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Review

Evaluating the effect of additives on improving asphalt mixtures fatigue behavior

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HIGHLIGHTS

- Additives are considered for improving tar and, consequently, asphalt mix properties.
- Use of such additives not only improves tar properties but also enhances resistance of asphalt mixes.
- Recycled additives used in asphalt mixes which has many environmental and economic advantages.

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ABSTRACT

Acting as a surface which is supposed to tolerate several reloading of heavy axes, pavement shall hold enough resistance against failures. Fatigue phenomenon is one of the most important causes of weakness in road pavement, which is occurred due to reloading of it. Many laboratory researches are carried out with the purpose to enhance fatigue life of asphalt concrete mix, in which researchers have tried to improve quality of asphalt concrete mix against load carrying transportation vehicles. During recent years, additives like polymer, iron powder, hydrated lime, glass wastages, and crumb rubber are also considered for improving tar and, consequently, asphalt mix properties. In this article, effect of using different additives in previous researches on fatigue parameters of asphalt mix was analyzed. Results of this research indicate positive effect of these additives on improving fatigue behavior of asphalt mix.

Contents

1. Introduction

Asphalt layers play the role of protecting road structure and transferring compressive stress from upper layers to lower layers. Quality of these layers is one of the determinative factors of safety and comfort of road users, which factor is now turned to one of the most important factors in asphalt mix design [1].

Since we face various ranges of simple and compound axes due to increasing number of transportation vehicles in the world and consequent dimension increase of transportation vehicles, importance of fatigue behavior as one of the important factors in road pavement failure is felt now more than ever [2]. Fatigue phenomenon is one of the most important factors reducing life of road pavement, which is firstly started by micron cracks on lower

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asphalt layers and is gradually expanded to upper layers. There are two methods to increase tolerance of asphalt mix against fatigue both of which methods need raising executive expenses of road pavement [3];

- Increasing tolerance of asphalt mix against dynamic loads and use of more resistant asphalt mix.
- Increasing pavement diameter.

Therefore, application of various additives is considered by researchers within recent years for improving fatigue parameters of asphalt mix. Additives are materials which are previously added to tar and are mixed with it under determinate conditions and/or added during preparation of asphalt mix and in the process of admixing tar and stone materials to mixing unit of asphalt factory [4]. In this research, effect of different admixtures on fatigue resistance of asphalt mix is studied.

2. Fatigue phenomenon in pavement

Cracking is the most important state of road failure. This means that construction of a pavement, which experiences no cracking within a determinate period, is almost impossible. Expansion of cracks on pavement surface indicates loss of cohesion serving ability of pavement. When cope with a stress more than their capacity, materials are cracked. On the other hand, increasing transit of transportation vehicles intensify cracks and cause higher damages on surface and underneath layers [5].

Cracking occurs in different forms the most common among which is alligator cracking that happens due to fatigue phenomenon on asphalt pavement and under the pressure of several reloads. Fig. 1 represents alligator cracking due to fatigue phenomenon [6].

3. Fatigue resistance estimation methods in asphalt mix

Fatigue traits of asphalt mix can be stated based on the relation between primary strain or stress and quantity of cycles resulting in crack with the help of Eqs. (1) and (2) in which N_f indicate number of cycles causing crack (fatigue life), ε_0 is primary strain, σ_0 is primary stress, S_0 is rigidity of mixes, and a–f are experimental coefficients [7].

$$N_f = a\left(\frac{1}{\varepsilon_0}\right)^b \times \left(\frac{1}{S_0}\right)^c \quad (1)$$

$$N_f = d\left(\frac{1}{\sigma_0}\right)^e \times \left(\frac{1}{S_0}\right)^f \quad (2)$$

There are similar models for predicting fatigue life of asphalt pavements. Eqs. (3) and (4) present another relation between strain or tensile stress underneath the pavement layer and number of crack cycles on that layer. In these equations, N_f quantity of crack cycle (fatigue life), ε_t tensile strain, σ_t tensile stress, and K_1 and K_2 are constants [8].

Fig. 1. Fatigue cracks in asphalt pavement.

$$N_f = k_1(\varepsilon_t)^{k_2} \quad (3)$$

$$N_f = k_1(\sigma_t)^{k_2} \quad (4)$$

Fatigue life of an asphalt sample depends on the tensile strain which expands under the load in the sample. Even it is witnessed in different temperature conditions and loading tone that the life length of sample pavement has a unique relation with tensile strain. This proven law may be stated in a fixed equation in relation 5 in which N is quantity of loading until crack time and n power is usually about 4 [9].

$$N = A\left(\frac{1}{\varepsilon_t}\right)^n \quad (5)$$

When cracking starts, its expands upward and weakens structure gradually. The damage caused by fatigue on asphalt pavements is a complex phenomenon which is caused by consecutive bending and give birth to micron cracks on pavements.

Energy methods can also be used for predicting fatigue life of asphalt mix. Damage caused by fatigue is in relation with the scale of the wasted energy in a sample during experiments. Furthermore, various researchers have used energy-based models for predicting fatigue behavior of asphalt mix. Therefore, wasted energy can be used for depiction of reduced mechanical properties including rigidity during experiment. Wasted energy in each volume unit of every cycle is represented via Eq. (6) for viscoelastic materials.

$$W_i = \pi \times \sigma_i \times \varepsilon_i \times \sin \delta_i \quad (6)$$

In this equation, W_i is the wasted energy in each cycle of i time, σ_i pressure range in each cycle of i time, ε_i is tensile range in each cycle of i time and δ is the angle of the phase between wave signal of tensile pressure and degree. Wasted energy is against number of crack cycles in Eq. (7). In this relation, N_f is number of crack cycles, W_i is wasted energy and K_1 and K_2 are experimental coefficients [10].

$$N_f = K_1 \times \left(\frac{1}{W_i}\right)^{K_2} \quad (7)$$

4. Evaluating effect of using additives on fatigue performance of asphalt mix

Additives are materials added to tar or mix in the time of preparing asphalt with the purpose to apply special changes in asphalt resulting in improvement of technical properties [11]. The matter of additive in asphalt production is not a new subject. However, it has absorbed further studies to itself within recent decade.

In the research carried out by Zhang et al. on HMA additive containing recovered asphalt pavement (RAP), bar fatigue was analyzed and tested. In this research, asphalt samples were provided with varying quantities of 0%, 10%, 20% and 30% of RAP. According to Fig. 2, results of this research indicated that based on rupture scale with reduced rigidity of 50%, adding RAP increases fatigue life of HMA mix and mix with higher RAP have prolonged fatigue life [12].

In two completely similar research, fatigue and dynamic properties of mix reformed by polymer are studied through Indirect Tension Fatigue Test ITFT in a temperature of 15 °C and ratio of 0.3, 0.4, and 0.5 stresses was studied. Three types of fiber including cellulose fiber, polyester fiber and mineral fiber are used as