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Influence of internal structure on the permanent deformation behavior of a dense asphalt mixture

Jingang Wang [a,*], André A.A. Molenaar [b], Martin F.C. van de Ven [b], Shaopeng Wu [c]

[a] Key Laboratory of Road and Traffic Engineering of Ministry of Education, Tongji University, Shanghai 201804, China
[b] Department of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands
[c] State Key Laboratory of Silicate Materials for Architectures, Wuhan University of Technology, Wuhan 430070, China

HIGHLIGHTS

- The resilient moduli are linear with the permanent deformation rates.
- Tension failure, shear failure and shear failure with barreling were observed.
- A significant correlation exists between failure modes and the resilient moduli.
- The internal weak zones dominate the permanent deformation of asphalt mixture.
- Internal structure should be considered when selecting specimens.

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ABSTRACT

Remarkable variances were observed in permanent deformation curves of a dense asphalt mixture captured in triaxial repeated load permanent deformation (TRLPD) tests. In order to explore the causes of such variances, each permanent deformation curve was characterized firstly by an indicator (*B*) of the permanent deformation rate at a steady state stage. Meanwhile, a linear relationship was found between the values of indicator *B* and the resilient moduli of specimens after 1000 load repetitions. Secondly, a profound discussion on the potential relationship between resilient moduli and air voids content was performed. The discussion showed that air voids content appears to have no contributions to the observed variances. Nevertheless, three failure modes, tension failure, shear failure and shear failure with barreling, were observed in the X-ray Computed Tomography (CT) images of failed specimens subjected to triaxial compressive stresses. Furthermore, a significant correlation between failure modes and the resilient moduli was found by means of one-way analysis of variance (ANOVA). Moreover, it was found that the internal weak zones observed in the CT images of intact specimens dominate the behavior of the permanent deformation of asphalt mixture and the internal structure is the essential cause of such variances in the case of this study. This exploration highlights the influence of the internal structure on the mechanical performance of asphalt materials and thus recommends that considerable attention should be paid on the internal structure other than the volumetric properties when selecting test specimens.

1. Introduction

Permanent deformation (PD) as one of two major distresses of asphalt pavements, the other one is cracking due to fracture damage, appears as a surface depression in the wheel track along the driving direction. It is an accumulation of viscous and plastic deformation mainly in the asphalt layers and results from the inability of the materials to withstand the stresses (compressive and shear stresses) introduced by traffic loading [1].

The resistance to permanent deformation of asphalt materials is a critical input for pavement design. The permanent deformation of asphalt materials is usually studied in the field by conducting accelerated traffic pavement (ATP) tests. While on laboratory scale, the triaxial repeated load permanent deformation (TRLPD) test is the most advanced technique to characterize the permanent deformation of asphalt mixtures. In this test, each load pulse is followed

* Corresponding author.
E-mail addresses: jgwang@tongji.edu.cn (J. Wang), M.F.C.vandeVen@tudelft.nl (M.F.C. van de Ven), spwu@whut.edu.cn (S. Wu).

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by a rest period and a large number of cyclic loadings are applied on the specimen with or without confining pressure. From the permanent deformation curve, indicators can be derived to describe the permanent deformation characteristics of asphalt mixtures.

As mentioned before permanent deformation resistance of asphalt mixtures is a very important factor in design procedures for flexible pavements. It is therefore essential to be able to precisely characterize the resistance to permanent deformation of a proposed asphalt mixture on a laboratory scale. For a well-designed asphalt mixture, however, many other factors could have an influence on the test results, such as the test stress or strain levels, the temperature, the volumetric properties and internal structure of the test specimens [2]. The influences could be minimized through a careful design of testing program, implying the selection of an appropriate test setup, proper control of the temperature to which the test specimen is subjected, determination of the presentative specimen size, improvement of the contact conditions between the specimen and loading platens and a reliable measuring and data acquisition system and so on.

Among the aforementioned factors, the specimen size directly affects the test results and this is extensively studied by many researchers. One of the most important studies on the effect of aggregate size and specimen size and geometry on asphalt mixture properties was conducted by Witczak et al. [3,4]. The complex modulus test was used to evaluate these effects for low strain responses, while the permanent deformation test was used to evaluate these effects for large strain tests. For uniaxial compression tests, it was concluded that a sample size of 100 mm in diameter and 150 mm in height is adequate to characterize accurately the dynamic modulus and permanent deformation response. It was also concluded that the ratio of height to diameter of 1.5 is large enough for the permanent deformation characterization of a material in uniaxial compression conditions. Regarding the ratio of specimen diameter to maximum aggregate size, it is generally required that the minimum dimension of the asphalt test specimens is usually four to six times the nominal maximum aggregate size for laboratory prepared specimens.

