Experimental Study on the Creep Characteristics of FRC Base for Composite Pavement System

Woo-tai Jung, Sung-yong Choi, Young-hwan Park

***Abstract*—**The composite pavement system considered in this paper is composed of a functional surface layer, a fiber reinforced asphalt middle layer and a fiber reinforced lean concrete base layer. The mix design of the fiber reinforced lean concrete corresponds to the mix composition of conventional lean concrete but reinforced by fibers. The quasi-absence of research on the durability or long-term performances (fatigue, creep, etc.) of such mix design stresses the necessity to evaluate experimentally the long-term characteristics of this layer composition. This study tests the creep characteristics as one of the long-term characteristics of the fiber reinforced lean concrete layer for composite pavement using a new creep device. The test results reveal that the lean concrete mixed with fiber reinforcement and fly ash develops smaller creep than the conventional lean concrete. The results of the application of the CEB-FIP prediction equation indicate that a modified creep prediction equation should be developed to fit with the new mix design of the layer.

***Keywords*—**Creep, Lean concrete, Pavement, Fiber reinforced concrete, Base.

I. Introduction

THE composite pavement system is also known as semi-rigid pavement or durable pavement. Dedicated research started actively in early 1960s in USA and Europe. The term "composite pavement" was derived owing to its composite structure combining more than two layers with different materials playing different structural roles. The most common composite pavement combines a rigid base covered by a ductile surface layer. The rigid base is generally made of cement treated base (CTB), rolled-compacted concrete (RCC) or lean-mix concrete [1].

In this study, the composite pavement system is composed of a functional surface layer, a fiber reinforced asphalt middle layer and a fiber reinforced lean concrete base. The mix design of the fiber reinforced lean concrete corresponds to the mix composition of conventional lean concrete but reinforced by fibers. The lean-mix concrete used in road pavement is characterized by a small content in microfines owing to a high W/C ratio and poor quantity of cement. This mix is one of the mixes which require compaction to achieve the specified compactness. The quasi-absence of research on the durability or long-term performances (fatigue, creep, etc.) of such mix characterized by a high internal porosity and poor structural mechanical performance stresses the need to evaluate experimentally the long-term characteristics of this base composition [2].

This study tests the creep characteristics as one of the long-term characteristics of the fiber reinforced lean concrete (FRC) layer for composite pavement using a new creep device. The test variables are selected to be the eventual presence of fiber and the eventual admixing of fly ash for further comparison of the creep characteristics of the fiber reinforced lean concrete.

II. Test Setup

A. Test Setup and Variables

Two types of fiber that are Nylon (NY)-Micro and Polypropylene (PP)-Macro (Fig. 1, Table I) as well as replacement ratios of 0 and 30% by fly ash (FA) are applied to examine the creep characteristics of the fiber reinforced lean concrete. The different combinations of the test variables of the fiber reinforcement for the base are arranged in Table II.

(a) NY-Micro (b) PP-Macro

Fig. 1 Fibers

TABLE I
Applied Fibers

Fibers	Length	Diameter	Shape
NY-Micro	12 mm	25 μm	Straight
PP-Macro	30 mm	0.79 mm	Crimped

B. Fabrication of Specimens and Test Method

The common creep test adopts the hydraulic loading device with the setup presented in Fig. 2 as proposed by ASTM C 512 (KSF 2453) [3], [4]. The loading device for creep enables to apply uniformly and continuously the specified load even if the specimen undergoes deformation. However, this hydraulic loading device requires continuous recharging of its hydraulic pressure according to time, which results in slight variations of the permanent load at each recharge. Accordingly, precise experimental results cannot be secured due to the fluctuating loading in the case of creep test in which the time-dependent behavior has to be examined for long periods exceeding 6 months. Therefore, the gravity load-amplifying loading device (amplification by approximately 37 times) shown in Fig. 3, Fig.

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4 was used in this study. This device provides constant as well as continuous and uniform permanent loading with time.

Creep loading was conducted on each specimen at 28 days and loading was applied during 6 months at 40% of the compressive strength of the specimens.

