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Evaluation of fatigue behavior of hot mix asphalt mixtures prepared by bentonite modified bitumen

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HIGHLIGHTS

- Marshall stability, flow and MQ values of modified mixtures are higher than the control mixture.
- The resilient modulus of mixtures prepared with modified bentonite bitumen is higher than the control mixture.
- Mixtures containing 10% and 15% bentonite modified bitumen have longer fatigue lives.
- Mixtures containing 10% and 15% of modified bentonite bitumen have higher dissipated energy than the control mixture.
- Models for prediction of the fatigue behavior of control and modified HMAs under different strain levels were obtained.

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ABSTRACT

The objective of this research study was to investigate and evaluate effects of bentonite on fatigue properties of hot mix asphalt (HMA) mixtures. The experimental program for this study included use of five percentages of bentonite (10%, 15%, 20%, 25% and 30%) by weight of bitumen for modifying base bitumen. Several tests such as: marshal stability, indirect tensile strength, resilient modulus and fatigue test were conducted. The fatigue tests were based on four-point bending test in strain-controlled mode at 3 micro-strain levels (600–800–1000 lm/m) with sinusoidal loading. The fatigue life of mixtures has been evaluated based on the 50% reduction of the initial stiffness modulus. The results show that fatigue life of asphalt mixtures prepared with bentonite modified bitumen is longer than conventional HMAs. Also, bentonite leads to relative increase in indirect tensile strength and resilient modulus of asphalt mixtures. Finally, based on experimental results, a model is proposed to describe the fatigue behavior of asphalt mixtures containing bentonite modified bitumen.

1. Introduction

Fatigue cracking, is a load associated cracking that is caused due to repeated traffic loading. This type of cracking is considered to be one of the most significant distress modes in flexible pavements. The fatigue life of an asphalt pavement is directly related to various engineering properties of hot mix asphalt (HMA) mixtures. The complicated microstructure of asphalt concrete is related to the gradation of aggregate, the properties of aggregate–bitumen interface, the void size distribution, and the interconnectivity of voids. As a result, the fatigue property of asphalt mixtures is very complicated and sometimes difficult to predict [1–4]. Many studies have been conducted to understand the occurrence of fatigue and how to extend pavement life under repetitive traffic loading [3,5]. Various admixtures are used to elongate the service life of pavements via prevention or retardation of cracks in pavements without negatively affecting the diverse performance parameters of asphalt mixtures [6,7].

In several studies conducted, it was determined that the strength of HMA mixtures against permanent deformation [8,9], fatigue [10] and moisture induced damage [11,12] increase after utilization of SBS in bitumen modification.

Nowadays, a great amount of mineral, organic, natural and industrial additives are used for improvement and modification of some properties of asphalt binders such as resistance to thermal and shrinkage cracking, reduction in permanent deformation and asphalt bleeding as well as reduction of hardness due to aging of asphalt binder [13]; however, considering geographic conditions and existent facilities in various countries, selecting an appropriate modifier differs from one country to another.

Most laboratory and field experiments have indicated that use of rubberized asphalt concretes (RAC), in general, increase durability, reduction of crack reflection, fatigue life and skid resistances,

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and resistance to permanent deformation of asphalt overlay and the stress absorbing membrane (SAM) layers [14,15].

The use of crumb rubber (CRM), expanded to HMA mixtures, continues to evolve since the CRM bitumens enhance the performance of asphalt mixtures by increasing the resistance of the pavements to permanent deformation and thermal and fatigue cracking. Many researchers have found that utilizing crumb rubber in pavement construction is both effective and economical [16–20]. High temperature rutting and low temperature cracking are two disturbing drawbacks of unmodified and pure bitumen [21]. Clay based chemicals are pioneered as one of the most well-known and profitable new generation of bitumen additives. In the recent decades, bentonite clay and organically modified bentonite (OMBT) were used as reinforcement in order to modify bituminous pavements. In the literature, a vast amount of experiments performed on bitumen and the variation of softening point, viscosity and ductility as a function of clay content and clay type were reported. Bending beam rheometer test results for aged specimens through RTFO and PAV indicated that, modifying bitumen with bentonite and OMBT, will improve low temperature properties of bitumen and significant improve resistance of asphalt mixtures to cracking [21].

Although various additives such as polymers and rubber powder may improve the performance of bitumen, suitable performance of a special additive should not be the criterion for choosing it, but there are also some other factors such as economical issues, production of modifier and environmental compatibility that should be considered when selecting an additive.

The simplest fatigue models consider the fatigue prediction on the basis of either the strain-controlled mode or stress-controlled mode. Eqs. (1) and (2) show the simplest fatigue models for controlled-strain and controlled-stress modes, respectively. This type of fatigue model does not consider effects of temperature, modulus, and loading frequency on the behavior of HMA mixtures. The relationships between fatigue life and stress–strain level were consistently confirmed in the SHRP project for the ranges of stresses and strains under laboratory measurements of the asphalt specimen [22].

$$N_f = a(1/\varepsilon)^b \tag{1}$$

$$N_f = a(1/\sigma)^b \tag{2}$$

where ε = tensile strain at the bottom of specimen (in./in.), σ = applied tensile stress (psi), and a, b = experimentally determined coefficients.

