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Blending efficiency evaluation of plant asphalt mixtures using fluorescence microscopy

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HIGHLIGHTS

- A procedure based on fluorescence microscopy for mobilization rate was proposed.
- The mobilization rate was calculated on the basis of aggregate surface area.
- Compared with hot mix, warm mix showed a slightly higher mobilization rate.

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ABSTRACT

With the use of high percentage recycled asphalt pavement (RAP), there is an increasing concern over how much of the aged binder in RAP that can be blended into virgin binder. In this study, a laboratory procedure was proposed based on fluorescence microscopy for quantifying the mobilization rate of aged binder in plant-produced RAP mixtures. This procedure was derived from the mean gray value of an asphalt-coated aggregate particle. A linear blending chart was developed and used to relate aged binder content to the mean gray value of binder blend. The mobilization rate of aged binder was calculated on the basis of surface area proportion of aggregates with different size. Three types of asphalt mixtures, including one warm mix with foaming technology, two hot mixes with or without rejuvenator, were used to validate the proposed method. Results indicated that the mobilization rate varied by aggregate type (virgin or RAP). Compared with hot mix, warm mix with foaming technology showed a slightly higher mobilization rate.

1. Introduction

With the ever-increasing cost of aggregate and asphalt binder, the incorporation of recycled asphalt pavement (RAP) into asphalt mixtures has become more and more popular [1–4]. The use of RAP can produce significantly economic and environmental benefits. RAP has gone through a service life of aging and its binder has become highly stiff and brittle. In the production process, RAP is heated by hot aggregate instead of directly by fire to avoid further aging. Therefore, the stiff binder on RAP may not be able to flow freely. Lack of a clear understanding of blending efficiency of recycled asphalt has been a major concern in determining the effective asphalt binder in asphalt mixtures containing RAP. The blending efficiency is defined as the percentage of the aged asphalt binder in RAP that can be blended into virgin asphalt binder and thus become available to coat aggregate. If RAP binder is not 100% blended with virgin binder, the effective asphalt content in a mixture would be lower than its design asphalt content and the mixture performance be compromised.

Previous studies [5–8] have shown that partial blending happened during the mix process of RAP. This conclusion indicates that only part of the aged binder can be utilized to coat the aggregate. Under this situation, the assumption of 100% blending efficiency may result in two problems. First, the coating of virgin aggregate will be too thin to reach the target film thickness. Second, the binder on RAP aggregate will be stiffer than expected, lowering resistance to fatigue and low temperature cracking. Therefore, it is critical to accurately determine blending efficiency of RAP mixtures.

The methods for determining blending efficiency are based on two major categories of asphalt properties: chemical properties and mechanical properties. Mechanical property method involves

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measuring dynamic modulus [9], binder content [10,11], and so on. Chemical property methods use such chemical testing techniques as gel permeation chromatography (GPC) [4,5,7,12,13], Fourier transform infrared (FTIR) [5] and fluorescence microscopy [14] to determine the RAP binder content in a blend of virgin and RAP binders. Among the above-mentioned chemical techniques, GPC and FTIR methods need to extract asphalt binder from aggregate particles to make samples for further testing. Therefore, the heterogeneity of binder on aggregate cannot be determined. In addition, the process of using chemical a chemical solvent to dissolve asphalt binder makes the test time-consuming and complicated. The extraction and recovery process may also affect the accuracy of the test result. Therefore, a new method without tedious binder extraction and recovery is more desirable for determining the blending efficiency of RAP binder. Fluorescence microscopy has the potential to be one of these methods.

The fluorescence microscopy is an optical microscopy that uses the emission of fluorescence to study properties of organic or inorganic substances [15–17]. Fluorescence microscopy has been used for the analysis of oil and petroleum products since the 1980s [18]. Navaro et al. [14] first utilized fluorescence microscopy to investigate the degree of blending between virgin and aged binders. They analyzed fluorescence microscope images using a pair of photographs, taken under white light (WL) and ultraviolet light (UVL) of the same position of a section of compacted recycled asphalt mixtures sample. They then utilized an image processing software to quantify the degree of blending between the virgin and RAP binders. To eliminate the influence of aggregate two masks were used to hide the aggregate from the binder in an image. In the UVL photograph, the aged binder can be distinguished from the virgin binder, as the latter is fluorescent. However, the threshold value to distinguish between mastic and aggregate can only be chosen by experience. There is not a quantified index available to determine whether all the aggregate have been hidden. In addition, the test procedure proposed by Navaro et al. [14] seems too complex to be used in the field.

