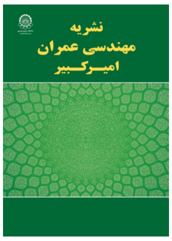

Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 50(2) (2018) 109-112
DOI: 10.22060/ceej.2016.869

Evaluating Fatigue Life of Asphalt Mixtures Using Surface Free Energy Parameters

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ABSTRACT: Fatigue cracking is one of the main and dominant distresses of hot mix asphalt (HMA) at moderate temperatures. This distress happens mainly because of two reasons: 1) Cohesive fracture in the asphalt binder or mastic phase, and 2) Adhesive fracture at the interface of asphalt binder and aggregate. Therefore, one of the main features of the materials used in asphalt mixtures, which affects their fracture type, is the surface free energy (SFE) of asphalt binder and aggregates. In this study, SFE components of aggregates and asphalt binders were respectively determined by universal sorption device (USD) and sessile drop (SD) tests. Also, to evaluate the effects of adhesive and cohesive parameters on the fatigue life of asphalt mixtures, the samples prepared with different combinations of asphalt binder and aggregate were examined by indirect tensile fatigue test. Results showed that the asphalt mixtures with limestone aggregates and asphalt binder 85-100 had the highest fatigue life compared to the mixtures produced by other aggregates. This feature can be caused by three parameters: 1) Limestone due to the high specific surface area has the highest adhesion with asphalt binder. 2) By using the asphalt binder 85-100, greater adhesion energy was created between the asphalt binder and aggregate, which increased the energy required for separating the asphalt binder from the aggregate surface and the occurrence of adhesion rapture distress. 3) By using asphalt binder 60-70 caused less significant free energy of cohesion in the asphalt binder which resulted in the increased possibility of distress in mastic.

Review History:

Received: 25 January 2016
Revised: 6 November 2016
Accepted: 21 November 2016
Available Online: 5 December 2016

Keywords:
Hot Mix Asphalt
Fatigue Cracking
Surface Free Energy
Adhesion
Cohesion

1- Introduction

In flexible pavements, the dominant distress includes fatigue cracks, rutting and thermal cracking. These distresses are sometimes related to the quality of materials, weak maintenance, increased axle loads, traffic volume and environmental factors [1]. Fatigue cracks as one of the mentioned distresses that occur at moderate temperatures under repetitive traffic loading. This distress happens mainly because of two reasons: 1) Cohesive fracture in the asphalt binder or mastic phase, and 2) Adhesive fracture at the interface of asphalt binder and aggregate [2].

Fatigue behavior of asphalt mixtures is affected by a combination of positive and negative effects of the features of their constituents. These features include bond energy (like cohesive energy in asphalt binder and adhesive energy on the contact surface between asphalt binder and aggregate) in the mixtures, viscoelasticity of the asphalt binder, and internal structure distribution. Surface free energy (SFE) method is one of the most important methods of measuring adhesive and cohesive parameters, which is based on the fundamental properties of materials that affect the strength of asphalt mixtures against loss of adhesion and cohesion. The most important parameters used in SFE method include asphalt binder's cohesion and adhesion between asphalt binder and aggregate in dry and moisture conditions [3].

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2- Surface free energy method

SFE components of asphalt binder and aggregates are mainly composed of non-polar and acid-base parts. Cheng et al. [2] used the relation proposed by Good and Van Oss [4] to determine SFE components of asphalt binder and aggregate. Therefore, the total SFE in asphalt binder and aggregate was calculated according to the following equation:

$$\Gamma = \Gamma^{LW} + \Gamma^{AB} \tag{1}$$

where Γ = SFE of asphalt or aggregate; Γ^{LW} = Lifshitz-van der waals component of the SFE; and, Γ^{AB} = acid-base component of the SFE.

Acid-base part of the above equation can also be divided into two parts, namely Lewis acid and Lewis base:

$$\Gamma^{AB} = 2\sqrt{\Gamma^{+}\Gamma^{-}} \tag{2}$$

where Γ^{+} = Lewis acid component of surface interaction; and Γ^{-} = Lewis base component of surface interaction.

Free energy of cohesion is defined as the work required for separating a certain material with unit surface area under vacuum condition and is divided into two parts [2]. Based on SFE definition, it is easy to show the total cohesion work for different materials as follows:

$$\Delta G_i^c = 2\Gamma \tag{3}$$

Similar to cohesion, SFE of adhesion between asphalt binder and aggregate is equal to the amount of work required for a crack to initiate at the interface of asphalt binder and aggregate in vacuum conditions [2]. Equation 4 shows the amount of SFE of adhesion in asphalt mixtures:

$$\Delta G_i^a = \Delta G_i^{aLW} + \Delta G_i^{aAB} = 2\left[\left(\sqrt{\Gamma_s^{lw}\Gamma_l^{lw}}\right)+\left(\sqrt{\Gamma_s^{+}\Gamma_l^{-}}\right)+\left(\sqrt{\Gamma_s^{-}\Gamma_l^{+}}\right)\right] \tag{4}$$

where ΔG_i^c = free energy of adhesion; ΔG_i^{aLW} = non-polar or Lifshitz-van der waals part of adhesion; ΔG_i^{aAB} = acid-base or polar part of adhesion; Γ_l^{LW}, Γ_l^{+} and Γ_l^{-} = SFE components of asphalt binder; and ; Γ_S^{LW} , Γ_S^{+} and Γ_S^{-} = SFE components of aggregate.

