Construction and Building Materials 136 (2017) 184–191

Contents lists available at ScienceDirect

Construction and Building Materials

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

# Fatigue performance evaluation of modified asphalt binder using of dissipated energy approach

Mahmoud Ameri [a,1], Mohammadreza Seif [b,2], Massoumeh Abbasi [c,3,*], Mohammad Molayem [d,4], Alireza KhavandiKhiavi [e,5]

[a] School of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, 16846-13114, Iran
[b] School of Civil Engineering, Iran University of Science and Technology, Tehran, Iran
[c] Islamic Azad University, East Tehran Branch, Department of Chemistry, Faculty of Science, Tehran, PO Box 33955-163, Iran
[d] School of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran
[e] Department of Civil Engineering, University of Zanjan, Zanjan, Iran

## HIGHLIGHTS

- The modified asphalt binders perform better at high strain levels.
- The initial dissipated energy has the potential to become a rapid method to describe the fatigue resistance of asphalt.
- In nonlinear strains, the curve slope of modified binder is less than curve slope of pure binder.
- In nonlinear strains, unmodified and modified asphalt binders with increasing loading cycles, DE decreased.

ARTICLE INFO

*Article history:*
Received 7 August 2016
Received in revised form 16 December 2016
Accepted 3 January 2017
Available online 19 January 2017

*Keywords:*
Asphalt binder
Fatigue life
Time sweep test
Dissipated energy
IDE

ABSTRACT

In this paper dissipated energy (DE) versus loading cycles is plotted, at the same time fatigue life of asphalt binders were investigated using of dissipated energy (DE) approach and based on linear and nonlinear strain levels. It was found that based on results obtained of time sweep test; there is a fair correlation between dissipated energy at the 50th loading cycle and fatigue life of asphalt binders in all strain levels. As a result, initial dissipated energy (IDE) is a parameter obtained from time sweep test, so the amount of initial dissipated energy (IDE) at the 50th loading cycle can be predicted the fatigue of asphalt binders without performing millions of loading cycles.



## 1. Introduction

Bituminous materials are widely used in construction of flexible pavements. Fatigue cracking is one of the major distresses of flexible pavements and is defined as the damage in asphalt pavements by repetitive stresses and strains due to traffic loading and environmental factors [1,2,3]. According to report NCHRP-RPT-459, there are several factors effective in estimating and prediction fatigue life asphalr binders [4,5]. The six most important factors that influence on fatigue life asphalr binders are binder type, strain level, temperature, frequency, number of cycles and rest period. It has been shown that the asphalt mixture fatigue resistance is strongly correlated with asphalt binder fatigue properties at intermediate temperatures [6,7,9,9].

Utilizing the concept of energy in assessing the fatigue behavior of asphalt binders has two advantages. First, the energy is a scalar function which is independent of the direction of the applied stress or strain. Secondly, it includes stress, strain the material's properties in a single unit of measure [22]. Evaluation of binder fatigue performance under cyclic loading has continuously been one of the most popular research topics for engineers during the past few years [10].

Airey et al. [8,11] conducted stress sweep tests using of DSR to obtain the linearity limits of various asphalt binders at different

* Corresponding author at: Department of Chemistry, Faculty of Science, Islamic Azad University, East Tehran Branch, Tehran, Iran.
*E-mail address:* massoumeh.abbasi@yahoo.com (M. Abbasi).

[1] Professor.
[2] Ph.D. Research Scholar.
[3] Assistant Professor.
[4] Ph.D. Research Scholar.
[5] Assistant Professor.

http://dx.doi.org/10.1016/j.conbuildmat.2017.01.010
0950-0618/

temperatures. Furthermore, Bahia in 1999 reported the fatigue performance of asphalt binders at various strain levels in the linear and nonlinear range and their effects on mixture performance [4,5].

There are several developments in terms of asphalt binder fatigue tests which time sweep test, according to project NCHRP 9-10, has reported to be an effective test method to evaluate binder fatigue life [4,6,7,12]. So that Time sweep (TS) test is reported to be a promising method to estimate fatigue performance of asphalt binders. This test provides a simple method of applying repeated cycling of stress or strain loading at selected temperatures and loading frequencies. Another advantage of this test is that it can be used to calculate fatigue life of asphalt binders based on dissipated energy approach. Dissipated energy approach has been broadly used as a simplified method to characterize fatigue performance of viscoelastic materials based on modulus and phase angle in each loading cycles. Van Dijk introduced the approach to evaluate fatigue performance of viscoelastic materials in terms of dissipated energy [13,14]. He proposed equation (1) to calculate dissipated energy during a single load cycle.

$$W_n = \pi \sigma_n \varepsilon_n \sin \theta_n \tag{1}$$

where $W_n$ $n$ is the dissipated energy, $\sigma_n$ and $\varepsilon_n$ are the applied stress and strain, $\theta_n$ is the phase angle and $n$ represents number of loading cycles. In this research study in order to have a more meaningful of the fatigue properties of asphalt binders, the dissipated energy approach was utilized. According to this concept, the dissipated energy in each cycle can be determined by Eq. (1).

