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Effect of tack coat dosage and temperature on the interface shear properties of asphalt layers bonded with emulsified asphalt binders

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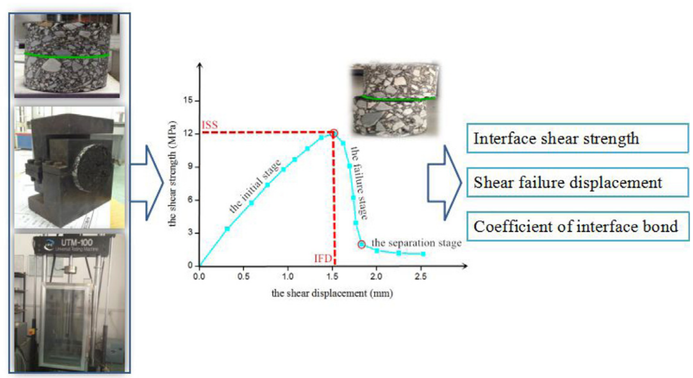
HIGHLIGHTS

- The interface characteristics depend on tack binder type and temperature.
- The favorable flowability of tack binder is crucial for the shear strength.
- The high viscosity of residual binder enhanced the interface shear strength.
- The high dosage of tack binder improved the shear properties at low temperatures.

GRAPHICAL ABSTRACT



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ABSTRACT

The shear strength of the interface of asphalt concrete structure has a great influence on the mechanical properties and durability of asphalt pavement. This paper describes the experimental design and analysis of the shear properties of the interface between asphalt layers. A self-designed device was employed to measure the direct shear strength of the interface with the aid of the Universal Test Machine (UTM-100). The effect of temperature, dosage of tack coat and type of tack coat on the shear properties of the interface were studied through laboratory testing. Two types of emulsified asphalt binders, namely PC-3 and HV, were selected as the tack coats. The property was evaluated in three tack coat dosages (0.25 Kg/m^2, 0.5 Kg/m^2 and 0.75 Kg/m^2 based on residual binder) and at four test temperatures (−10 °C, 0 °C, 25 °C and 50 °C). Hence, a total number of 72 composite specimens made of AC-13 and AC-20 were subjected to the shear test to evaluate the interface shear characteristics in terms of interface shear strength, the shear failure displacement and the coefficient of interface bonding at the initial stage of shear. The results showed that the shear strength at the interface decreases gradually with increasing temperature. The least failure shear displacement of all specimens was observed at the highest temperature of 50 °C. Moreover, the results indicated that the brittleness at low temperatures, the flowability at intermediate temperatures, and the viscosity at high temperatures of tack binder have the most significant effects on the shear property of the interface of asphalt pavement.

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1. Introduction

The structure of the asphalt pavement is a typical multi-layered system, and the stress-strain distribution of the pavement is influenced, to a degree, by the bonding property of the interface. Generally, the asphalt pavement interface contains prime coat and tack coat. Both the prime coat and tack coat are influential factors in providing an integrated structure for transmitting stress of pavement subjected to traffic loading and changing environmental conditions. Hence, the interface bonding property between asphalt layers plays an important role in the mechanical behavior, durability performance and fatigue characteristic of asphalt pavement. Slippage is one of the typical distresses caused by de-bonding of the interface of the pavement structure. Furthermore, slippage has an adverse influence on traffic safety and increased the extent of damage of the pavement structure.

To explore the properties of the interface, many tests and devices, including tensile, torsion and shear tests, had been studied. In terms of interface shear property, the direct shear test is one of the popular methods investigating bonding characteristics between asphalt layers. The mechanical behavior of de-bonding and slippage can be simplified as a shear model [1]. In order to measure the shear strength of the interface, the direct shear test has been widely applied due to the mobility and effectiveness of the device. Raab et al. evaluated some popular interlayer shear bond devices for asphalt pavements [2]. D'Andrea et al. investigated the shear and fatigue properties of the interface of asphalt layers through the dynamic shear test and designed a finite element model to evaluate the stress state of the interface under wheel loading [3–6].

