Construction and Building Materials 23 (2009) 1456–1464

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effect of polyethylene on life of flexible pavements

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A R T I C L E I N F O

Article history:
Received 22 April 2008
Received in revised form 26 June 2008
Accepted 1 July 2008
Available online 21 August 2008

Keywords:
Low density polyethylene
Modifiers
Asphalt cement
Durability
Stone matrix asphalt
Multi-layer elastic analysis

A B S T R A C T

The present study investigates the potential use of pyrolysis low density polyethylene (LDPE) as a modifier for asphalt paving materials. Five different blends including conventional mix were subjected to binder testing such as rheological tests, as well as to some other tests related to the homogeneity of the system. Further, its effect on the moisture sensitivity and low temperature performance of stone matrix asphalt (SMA) mixtures was studied. Research results indicate that modified binders showed higher softening point, keeping the values of ductility at minimum range of specification of (100^{+} cm), and caused a reduction in percentage loss of weight due to heat and air (i.e. increase durability of original asphalt). The results indicated that the inclusion of LDPE in SMA mixtures can satisfy the performance requirement of high-temperature, low temperature and much rain zone. In addition, the horizontal tensile strain at the bottom of asphalt concrete layer (E_t) and the vertical compressive strain at the top of subgrade layer (E_c) were calculated using multi-layer elastic analysis program, BISAR under 50KN set of dual tires with 106.5 mm contact radius. These responses were used for estimating the improvement in service life of the pavement or reduction in thickness of SMA and base layer for the same service life due to modification the SMA mixtures.

1. Introduction

Asphalt is a viscous material that is derived from crude petroleum and is used in paving roads. Asphalt is generally understood to include asphaltenes, resins, and oils. While asphalt is primarily composed of hydrocarbon molecules (hydrogen and carbon), it also contains elements such as oxygen, nitrogen, and sulfur. Asphalt has an extremely diverse molecular structure depending on the crude source. Asphalts are thermoplastic materials – that is, they gradually liquefy when heated. Asphalts are characterized by their stiffness, consistency, or ability to flow at different temperatures.

Asphalt that has been specially prepared for use in pavement by controlling its quality and consistency is called asphalt cement. Asphalt cement is ordinarily used in a "hot mix" pavement composition that also contains coarse and fine aggregate. This composition, also called asphalt concrete, is blended at specified temperature, applied to the roadbed, and compacted with rollers to produce a smooth driving surface.

A problem with all applications that involve asphalt is the tendency for the asphalt to become brittle at low temperatures and to become soft at high temperatures. This change due to temperature is called "temperature susceptibility". Some asphalts, depending on crude oil source and refining practice are more temperature susceptible than others. Asphalt cement may be modified by the addition of components that increase the strength of the material or otherwise alter its properties. Various additives, polymers, etc., have been utilized for the purpose of improving the high and low temperature characteristics of asphalt compositions, as well as to improve their toughness and durability. Additives such as styrene based polymers, polyethylene based polymers, polychloroprene, gilsonite, various oils, and many other modifiers including tall oil have been added to asphalt to enhance various engineering properties of asphalt.

Asphalts with polymers from multiphase systems, which usually contain a phase rich in polymer and a phase rich in asphaltenes not absorbed by the polymer. The properties of asphalt-polymer blends depend on the concentrations and the type of polymer used. The polymer is usually loaded in concentrations of about 4–6% by weight with respect to the asphalt [1]. Higher concentrations of polymers are considered to be economically less viable and also may cause other problems related to the material properties.

Polymers used for asphalt modification can be grouped into three main categories: thermoplastic elastomers, plastomers, and reactive polymers. Thermoplastic elastomers are obviously able to confer good elastic properties on the modified binder; while plastomers and reactive polymers are added to improve rigidity and reduce deformations under load. Examples of the plastomeric types of polymers studied for asphalt modification are polyethylene (PE), ethylene-vinyl acetate (EVA), and ethylene-butyl acrylate (EBA) random copolymers [1].

The literature on asphalt modification with plastomeric polymers is quite scarce, especially with respect to rheological properties. Some preliminary data were reported in [2–9]. Al-Dubabe

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doi:10.1016/j.conbuildmat.2008.07.004

et al. [4] were tried to evaluate the effectiveness of the PE-modified Arab asphalt. They collected asphalt binders from four refineries in Gulf countries. It was found that the softening point tend to increase with the addition of PE, which indicates improvement in resistance to deformation.

Punith and Veeraragavan [9] used reclaimed PE as an additive in asphalt concrete mixtures. They found that the performance of PE-modified asphalt mixtures are better when compared to conventional mixtures. The rutting potential and temperature susceptibility can be reduced by the inclusion of PE in the asphalt mixture.

Sinan and Emine [10] tried to investigate the possibility of using various plastic wastes containing High Density Polyethylene (HDPE) as polymer additives to asphalt concrete. It was investigated that the influence of HDPE-modified binder obtained by various mixing time, mixing temperature and HDPE content on the Marshall Stability, flow and Marshall Quotient (Stability to flow ratio). The binders used in Hot Mix Asphalt (HMA) were prepared by mixing the HDPE in 4–6% and 8% (by the weight of optimum bitumen content) and AC-20 at temperatures of 145–155 and 165 °C and 5–15 and 30 min of mixing time. They concluded that the HDPE-modified asphalt concrete results in a considerable increase in the Marshall Stability (strength) value and a Marshall Quotient value (resistance to deformation). Four percent HDPE, 165 °C of mixing temperature and 30 min of mixing time were determined as optimum conditions for Marshall Stability, flow and Marshall Quotient (MQ). MQ increased 50% compared to control mix. It can be said that waste HDPE-modified bituminous binders provide better resistance against permanent deformations due to their high stability and high MQ and it contributes to recirculation of plastic wastes as well as to protection of the environment.

