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Performance characteristics of fiber modified hot mix asphalt

L.M.G. Klinsky [a], K.E. Kaloush [b], V.C. Faria [a], V.S.S. Bardini [c],*

[a] *Centro de Pesquisas Rodoviárias, CCR Group, Presidente Dutra Road, km 184.3, Santa Isabel, Brazil*
[b] *Department of Civil, Environmental and Sustainable Engineering, Arizona State University, P.O. Box 875306, Tempe, AZ, United States*
[c] *Universidade Estadual Paulista "Júlio de Mesquita Filho", Instituo de Ciência e Tecnologia, Presidente Dutra Road, km 138.5, 12247-004 São José dos Campos, Brazil*

HIGHLIGHTS

- The addition of fibers to hot mix asphalt enhance performance characteristics.
- Pavement overlays with fiber modified hot mix asphalt can better resist reflective cracking.
- Rutting is developed in all hot a mix asphalt, but the addition of fibers can reduce de rutting rate evolution.

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ABSTRACT

A mixture of polypropylene and aramid fibers was used in this study to evaluate the performance characteristics of a modified asphalt mixture. A conventional dense-graded hot mix asphalt (HMA) used in Sao Paulo, Brazil was used. The laboratory experimental program included the evaluation of: resistance of compacted hot mix asphalt (HMA) to moisture-induced damage, resilient modulus, dynamic modulus; flow number test; fatigue by flexural bending, and fracture energy using the semi-circular test. Two asphalt mixtures were used in the laboratory program: a control HMA with no fibers, and a fiber reinforced HMA, which contained the fibers. The data was used to compare the performance of the fiber modified mixture to the control. The results showed that the fibers improved the mechanical properties of the control hot mix asphalt. The use of polypropylene and aramid fibers in HMA could enhance the performance of asphalt pavements against common distresses as rutting, raveling, fatigue and reflective cracking.

1. Introduction

Asphalt pavements deteriorate over time because of combined effect of traffic loading and the environment. The service life of asphalt pavements can even be cut short if quality materials are not used in the hot mix asphalt (HMA) design and manufacturing. A properly designed pavement will perform well during its design life, and the distresses will not exceed allowable limits.

The quality of the HMA materials used will also notably affect the performance. As quality materials are increasingly challenging to find, modified mixtures have been getting more acceptance. Different types of distresses can be identified in asphalt pavements during their service life, and they are caused by different factors. Moisture sensitivity is one of the factors that leads to premature failure of pavements. The presence of water in pavements can be detrimental if combined with other factors, such as freeze-thaw cycling. A progressive disintegration of an HMA, called raveling, could be developed from the surface downward as a result of the dislodgement of aggregate particles. This distress can be associated to material selection and also poor compacted asphalt layers.

Rutting is another type of asphalt pavement distress. It is a longitudinal depression in the wheel path that can be also caused by shear failure of the bituminous concrete layer. Slow moving traffic and high temperatures facilitate the development of this type of deterioration.

Fatigue cracking is a major distress mode that causes premature failure in flexible pavements. This deterioration mode can affect pavement serviceability, structural capacity and appearance. It can be associated to poor pavement design, excessive repeated traffic loading and poor material selection.

Reflective cracking in asphalt pavements has been also a concern for many years. The primary cause of the reflective cracking is the differential movement of the pavement layers due to the stress produced by the traffic and the environment.

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* Corresponding author.
E-mail addresses: kaloush@asu.edu (K.E. Kaloush), valeria.faria@grupoccr.com.br (V.C. Faria), vivian.bardini@ict.unesp.br (V.S.S. Bardini).

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The reflective cracks are common in asphalt overlays on cracked asphalt concrete pavements. The main problems of the reflective cracks are the infiltration of water into the lower layers, weakening the pavement as a whole; in addition to an increase in the maintenance time and costs and poor ride quality and service conditions [1].

Many studies and researches look for better materials and/or modifications that could enhance the characteristics of hot mix asphalt and reduce or eliminate the development of asphalt pavement distresses. Thereby, different types of fibers have been used in asphalt pavements to improve performance [2].

The addition of fibers to HMA can improve its fatigue and rutting-resistance properties [3]. The benefits provided by the use of fibers can be identified as following [4]:

- Helps to fix the asphalt binder in the mix and prevents draindown;
- Reinforce the mastic;
- Reduce temperature susceptibility of the mastic because of the 3D network created.

Carpet fibers, for example, may increase the fatigue cracking resistance of asphalt concrete [5], however, some types may not be compatible with asphalt binder. Carbon fibers stiffen the concrete asphalt and make it more resistant at high temperatures to permanent deformation and higher tensile strength, but at lower temperatures improvements may not be noted [6].

Glass fibers can increase stiffness and tensile strength of hot mix asphalt but they must be handled carefully during construction [7]. However, stability and stiffness reduction and increasing the voids in the mix have been reported [8].

