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Addressing the permanent deformation behavior of hot mix asphalt by triaxial cyclic compression testing with cyclic confining pressure

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ABSTRACT

Rutting or permanent deformation is one of the major distress modes of hot mix asphalt in the field. Triaxial cycle compression testing (TCCT) is a standardized and scientifically accepted test method to address this distress mode in the lab and to characterize the resistance to permanent deformation. In most labs and according to EN 12697-25, standard TCCTs are carried out with cyclic axial loading and a constant confining pressure. In road pavements on the other hand, dynamic traffic loading due to passing wheels leads to cyclic confining pressure. In order to bring the TCCT closer to reality, the radial reaction and its phase lag to axial loading in standard TCCTs are analyzed and an enhanced TCCT with cyclic confining pressure is introduced. The cyclic confining pressure takes into account the viscoelastic material response by the radial phase lag to axial phase loading. In a subsequent test program, TCCTs with different confining pressure amplitudes were carried out on two hot mix asphalts. Results from standard and enhanced TCCTs were analyzed, compared and discussed. It is shown that the resistance to permanent deformation increases significantly when the viscoelastic material response is taken into account in the TCCT by introducing cyclic confining pressure.

1. Introduction

Besides low-temperature and fatigue cracking, permanent deformation at elevated temperature is a third major distress mode of bituminous bound pavements. Permanent deformation or rutting occurs especially as transverse profile deformations within the wheel paths but can also be seen as longitudinal profile irregularities (Verstraeten, 1995). Rutting is an important deterioration mode since it affects the comfort and safety of road users. Thus, various test methods have been developed to address the permanent deformation behavior of hot mix asphalt (HMA). For comparison of the different HMAs and pavement design the wheel tracking test (WTT) (EN 12697-22, 2007) is commonly used. In this test method a moving wheel stresses a pavement slab at elevated

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temperatures for a number of cycles and permanent deformation (i.e. rutting) is recorded. The loading produces a non-homogeneous stress distribution in the slab and thus, results are difficult to interpret when it comes to the rheological behavior of the material (Gabet et al., 2011; Perraton et al., 2011).

An alternative test method to assess the permanent deformation behavior of HMA is the triaxial cyclic compression test (TCCT) with a well-defined external stress state. Research in this field in the 1970s and 1980s (Krass, 1971; Francken, 1977; Jaeger, 1980; Weiland, 1986) was a major source for developing a European standard for TCCTs (EN 12697-25, 2005). Recent studies show the importance of taking into account triaxial behavior with confining pressure (De Visscher et al., 2006; Ebels and Jenkings, 2006; Taherkhani and Collop, 2006; Clec'h et al., 2009; Hofko and Blab, 2010). In the standard TCCT according to EN 12697-25 cylindrical specimens are stressed by a cyclic axial loading in the compressive domain to simulate traffic loading by passing tires. The axial loading can either be shaped as a sinusoidal function or a block-impulse. The confining pressure can either be held constant or cyclic without giving more specific information in the standard. However, most laboratories that have integrated the TCCT on HMA into their test procedures use constant confining pressure, especially since the test control gets even more complex with two independent cyclic loadings.

Research on TCCT with cyclic confining pressure was mainly carried in the area of unbound granular materials (Allen and Thompson, 1974; Brown and Hyde, 1975; Nataatmadia and Parkin, 1989; Zaman et al., 1994; Rondón et al., 2009). While earlier studies (Brown and Hyde, 1975) did not find significant differences in the deformation behavior of unbound material for tests with constant and cyclic confining pressure, more recent studies (e.g. Rondón et al., 2009) showed that differences in permanent deformation occur depending on the ratio of the axial and radial stress amplitude.

The main difference between testing of unbound granular materials and bituminous bound materials (e.g. HMA) is that due to the viscoelastic nature of bituminous bound materials the phase lag between axial loading and radial reaction ($\varphi_{ax,rad}$) must be analyzed and used for cyclic confining pressure to address the viscoelastic material response correctly. Kappl (2004) showed by finite element simulation of a pavement under a passing tire that cyclic axial loading leads to cyclic radial confining pressure within the pavement structure. Thus, the present practice of testing HMA specimens with constant confining pressure is a simplification. Only a small number of studies that work with the TCCT on HMA (von der Decken, 1997; Weise and Wellner, 2008) have been carried out with cyclic confining pressure. The mentioned studies set a constant phase lag between axial loading and radial reaction of 36° for all tested materials at all temperatures and frequencies. Knowing that HMA shows a temperature and frequency dependent viscoelastic behavior, it is questionable whether this constant radial phase lag is correct for all materials, temperatures and frequencies.

2. Objectives and approach

Since the standard TCCT with constant confining pressure does not represent the state of stress in a pavement structure and the phase lag between axial loading and radial reaction for TCCTs given in literature do not match the common understanding of the theory of viscoelasticity (Findley et al., 1989) that viscoelastic material properties change with temperature and frequency, the main objectives of this study are to measure the radial phase lag $\varphi_{ax,rad}$ between axial loading and radial reaction accurately and to incorporate cyclic confining pressure with a well-defined phase lag $\varphi_{ax,rad}$ to have a more realistic simulation in the TCCT. Results from TCCTs with constant and cyclic confining pressure shall be compared for different mixes. To reach the objectives, the following approach is taken that is also depicted in Fig. 1.

- Carry out standard TCCTs with constant confining pressure, record and analyze the phase lag between axial loading and radial reaction $\varphi_{ax,rad}$ with high precision.

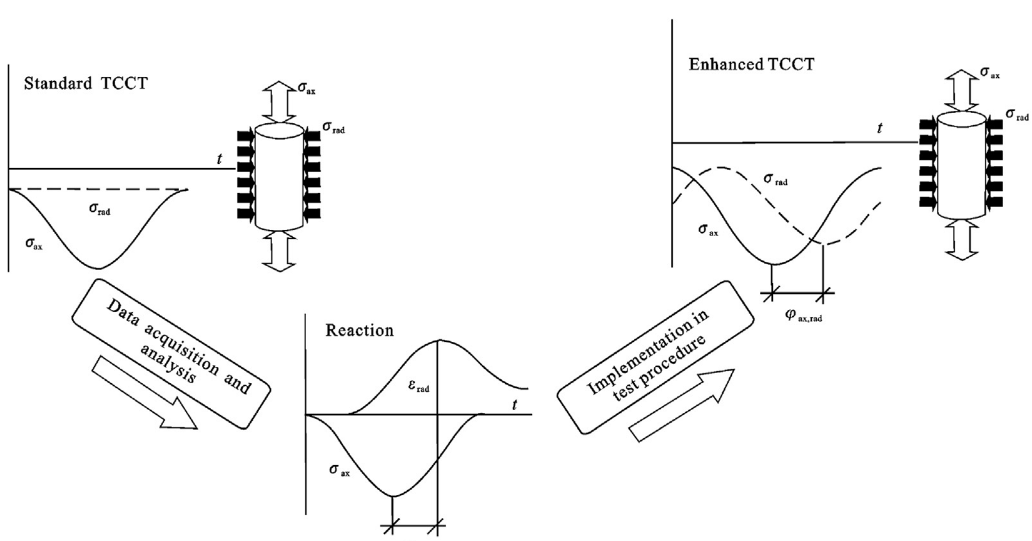

Fig. 1 – Approach to introduce cyclic confining pressure in TCCT.