In addition to the simple models 1 and 2, there are different fatigue models that were used by different agencies or were based on different considerations, such as the Asphalt Institute model and the Shell model. The major role of these models is to provide a relationship between mixture properties, pavement response (strain), and load repetitions to failure. The parameters of these models are mainly based on a continuous-loading sequence, and the coefficients are determined from empirical data regression. Eqs. (3) and (4) show the Asphalt Institute model and the Shell model, respectively.

$$N_f = 0.0796(\varepsilon_t)^{-3.291}(E_t)^{-0.854} \tag{3}$$

$$N_f = 0.0685(\varepsilon_t)^{-5.671}(E_1)^{-2.363} \tag{4}$$

where E_1 is the initial flexural modulus of asphalt concrete (psi).

Monismith et al. [23] introduced fatigue life prediction model using initial modulus and tensile strain of HMA mixtures. Eq. (5) shows the fatigue life prediction model proposed by Monismith et al. [23].

$$N_f = k_1(1/\varepsilon_t)^{k_2}(1/E)^{k_3} \tag{5}$$

where k_1, k_2, k_3 = experimentally determined coefficients, E = asphalt concrete initial modulus (psi).

In this research study, bentonite is used to modify bitumen. Bentonite is a sedimentary rock consisting, to a large proportion of clay minerals with a typical 2:1 layered structure (smectites) and a high concentration in sodium ions [24]. In fact, bentonite is a clay mineral, which has high montmorillonite in its structure [25]. Iran is located in a point of the world in which there are numerous sources of bentonite. Studies on the present data provided by the Geological Organization of Iran show that the rich sources of bentonite in Iran, which are mainly located in the central region of Iran. Considering low cost of bentonite compared with other additives and existence of numerous sources of bentonite in Iran, evaluation of modified asphalt binders by bentonite has been the main reason for this research.

The objective of this research study was to gain an improved understanding of the long-term performance characteristics (fatigue behavior) of the modified asphalt concrete mixtures containing bentonite additive through a series of experimental tests. Experiments were carried out to evaluate engineering properties of the mixture, such as the marshal stability, mixture stiffness, indirect tensile strength and fatigue life performance through flexural bending beam fatigue test. At last, based on experimental studies, a model is proposed to describe the fatigue life of asphalt mixtures containing bentonite modified bitumen.

2. Experimental methods

2.1. Aggregate and bitumen

Aggregates used in this study were obtained from the Boomehen mine in Tehran, Iran. The gradation of the blended aggregates is shown in Fig. 1. Table 1 lists engineering properties of the raw material used in the current research.

In this study, a 60/70-penetration grade bitumen was obtained from Tehran refinery which was supplied by Pasargad Oil Co, Tehran, Iran. The physical properties of the bitumen are presented in Table 2.

2.2. Additive

The bitumen was modified with bentonite manufactured by Dorinkashan Co. Five levels of bentonite content were used, namely 10%, 15%, 20%, 25% and 30% by weight of bitumen. The modified bitumens were prepared by using a high shear mixer. The bitumen was heated to 140 °C for thirty minutes and then subjected to fifteen minutes of mixing time with bentonite at 140 °C and 4000 rpm shear rate. The physical properties and chemical composition of bentonite are presented in Tables 3 and 4, respectively.

2.3. Mix design procedure

The mix design of the asphalt mixtures was performed by using the standard Marshall mix design procedure with 75 blows on each side of cylindrical samples (10.16 cm in diameter and 6.35 cm thick) for compaction. Marshall Samples were compacted and tested by the following standard procedures: bulk specific gravity (ASTM D2726), stability and flow test (ASTM D1559). For each test (Marshall stability and flow, indirect tensile strength, resilient modulus test, fatigue test) three test specimens were used.

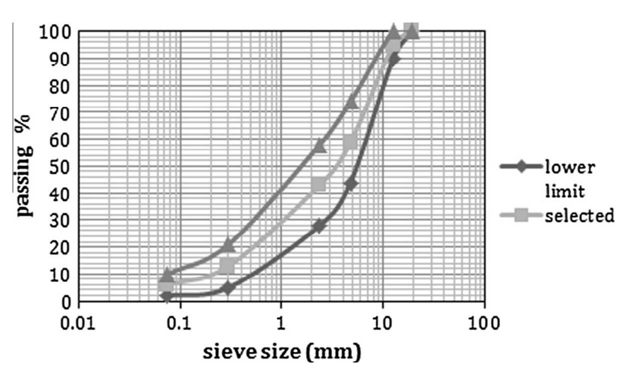

Fig. 1. Grading curves of aggregates.