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Evaluating the effect of laboratory aging on fatigue behavior of asphalt mixtures containing hydrated lime

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HIGHLIGHTS

- Replacement of aggregate filler with hydrated lime increases the flexural stiffness of asphalt mixtures.
- Replacement of aggregate filler with HL decreases the phase angle of asphalt specimen.
- Mixtures that contained 1.5% of hydrated lime exhibited the best improvement in fatigue life.

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ABSTRACT

Hydrated lime (HL) is typically used as an additive to enhance the anti-stripping resistance of asphalt mixtures. As a result, this particular feature of hydrated lime has received the greatest share of academic attention, and its other long-term effects such as the resulting resistance against fatigue cracks have been relatively neglected. In the present study, effects of different quantities of HL (by weight of aggregate) on the fatigue properties of asphalt mixtures was investigated by four-point bending fatigue testing of unaged and aged specimens. Laboratory long-term aging procedure was carried out in accordance with AASHTO PP2 (120 h of treatment at 85 °C). Fatigue tests were conducted in strain-controlled mode with a sinusoidal load applied with frequency of 10 Hz (without rest) at 20 °C. Fatigue life was analyzed with the stiffness reduction and dissipated energy methods. Test results showed that fatigue life of asphalt mixtures is sensitive to their HL content. Addition of 1%, 1.5% and 2% of hydrated lime to mix design was found to improve the fatigue life of unaged asphalt specimens. For the aged specimens, adding of 1% and 1.5% HL increased the fatigue life by, respectively, 25% and 50%, but use of 2% HL led to 40% reduction in this property. For all asphalt mixtures, the best improvement in the fatigue life was achieved by mixes containing 1.5 of hydrated lime.

1. Introduction

Adequate knowledge about the fatigue behavior of asphalt mixture allows us to estimate its durability and long-term performance in field. Asphalt fatigue is typically caused by repeated stresses and strains due to traffic loads applied at intermediate temperatures, which gradually lead to reduced pavement stiffness, cracks initiation in the bottom of asphalt layer, and crack propagation toward the pavement surface (However, load-related fatigue cracking can also be started at the surface of the pavement and propagate downward through the asphalt layer.). With time, these cracks expand in various directions and eventually emerge as what is known as alligator or fatigue cracks [1–3].

Hydrated lime (HL) has a long history of use as an anti-stripping additive in asphalt mixtures. Due to its favorable chemical and physical properties, hydrated lime is known to be desirably effective in preventing a variety of failures, and possess some advantages that distinguish it from other anti-stripping agents and make it the additive of choice for many engineering applications. Hydrated lime is commonly used as an additive to enhance the anti-stripping resistance of asphalt mixtures, therefore, this particular feature of hydrated lime has received the greatest share of academic attention and its other long-term properties, including the resistance against fatigue cracks, have been relatively neglected [4].

Hydrated lime can improve the properties of asphalt mixtures in three ways: by improving the resistance to stripping, improving the resistance to permanent deformation, and reducing the rate of stiffening due to bitumen oxidation. Various studies have shown the positive effect of hydrated lime on the asphalt's resistance to

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stripping in the presence of moisture [5]. Unlike most mineral fillers, hydrated lime is a chemically active substance that binds the aggregates to bitumen and improves mixture adhesion and stiffness, thus enhancing its resistance against rutting [6]. Studies on the effect of hydrated lime on the oxidative bitumen aging have shown that this agent can reduce the rate of bitumen's chemical aging. The anti-aging effects of hydrated lime on bituminous materials were first observed in Utah in the late 1960's, when it was reported that bitumen recovered from asphalt mixtures that contained hydrated lime were surprisingly softer than control specimens [5].

There is no consensus among researchers regarding the effect of hydrated lime (HL) on fatigue life of asphalt mixtures. The results of a study on the effect of hydrated lime on the mechanical properties of asphalt mixtures have shown that addition of hydrated lime as filler improves the resistance against permanent deformation of asphalt mixture [7]. Using the results of dynamic modulus tests on HL-containing specimens, these researchers managed to predict the probability of early cracking in the asphalt layer and, thereby, fatigue life of pavement. Another study has shown that introduction of different percentages of hydrated lime to Hot Mix Asphalt (HMA) at different temperatures can increase its dynamic modulus by 17–65%. In that study, dynamic modules of the HL-containing mixtures (1–2% by weight of aggregate) was on average 25% higher than that of control specimens [8]. The Linear Viscoelastic characteristics and fatigue properties of asphalt mixes containing hydrated lime [9] showed that the substituting limestone filler by HL filler can increase complex modulus of mixes; however, it does not change the fatigue properties of mixes.

