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Estimation of relative performance of reinforced overlaid asphalt concretes against reflection cracking due to bending more fracture

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ABSTRACT

Most of overlaid asphalt pavements are facing with reflection cracking in an early age of service life. In this study, a numerical prediction model for fatigue life was developed by modifying crack growth rate, d*a*/d*N*, of Paris law with horizontal deformation rate, d*u*/d*N*, to compare relative performance of the material choice based on experimental test result. Experimentally, an interlayer between old concrete pavement and overlay asphalt pavement, polymer modifiers and fiber were used to retard initiation and progress of reflection crack. An expedited reflection cracking test method was developed and applied to various bitumen mixture-concrete block test bodies. The results were compared with one another in terms of resistance against reflection cracking. The coefficient of determination of predicted life and measured life was very high ($r^2 = 0.98$). Therefore, it was shown that the fatigue life of each bitumen material and interlayer combination can be estimated using the prediction model developed in this study.

1. Introduction

As the concrete pavement being used for a long time, many types of distresses, such as cracking, scaling and joint deterioration appear on the pavement slab. Bitumen mixture overlay is one of the most widely used choice for rehabilitation of the damaged cement concrete pavements. In most cases, however, the reflection cracking begins to appear on the bitumen surface due to cracks existing in the concrete slab underneath the overlaid asphalt pavement within a year or two. Development of the reflection crack is a result of stress concentration due to vertical wheel loadings by traffic and horizontal movement (shrinkage) of base concrete slabs due to temperature change.

A vertical wheel load creates bending stress at the bottom of bitumen mixture layer, which is the top of an opening of old concrete slabs. At almost the same time, the wheel load induces shear stress in bitumen concrete body perpendicular to the bottom face of bitumen layer when it is simultaneously moving across the crack. The former is responsible for mode I fracture cracking, together with the shrinkage due to temperature drop. The later is responsible for mode II fracture cracking.

Many studies have been performed in efforts of retarding initiation and progression of reflection cracking through the bitumen layer. However, no perfect solution has yet been developed for preventing reflection cracking because of too much complication in the cause of reflection cracking. Therefore, effective cracking retardation is the best way to extend service life of the overlaid asphalt pavement as many researchers suggested. Some of the possible choices include employing an interlayer and strengthening bitumen mixture materials for retarding initiation of reflection crack and delaying progress of the initiated crack.

However, mathematical models of those techniques have been limited to mode I fracture and few models were applied to the mixed mode of fracture [8,3]. Those mathematical models were estimated fatigue life of overlaid asphalt pavements based on fatigue crack growing theory by using vertical crack propagation concept. However, because there is an interlayer, which is made of completely different materials, the crack growing theory is not directly applicable. Instead, it is possible to estimate fatigue life using expansion of horizontal deformation in place of vertical crack propagation.

In this study, as a simplified assumption, progress of reflection cracking was evaluated as a result of bending fracture due to dynamic load application vertically in the laboratory as the first stage of study for developing models for predicting reflection cracking of overlaid asphalt pavement. The objective of this study is to show possibility of fatigue life estimation of overlaid bitumen mixture pavement with interlayer by using horizontal deformation in place of vertical crack propagation of Paris law. A limited number of reinforcing materials were used for the overlay bitumen mixture and these performances against reflection crack were relatively compared based on laboratory test results.

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2. Materials and methods

2.1. Materials

The base bitumen with a 85/100 penetration grade was used as a binder for mixture preparation. The base bitumen was modified using a low-density polyethylene (LDPE) + carbon black (CB) and a styrene–butadiene–styrene (SBS). Appropriate contents of LDPE + CB and SBS were selected as 6% + 10% and 5% by weight of total binder, relatively.

In addition, three reinforcing materials were used based on previous studies [7,8,5] and these include a polyethylene fiber (PF), a polyethylene film (vinyl: PV) and a glass fiber grid (GG). Table 1 describes the mixture name and materials used for each mixture. Thickness of PV and length of PF are 0.2 mm and 6 mm, respectively. LDPE and SBS were pre-mixed in bitumen using a high shear mixer. A 0.35% of PF by weight of total mixture was added into the mixture just before mixing. Single layer of PV and GG were placed at the bottom of slab specimen mould before dumping loose hot mix for roller compaction.

A gneiss aggregate, with maximum size 19 mm, was used for a dense-graded bitumen mixture. Table 2 shows gradation of the aggregate. The gradation meets the specification limit given by Ministry of Construction and Transportation (MCT) of Republic of Korea. Table 3 shows physical properties of aggregate.

Marshall mix design was carried out for each mixture combination to determine optimum bitumen content (OBC) [2]. The OACs were used for slab specimen mixture. Two beam specimens were prepared by saw cutting a slab specimen which was compacted using a hydraulic roller, making the size of a beam specimen being 340 mm (length) × 120 mm (width) × 53 mm (depth).

2.2. Methods

Marshall stability, air void, flow, and indirect tensile strength (ITS) were measured for each mixture by appropriate standard methods. To simulate an asphalt pavement being overlaid on top of a crack in a cement concrete pavement, the beam specimen was bonded using tack coat with discontinuous cement concrete of thickness 100 mm and width 120 mm. Two discrete-concrete bases were separately placed with a 10 mm gap from top to 1/3 depth to create a pseudo crack (gap) underneath the asphalt pavement layer.

