Construction and Building Materials 96 (2015) 47–54

Contents lists available at ScienceDirect

Construction and Building Materials

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

Rheological and low temperature properties of asphalt composites containing rock asphalts

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HIGHLIGHTS

- Mechanical properties of composites with rock asphalts are evaluated and compared.
- A method that does not need extraction of binder from rock asphalt is pursued.
- Rock asphalt increases stiffness but decreases low temperature performance of composites.
- Rock asphalt decelerates the aging rate of composites.

ARTICLE INFO

Article history:
Received 29 May 2014
Received in revised form 6 July 2015
Accepted 15 July 2015
Available online 5 August 2015

Keywords:
Rock asphalt
FAM mixtures
Rheological properties
Low temperature properties
Long-term aging

ABSTRACT

This paper presents the findings from a study conducted to evaluate the potential impact of different types of rock asphalts on performance of asphalt composites. Fine aggregate matrix (FAM) mixtures were prepared by incorporating three different types of rock asphalts – Buton, QC and UM for this study. The methodology used in this study avoided the extraction of asphalt binder from rock asphalt and simplified the process of evaluating the potential impact of rock asphalts on mixture performance. Rheological properties were measured using frequency–temperature sweep tests with a dynamic shear rheometer and creep–relaxation tests with a bending beam rheometer. Tensile strengths of the composites at low temperatures were also measured by applying monotonically increasing deflection. The critical cracking temperatures were computed using a hypothetical cooling rate for the purposes of comparing material durability. Results from this study demonstrated that addition of rock asphalts increases material stiffness and slightly reduces relaxation potential of asphalt composites at low temperatures. A comparison of properties before and after long-term aging also revealed a slightly lower rate of aging for mixtures modified with rock asphalt as compared to the control mix.

1. Introduction

Rock asphalt is a naturally occurring material that can be used as a partial substitute for conventional asphalt binder in the production of hot-mix asphalt. In certain parts of the world, rock asphalt has gained attention because of its benefits in terms of reduced costs and ease of use during mixture production. Rock asphalt is naturally produced by impregnation of petroleum or oil into rocks such as limestone followed by the combined action of heat, pressure, oxidation, and bacteria over millions of years. As a result, asphalt binder and mineral fillers are the two predominant constituents of rock asphalt. Physically, rock asphalt is black in color and can be easily crushed into a powder form [1]. The mechanical properties of rock asphalts vary considerably depending on the type and proportion of its constituents and the type of physical and chemical alteration it undergoes over time [2].

Previous studies have reported improvement in the performance and cracking resistance of pavement mixtures modified by incorporating different types of rock asphalts such as Gilsonite from USA, Buton from Buton Island of the South Pacific Indonesia, QC from China and UM from Iran. Studies by Widyatmoko et al. [2], Anderson et al. [3], and Yilmaz et al. [4] investigated the effect of modifying asphalt mixtures with Gilsonite rock asphalt and found improved performance at higher temperatures. However, there is limited information in the literature that describes the characteristics of other rock asphalts. Similar studies by Siswosoebrotho et al. [5]

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http://dx.doi.org/10.1016/j.conbuildmat.2015.07.150
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and Affandi [6] about the effect of Buton rock asphalt reported higher values of stiffness, stability, resistance to deformation, and temperature susceptibility than the control mixtures. Another study by Fan et al. [7] reported that QC rock asphalts increased the viscosity and stiffness of asphalt binder at higher temperatures but decreased the ductility at lower temperatures. Similarly, Lu et al. [8] measured the properties of QC rock modified binder and reported that there was no negative influence to the low temperature properties of the mixture as long as the concentration of the binder from rock asphalt was within 8% by weight of the original binder content. Also, Ameri et al. [9] found that UM rock asphalt increased the rutting resistance of binder, but adversely affected its low temperature cracking resistance. Other forms of natural rock asphalt also include natural asphalt binder mixed with fine mineral aggregates such as the one from Selenice in Albania [10].