In view of above reports, one might question that, setting aside the contribution of hydrated lime to anti-stripping resistant of asphalt pavement, can the increased stiffness induced by this agent undermine the resistance of pavement to fatigue cracking? To answer this question, we conducted a series of tests to determine the fatigue behavior of HL-containing asphalt mixture and investigate the effect of quantity of added HL on the fatigue life and related parameters. The best way to evaluate the mechanical behavior of asphalt mixtures is by testing under realistic conditions. The best approach to achieve the satisfactory level of realism is through field tests, but since these tests are time-consuming and expensive, the best alternative method, that is, laboratory tests with sufficiently accurate environment and loading simulations are more recommended. What distinguishes the present study from previous works in this field is: (1) the use of bending beam fatigue test instead of typically used indirect tensile test; and (2) investigation of the effect of long-term aging on fatigue behavior, which is a novel objective. To achieve this objective, we evaluated the effect of hydrated lime on the fatigue behavior of asphalt mixture specimens in two conditions: (i) unaged, and (ii) aged in laboratory as per AASHTO PP2. As mentioned, to achieve more realistic results, the specimens were subjected to four-point bending beam fatigue test. The results of fatigue life tests were analyzed with the stiffness reduction and dissipated energy methods. Considering the existing evidence regarding the role of HL particles in prevention of cracking, the results were analyzed with the dissipated energy techniques with a failure criterion based on micro-crack formation and propagation regime, which is more refined and reliable than the conventional method of 50% reduction in the initial flexural stiffness.

2. Materials

Hydrated lime (HL) was acquired from a lime plant near Tehran, and then tested to make sure that its physical and chemical properties satisfy the criteria specified in ASTM C1097 (Table 1). Previous studies have shown that in most countries, HL content of asphalt mixture never exceeds 2% by weight of aggregate [4]; therefore, specimens were made with HL content of 1–2 wt%. Siliceous aggregate with specifications shown in Tables 2 and 3 and well graded in accordance with Gradation No. 4 of Iran's Asphalt Pavement Regulations (Publication 234) was acquired from an asphalt plant near Tehran (Fig. 1). Bitumen with 60/70 penetration grade was acquired from Tehran refinery (Table 4).

3. Specimen preparation and test method

The optimum bitumen content based on The Marshall test method (ASTM D1559: 75 blows per face, 4% air voids, mixture and compaction temperature 145°C and 135°C respectively) was obtained 5.7%. Specimens were prepared by replacing filler with hydrated lime in amounts corresponding to 1%, 1.5%, and 2% by weight of dry aggregate. The HL was added to dry aggregates, and finally asphalt slabs were prepared. As per AASHTO PP2, all slabs were subjected to short-term aging (4-h treatment of non-compacted mixture at 135 °C) followed by long-term aging (120-h treatment of compacted mixture at 85 °C).

Four-point bending fatigue test (Fig. 2) is a reliable method of fatigue characterization for asphalt specimens. This particular test is highly regarded as one of the few procedures whose results can be interpreted by methods such as dissipated energy and fracture mechanics. In this study, fatigue behavior of specimens was analyzed with the stiffness reduction method (50% reduction in the initial flexural stiffness and Rowe and bouldin's method) and the dissipated energy technique. The effect of HL content on the fatigue behavior was studied by four-point bending fatigue test of specimens of length 380 ± 6 mm, width 63 ± 6 mm, and height 50 ± 6 mm extracted from asphalt slabs in accordance with AASHTO T321. As per AASHTO T321, fatigue test was conducted in strain-controlled mode at strain levels of 500, 600, 700, and 900 microstrains using a sinusoidal load applied with frequency of 10 Hz (without rest) at 20 °C (as specified by AASHTO T321 and ASTM D7460).

4. Results and discussion

4.1. Effect of hydrated lime on flexural stiffness

Flexural stiffness is a major determinant of the fatigue life of asphalt mixtures. The initial flexural stiffness has been defined as

Table 1
Chemical and physical requirements of standard hydrated lime (according to ASTM C1097).

Characteristic	Limit	Test results
Retained on a No. 30 sieve	Maximum 3%	0.13
Retained on a No. 200 sieve	Maximum 30%	0.5
Calcium and magnesium oxides	Minimum 90%	95.95
Carbon dioxide	Maximum 5%	5.34
Unhydrated calcium and magnesium oxides	Maximum 5%	3.82
Free moisture of dry hydrates	Maximum 2%	0.88
Specific gravity (g/cm^3)	–	2.12

Table 2
Specific gravity and water absorption of aggregate.

Parameter measured	Aggregates type		
	Coarse	Fine	Filler
Bulk specific gravity (gr/cm^3)	2.501	2.487	–
Bulk specific gravity SSD (gr/cm^3)	2.563	2.571	–
Apparent specific gravity (gr/cm^3)	2.665	2.715	2.534
Water absorption (%)	1.9	2.4	
Test method	ASTM C127	ASTM C128	ASTM C188