Construction and Building Materials 68 (2014) 49–54

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Aging of bituminous mixes for rap simulation

Aybike Ongel *, Martin Hugener [1]

Laboratory for Road Engineering/Sealing Components, EMPA, Swiss Federal Laboratories for Materials Science and Technology, CH-8600 Duebendorf, Switzerland

HIGHLIGHTS

- Aging of asphalt is solely controlled by oxidation.
- Aging of asphalt initially increases rapidly then slows down to a constant rate.
- Humidity slows down the asphalt aging process.
- There is no difference in age hardening for different asphalt sample depths.
- Asphalt aging is affected by trace substances in the air.

ARTICLE INFO

Article history:
Received 20 March 2014
Received in revised form 16 June 2014
Accepted 18 June 2014

Keywords:
Bitumen
Asphalt recycling
Asphalt aging
Rheological properties
RAP
Laboratory aging tests

ABSTRACT

The use of reclaimed asphalt pavement (RAP) has gained considerable importance due to increasing environmental concerns and the search of more economic ways in road paving. Although a large amount of RAP is produced each year, only a part of it can be recycled in a suitable way. The efforts have been towards increasing the RAP content, and if possible, making complete use of RAP in road pavement construction. There have been many studies conducted on the aging of bitumen and compacted bituminous mixes, however the effects of aging conditions on the loose bituminous mixture to simulate RAP has not been examined in detail. As part of a research project on hot mix asphalt recycling, the effect of temperature, aging duration, humidity, oxygen concentration, and sample thickness on loose asphalt aging for the production of RAP was investigated. Bituminous mixture was aged in the forced draft oven in a special aging box and representative samples of asphalt were taken at defined time intervals for rheological tests. Hyperbolic-like curves were observed for rheological properties of bitumen versus aging duration. Asphalt aging was shown to be not only affected by the temperature, oxygen content, aging duration, and humidity but also the presence of trace substances in the air. No effect of layer thickness on the bitumen aging was found.

1. Introduction

In the last decade, there has been growing concern about the increased demand placed on natural resources such as aggregates and crude oil for the bitumen production. The use of reclaimed asphalt pavement (RAP) has been a viable alternative for transportation agencies and asphalt producers to make more efficient use of the resources. RAP material is a reusable mixture of bitumen and aggregates that is generated from milling and/or crushing of old and damaged pavements for addition into new asphalt mixes. There is a trend towards increasing the RAP content in hot mix asphalt not only because it helps conserve non-renewable resources but also eliminates disposal problems as it reduces the need for landfills, and reduces energy consumption and costs.

The construction of new asphalt plants with special drums for the addition of high percentages of RAP makes it technically possible to recycle asphalt up to 100%. However, there are concerns about the durability of pavements with high RAP content which impose restrictions in many countries on the maximum percentages of RAP incorporated into the mix with respect to rutting, fatigue life, and durability. In order to overcome the restrictions on the maximum RAP percentages, extended research activities have started all over the world.

RAP generally has to be produced artificially in the laboratory, since the RAP available from the roads is not suitable to study specific conditions such as effects of repeated recycling on the asphalt properties. However, there is not yet a standardized procedure for

---

* Corresponding author. Permanent Address: Bahcesehir University, Ciragan Cad. No: 4, 34353 Besiktas/Istanbul, Turkey. Tel.: +90 555 690 5508.

E-mail addresses: aybike@gmail.com (A. Ongel), Martin.Hugener@empa.ch (M. Hugener).

[1] Tel.: +41 58 765 4487.

http://dx.doi.org/10.1016/j.conbuildmat.2014.06.030

the production of RAP in the laboratory. The RILEM TC-ATB-TG5 group aimed to develop an aging methodology to reproduce aging of bituminous mixtures until the end of their service life and simulate RAP in the laboratory [1]. However, before adapting a test protocol to simulate RAP, there is a need to understand the effects of temperature, aging duration, asphalt layer thickness, humidity, and oxygen concentration on the aging of the loose bituminous mix.

In general, asphalt binder aging has two distinct phases: short-term and long-term. Aging occurring during production and transportation of asphalt at elevated temperatures due to volatilization and oxidation is referred to as short-term aging. Oxidation that continues through the service life of the pavement at ambient temperatures, due to exposure to sunlight, temperature variations, rainfall and traffic loading after pavement is opened to traffic, is referred to as long-term aging. Peterson [2] summarized three factors contributing to the aging of the bituminous binder: loss of oily components by volatility or adsorption to mineral aggregates, changes in the chemical composition by reaction with atmospheric oxygen, and molecular structuring that produces thixotropic effects (steric hardening).

Volatilization is the loss of lighter constituents of bitumen resulting in hardening of bitumen and is mainly controlled by temperature. Penetration graded bitumen below a penetration of about 100 0.1 mm, which are commonly used in hot and moderate climates, show little volatilization and therefore insignificant hardening [3]. Oxidation is the interaction of bitumen with oxygen from the environment resulting in a change in the composition of asphalt due to the formation of polar functional groups containing oxygen. The newly formed polar groups cause marked increases in bitumen stiffness and viscosity as they have stronger molecular interactions [2]. For all bitumen, the viscosity change with time on oxidation follows a hyperbolic curve, an initial rapid increase in viscosity followed by a leveling off to a slower and rather constant rate [4–7]. In addition to the formation of polar functional groups by oxidation, bitumen properties can also be significantly altered by isothermal and reversible molecular structuring, called steric hardening [2,8]. However, it is usually hard to quantify since structuring is destroyed during the solvent recovery of binder from the aged pavement [9].