Other factors related to volumetric properties of asphalt specimen also have a significant influence on the test results. The basic volumetric property of asphalt specimen is air voids content that is highly related to the other volumetric properties such as volume of voids in Mineral Aggregate (VMA), volume of voids filled with asphalt (VFA). Extensive research work has been carried out in the past to study the effect of the air voids content, size and distribution on the performance of asphalt mixtures [5–10]. In the viscosity-based dynamic modulus model developed by Witczak and commonly adopted in the Mechanistic-Empiric Pavement Design Method (MEPDG), dynamic modulus is predicted at different temperatures as a function of the mix aggregate gradation, air void content, effective binder content, loading frequency and bonder viscosity [11]. In laboratory practice the air voids content criterion is normally adopted to select specimen for minimizing the test variance. However, from the perspective of material composition, the mechanical response of a specimen under certain stress or strain conditions is not only dependent on the volumetric properties but also the internal structure of the specimen, in other words, the distribution of air voids, aggregates and bituminous mortar.

This paper presents the test results of permanent deformation of dense asphalt specimens captured from triaxial repeated load test. Remarkable variances were observed in permanent deformation curves of a dense asphalt mixture. Therefore, the objective of this paper is to explore the cause of such variances in the permanent deformation behavior of a dense asphalt mixture.

2. Materials and experimental design

2.1. Materials

The work presented in this paper is part of a research project on the characterization of permanent deformation of a dense asphalt mixture (DAC). The aggregates used for the mixture design consists of crushed Norwegian aggregates with maximum nominal size of 16 mm, mixtures of crushed and natural sand with a ratio of 3:1 by mass and Wigro filler. A 40/60 penetration grade of bitumen (obtained from Q8 company) with a softening point of 51 °C was used. The target air voids content of the asphalt mixture is designed as 3% in volume, which is corresponding to the field voids content after post densification by initial traffic load. The gradation of the dense asphalt mixture was designed in accordance with the Dutch RAW specification (CROW 2010) [12] and shown in Fig. 1.

The specimens used in this paper were cored from asphalt blocks with a dimension of 150 mm × 150 mm × 450 mm, fabricated by using a shear box compactor. The size of specimen is 130 mm in length and 65 mm in diameter, which is approximate 4 times of the maximum nominal aggregate size.

2.2. Test setups

The loading frame used is a Universal Testing Machine 25 (from IPC Company in Australia) equipped with a climate chamber and a servo-hydraulic control system. It can provide a maximum compression or tension force of 25 kN for static tests. For the purpose of a more accurate force control and measurement the original load cell and servo-valve were replaced by a smaller load cell with a capacity of 15 kN and a more powerful servo-valve. The confinement was applied by air pressure through a pressure regulator with a pressure gauge. A latex tube with a diameter of 70 mm and a thickness of 0.5 mm was fitted around the specimen and O-ring seals are used. A "latex rubber-vacuum grease-latex rubber" friction reduction system was used to minimize the end friction effect between the specimen and the loading platens.

The built-in LVDT adopted in this research had a measuring range of 50 mm with an accuracy of 0.001 mm, and the applicability of the built-in LVDT instead of on-specimen gauges to measure the deformation of specimen is discussed and proved feasible. The specimen was conditioned in a climate chamber for 4 h to reach a stable temperature of 50 ± 0.1 °C prior to the test.

2.3. Experimental design

This research work includes two test programs designed to investigate the influence of levels of deviator stress, confinement

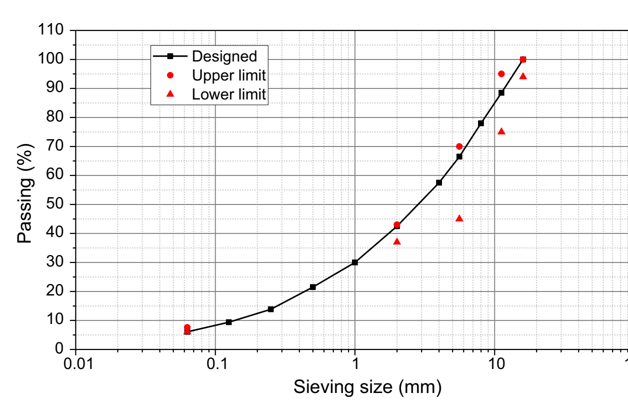

Fig. 1. Grading curve of dense asphalt mixture.