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Investigating the fatigue endurance limit of HMA mixture using RDEC approach

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HIGHLIGHTS

- Dissipated energy remains almost constant in significant portion of loading cycles at low strain tests.
- The fatigue endurance limit value depends on the properties of hot mix asphalt mixture, test type and analysis method.
- There is a transition point in semi log strain–N_{f50} curve when the curve is regressed using the power law relation.

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ABSTRACT

The endurance limit is level of strain below which fatigue damage does not occur for any number of load repetitions. The evaluation and the determination of the fatigue endurance limit requires for testing at low strain levels. Various extrapolation methods were presented for the determination of fatigue lives at low strain levels. In this research study, the four point beam fatigue tests were conducted in accordance with AASHTO T321 using a semi sinusoidal loading at 10 Hz for 70, 150, 200, 250, 400, 700 and 1000 microstrain levels. The test data were investigated via the RDEC approach and PV–N_{f50} unique relationship to obtain the fatigue endurance limit. The results showed that there is a transition point in semi log strain–N_{f50} curve when the curve is regressed using the power law relation. The results also showed that the number of load cycles corresponding to transition strain (endurance limit) is different with load cycles corresponding to PV_L (1.1E+7).

1. Introduction

In recent years, researchers have conducted various studies to validate and determine the fatigue endurance limit of hot mix asphalt. The studies showed that there is a tensile strain below which asphalt mixtures tend to have almost unlimited fatigue life [1]. The endurance limit is defined as the tensile strain below which no fracture or fatigue damage occurs [2].

For determination of endurance limit, fatigue tests must be conducted at low strain levels. Recent research studies showed that the fatigue tests consume much time at low strain so, generally, researchers have used a number of extrapolation techniques to predict the fatigue life. For low strain testing, extrapolation is necessary to predict N_{f50} (the number of load cycles corresponding to 50% of initial stiffness) because failure cannot be reached in an acceptable time frame [3].

In 2010, NCHRP 646 report presented the findings of research performed to investigate the existence and determination methods of a fatigue endurance limit for hot mix asphalt (HMA) mixtures. In NCHRP 646 report, also, a number of extrapolation techniques were evaluated and finally, for fatigue life determination at low strain, several standard drafts presented including the standard practice for extrapolation long-life beam fatigue tests using the Ratio of Dissipated Energy Change (RDEC) approach [4]. This report shows that RDEC approach has potential to be used for fast determination of the fatigue life of asphalt mixtures [5]. Using the RDEC approach, the fatigue life of a low strain test can be predicted with shortened testing and still maintains sufficient accuracy [3].

RDEC is calculated with following equation [3]:

$$RDEC_a = \frac{(DE_a - DE_b)}{DE_a(b - a)} \quad (1)$$

where $RDEC_a$ = the average ratio of dissipated energy change at cycle a, comparing to cycle b; a, b = loading cycle a and b, respectively; DE_a, DE_b = dissipated energy at cycle a and b, respectively, which were calculated directly by fatigue testing program.

As shown in Fig. 1, when the RDEC is plotted versus number of load cycles (RDEC–LC curve), a curve is produced that decreases rapidly at the beginning application of load cycles, then reaches

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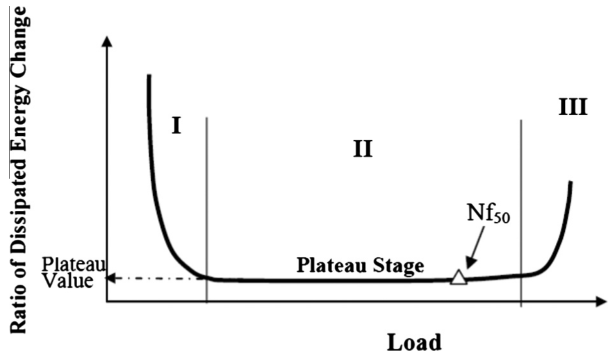

Fig. 1. Typical RDEC versus loading cycles plot and the indication of PV [3].

to an steady state and continues for a long number of load cycles (plateau stage) and increases rapidly at the end [6]. In the plateau stage (stage II), the RDEC value is almost constant, characterizing a period where there is a constant percentage of input energy being terned into damage. A plateau value, PV, is defined as the RDEC value corresponding to the 50% stiffness reduction load cycles (N_{f50}) [7]. The PV provides a unique relationship with N_{f50} for different mixture, loading modes and loading levels. PV–N_{f50} relationship is presented in Eq. (2) [3,4]:

$$PV = 0.4428 N_{f50}^{-1.1102} \tag{2}$$

For fast determination of fatigue life, the RDEC–LC curve (log–log) of low strain testing for one mix and the unique PV–N_{f50} curve are plotted together. The RDEC–LC curve is extended until it crosses the unique PV–N_{f50} curve. The intersection point of these two curves produces: y = PV, x = N_{f50} [8]. Fig. 2 shows the examples of this process [3].