Oxidation has been shown to be the principal factor leading to the hardening and embrittlement of bitumen [2,10]. Oxidation rate depends on bitumen composition and diffusion rate of oxygen [11,12]. Oxygen reactivity increases with increasing fraction polarity, therefore different bitumens would age differently under the same conditions [13]. In addition, the diffusion coefficient of oxygen increases with increasing temperature, and decreasing viscosity (penetration) and chemically bound oxygen in bitumen [11,12]. Temperature affects the oxidation process in terms of both reaction rate and relative amounts of the oxidation products [13]. According to Arrhenius Law, an approximately 10 °C increase in temperature would double the rate of most oxidation reactions [14]. However, Herrington et al. [15] suggested that asphalts have a limiting viscosity on oxidation for each temperature as the relative rates of oxidation products and the reaction extent would be different at different temperatures. Therefore, temperature effects on oxidation kinetics may not be demonstrated for all points on the asphalt viscosity-time curve at different temperatures.

Humidity or water content was also shown to influence the age hardening of bitumen. However, the findings have been quite variable. Polymer modified binders experienced less hardening when aged in the presence of water compared to that aged under dry conditions [16]. The retarding effect of water has been attributed to the higher amount of chemically bound oxygen found in bitumen in presence of water which would reduce the diffusion of oxygen rate [16,17]. However, Hagos et al. [18] and Campbell and Wright [19] showed increased oxidation with the presence of water during aging. Thomas [20] suggested that the effect of water during aging on asphalt hardening, as in the case of oxidation extent, depends on the fractional composition of the bitumen.

The extent of aging was also shown to vary throughout the depth of the pavement. The aging of bitumen decreases with increasing distance from the surface [21,22]. Coons and Wright [23] showed that only the top 12.5 mm of the dense pavements was shown to have increased viscosity. This effect was attributed to the decreasing maximum temperatures as well as less exposure to oxygen with increasing depth in the pavement. However, the relative contribution of these factors is unknown.

Aging data are generally obtained from laboratory aging tests and used to help predict the long-term performance of asphalt pavements in the field. Most of the research has focused on the factors contributing to aging of bituminous binder. However, aging of bituminous mixtures can be quite different than the bitumen itself. When bitumen is mixed with aggregates, the bitumen molecules interact with aggregates. Aggregates may smooth [24] or catalyze [25] the oxidation process, therefore there is a need to take into account bitumen-aggregate interaction effects on aging. An aging study on bitumen–filler mixes showed that both bitumen and filler influence the binder hardening [26].

The short-term and long-term oven aging procedures developed under the SHRP-A-003A [5] have been the most widely adapted aging protocols for asphalt. The SHRP short-term oven ageing (STOA) procedure requires that prior to compaction, the loose bituminous mix should be aged in a forced draft oven at 135 °C for 4 h. The SHRP long-term oven aging (LTOA) procedure is a continuation of the STOA treatment, where the compacted samples are heated in the oven at 85 °C for further 120 h. When the results were compared with field aging (mixes with typically 5% air voids), it was found that the STOA method was roughly equivalent to 0–2 years in the field, and the LTOA method to 5–15 years, depending on climate. There are other accelerated long-term aging protocols for bituminous mixes including the use of higher temperatures (100 °C and above), high oxygen/air pressures, and feeding air/oxygen or humid air into the mix. However, all these methods use compacted samples and in order to produce RAP in the laboratory, these samples should be reheated to obtain a loose mix.

A study was initiated at EMPA in order to verify the earlier findings on aging and investigate the aging behavior of loose bituminous mixes. This helps determine the aging parameters relevant for the RAP simulation in the laboratory. In this study, a dense asphalt mixture, AC 11 was produced in the laboratory and aged in a special aging box in the draft force oven at different temperatures, durations, oxygen concentrations, and humidity levels. The loose bituminous mixture was sampled at different time intervals and tested for its rheological properties on the recovered binder in order to follow the aging progression. The effect of sample thickness on aging was also investigated.

2. Methodology

2.1. Experimental test setup

In this study, a loose asphalt sample was aged using a forced draft oven. Since the main objective was to compare different variables affecting aging over time, only long-term aging was assessed. A dense asphalt mixture, AC 11 prepared according to EN 13108-1 [27] with standard penetration grade bitumen 70/100 was used in testing. Binder content of the mix was 6.12% by mass. The aggregate gradation of the AC11 mix is given in Table 1. A batch of 150 kg of asphalt mixture was prepared in the lab at a mixing temperature of 160 °C. After production, it was partitioned and placed into boxes, each containing 6 kg of the mix, and stored at room temperature.

Asphalt mix samples of 6 kg were pre-heated in an oven at 120 °C for 30 min then placed into a metal aging box with an approximately 3.5 cm thick even layer. The box had a volume of 0.01 m^3 (10 × 28 × 35 cm) as shown in Fig. 1, and was