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Investigation of diffusion of rejuvenator in aged asphalt

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Abstract

Recycling asphalt pavement creates a cycle of reusing materials that optimize the use of natural resources. For optimal rejuvenation of the aged binder, the diffusion rate of the rejuvenator should be considered. However, the diffusion mechanism between the rejuvenator and aged asphalt is still far from understood. In this study, two experimental methods were conducted to research the diffusion of rejuvenator in aged asphalt. The two asphalt binders were identical in terms of asphalt A7 (60/80 pen) and asphalt A11 (100/120 pen) and two rejuvenators were identical in terms of RA (containing 90% alkyl aromatic oil and 10% saturate oil), and RS (containing 10% alkyl aromatic oil and 90% saturate oil). Experimental results indicated that two experimental methods are also an effective means to research the diffusion of rejuvenator in asphalt in spite of a slight difference. The effect of temperature on the diffusion coefficient is large and the effect of layer thickness of the rejuvenator on diffusion coefficient is obviously not. The rejuvenator RA has a high diffusion rate in asphalt over a wide range of temperatures. In addition, the diffusion coefficient of rejuvenator in asphalt A11 is larger than that in asphalt A7. The test data suggested that the use of rejuvenator with high diffusion is a viable option for recycling old asphalt mixture.

Keywords: Recycling; Rejuvenator; Diffusion; Asphalt; Fickian law

1. Introduction

Asphalt is used extensively as an adhesive material in many fields, especially in asphalt pavement construction. About 5.0% of asphalt in asphalt mixture is usually needed for acceptable pavement performance [1]. But asphalt binder is easy to age during applying and service, especially under thermal and/or ultraviolet radiation (UV) conditions [2–4]. In addition, asphalt pavement suffers from different kinds of distresses, such as cracking, deformation, fatigue. Existing asphalt pavement materials are commonly removed during resurfacing, rehabilitation, or reconstruction operations. Once removed and processed, those become waste asphalt mixture, which contains valuable asphalt binder and aggregate [5]. Compared with virgin asphalts, the asphalt in waste asphalt mixture is more brittle and has worse relaxation characteristics that make asphalt more prone to cracking. But incorporating the waste asphalt mixture into new pavements significantly reduces the usage of new asphalt and aggregate, conserves natural resources and solves disposal problems [6]. There has been renewed interest in increasing the amount of recycling asphalt pavement used in hot mix asphalt [7,8]. Thus, how to use this waste asphalt mixture is a major issue.

Over the past three decades, most research about recycling asphalt pavement (RAP) has led the different country, company, and local agencies to consider a variety of potentially recyclable materials for pavement applications. Initially, the use of reclaimed asphalt mixture in hot asphalt

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mixture is allowed with a percentage varying between 0 to 30%. Long term pavement performance (LTPP) program has been established that the performance of pavements containing RAP is similar to that of pavements constructed from virgin materials with no RAP [9–11]. Over the years, considerable experience has been gained; the recycling ratio may be close to 100%. However, ensuring confidence in the success of using reclaimed asphalt mixture would require low recycling ration, such as lower than 70%, and addressing much durability concerns related to the interaction between reclaimed asphalt and the new binder [12,13]. Collected data indicated that the use of new binder is a viable option for recycling asphalt mixture with high RAP material content. One major factor that remains unclear is the interaction between aged asphalt and new binder. The new binder goes by different names as rejuvenators, softening agent, modifiers, extender or recycling. Just for the sake of name, the term rejuvenator is used to denominate all products used for rejuvenation of aged asphalt [14–16]. Some hypothesized that the rejuvenator forms a very low viscosity layer that surrounds the aged asphalt binder and rejuvenator penetrates the aged asphalt layer [17]. After penetration, the aged asphalt binder is softened and the rejuvenator disappears into the asphalt binder. This process is the diffusion of a rejuvenator into aged asphalt. But previous research focuses on the rejuvenation process using extraction of the old asphalt binder from waste asphalt mixture [18]. Mixing the rejuvenator with extracted binder and the diffusion of the rejuvenator in the layers of aged binder on the exterior of aggregates is a separate process.

Diffusion is the process responsible for the movement of matter from one part of a system to another, and it is mainly due to random molecular motions. A good rejuvenator should not only have superior regeneration and anti aging properties, but also should have appropriate diffusion. Diffusion is deemed to depend on temperature, viscosity and time. In addition, the materials structure, molecules size, molecules shape and intermolecular forces also influence the diffusion rate. This study aims to understand the diffusion process between rejuvenators and aged asphalt binders because it is an ordinary process in reclaimed asphalt pavement materials during waste asphalt mixture recycling operations in pavement construction [19]. Two experimental methods were designed to research the diffusion of rejuvenators into asphalt, which is a simplistic and convenient method. The effects of diffusion rate, application of two methods, are illustrated by studies of parameters such as the rejuvenator film thickness, temperature, rejuvenator and the type of asphalt.

2. Basic concepts and theory

Asphalt is typically regarded as a colloidal system consisting of high molecular weight asphaltene micelles dispersed or dissolved in a lower molecular weight oily medium (maltenes). The micelles are considered to be asphaltene clusters together with an absorbed layer of high molecular weight aromatic resins which act as a stabilizing solvation medium. According to the colloidal nature of the asphalt, asphalt is divided into sol asphalt, gel asphalt and sol-gel asphalt. In practice, asphalt that is applied in pavement is sol-gel asphalt [20]. The aromatic and resin fraction of asphalt will decrease after aging and it lost the solvation power to fully peptize the asphaltenes. During asphalt aging, heat first promotes the migration of oils out of the asphalt. Then, some of these oils are volatilized, and others are washed away because of subsequent solubility in water. Finally, oxygen migrates into the system, leading to the formation of more polar molecules known as asphaltenes.

Diffusion in asphalt is complex and the diffusion rates should not be like those in liquids or in solids. It remains a challenge to understand, predict and control the diffusion of rejuvenators in old asphalt. It depends strongly on the concentration and degree of swelling of asphaltenes. But the theories and physical models of diffusion may help to realize the diffusion of rejuvenators in old asphalt systems. Fig. 1 shows the colloidal structure and the diffusion of rejuvenator in old asphalt.

Fickian law is the most popular approach to evaluate diffusion due to its simplicity. Fickian law actually has two forms. Fickian first law describes the correlation between the diffusive flux of a gas component and the concentration gradient under steady-state conditions.

$$J = -Aj = -AD\frac{\partial C}{\partial x} \tag{1}$$

where J is the flux, A is the area across which diffusion occurs, j is the flux per unit area, D is the diffusion coefficient, C is the concentration, x is the diffusivity distance. $\frac{\partial C}{\partial x}$ is the concentration gradient along the x direction.

In the case of diffusion without convection and a unitary area, Eq. (1) can be written as follows.

$$J = -D\frac{\partial C}{\partial x} \tag{2}$$

Most practical diffusion situations are nonsteady-state ones. The diffusion flux and the concentration gradient at some particular point in a solid vary with time, with a net accumulation or depletion of the diffusing species resulting. Fickian second law relates the unsteady diffusive flux to the concentration gradient.

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right) \tag{3}$$

If the diffusion coefficient is independent of composition, Eq. (3) simplifies to Eq. (4).

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \tag{4}$$