest adhesion work to asphalt in dry condition. Cohesion failure usually occurs in dry condition, while adhesion failure corresponds to damp condition. There are strong correlations between macro mechanical evaluation indicators and surface free energy calculated indices, which indicates that energy indices are a good method to quantize the moisture damage resistance of CMA. Limestone is generally better at resisting moisture damage than granite and basalt.

1. Introduction

Nowadays, asphalt pavement is used widely as one of main pavement styles. However, over time its performance will degenerate, and many kinds of distresses can occur, such as potholes. In southern China, many pavements are located in moist highland mountainous areas, and ice freezing usually occurs, which can easily lead to a pitted, loose surface with many potholes. In order to solve these problems, and recover the traffic capacity of road in a short time, the maintenance department usually applies cold mix asphalt (CMA) as an emergency repair. CMA has several advantages over the more common HMA, particularly the fact that it requires no heat to manufacture or lay over the pavement. As a result, such pavement has less of an environmental impact, is more cost effective, and requires less energy consumption. However, the performance of cold mix asphalt is usually worse than hot mix asphalt or warm mix asphalt because of the limited construction conditions, especially in terms of adhesion properties and moisture damage resistance. In addition, the evaluation methods and indicators related to cold mix asphalt are also not very clear and convincing.

Many researchers have done a lot of work evaluating cold mix asphalt, and they have found that there are obvious difference between CMA and HMA. Anna Abela Munyagi evaluated the proprietary cold mix asphalts available in South Africa. He found

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that the Indirect Tensile Strength values of all the tested cold mix asphalt were very low compared to minimum value of 800 kPa specified for Hot Mix Asphalt. And all tested cold mix asphalt were highly susceptible to rutting compared to Hot Mix Asphalt [1]. In order to solve the rutting problem of cold mix asphalt, Chavez-Valencia et al. thought that the compressive strengths of cold mix asphalt must be improved. For this reason they added polyvinyl acetate emulsion (PVAC-E) to a cationic quick set emulsified asphalt to obtain a modified asphalt emulsion that was mixed with a local aggregate in order to prepare two types of CMA. They found that the compressive strength was improved by 31% compared to the values obtained with the unmodified CMA [2]. Similarly, Benedito et al. selected fiber to reinforce CMA, and they found the addition of fiber is responsible for a small variation in mixture strength parameters, as well as for substantial drops in the mixture resilient moduli when compared to plain mixtures [3]. Al-Busaltan et al. used waste materials to mix a new CMA, and found it has superior mechanical properties compared to traditional HMA [4]. Due to the associated peculiarities with cold asphalt encompassing the presence of water, emulsion–aggregate reactivity, evolving characteristic with time and an undeveloped internal structure, CMA does not lend itself very well to investigation of the influence of material and/or process variables, such as moisture condition, on its mechanical properties [5]. Hussain et al. did research on the effects of moisture ingress on the mechanical properties of a cold-laid grave emulsion asphalt mixture by developing a vacuum moisture saturation technique. They found that the cold mixture's results were only marginally lower, even though the hot mixture had good fracture properties. The vacuum saturation treatment led to enhanced yield performance at low temperatures of both mixtures in the fracture test. The high level of moisture treatment given to the cold mixture made it behave like the hot asphalt mixture at low temperatures [6]. In terms of assessment methods for CMA, Thomas et al. presented the development of a maturity approach for the assessment of cold mix bituminous materials and its application for predicting the effects of climatic variations on in-situ mixture performance. They observed a strong correlation existing between the calculated maturity and the measured stiffness for a range of conditioning temperatures and durations thus enabling the prediction of long and short-term materials performance in situ where ambient conditions are known [7].

In order to evaluate the moisture damage resistance of asphalt mixture, most researchers focus on the experiential methods, such as immersion Marshall test and freeze–thaw splitting test. Recently, some researchers paid attention to the interface adhesion property in asphalt mixture, and they think it can explain the moisture damage mechanism substantially [8–11]. Bhasin et al. thought that physical adhesion is probably the adhesion component (as opposed to the chemical interactions and mechanical interlocking) that predominantly contributes to the overall adhesion of the asphalt–aggregate systems. They found that surface free energy is an effective method to study the adhesion property, and they successfully obtained the surface free energy parameters for asphalt binder and aggregate [9]. Following that, Tan and Guo used different methods to test surface free energy parameters of asphalt binder and fillers, and calculated the adhesion work of asphalt mastic [12]. Based on surface free energy, Bhasin et al. proposed two parameters to evaluate the moisture damage resistance of asphalt mixture [9,13]. In the study of asphalt mixture, there are two main methods of evaluating moisture damage resistance. One is the traditional experimental method, and the other is quantized surface free energy method. However, the relationship between the two scales is not very clear currently.

Our research focused on the adhesion property between asphalt and aggregate based on surface free energy theory and mechanical pull-off test, and analyzed the relationship among different scales adhesion properties. This is significant for the establishment of evaluation methods and indicators for cold mix asphalt.

2. Materials and test methods

2.1. Experimental materials

2.1.1. Asphalt binder

The grade of asphalt binder used in our research is 90. Its basic properties are shown in Table 1.

2.1.2. Aggregate and filler

The chemical constituent and surface morphology both play an important role in enhancing the adhesion property between asphalt binder and aggregate. Generally, alkaline aggregate has better adhesion property than acidic aggregate. In our research, we selected three kinds of aggregates: granite, limestone and basalts. Fillers were made from the above aggregates through magnetic milling.

2.1.3. Diluents

The viscosity of asphalt binder at low temperature is very high, so some diluents must be used to decrease its viscosity to improve the workability. The diluents used in our research include 0# diesel, 90# gasoline, ordinary kerosene and aviation kerosene. Their basic properties are shown in Table 2.

2.1.4. Additives

The diluents can make the asphalt binder much softer, but at the same time they can also change other properties of asphalt binder so that the asphalt mixture cannot meet the actual requirements. So we added some additives to improve the performance of cold mix asphalt. Generally, the additives can improve the adhesion property between asphalt binder and aggregate to enhance the moisture damage resistance ability. It can also increase the early strength of CMA while improving the workability. We selected four typical kinds of additives, which are KN, LB, GS and SJ.

2.1.5. Grading of mixture

The grading of mixture used in our research is shown in Fig. 1, and its optimum asphalt content is 5.3%.

2.2. Laboratory testing methods

2.2.1. Sessile drop method

Sessile drop method used in our research is similar with literature [12], and the surface free energy parameters of three kinds of test liquids are shown in Table 3.

In order to study the effect of diluent types, additive types, diluent content, and additive content on surface free energy of asphalt binder, we applied orthogonal experiment design method. The design plan is shown in Table 4. The test results are shown in Table 5.

Table 1
The basic properties of 90# asphalt binder.

	Items	Units	Results	Requirements
Before aging	Penetration (25 °C, 100 g, 5s)	0.1 mm	83.3	80∼100
	Penetration Index	–	0.47	−1.5∼ + 1.0
	Ductility	cm	133	⩾100
	Soft point	°C	51.4	44
	Density (15 °C)	g/cm^3	1.03	–
	Flash point (COC)	°C	310	⩾245
After aging	Mass loss	%	0.75	⩽±0.8
	Residual ductility, (5 cm/min, 15 °C)	cm	22	⩾20
	Residual penetration ratio (25 °C, 100 g, 5s)	%	66.8	⩾57