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Evaluation of permanent deformation of geogrid reinforced asphalt concrete using dynamic creep test

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A R T I C L E I N F O

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A B S T R A C T

Permanent deformation (rutting) is one of the distresses that can adversely affect the bituminous surface of pavement structures, particularly in hot climates. The geosynthetics reinforcement of hot mix asphalt is one of the means to combat rutting. In this study, a dynamic creep test was performed on asphalt concrete samples reinforced with four different types of fiberglass grid as well as on unreinforced samples. The fiberglass grids used in this study contained two different sizes of grid openings and two tensile strengths, allowing us to test for the mesh size and tensile strength effects of the grids on the permanent deformation behavior of double layered asphalt concrete. In addition, we tested a recently developed creep curve model has been verified and used this to study the creep behavior of the samples in the primary and secondary regions of the creep curve, as well as determining the boundary point of the regions. The results suggest that not only grid tensile strength, but also grid mesh size is of great importance in combatting permanent deformation of fiberglass grid reinforced asphalt concrete within the conditions and grids used in this study. In a nutshell, higher tensile strength and/or smaller mesh size grids lead to overall better performance of grid reinforced samples. Moreover, great care must be taken when the creep curves are not reached in the tertiary region, and the creep rate must be taken into account to avoid any misinterpretation of the results.

1. Introduction

1.1. Overview

A bituminous mixture applied to the surface or the base layer of a pavement structure serves to distribute the traffic load and prevent water from penetrating into underlying unbound layers (Epps et al., 2000). Due to applied traffic loading, there are many different types of distresses that can affect bituminous surface layers, including permanent deformation (rutting), and fatigue cracking.

In recent years, because of increases in the volume of traffic and of heavy vehicles, rutting is one of the most frequent defects found in flexible pavements, particularly in hot climates. Rutting shows up as depressions formed in the wheel path in a pavement. It normally occurs when a permanent deformation of each layer in the pavement structure accumulates under a repetitive traffic load (Tayfur et al., 2007). There are generally two modes of ruts that occur on pavements, compactive and plastic (Gabra and Horvli, 2006; Lee et al., 2010).

Accumulation of residual strains in wearing course may cause serious problems, particularly through aquaplaning on wet pavements (Fwa et al., 2004; Sivilevičius and Petkevičius, 2002; Verhaeghe et al., 2007). Thus, not only does pavement rutting lead to higher road maintenance costs, but it also increases the risk to human life through accidents caused by water accumulating in depressions (ruts) in pavements.

Various laboratory testing methods have been developed to investigate the resistance to rutting of asphalt concrete. These include the static/dynamic creep test, wheel track test, and indirect tensile test. Monismith et al. (1975), quoted by Kalyoncuoglu and Tigdemir (2011), developed the dynamic creep test which is thought to be one the best methods to evaluate the resistance of asphalt concrete to permanent deformation. Furthermore, a report by the NCHRP (Cominsky et al., 1998), quoted by Kaloush and

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Witczak (2002), identified the dynamic creep test as having the potential to be utilized as a field quality control.

One of the most important outputs of the dynamic creep test is the creep curve, which illustrates permanent deformation versus loading cycles. Since creep curves obtained by the dynamic creep test are used to assess the resistance to permanent deformation of asphalt concretes, not only is the behavior of each region of the creep curve of great importance, but the identification of the boundary points connecting the primary to the secondary region, and the secondary to the tertiary region, is also important. Analyzing the creep curves obtained from a dynamic creep test in this way can provide a better understanding of the resistance to permanent deformation of asphalt concrete.

1.2. Literature review

During the past decade or so, there have been a lot of studies by various researchers into how to hinder rutting in pavements through geosynthetic reinforcement (Austin and Gilchrist, 1996; Collin et al., 1996; Laurinavičius and Oginskas, 2006; Leshchinsky and Ling, 2012; Ling and Liu, 2001; Perkins, 1999; Thakur et al., 2012; Yang et al., 2012). Virgili et al. (2009) reported that the reinforcement of bound layers can be divided into three elements: fatigue life extension, the reduction of reflection cracking, and the reduction of permanent deformation. Geogrids are high-strength extruded sheets of polyethylene or polypropylene with holes punched to produce a regular, grid-like pattern. Geogrids are quite stiff compared to the fibers of geotextiles, and have a higher modulus (Appea, 1997). Various literature points to the fact that stiffer geogrids lead to better performance in pavements (Collin et al., 1996; Ling and Liu, 2001; Perkins, 1999). Past research further suggests that some geosynthetics, and particularly certain geogrids, have a positive influence on permanent deformation in asphaltic pavements. This influence is stronger when the geogrid reinforcement is laid at mid-depth of the asphalt concrete, rather than embedded at the bottom (Sobhan et al., 2005). Similarly Perkins (1999) reported that the closer the placement positions of the geosynthetic to the applied load, the higher the reinforcement effect.

