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Correlating creep properties of bituminous binders with anti-rutting performance of corresponding mixtures

Ezio Santagata [a], Orazio Baglieri [a], Pier Paolo Riviera [a,*], Muhammad Alam [b]

[a] Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, 24, corso Duca degli Abruzzi, Turin 10129, Italy
[b] Department of Civil Engineering, Abasyn University Peshawar Campus, Khyber Pakhtunkhwa, Pakistan

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Abstract

In the experimental study described in this paper, rutting properties of different bituminous binders and those of corresponding mixtures characterized by common composition and volumetrics were investigated and compared. Single shear creep-recovery (SSCR) tests were carried out on binders for the determination of their creep compliance rate (CCR), whereas bituminous mixtures were evaluated by referring to their Flow Number (FN), derived from repeated compressive loading tests. Analysis of experimental data revealed the existence of a strong correlation between rutting parameter of binders and permanent deformation response of mixtures. This confirmed the potential of the proposed testing procedure of being adopted for the evaluation of rutting properties of bituminous binders and for their consequent performance-related ranking.

Keywords: Rutting; Bituminous binders; Bituminous mixtures; Creep; Flow Number

1. Introduction

Formation of ruts in asphalt pavements resulting from accumulation of permanent deformation under repeated traffic loading is significantly affected by the rheological properties of bituminous binders [1,2]. Due to the thermal susceptibility and viscoelastic behaviour of these materials, rutting is greatly promoted at high in-service temperatures and in presence of heavy slow-moving vehicles. The use of binders characterized by enhanced properties in terms of permanent deformation resistance is thus essential in preventing such a phenomenon, which generally leads to a reduction of comfort and safety perceived by road users. To achieve this goal, materials need to be properly selected by referring to the results of reliable laboratory tests, capable of evaluating their non-reversible strain response under loading and of yielding a truly performance-related ranking.

The traditional SHRP parameter $G^*/\sin\delta$ [3,4] adopted in performance grading has been demonstrated to be inadequate in evaluating the real anti-rutting potential of binders, especially in the case of polymer-modified products [5,6]. Limits of the SHRP approach are mainly related to the fact that the abovementioned parameter is determined from small-strain oscillatory loading in the linear viscoelastic domain, far away from actual damage conditions.

A number of studies [5,7–11] have been carried out to overcome these limitations, leading to the development of several standard methods to be used for the assessment of rutting properties of bituminous binders [12,13]. Among these, the Multiple Stress Creep-Recovery (MSCR) test [14]

* Corresponding author. Fax: +39 0110905614.
E-mail addresses: ezio.santagata@polito.it (E. Santagata), orazio.baglieri@polito.it (O. Baglieri), pierpaolo.riviera@polito.it (P.P. Riviera), emalam82@gmail.com (M. Alam).
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has held a prominent role due to its aptitude in simulating the intermittent nature of traffic loading and the stress-dependency of materials. Some authors, however, have questioned the use of 1 second creep followed by 9 second recovery prescribed by the current MSCR protocol since it may not allow the material to reach steady-state flow conditions under loading and may not ensure the complete recovery of deformation at the end of unloading, especially for cross-linked binders characterized by a pronounced delayed elastic strain component [15,16]. A further criticism questions the use of non-recoverable creep compliance (J_{nr}) for binder performance characterization, due to the fact that it is a mechanical parameter not univocally connected with non-reversible deformation [17].

More recently, Santagata et al. [18] proposed a novel test procedure consisting in single shear creep-recovery (SSCR) tests carried out at different temperatures and at predefined loading and recovery times. Results obtained on a wide set of materials indicated the effectiveness of the procedure in discriminating high-temperature characteristics of bituminous binders of different types and origin. Moreover, synthetic information on resistance to flow was obtained by referring to a new control parameter, the so-called creep compliance rate (CCR), which was found to be adequate for the purpose of performance-related ranking.

In order to further corroborate the validity of the method and in accordance with a multi-scale approach, the research scope was extended by including the evaluation of rutting properties of bituminous mixtures. In particular, the aim of the investigation reported in the paper was to correlate results obtained from rheological tests carried out on several bituminous binders with those derived from permanent deformation tests carried out on corresponding mixtures. Data gathered from testing were analysed with the specific goal of verifying the existence of relationships to be used for materials performance prediction.

2. Materials

The set of bituminous binders employed in the experimental investigation was selected in order to cover a wide spectrum of viscoelastic properties. It included two unmodified bitumens (A and B) sampled from two refineries which operate on crudes of different source and origin, one polymer-modified binder (C) containing a high percentage (ranging in the interval 4–5% by weight of base bitumen) of styrene–butadienestyrene co-polymer (SBS), and one asphalt rubber (D) containing 18% crumb rubber (by weight of base bitumen) derived from the grinding of end-of-life tyres. Binders C and D were supplied by specialized manufacturers that did not provide specific information on the adopted production schemes.

All binders were investigated in short-term aged conditions simulated by means of the Rolling Thin Film Oven (RTFO) in accordance with AASHTO T240 [19]. Basic dynamic shear tests were carried out in order to determine upper limiting performance grade (PG) temperatures (T_{PG-U}, corresponding to $G^*/\sin\delta$ equal to 2.2 kPa). Moreover, in the preliminary characterization phase, binders were also subjected to MSCR tests with the consequent evaluation of non-recoverable creep compliance parameters ($J_{nr0.1}$ and $J_{nr3.2}$ corresponding to applied stress levels of 0.1 and 3.2 kPa, respectively).

Obtained results are synthesized in Tables 1 and 2.

For each type of binder, a corresponding mixture (named, in the order, MA, MB, MC and MD) was manufactured in the laboratory by making use of mineral aggregates provided by a local contractor in four different size fractions (sand 0–5 mm, fine gravel 3–8 mm, medium gravel 8–12 mm and Portland cement filler). Aggregate gradation of the mixtures was defined according to Italian technical specifications for standard wearing courses [20], characterized by a maximum aggregate size of 16 mm (Fig. 1). Reconstruction of the target gradation curve was made by subjecting available fractions to washed sieve separation and by thereafter combining single-size fractions in the needed quantities. Binder dosage was set at 5.5% by weight of dry aggregates.

Loose blends were analysed in order to determine their Theoretical Maximum Density (TMD) to be used for the evaluation of air voids of compacted specimens. TMD values reported in Table 3 were obtained by means of the pycnometer method according to EN12697-5 [21].

3. Methods

Rutting potential of bituminous binders considered in this paper was investigated by adopting the SSCR test protocol mentioned above. For the purposes of the research, analysis of experimental data was limited to the creep phase, from which values of the CCR parameter were determined.

The apparatus employed for testing was a stress-controlled dynamic shear rheometer (DSR), equipped with a permanent magnet synchronous drive (minimum torque = 0.1 μNm, torque resolution <0.1 μNm) and an optical incremental en-coder for the measurement of angular rotation (resolution <1 μrad). The standard 25 mm parallel plates geometry was used with 1.0 mm gap.

Measurements were performed at four temperatures (ranging from 46 to 64 °C in the case of binder A and B, from 58 °C to 76 °C in the case of binders C and D) at a single stress level (equal to 100 Pa). Conditioning of binder specimens was carried out until target test temperature was stable for at least 15 min. At least two replicates were run at each temperature and average data were considered in the analysis.

Table 1
T_{PG-U} values obtained from dynamic shear tests.

Binder code	A	B	C	D
T_{PG-U} [°C]	68.3	66.0	81.7	101.5