The quality and content of the binder present in rock asphalt varies from one source to another. Therefore each source must be evaluated individually potential use in asphalt mixture production. One of the problems faced by researchers in evaluating binders from rock asphalts or other similar sources is the complexity in extracting or separating the asphalt binder from the mineral aggregate. The methodology used in this study investigates the effect of rock asphalt on asphalt mixtures without having to extract the binder from the rock asphalt. Instead, the rock asphalt was carefully proportioned and mixed with a fresh sample of asphalt binder and fine aggregates to produce a fine aggregate matrix (FAM) mixture. The proportioning was carried out by replacing the weight and volume contribution of aggregates and binder from the rock asphalt in the final mixture. Test specimens from the gyratory compacted FAM samples were then fabricated for further testing and evaluation. This is not only an efficient approach to evaluate rock asphalt, but it is also more realistic because it reflects the manner in which rock asphalt would be introduced during hot-mix asphalt production. Note that the use of FAM specimens is also more efficient in terms of the cost, time and capital equipment required compared to testing a full asphalt mixture, while at the same time providing meaningful insights into expected material behavior. This same method can easily be extended and used to evaluate the influence of other forms of natural asphalt as well as the pulverized form of reclaimed asphalt pavement (RAP) mixed with or without rejuvenators on the expected performance of asphalt mixtures.

In short, the main objective of this paper is to compare the influence of rock asphalt from three different sources: Buton, QC and UM (see Fig. 1.) on the overall properties of asphalt composites. More specifically, this study investigates (1) the influence of rock asphalt on mechanical properties of FAM mixtures at different loading conditions and temperatures, (2) the influence of aging on mechanical properties of FAM mixtures with and without rock asphalt, and (3) the influence of percentage of rock asphalt on the aforementioned properties. The secondary objective of this paper is to present a methodology that can be used to achieve the first objective (and similar scenarios such as in the case of recycled asphalt pavement materials), without having to separate the binder from the rock.

2. Methodology

2.1. Materials

Limestone aggregates and fillers from Buda, Texas and a Superpave PG 64-22 asphalt binder obtained from a refinery in Texas were combined with rock asphalt from three different sources – Buton, QC and UM to produce the FAM mixtures and test specimens. Previous studies [11,12] conducted by the co-authors of this paper recommend using 8% binder from the QC or UM rock asphalt and 20% binder from the Buton rock asphalt by weight of total binder content in the mixture. The aforementioned concentrations refer to the percentage of binder from the rock asphalt expressed as a percentage of the binder in the original mix design by weight. For example, 8% by weight of QC rock asphalt implies adding an amount of QC rock asphalt such that the binder content from this rock asphalt is 8% of the optimum binder content obtained from the original mix design. In order to compare the influence of the source of rock asphalt, 8% content was used for rock asphalts from each of the three sources. An additional mix with 20% concentration of Buton rock asphalt was also used to evaluate the effect of concentration of rock asphalt on the performance of FAM mixtures. In summary, five different types of FAM mixtures were used: a control mixture, three different types of rock asphalt mixtures at 8% concentration and Buton rock asphalt at an additional 20% concentration.

Table 1 presents the basic properties of the three different rock asphalts used in this study, while Fig. 2 presents the gradation of aggregates in the FAM mixture. This gradation reflects the relative proportion of fine aggregates in a typical dense graded asphalt mixture. The control mix was prepared using 89% of fine aggregates and 11% of PG 64-22 binder by total weight of the mixture. As mentioned earlier, FAM mixtures with rock asphalts were prepared by substituting an appropriate amount of fines and binder with the rock asphalt. The substitution was done such that the binder content from the rock asphalt was 8% of the optimum binder content for the QC and UM rock asphalts, and 8% and 20% of the optimum binder content for the Buton rock asphalt. The percentages of the PG 64-22 binder and limestone fines were reduced for each mix to compensate for the binder and fines added in the form of rock asphalt. In other words, the mixes with rock asphalt had the same final gradation and binder content as the control mix.

2.2. Sample preparation

Rock asphalt, commercially obtained in the form of a powder, was first mixed with oven dried limestone aggregates, and subsequently with the PG 64-22 asphalt binder. The loose mixture was then placed in an oven at 135 °C for 2 more hours to simulate short-term aging (STA) and then compacted into cylindrical samples (150 mm diameter and 120 mm height) of maximum possible density using the Superpave gyratory compactor. Similarly, another set of loose mixtures from each rock asphalt source was placed in the environmental chamber at 60 °C for 30 days prior to compaction to simulate long-term aging (LTA). The aforementioned conditions produce approximately the same extent of aging as the pressure-aging vessel used for asphalt binders [13,14]. Table 2 presents volumetric properties of the five different short-term aged and long-term aged FAM mixtures prepared for this study. All specimens, irrespective of aging, were compacted until refusal (maximum density possible when using the Superpave Gyratory Compactor). The bulk specific gravity and maximum specific gravity were measured using the compacted specimens and samples of loose mixtures set aside form the same batch used for compaction, respectively, following procedures similar to those used with asphalt

Fig. 1. Three different types of rock asphalt.