The elasticity modulus of asphalt concrete can be improved by incorporating materials with certain properties, such as grid reinforcement, within the asphalt mixture. There is evidence that the rutting depth of asphalt concrete depends on its modulus of elasticity, while the modulus of elasticity is in turn dependent on the type of geosynthetic material used (Laurinavičius and Oginskas, 2006). Moreover, lateral tensile strains can be restricted through geosynthetics, which are stiff when under tension (Perkins and Ismeik, 1997). FEM calculations have shown that the mechanically restrained system generated by geogrids can hold back the movement of aggregates and increase the transverse binding force of an asphalt layer, which can contribute to increased resistance to rutting (Fei and Yang, 2009). Furthermore, the opportunity provided by grid-shaped geosynthetics for aggregates from the top and bottom layers to interlock should logically lead to greater friction between layers (Tutumluer et al., 2010).

Researchers generally agree that geogrid reinforced asphalt concrete is more resistant to surface deformation than unreinforced concrete (Austin and Gilchrist, 1996; Bertuliene et al., 2011; Komatsu et al., 1998; Siriwardane et al., 2010; Sobhan et al., 2005). Yet very few researchers have provided a full-range comparison of the effects of the mesh size and tensile strength of such grids on the permanent deformation of bituminous systems. Tests of asphalt concrete plastic flow resistance suggest that durability increases when the size of grid openings (Komatsu et al., 1998). Similarly, Jenkins et al. (2004) observed slightly less rutting in grids reinforced with smaller grid mesh sizes than those with larger mesh sizes.

As quoted by Zhou et al. (2004), different mathematical models such as Barksdale's Semilog model (1972), Power-law models based on the Monismith model (1975), and Tseng and Lytton's model (1989), have been developed in order to fit the creep curve and estimate the flow number parameter in asphalt mixtures. For fitting and distinguishing between regions of the unmodified asphalt mixture creep curve, Zhou et al. (2004) proposed a three-stage model: a power model for the primary region, a linear model for the secondary, and an exponential model for the tertiary region. In other words, they modeled each region of the creep curve separately. At the same time, some other researchers believe that the logarithmic model simulates more accurately the primary region of the creep curves in SBS modified asphalt mixtures (Kalyoncuoglu and Tigdemir, 2011; Ahari et al., 2013).

Ahari et al. (2013) developed a two-stage model for the primary and secondary regions of creep curves in SBS modified asphalt mixtures. They proposed two different approaches for modeling the primary and secondary regions of the creep curve as follows:

Approach 1. Both the primary and secondary regions of the creep curve can be modeled simultaneously using the following logarithmic function:

$$\varepsilon_P = a \times Ln(X) + b$$

where:

X: is loading cycle
ε_P: is accumulated permanent strain at loading cycle X
a, b: are constants

Then, in order to check if the developed logarithmic function fits well with both regions, the deviation errors of all the points, re calculated as below, must be less than or equal to 1%:

$$D_e = \frac{\left|\varepsilon_{P(Calculated)} - \varepsilon_{P(Measured)}\right|}{\varepsilon_{P(Measured)}} \times 100$$

where:

D_e: is deviation error (%)

Approach 2. In order to identify the boundary points of the primary and secondary regions of the creep curve, the following steps are taken:

1 Visual selection of loading cycles among the initial loading cycles of the secondary region. [It must be noted that this loading cycle is not necessarily the boundary point]
2 Removal of the loading cycles before the selected loading cycles, and plotting a new graph representing the approximate secondary linear region.
3 Fitting a linear model to the approximate secondary region and determining the model coefficients.
4 Calculating the accumulated permanent strain for all the loading cycles of the approximate secondary region, based on obtaining model coefficients.
5 Determining the deviation error (D_e) for all of the calculated accumulated permanent strains.
6 If simultaneously all the D_e(s) $\leq$ 1% → the criterion is met and the linear model is assumed to be representative.