Cheng et al. (2002) showed that the energy balance is influenced by rheological properties of the mix and the asphalt binder, and also fatigue damage in viscoelastic materials can be due to stored and dissipated energies [15]. Eq. (2) was proposed to characterize the number of cycles to failure using dissipated energy. Where: $N_f$ is number of load application to failure, Wi is dissipated energy and $K_1$, $K_2$ are experimentally determined coefficients.

$$N_f = K_1 \left(\frac{1}{W_i}\right)^{K_2} \tag{2}$$

Baburamani and Porter [16], Rowe [17] and Ghuzlan [18] indicated that initial dissipated energy also can be an accelerate method to evaluate fatigue life of viscoelastic materials [16,17,18]. Initial dissipated energy (IDE) is defined as the dissipated energy measured at 50th loading cycle. However, Carpenter and Shen (2003) found that the initial dissipated energy approach is not appropriate for the whole loading range, especially at low strain fatigue tests [19].

The objective of this study is to determine the linear and nonlinear strain ranges of six asphalt binders in a constant frequency using of strain sweep test. In during to strain sweep tests, for determining of linear and nonlinear range, strain 0–20% applied on all asphalt binder samples. Next, dissipated energy versus loading cycles is plotted on linear and non linear strain levels. According

**Table 1**
The properties of neat binders used in this study.

| Parameters | Unit | Test methods | | 60/70 | 85/100 Tabriz |
|---|---|---|---|---|---|
| | | ASTM | AASHTO | | |
| Specific gravity | g/cm$^3$ | D70 | T228 | 1.016 | 1.009 |
| Penetration (100 g) | 0.1 mm | D5 | T49 | 66 | 99 |
| Softening point | °C | D36 | T53 | 51 | 46.4 |
| Ductility | Cm | D113 | T51 | >100 | >100 |
| Solubility | (%) | D2042 | T44 | 99.5 | 99.56 |
| Flash point (Cleveland) | °C | D2170 | T201 | 303 | 260 |
| Kinematic viscosity 135 °C | Centistokes | D6 | – | 361 | 240 |
| Heating loss | (%) | – | – | 0.04 | 0.15 |
| Penetration after heating loss | 0.1 mm | – | – | 47 | 66 |
| Penetration after heating loss original penetration | (%) | – | – | 85.4 | 66 |
| Ductility after heating loss | cm | – | – | >50 cm | 80 |
| Penetration Index (PI) | – | – | – | −0.73 | −0.3 |
| PVN(25-135) | – | – | – | −0.39 | 3.21 |

**Table 2**
Properties of SBS and CR used in this study.

| Physical properties | Unit | Specification | Test method | | |
|---|---|---|---|---|---|
| Density | g/cm$^3$ | 0.94 | ISO 2781 | | |
| Volatile material | wt% | Max. 0.5 | ASTM D1416 | | |
| Styrene content | % | 31 | LSYQS1DO11 | | |
| Mechanical Properties | | | | | |
| Melt index | g/10 min | <1 | ASTM D1238 | | |
| Hardness T | Shore A | 79 | ASTM D2240 | | |
| T.S.V. | cst | 13.4 | ASTM D445 | | |
| Other | | | | | |
| Appearance | – | Pellet | – | | |
| Structure Melt Index: 200 C, 5 kg | – | Linear | – | | |
| Crumb rubber | | | ACR | CCR | |
| | Specific gravity (gcm$^3$) | | 1.042 | | 1.053 |
| | Moisture content (wt%) | | 0.76 | | 0.77 |
| | Ash content (wt%) | | 6.01 | | 4.66 |
| | Carbon black content (wt%) | | 32.98 | | 30.41 |
| | Extract content (acetone and chloroform) (wt%) | | 9.86 | | 11.69 |
| | Sulphur content * (wt%) | | 2.02 | | 1.24 |
| | Source | | Car tires | | Car tires |