TABLE II
MIX COMPOSITION FOR CREEP TEST

Specimen	W/C	S/a	Fiber reinforcement ratio (%)		Unit material quantity (kg/m^3)				
			NY	PP	W	C	F.A	C.C	F/A
Plain	0.795	40	-	-	119	150	825	1350	
FA			-	-		105	818	1339	45
FRC			0.1	0.1		150	825	1350	
FRC-FA			0.1	0.1		105	818	1339	45
FRC-FA-PP			-	0.2		105	818	1339	45

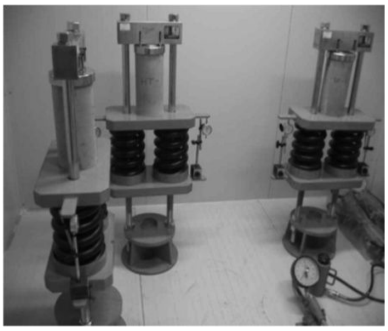


Fig. 2 Hydraulic creep test device

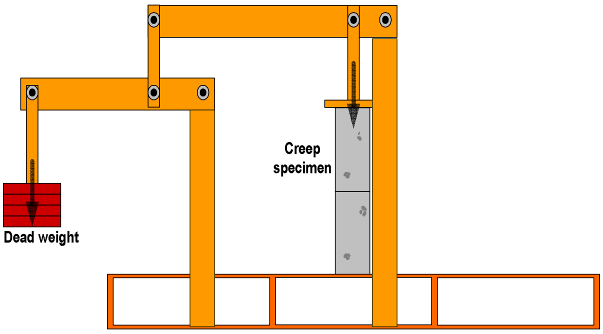


Fig. 3 Gravity load-amplifying loading device

Fig. 4 Creep test of base course mixes

III. TEST RESULTS AND DISCUSSION

A. Creep Prediction Equation of Concrete

In concrete structures, the creep is a critical factor for the prediction of the time-dependent long-term behavior of the structure. Currently, various creep prediction formulae are used but their applicability to the fiber reinforced lean concrete needs to be examined by comparing the test results to the values calculated using the CEB-FIP creep prediction equation. When a stress $f_c(t')$ is applied at t' days, the total strain at t days including the elastic strain and creep can be expressed as follows[5].

$$\varepsilon_{\omega}(t,t') = f_c(t')\left[\frac{1}{E_{ci}(t')} + \frac{\phi(t,t')}{E_{ci}}\right] \tag{1}$$

where E_{ci} and $E_{ci}(t')$ are the early tangent moduli of elasticity at 28 days and t' days, respectively; and, $\phi(t, t')$ is the creep coefficient of concrete.

$$\phi(t,t') = \phi_0 \beta_c (t - t') \tag{2}$$

$$\phi_0 = \phi_{RH} \beta(f_{cu}) \beta(t') \tag{3}$$

$$\phi_{RH} = 1 + \frac{1 - 0.01RH}{0.10\sqrt[3]{h}} \tag{4}$$

$$\beta(f_{cu}) = \frac{16.8}{\sqrt{f_{cu}}} \tag{5}$$

$$\beta(t') = \frac{1}{0.1 + (t')^{0.2}} \tag{6}$$

$$\beta_c(t-t') = \left[\frac{(t-t')}{\beta_H + (t-t')}\right]^{0.3} \tag{7}$$

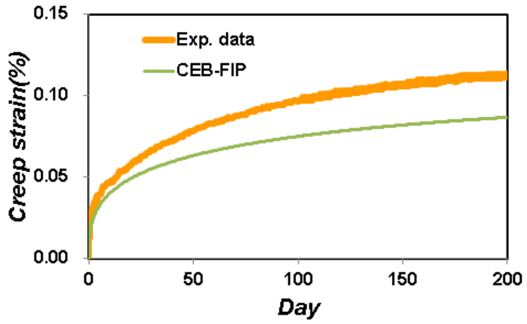
B. Test Results and Discussion

Tests were conducted to investigate the long-term creep strain with respect to the fiber reinforcement and replacement ratio by fly ash in the lean concrete. The selected target load and actually applied loading according to the test variables are arranged in Table III. The creep strain measured for each variable is plotted in Fig. 5. Here, the creep strain is the varying creep strain according to time after the instantaneous elastic strain and is presented together with the values predicted by the prediction equation of CEB-FIP.