In this study, a new term, mean gray value, was derived from the image of fluorescence microscopy. Results show that there existed a linear relationship between mean gray value and RAP binder content for binder blends. Aggregate particles coated with asphalt binder can be directly tested by fluorescence microscopy to estimate binder content. There is no need to cut asphalt mixture samples and hide the aggregate like Navaro et al. did [14]. Therefore, fluorescence microscopy is potentially a simple, effective and efficient method for determining RAP blending efficiency.

2. Objective and scope

The primary objective of this study was to examine the potential of using fluorescence microscopy to determine the blending efficiency of asphalt mixtures containing RAP. The proposed method directly used mixtures collected from asphalt plant without cutting or dissolving them. A blending chart was first developed to show the relationship between the mean gray value of a mixture sample and the content of aged binder and then employed as a baseline to determine RAP binder content. On the basis of the blending chart, a new method was adopted to determine the RAP binder mobilization rate of a mixture, which considered the proportion of the surface area aggregates with different size. The proposed method was validated with three asphalt mixtures, including one warm mix with foaming technology, two hot mixes with or without rejuvenator.

3. Methodology

The proposed fluorescence microscopy method for determining blending efficiency of RAP mixtures is based on the differences in fluorescence between virgin and RAP binders. The procedure of this method includes three steps as shown in Fig. 1.

3.1. Building a blending chart in terms of mean gray value

Since the fluorescent effect of a material is inherently related to its chemical composition and structure, the different components of asphalt show different fluorescence, especially for virgin and aged binders [16]. Fluorescence in asphalt molecules is essentially related to electronic excitation of the conjugated π-systems (aromatic components) and of C = O groups [16,19–22]. For the two-component asphalt system (asphaltenes and maltenes), asphaltenes produce little to no emissions, but maltenes exhibit strong fluorescence in the observed spectral region [23]. For the four-component asphalt system (saturates, aromatics, resins and asphaltenes, i.e., SARA), aromatics and resins are the only components capable of sufficiently intense fluorescent emission [23]. Research also indicates that as asphalt binder ages, its fluorescence emission intensity decreases [24]. It is generally believed that the decrease in fluorescence emission during aging is due to the conversion of resins into asphaltenes. Therefore, fluorescence intensity can be used to distinguish between virgin and aged asphalt binders.

Fig. 2 shows the blending process between virgin and RAP binders in fluorescence images. RAP binder was extracted and recovered according to AASHTO T 319 Method [25]. The fluorescence

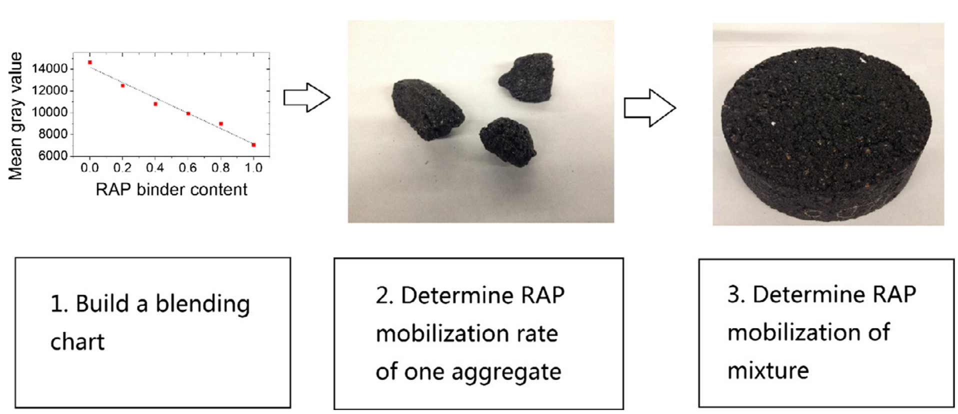

Fig. 1. The main steps of the test method.