Construction and Building Materials 158 (2018) 320–325

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Flexural fatigue evaluation of cement-treated mixtures of reclaimed asphalt pavement and crushed aggregates

Mario Alexander Castañeda López, William Fedrigo *, Thaís Radünz Kleinert, Matheus Ferreira Matuella, Washington Peres Núñez, Jorge Augusto Pereira Ceratti

Department of Civil Engineering, Federal University of Rio Grande do Sul, Porto Alegre, Brazil

HIGHLIGHTS

- Reclaimed asphalt pavement and crushed aggregates mixtures were cement treated.
- Evaluation of fatigue life of cement-treated mixtures of RAP and crushed aggregates.
- Flexural strength, strain at break, flexural static modulus and resilient modulus.
- Strain based fatigue relationships used in mechanistic pavement analysis.

ARTICLE INFO

Article history:
Received 23 June 2017
Received in revised form 28 September 2017
Accepted 2 October 2017

Keywords:
Pavement recycling
Full-depth reclamation with cement
Fatigue
Flexural strength
Flexural modulus
Resilient modulus

ABSTRACT

This paper evaluates the fatigue behavior of cement-treated recycled pavement materials. Six mixtures with different cement contents and reclaimed asphalt pavement (RAP) percentages were tested under static and cyclic flexural loading. Cement content was the main factor affecting strength, whereas RAP percentage showed major effect in strain at break. Similar moduli were obtained under both loading conditions, which is useful for design by allowing estimating resilient modulus through static results. Tests results and mechanistic analysis showed that the fatigue life of cement-treated recycled bases depends on the mixture composition and on the thicknesses of asphalt wearing courses and recycled layers.

1. Introduction

Full-depth reclamation with Portland cement (FDR-PC) is a technique that allows the reuse of part of the materials of a failed pavement structure. This technique pulverizes the existing asphalt wearing course while blends it with underlying materials and cement; the resulting mixture is then compacted in order to provide a new cement-treated base (CTB) layer [1].

Portland cement addition in FDR process considerably increases the failed pavement material strength and stiffness [2–4] and the resulting CTB initially shows little distress. However, as a cement-treated material (CTM), the recycled base layer inherently exhibits fatigue deterioration under cyclic loading and may rapidly deteriorate once distress initiates. Therefore, fatigue failure is the main design criteria for long-term performance of pavements with a cement-treated recycled layer [5].

The CTM obtained through FDR-PC differ from regular cement-treated unbound granular materials, due to the presence of reclaimed asphalt pavement (RAP) aggregates in their matrix. Although several studies on FDR-PC indicate that the presence of RAP reduces the mixture strength and stiffness [3,6–11], its effects on the fatigue behavior are not well known. Studies on the fatigue properties of FDR-PC are necessary for a mechanistic-empirical design method for pavements with cement-treated recycled layers, since the most common practice is to consider empirical approaches. The few studies on that subject investigated recycled

* Corresponding author at: Department of Civil Engineering, Federal University of Rio Grande do Sul, Avenida Osvaldo Aranha, 99, 302, Porto Alegre, Rio Grande do Sul 90035-190, Brazil.

E-mail addresses: 00246571@ufrgs.br (M.A. Castañeda López), william.fedrigo@ufrgs.br (W. Fedrigo), thais.kleinert@ufrgs.br (T.R. Kleinert), matheus.matuella@ufrgs.br (M.F. Matuella), washington.nunez@ufrgs.br (W.P. Núñez), jorge.ceratti@ufrgs.br (J.A.P. Ceratti).

https://doi.org/10.1016/j.conbuildmat.2017.10.003
0950-0618/

pavement materials stabilized with both cement and bituminous binders, such as emulsion or foamed asphalt [12–14].

The research here reported was carried out with the objective of measuring flexural strength, strain at break and flexural modulus (static and resilient) and obtaining fatigue relationships of cement-treated mixtures of RAP and crushed aggregates, as well as verifying the effects of cement content and RAP percentage. The research also focused on evaluating the obtained fatigue relationships through mechanistic analysis of hypothetical pavement structures containing FDR-PC base layers.

2. Testing program

2.1. Materials and specimens

Laboratory tests were performed on samples made of cement, crushed aggregates (CA) and different percentages of RAP (20%, 50% and 70%). The materials were collected at the same site as those studied by Fedrigo et al. [11]. The mixtures grain size distributions were within the envelope for FDR-PC [15] as shown in Fig. 1. Two contents (2% and 4%) of Portland cement with ground-granulated blast-furnace slag addition (Brazilian type CP II E 32) were used. All the mixture procedures were based on dry mass of each material. Modified Proctor compaction tests were undertaken to determine the optimum moisture content (OMC) and maximum dry unit weight (MDUW) of each mixture. The six studied mixtures are identified by codes in which the first number represents the cement content and second represents the RAP percentage, as shown in Table 1 (Section 3).