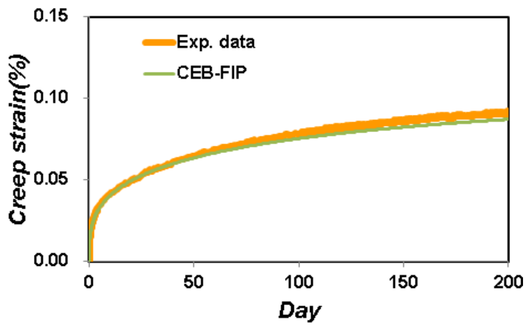
Even if the creep loading time of the mix variables experienced some deviation, measurement was completed after 200 days and the corresponding creep data per variable were analyzed. The creep strain of the plain lean concrete specimen showed larger values than those predicted by the equation of CEB-FIP whereas the other specimens developed creep strains similar or smaller than those predicted by CEB-FIP. Specimen FRC mixed with 0.1% of each macro and micro (hybrid) fibers exhibited the smallest creep strain. Besides, specimen FRC-FA mixed with fly ash and hybrid fibers presented the lowest creep coefficient.

TABLE III
LOADS AND CREEP COEFFICIENTS WITH RESPECT TO THE TEST VARIABLES

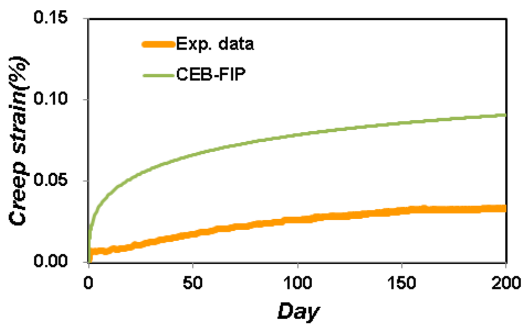
Specimen	Target load (kN, 40% of failure load)	Actual load (kN)	Creep coefficient
Plain	35.241	35.202	1.158
FA	36.221	36.191	0.346
FRC	46.178	46.060	0.294
FRC-FA	33.947	33.937	0.259
FRC-FA-PP	35.153	35.133	0.314



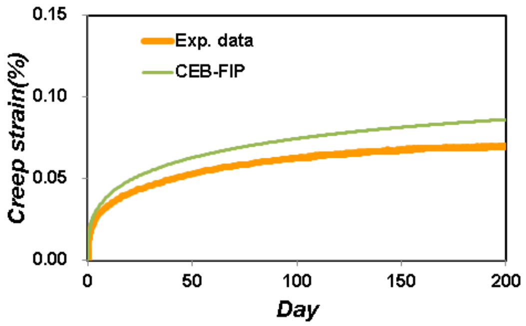
(a) Plain



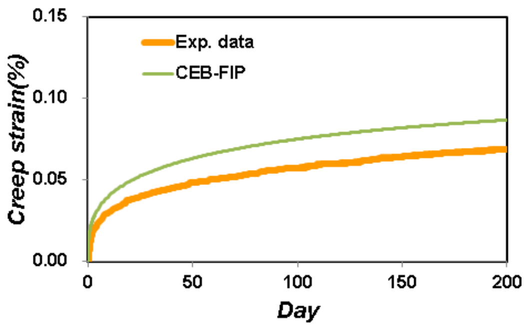
(b) FA



(c) FRC



(d) FRC-FA



(e) FRC-FA-PP

Fig. 5 Variation of creep coefficient of specimens according to time

On the whole, specimens FA, FRC-FA and FRC-FA-PP showed a reduction tendency of their creep deformation compared to Plain. The creep loading started to be applied on concrete at 28 days. The reduction of creep according to the replacement by fly ash can be explained by the pozzolanic reaction of fly ash. The pozzolanic reaction induces hardening by the reaction of the calcium hydroxides generated during the hydration process of cement with the SiO_2 of fly ash and occurs generally at ages after the occurrence of the hydration of cement. Therefore, at the start of the creep loading after 28 days, the pozzolanic reaction continued to occur according to the replacement by fly ash. The aging effect of the products of this pozzolanic reaction increased the resistance due to the action of the resulting stress, which in turn reduced the creep deformation and provoked the maturing creep of concrete.

IV. Conclusions

Creep tests were conducted on fiber reinforced lean concrete for pavement using a new creep loading device. The following results were derived.

(1) Specimen FRC mixed with 0.1% of each macro and micro (hybrid) fibers exhibited the smallest creep strain whereas specimen FRC-FA mixed with fly ash and hybrid fibers presented the lowest creep coefficient.

(2) Specimens FA, FRC-FA and FRC-FA-PP showed a reduction tendency of their creep deformation compared to Plain.

(3) The comparison with the measured creep strain with the values obtained from the CEB-FIP prediction equation revealed that the predictions underevaluate the creep strain of specimen Plain and overestimate the creep strains of the other specimens except specimen FA. Therefore, it appears that a prediction equation for the creep should be established to fit with the characteristics of the new base material.

Acknowledgment

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