Mahabir and Mayajit [11] used LDPE as a modifier for asphalt paving materials. The basic properties of modified binder and mixes containing such binders were studied and compared with those of asphalt cement. It was observed that the optimum requirement of PE is 2.5%. Marshall stability, resilient modulus, fatigue life, and moisture susceptibility of mixes were improved as a result of modification of asphalt cement by reclaimed polyethylene.

Zoorob and Suparma [12] discussed the laboratory design of continuously graded Asphaltic concrete (AC) mixtures containing recycled plastics aggregate replacement (Plastiphalt). Recycled waste plastics, predominantly composed of LDPE in pellet form, were used in dense graded bituminous mixes to replace (by volume) a portion of the mineral aggregates of an equal size, i.e., 5.00–2.36 mm. They indicated that at the same air-void content, the compacted Plastiphalt mix has lower bulk density than that of the conventional control mix. A 30% aggregate replacement by volume with the LDPE, results in a reduction in bulk compacted mix density of 16%. This reduction in density is advantageous in terms of haulage costs. LDPE partial aggregate replacement also results in a 250% times increase in the Marshall stability (strength) value and an improved MQ value. The value of creep stiffness of the Plastiphalt mix after 1 h loading at 60 °C is found to be slightly lower than the control mix; however, the Plastiphalt gives 14% recovery after 1 h unloading time compared to 0.6% for the control mix. The indirect tensile stiffness modulus values of the Plastiphalt compacted mix were found to be lower than that of the control mix, whereas the static indirect tensile strength values were found to be much higher. They also investigated the future recyclability of the Plastiphalt. It was found that the mechanical properties of the recycled mix to be equal to that of the original Plastiphalt and better than the control mix.

On the other hand, and based on many research reports and engineering case studies [13,14]; it has been shown that the use of stone mastic asphalt (SMA) on road surfaces can achieve better rut-resistance and durability. The SMA mixtures are designed to have high aggregate content, high asphalt content typically 5.5–7% and high filler content. For ordinary SMA, the use of regular asphalt cement together with fibrous material as a drainage inhibitor is sufficient. Under high temperatures and heavy loading, a harder asphalt grade will also suffice. A polymer (such as pyrolysis polypropylene (PP), PE or styrene-butadiene-styrene (SBS)) modified binder may be used to substitute the fibrous material. It is possible to increase the capability of resistance to permanent deformation at the expense of a higher price and greater instability. The demand for higher pavement quality from users is ever-increasing. The cost of a pavement failure is also mounting higher .Hence; there is a strong desire to have better asphalt mixture from highway agencies. Recently, the Ministry of Housing and Construction in Iraq decided to introduce SMA in its road specification to control or limit the distress failure in most provinces such as rutting, shoving, stripping etc. through polymer modification.

However, this study is an attempt to satisfy the following objectives:

1. Possibility of using the South Carolina Department of Transportation (SCDOT) 13 mm SMA gradation on the Iraqi paving materials.
2. Using the pyrolysis LDPE as a modifier for asphalt paving materials to produce paving mixtures that resist the action of temperature and temperature changes, the action of air and water and the action of traffic.
3. Evaluation the benefits of LDPE modifying the SMA layer in flexible pavement using a mechanistic–empirical design approach.

A mechanistic–empirical design approach has been used in the present study to evaluate the benefits of modifying the SMA mixtures in terms of reduction in layer thickness and extension in service life of the pavement. The proposed methodology has a better capability of characterizing different material properties and loading conditions, and has the ability to evaluate different design alternatives on an economic basis.

Two design alternatives considered in the present study are as follows:

1. The same service life for the modified and unmodified pavement sections. It would lead to reduction in base, or SMA thickness and has been expressed in terms of Layer Thickness Reduction (LTR).
2. The same pavement sections for unmodified and modified SMA. It would result in more service life of the pavement due to the LDPE modification and has been expressed in terms of Traffic Benefit Ratio (TBR).

As input values, SMA modulus was determined based on the properties of binder and the volume concentration of the aggregate using Eqs. (1) and (2) mentioned by [15,16], and typical moduli of asphalt concrete (AC), base, subbase and subgrade in China were selected as shown in Fig. 1.

$$E_b = 1.157 \times 10^{-7} \times \tau^{-0.368} \times 2.718^{-P.I.}(T_{R\&B} - T_{asp})^5 \quad (1)$$

where E_b is the elastic modulus of the bituminous binder (MPa), $T_{R\&B}$ is the recovered bitumen ‘Ring and Ball’ softening temperature (°C), T_{asp} is the temperature of the asphalt layer (°C), P.I. is the recovered bitumen ‘Penetration Index’ and t is the loading time (secs).

Eq. (1) is only applicable when:

$$0.01\ s < t < 0.1\ s,$$

$$-1.0 < P.I. < 1.0,$$

$$20\ ^\circ C < (T_{R\&B} - T_{asp}) < 60\ ^\circ C.$$