Prismatic beams, with dimensions of 100 mm × 100 mm × 400 mm, were produced from the mixtures of CA-RAP, with the specified amount of cement and water at OMC. The mixtures were statically compacted in three equal layers to achieve the MDUW using a hydraulic press. In order to improve the bond between layers, the surface of the compacted layers was carefully scarified

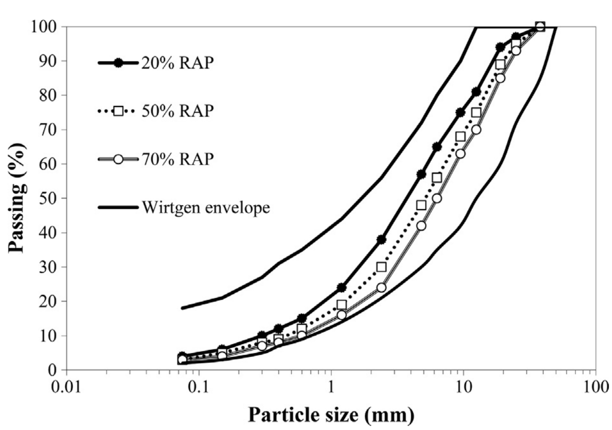

Fig. 1. Grain size distributions and FDR-PC envelope.

to a depth of at least one-tenth of the thickness of the layer. The specimens were cured for 28 days under constant temperature of 21 °C and relative humidity (RH) of 90%. A total number of 18 specimens were prepared for flexural static tests and other 53 were prepared for flexural fatigue (cyclic) tests.

It is acknowledged that repeated load fatigue test results are inherently variable. In order to reduce variability factors, the specimens were discarded and remolded when the following conditions could not be achieved: (a) dry unit weight of at least 95% of the MDUW; (b) effective moisture content deviating by less than 1% of the OMC, and; (c) variations of the beams dimensions lower than 3%.

2.2. Apparatus and testing procedures

A 250 kN capacity load testing machine was used for flexural static tests and a pneumatic testing machine capable of applying haversine load pulses was used for flexural fatigue tests. Static and fatigue tests were conducted in a controlled stress mode. Test temperature and RH were maintained at 24 ± 3 °C and 55 ± 15%, respectively.

Four-point bending test configuration was used for prismatic specimens spanning 300 mm. The mid-span deflection was measured using two linear variable differential transducers (LVDTs). These were mounted using a yoke arrangement based on JCI SF-4 [16]. The experimental setting was the same for both static and fatigue tests, as shown in Fig. 2.

2.2.1. Static test

Flexural strength tests were performed in accordance with NCHRP test method for testing cement-treated materials [17]. Monotonic increase of load was applied at a constant rate of 690 kPa/min (2.3 kN/min). Eq. (1) was used to calculate the flexural stress. The flexural tensile strain was calculated using Eq. (2). Strain at break corresponds to 95% of the ultimate flexural load. Flexural static modulus was determined from the stress-strain relationships shown in Fig. 3 (secant modulus corresponding to 40% of the normalized flexural stress). For each mixture, three specimens were tested.

$$\sigma_i = \frac{P_i * L}{w * h^2} \quad (1)$$

$$\varepsilon_i = \frac{108 * h * \delta_i * 10^6}{23 * L^2} \quad (2)$$

where σ_i (MPa) is the flexural stress corresponding to force P_i (N); ε_i (microstrain) is the flexural tensile strain corresponding to LVDTs average displacement δ_i (mm); L is the length between supporting rollers (300 mm), and; w and h are the average width and height of the specimen (mm), respectively.

2.2.2. Fatigue test

The procedures used for flexural fatigue tests were based on Austroads experience [18]. Specimens were subjected to 5 Hz haversine cyclic loading without rest period. The tests were

Table 1
Results of flexural static tests.

Mixture	Flexural strength (MPa)	COV (%)	Strain at break (microstrain)	COV (%)	Flexural static modulus (MPa)	COV (%)
2–20	0.26	13	117	16	3950	16
2–50	0.32	15	262	31	2900	9
2–70	0.21	7	371	25	1483	17
4–20	0.87	9	194	1	8100	1
4–50	0.77	19	288	17	4967	8
4–70	0.80	1	566	4	3000	28