3- Materials and Mix Design

In this study, three kinds of aggregates and asphalt binders were used to produce the samples. In addition, to evaluate the properties of the asphalt binder used in this study, conventional tests such as penetration, softening point and ductility tests were carried out. Also, asphalt mixtures were designed by Marshall Mix Design method according to ASTM D6927-15. The optimum asphalt binder contents were found to be 5.5, 5.2 and 5% for limestone, granite and quartzite, respectively.

4- Indirect Tensile Fatigue Test

Fatigue behavior of asphalt mixtures was obtained by indirect tensile fatigue test. The fatigue criterion was defined as the sample failure as suggested by CEN[1] [5]. A haversine load with the frequency of 2 Hz (0.1 s loading time and 0.4 s rest time) applied on a sample with 101.06 mm thickness and the height of 67.5 mm.

The stress level must be selected so that the strain measured during the first 10 applications was inside the strain range, 50 to 200 µm/m. Therefore, in this study, the fatigue test was performed with a stress of 600 kPa at 5 °C.

5- Result and Discussion

Results showed that by comparing fatigue lives of the samples produced by two kinds of asphalt binders used in this study, it can be concluded that granite and limestone aggregates had a similar and better behavior in terms of strength against fatigue cracks compared to the samples produced by quartzite aggregates. Since the aggregate gradations of the three groups were identical, it can be claimed that the reason for the similar fatigue life was the fact that physical strength of aggregates was better in granite aggregates; but in limestone aggregates, the mixture's adhesion (free energy adhesion multiplied by specific surface area of the aggregate) was better, which caused resistive behaviors of the samples of these two group to be almost the same as each other.

As mentioned before, specific surface areas of aggregate, limestone and quartzite vary respectively from the largest to smallest; this parameter not only increases adhesion force, but also causes better interlocking to provide better strength in the mixtures with higher specific surface area. Therefore, since aggregate's strength and adhesion to the asphalt binder in quartzite aggregates are lower than that in the limestone and granite aggregates, thus they have lower fatigue life.

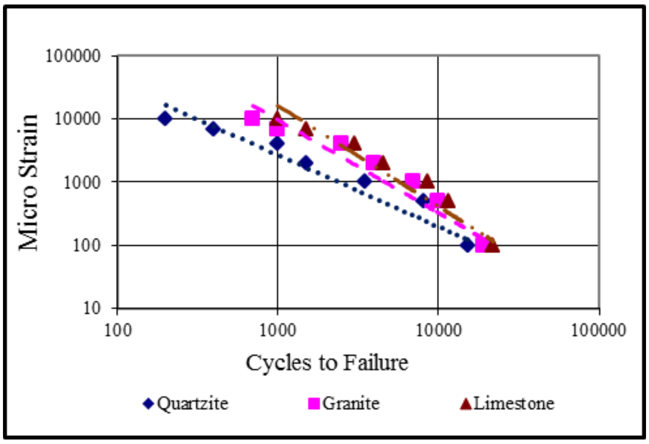

Figure 1. Fatigue behavior of the different mixes for asphalt binder 60-70

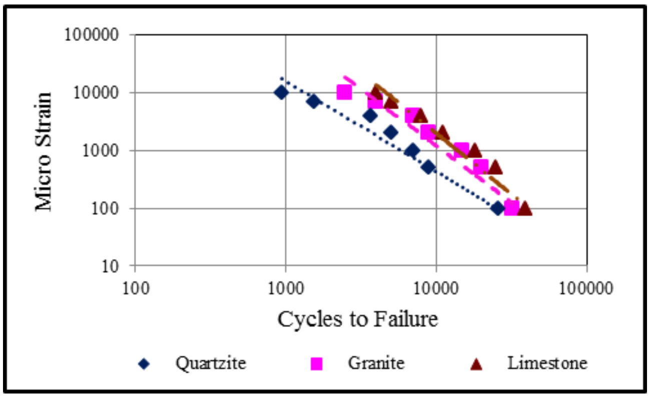

Figure 2. Fatigue behavior of the different mixes for asphalt binder 85-100

As observed in Figures 1 and 2, asphalt mixtures made of 85-100 penetration asphalt binder had greater fatigue life than the mixtures containing 60-70 penetration asphalt binders. As the type of aggregates used for producing the samples was similar for both types of asphalt binders, increased strength of the samples with similar aggregates could be attributed only to the different performance of asphalt binder type or compatibility between asphalt binder and aggregate.

Using 85-100 penetration asphalt binder caused greater significant free energy of cohesion in the asphalt binder which resulted in the increased possibility of distress in mastic. Also, by using the 85-100 penetration asphalt binder, greater adhesion energy was created between the asphalt binder and aggregate, which increased the energy required for separating the asphalt binder from the aggregate surface and the occurrence of adhesion rapture distress.

1 European Committee for Standardization

6- Conclusions

1. Asphalt mixtures made of the softest asphalt binder and limestone had the highest fatigue life.
2. Higher adhesion and larger specific surface area in limestone resulted in higher fatigue life in the samples.
3. The softer asphalt binder had larger values of cohesive SFE, indicating that strength of this asphalt binder against cracks was greater at the asphalt binder film.
4. The softer asphalt binders had greater adhesion energy with aggregates, which increased the energy required for separating the asphalt binder from the aggregate surface and the occurrence of adhesion rupture distress.

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Please cite this article using:

A.R. Azarhoosh, F. Moghadas Nejad, Evaluating Fatigue Life of Asphalt Mixtures Using Surface Free Energy Parameters, *Amirkabir J. Civil Eng.*, 50(2) (2018) 365-376.

DOI: 10.22060/ceej.2016.869