Construction and Building Materials 77 (2015) 117–123

Contents lists available at ScienceDirect

Construction and Building Materials

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

Using polymers to improve the rutting resistance of asphalt concrete

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HIGHLIGHTS

- We use amorphous polyolefin polymer and a combination of LDPE + EVA to modify asphalt.
- We assess rutting resistance of asphalt mixtures using wheel tracking tests.
- We assess stiffness and fatigue tests to confirm the performance of the asphalt mixtures.
- We improved rut resistance without compromising stiffness and fatigue.

ARTICLE INFO

Article history:
Received 17 July 2014
Received in revised form 16 October 2014
Accepted 24 December 2014

Keywords:
Asphalt mixtures
Polymers
Rutting

ABSTRACT

This study assesses rutting on two types of modified asphalt mixtures containing: (i) amorphous polyolefin polymer and (ii) a particular polymer obtained by combining LDPE (low density polyethylene) and EVA (ethyl-vinyl-acetate). Rutting tests were performed by a wheel tracking device. Stiffness and fatigue tests were carried out to confirm the performance of the asphalt mixtures. The testing showed that polymer modification in this study improved rut resistance without compromising the stiffness and fatigue behavior. The rutting results were fit in the NCHRP 1-37A model and the in situ rutting performance of asphalt mixtures can be predicted.

1. Introduction

The permanent deformation (rutting) of asphalt pavements has an important impact on the performance of the pavements during their lifetimes. Rutting not only reduces the useful service life of pavements, but it may affect basic vehicle handling, which can be hazardous to highway users. Rutting develops gradually as the number of load applications increases and appears as longitudinal depressions in the wheel paths and small upheavals to the sides. It is caused by a combination of densification and shear deformation; the main contributing factors are traffic, especially heavy loads, and high temperatures. These depressions or ruts are important because, if the surface is impervious, the ruts trap water causing hydroplaning (particularly for passenger cars), which is extremely dangerous. As the ruts become deeper, steering becomes increasingly difficult, leading to greater safety concerns [1–6]. The stiffness of the binder and its thermal susceptibility are some of the main causes of pavement failure due to rutting. Therefore, the adoption of modified binders is recommended to reduce failures due to rutting.

Modified asphalt involving natural and synthetic polymers was patented as early as 1843 [7]. Test projects were underway in Europe in the 1930s, and neoprene latex was used in North America in the 1950s [8]. In the late 1970s, Europe was ahead of the United States in the use of modified asphalts because European contractors provided warranties, which motivated them to have a greater interest in decreased life cycle costs, even if the initial costs were higher. The high upfront expenses for polymer modified asphalt limited its use in the US [9]. Modified asphalts have the ability to offer improved performance over conventional asphalts, but they are not a solution or panacea for all situations. Thus, a careful balance of asphalt properties and rheological parameters is generally required [10–13]. Examples of problems related to these phenomena can be found in most of the reports on modified asphalts [10–18] and are generally linked to the rheology of complex fluids.

Asphalt modification consists of adding an additive with the desired properties to the asphalt to improve it. Since the mid-1980s, polymer-modified asphalt concrete mixtures have been

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http://dx.doi.org/10.1016/j.conbuildmat.2014.12.060
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widely used to minimize rutting failures of asphalt pavements [4]. Therefore, a careful balance of asphalt properties is generally required to reduce one asphalt mixture distress mode without aggravating other modes, such as the use of a harder asphalt to prevent rutting without aggravating fatigue cracking. Therefore, polymers are mostly used to produce mixtures with longer life and better performance [14–15].

The polymers used for asphalt modification can be classified into two families based on their behaviors once added to the asphalt. Polymers that form a rigid three dimensional network and resist permanent deformation are called plastomers, while those that induce higher elasticity and recovery are called elastomers [19]. Some authors suggest an additional nominal class of reactive polymers that have the same properties as plastomers but include functional properties able to bond with asphalt molecules [16,20,21].

When a load is applied to the surface of an asphalt pavement, it deforms; however, because the asphalt is a viscoelastic material, as the load is removed, the deformation partially recovers. Therefore, a variable amount of irreversible deformation remains in the asphalt mixtures, resulting in a very small permanent residual strain. Accumulation of millions of these strains due to repeated axle loadings results in surface rutting [22–25]. Because the goal of the analysis in the laboratory is to reproduce the field, many different tests can be used to assess the resistance of asphalt mixtures (e.g., wheel tracking test, dynamic creep test [1]). In particular, dynamic loading systems that use a moving wheel can represent the passage of vehicles along the surface in both dry and soaked conditions at several temperatures.