Polypropylene fibers are extensively used in civil engineering, mainly in concrete as a three-dimensional secondary reinforcement. Due to adhesion between polypropylene fibers and bitumen, the strengthening mechanism in asphalt concrete is different [9]. These fibers can delay the reflective cracking caused by vertical and horizontal movements of underlying concrete slabs and reduce rutting development [10].

The most successful use of fibers in asphalt concrete mixtures has been a combination of polypropylene and aramid. The polypropylene would act as an adhesion and dispersing agent; whereas, the aramid provide the three-dimensional reinforcement. The combination of polypropylene and aramid fibers improve the performance of asphalt mixtures related to the permanent deformation and fatigue cracking. This improvement is not just because of the modification of the material strength, but also by the modification of the material behavior in resisting pavement distresses [11].

Asphalt plants usually have special components to add fibers and other additives to the hot mix asphalt during its productions. If asphalt plants have not these components, the fibers addition could be done manually.

Life Cycle Cost Analysis (LCCA) have been used to assess the costs of rehabilitation activities using hot mix asphalt with and without polypropylene and aramid fibers. The addition of fibers at 0.45 kg/ton can result in a saving in the net present worth dollar value ranges from $14,000 to $50,000 per mile/lane or a reduction in the equivalent annual cost ranges from 750 to 2000 mile/lane/year [12].

2. Objective and scope

The objective of this study was to evaluate the benefits of the polypropylene and aramid fibers in improving the performance characteristics of a modified asphalt mixture used in Brazil. A conventional dense-graded HMA used in Sao Paulo was used for this purpose. The laboratory experimental program included the evaluation of: resistance to moisture-induced damage, resilient modulus, dynamic modulus; flow number test; fatigue, and fracture energy using the semi-circular test. Two asphalt mixtures were used in the laboratory program: a control HMA with no fibers, and a fiber reinforced HMA, which contained the fibers.

3. Materials

The dense graded control HMA used had a maximum aggregate size of 12.5 mm. Table 1 shows the aggregate gradation requirement (per Brazilian DNIT – National Department of Transportation Infrastructure specifications) and the final obtained gradation for this study. It was used a conventional asphalt binder, PG 70-16 (ASTM D6373). Table 2 shows the mix design of the HMA, performed by the Marshall method with 75 blows and Table 3 present the asphalt binder characteristics.

The fibers used in this study were a blend of aramid and polypropylene fibers, designed for use in hot mix asphalt applications. Fig. 1 shows an image of these synthetic fibers and Table 4 shows their physical properties.

The fibers were added to the HMA with the same characteristics of the control mixture described before, at the rate of 0.5 kg/metric ton of total mix. Fibers were added to hot aggregates and a short dry mix was performed. After that, hot asphalt binder was added and mixed. Fig. 1 shows the fiber addition to hot aggregates at the laboratory.

4. Laboratory tests, results and analyses

4.1. Resistance to moisture induced damage

Certain HMA may be sensitive to presence of water, accelerating the process of failure of asphalt pavements. The AASHTO T 283 gives guidelines to determine if HMA materials may be subject to stripping and to measure the effectiveness of additives used to enhance this behavior.

This test is performed by compacting specimens to an air void level of 7 ± 1%. Three specimens are used as a control and tested without moisture conditioning and three specimens are selected to be conditioned by saturating with water undergoing a freeze cycle and subsequently having a warm-water soaking cycle. After this process, specimens are tested for indirect tensile strength. The tensile strength of the conditioned specimen is compared to the control specimens to determine the tensile strength ratio (TSR).

Table 5 shows results of moisture induced damage obtained for the control and a fiber-reinforced HMA. It is noted that both passed the minimum requirement that is 70%, usually adopted in Brazilian specifications. The Tensile Strength of the HMA with fibers was about 20% greater, when compared to Tensile Strength of the control HMA, for both conditioning situations. Thus, the HMA with fibers would stand for higher stress levels in asphalt pavements.

4.2. Resilient modulus test

For the Resilient Modulus test, a repeated-load indirect tension of fixed amplitude, with a duration of 0.1 s followed by a rest period of 0.9 s, is applied to the test specimen. During testing, the specimen is subjected to a dynamic cyclic stress and a constant stress (seating load). The resulting horizontal deformation of the specimen is measured and the resilient modulus is calculated. The Resilient Modulus is used in the evaluation of materials quality and as input for pavement design, evaluation and analysis (ASTM D 7369-09).

Table 6 shows average results of resilient modulus obtained from nine specimens for each condition, at 25 °C (77 °F). The resilient modulus for the HMA with fibers was 15% higher than the control HMA, indicating an increase of stiffness when fibers are added, which could lead to better asphalt pavements to withstand rutting. The standard deviation results show that this difference is statistically significant.