Regards of the contacting properties of the interface between the surface and base layer, Kruntcheva et al. investigated the influence of interlocking on the distribution of stress in the interfacial regions and found that the bearing capacity of pavement decreased with the rising stress level applied to the layer [7]. However, Kruntcheva et al. concluded that appropriate compaction is necessary to obtain a sufficient interlock based on the Nottingham shear test [8]. Miró Recasens et al. selected thermo-adherent emulsified asphalt as the tack coat binder and found that the appropriate dosages of residual asphalt binder ranged from 300 to 400 g/m^2 [9]. Raposeiras et al. focused their study on the effect of dosage of emulsified asphalt binder and the surface macro-texture of asphalt mixtures on the adhesion of tack coat and found that there exists an optimal tack coat dosage for obtaining the maximum shear strength on the base of the rough texture of 0.17 mm [10]. In addition, Raposeiras et al. developed a model to determine the optimal dosage of emulsified asphalt binder to ensure enough shear strength based on aggregate grading of asphalt mixtures [11]. Therefore, the dosage of tack binder should be applied within a certain range, as excess binder results in slippage while an insufficient dosage cannot provide sufficient bond strength. Baek et al. investigated the effects of interface conditions on the development of reflective cracking in HMA overlays by developing a three-dimensional finite model and found that the fractured area of the interface increased slightly as the interface stiffness became higher [12]. Song et al. investigated the shear fatigue features of interlayer between open-graded friction course and underlying layer through the direct shear fatigue test, and found that the dissipated energy decreased with increasing tack coat dosage [13]. Cho and Kim designed a modified advanced shear tester (MAST) for evaluating the interface shear bond strength of cylindrical specimen and developed a prediction model for interface shear strength of asphalt layers bonded with different tack coats [14]. Yao et al. selected epoxy asphalt and polymer modified asphalt as tact coat materials, and found that the shear strength increased with the increase in normal stress level in terms of steel-asphalt interface [15].

Temperature was a crucial factor for bonding characteristics of the interface, especially high temperatures. At low temperatures, the tack coat binder becomes stiffer and exhibits strong shear strength. When temperature reaches the softening point of emulsified asphalt binder, the tack binder becomes more flowable, and the shear strength is gradually reduced [16]. Bae et al. conducted a study on the effect of temperature on the interface shear strength of the interface of emulsified tack coat and concluded that the shear strength of the interface of the layers increased with decreasing temperature. Moreover, the relationship between the shear strength of the interface and the rheological parameter $G*/\sin\delta$ of binder is also investigated in the study [17].

Moreover, the curing time of emulsified asphalt is an important factor for the bonding property of tack coat. Deysarkar found that the de-emulsification time has a great influence on the shear strength of the interface between composite specimen layers. Waiting 30–60 min to compact the top layer can make the interface shear strength stronger than those within a 5 min wait after the application of tack coat [18]. Jaskula selected four compaction methods to analyze the interlayer bonding of asphalt layers and found that the shear strength of the interface of the double-layered specimen compacted by the Super Gyratory Compactor is relatively higher than that of the other compaction methods [19]. Tajdini found that the residual moisture at the interface has an adverse influence on the shear strength of the interface [20]. For the purpose of increasing the connection strength of the prime coat, Ge et al. used nails to connect the two layers [21].

Many studies on the shear property of the interface have been investigated so far. This paper takes the typical climate characteristics and asphalt pavement structure of the Central-southern China into consideration. This area is important for china's transportation system because of the large amount of important expressways, and the climate characteristics of the area are diverse. As shown in Fig. 1, the air temperature of the area ranges from −17.9 °C to 41.9 °C. Due to the absorption of heat from sunshine, the actual temperature of asphalt pavement may vary from −10 °C to 50 °C. Such a wide temperature range makes it necessary to investigate the interface of the typical asphalt pavement structure in that area.

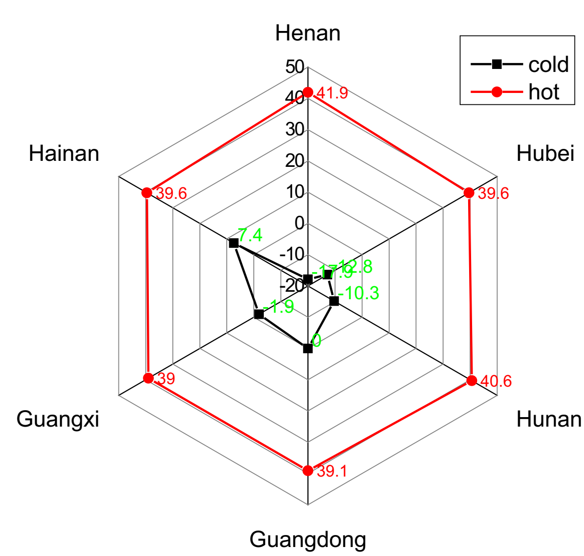

Fig. 1. The temperatures in six provinces of the Central-south China, unit: °C (Source: http://data.cma.cn).