Vertical loads were applied on top of the beam through a steel circular loading plate (100 mm diameter) at 10 Hz of square wave using Instron 8516 material testing system. The specimen was covered with a thin plastic pad at the interface between steel loading plate and specimen to simulate tire contact and to prevent bitumen from sticking to the plate. The maximum load of 5395.5 N was applied to cause 100 psi of tire pressure on the specimen through the loading plate and the minimum load of 196.2 N was applied to prevent circular loading plate separating from beam specimen. Test was carried out at 20 °C in a temperature-controlled chamber [4].

Table 1
Description of various asphalt mixture.

Mixture	Description
AP	Normal bitumen mixture
APG	Glass fiber grid (GG) reinforced AP mixture
APV	Polyethylene vinyl (PV) reinforced AP mixture
LC	LDPE 6% and CB 10% (LC) modified bitumen mixture
LCF	polyethylene (PF)-added LC mixture
LCG	GG reinforced LC mixture
LCV	PV reinforced LC mixture
LCFG	PF-added and GG reinforced LC mixture
LCFV	PF-added and PV reinforced LC mixture
LS	LDPE 4% and SBS 3% (LS) modified bitumen mixture
LSF	PF-added LS mixture
LSG	GG reinforced LS mixture
LSV	PV reinforced LS mixture
LSFG	PF-added and GG reinforced LS mixture
LSFV	PF-added and PV reinforced LS mixture
S	SBS 5% (S) modified bitumen mixture
SF	PF-added S mixture
SG	GG reinforced S mixture
SV	PV reinforced S mixture
SFG	PF-added and GG reinforced S mixture
SFV	PF-added and PV-reinforced S mixture

Table 3
Physical properties of gneiss aggregate.

Classification	Specific gravity	Abrasion (%)	Absorption (%)
Spec. limit	>2.5	<35	<3.0
Gneiss	2.72	18.1	0.7

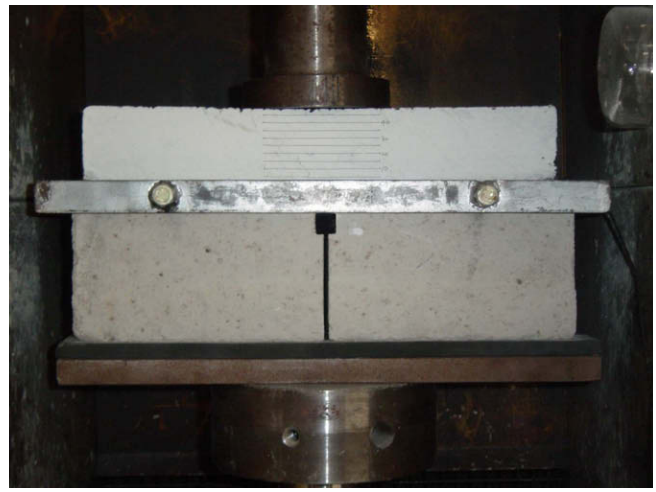

Fig. 1. Bending fracture (mode I) test setup.

Horizontal expansion of each beam was measured using an extensometer from the points which were installed in one side of beam before testing. Vertical crack growth as load cycle accumulating was visually monitored every 5000 cycles from the side at which white water color was pained (Fig. 1). Test was conducted until the vertical crack length reached at 50 mm [5]. But test of LCFG was finish at 25 mm of the vertical crack length because cracks did not progressed higher than that height.

3. Prediction model for bending fracture mode

When the load is applied repeatedly to a structural member which has an internal crack, the crack grows as the number of load cycle increases. In fatigue crack growing system, the crack growth rate due to load cycle is given by Paris law [10]

$$\frac{da}{dN} = C(\Delta K)^m \tag{1}$$

in which, C and m are material properties. ΔK is defined as the difference between maximum stress intensity factor ($K_{\max}$) and minimum stress intensity factor ($K_{\min}$)

$$K_{\max} = F\sigma_{\max}\sqrt{\pi a}, \quad K_{\min} = F\sigma_{\min}\sqrt{\pi a}, \tag{2}$$

$$\Delta K = K_{\max} - K_{\min} = F\Delta\sigma\sqrt{\pi a} \tag{3}$$

Replacing Eq. (1) with Eq. (3), a differential equation is obtained with number of cycle, N, and crack length a for uniform Δ. The number of cycle required for the crack to grow from a_1 to a_2 is determined by integrating the differential equation below

$$N_2 - N_1 = \frac{a_2^{1-m/2} - a_1^{1-m/2}}{C(F\Delta\sigma\sqrt{\pi})^m(1 - \frac{m}{2})} \tag{4}$$

Table 2
Gradation of gneiss aggregate.

Sieve size (mm)	25	19	13	4.75	2.38	0.6	0.3	0.15	0.075
Passing (%)	100	99.1	78.3	52.3	40.1	22.6	17.0	11.6	7.73