This study presents an assessment of the rutting resistance of two different types of modified asphalt mixtures containing (i) amorphous polyolefin polymer and (ii) a particular polymer obtained by combining LDPE (low density polyethylene) and EVA (ethyl-vinyl-acetate). Rutting tests were performed by a wheel tracking device to evaluate the rut depth and wheel-tracking slope (WTS), in accordance to EN 12697-22, of the studied asphalt mixtures, which were then compared to three conventional asphalt mixtures produced with different asphalt contents. The additives were used in three different amounts. All mixtures were produced in the laboratory using a kneading compactor in accordance to EN 12697-33. The rutting tests were performed at two different testing temperatures (30 and 60 °C).

Stiffness and fatigue tests were carried out to compare the performance of the modified asphalt mixtures to reference mixtures. The stiffness of the studied asphalt mixtures was evaluated by testing prismatic specimens in four-point bending at different temperatures and frequencies to develop the master curves of each mixture. The fatigue life was assessed by testing the previous specimens at 20 °C and 10 Hz. A comparison between the mixtures was conducted for a single strain level (300 μ).

The rutting results were fit in the model proposed by the NCHRP 1-37A project to verify the applicability of using wheel tracking results to predict the pavement performance.

2. Materials and testing procedures

2.1. Materials

Two polymers were used in the modification of the asphalt. The first is made of amorphous polyolefin with a low molecular weight and low fusion point and belongs to the family of EVA polymers. The second is composed of LDPE and EVA and other polymers with a low molecular weight and medium fusion point. The polymers were small pellets and were workable at room temperature so they could be easily stored or added directly into the hot asphalt. Fig. 1 shows the flexible semi-soft granules at room temperature. Table 1 reports the physical properties of both polymers.

Three different types of asphalt mixtures were evaluated containing: (i) no additive, (ii) amorphous polyolefin polymer and (iii) a particular polymer obtained by combining LDPE and EVA.

The asphalt mixtures design were designed according to the Italian specifications for a binder course and included conventional asphalt (85 mm/10 penetration, 44 °C softening point) and virgin aggregates. The amorphous polyolefin polymer modified asphalt presented the following penetrations: 67, 51, and 42, respectively for 3, 6 and 9 polymer content. In terms of softening point, the values are 50, 58 and 52 °C, respectively for 3, 6 and 9 polymer content.

The aggregate gradation for all the asphalt mixtures is reported in Table 2 and correspond to a 20 mm nominal maximum aggregate size. The determination of the binder content was carried out to obtain 4.0% air void content as defined in the Italian Standard. Thus, the optimum asphalt content was 4.1% of the weight of aggregate.

Polymers pellets were directly added into the asphalt mixture just before the hot asphalt.

Three dosages per additive were used: 3%, 6% and 9% of the asphalt weight. Three asphalt contents were considered for the reference mixture.

The labels used for all 9 mixtures studied in this work, as well as the asphalt content, air-void content, voids in mineral aggregate (VMA), voids filled with asphalt (VFA) and the maximum specific gravity are provided in Table 3.

After designing the mixtures, they were produced and compacted in slabs of 500 × 260 × 50 mm (Fig. 2: left) using a roller compactor to obtain 4 ± 1.0% air-voids. Mixtures containing amorphous polyolefin polymer were blended and compacted at 140 °C. Mixtures with LDPE + EVA polymer were mixed at 175 °C and compacted at 140 °C. The compaction equipment included a prismatic mold and a series of metal plates that were set on top of the mixture (kneading compactor) (Fig. 2: center). The compaction energy was transferred through two twin metal wheels (Fig. 2: right) that moved horizontally on the plates.

2.2. Testing procedures

The rutting resistance of mixtures was assessed by wheel tracking tests according to the European Standard EN 12697-22 using the "small device procedure B" (in air). A minimum of two slabs per mixture were compacted and tested up to 10,000 load cycles. Each slab was poured into the metal mold (Fig. 2: left) and tested in load control. The device's wheel applied a load of 700 N, while its speed was set to 26.5 passes per minute corresponding to 0.44 Hz.

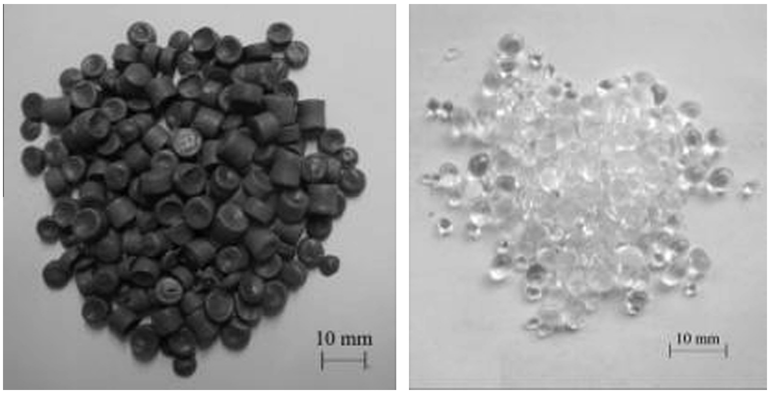

Fig. 1. Polymer pellets at room temperature: (left) LDPE, (right) EVA.