According to all related conducted Researches, there is a unique energy level, PV_L, energy based fatigue endurance limit, which is the onset of the fundamental change in HMA fatigue behavior. If the energy level of a HMA mixture is below the PV_L, the mixture is expected to have extended long fatigue life. The conducted studies indicate that PV_L is around 6.74E−9, which corresponds to the breakpoint of the fatigue life at 1.10E+7, as shown in Fig. 2 [3,7].

In this research study, using the four point beam fatigue test, proposed standard practice for extrapolating long-life beam fatigue tests using RDEC were investigated. For each tested mixture, the endurance limit values were determined based on analysis of strain–N_{f50} curves and a new proposed approach.

Table 1
Aggregates properties.

Properties	Test method	Result: Tabriz	Result: Arak
Coarse aggregate			
Los angeles abrasion (%)	AASHTO-T96	20	21
Angularity (%)	ASTM-D5821	100	100
Elongation	BS-812	11	12
Flakiness	BS-812	22	23
Bulk specific gravity (gr/cm^3)	AASHTO-T85	2.654	2.656
Apparent specific gravity (gr/cm^3)	AASHTO-T85	2.709	2.713
Water absorption (%)	AASHTO-T85	1.1	0.8
Fine aggregate			
Plasticity index	AASHTO-T89,90	Non-plastic	Non-plastic
Sand equivalent	AASHTO-T81769	85	87
Bulk specific gravity (gr/cm^3)	AASHTO-T84	2.617	2.621
Apparent specific gravity (gr/cm^3)	AASHTO-T84	2.719	2.718
Water absorption (%)	AASHTO-T84	1.4	1.1
Filler			
Plasticity index	AASHTO-T89,90	Non-plastic	Non-plastic
Specific gravity (gr/cm^3)	AASHTO-T100	2.702	2.710

Table 2
Aggregates gradations.

Sieve size (mm)	Type 1	Type 2	Type 3
	Lab samples		Field samples
	Percent passing (%)		
25	100	–	–
19	95	100	100
12.5	–	95	98
9.525	63	–	–
4.75	43	60	57
2.375	31	43	45
0.3	9	13	13
0.075	4	7	6

2. Background

The fatigue endurance limit concept was first proposed by Wöhler for metallic materials [5]. Barret et al. described the

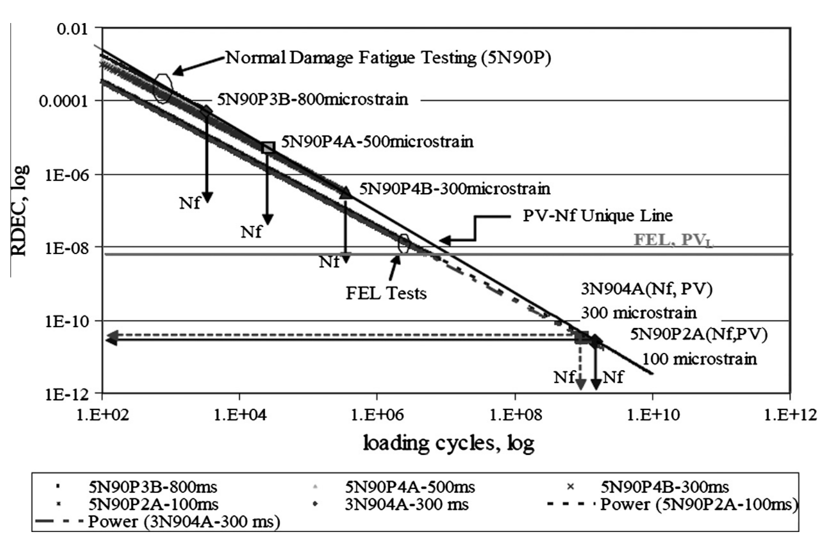

Fig. 2. Fatigue life prediction using RDEC approach and endurance limit PV_L [3,7].