Flexural Fatigue Evaluation of Cement-Treated Mixtures of Reclaimed Asphalt Pavement and Lateritic Soil

William Fedrigo[1], Washington Peres Núñez[2], Thaís Radünz Kleinert[3], Gabriel Grassioli Schreinert[4], Mario Alexander Castañeda López[5], Jorge Augusto Pereira Ceratti[6]
（[1] Federal University of Rio Grande do Sul，Porto Alegre, Brazil, william.fedrigo@ufrgs.br）
([2] Federal University of Rio Grande do Sul，Porto Alegre, Brazil, washington.nunez@ufrgs.br)
([3] Federal University of Rio Grande do Sul，Porto Alegre, Brazil, trkleinert@gmail.com)
([4] Federal University of Rio Grande do Sul，Porto Alegre, Brazil, gabrielgrassioli@hotmail.com)
([5] Federal University of Rio Grande do Sul，Porto Alegre, Brazil, maacastanedalo@gmail.com)
([6] Federal University of Rio Grande do Sul，Porto Alegre, Brazil, jorge.ceratti@ufrgs.br)

ABSTRACT

This paper evaluates the fatigue behaviour of cement-treated mixtures of reclaimed asphalt pavement (RAP) and lateritic soil. Six mixtures with different cement contents and RAP percentages were tested under static and cyclic flexural loading. Flexural strength and resilient modulus increased with RAP percentage, due to changes in grain size distribution, which led to denser mixtures. Strain at break increased with RAP addition, reducing brittleness. On the other hand, strain at break decreased with cement content, resulting in more brittle materials. Increasing cement content led to stronger and stiffer mixtures. Some mixtures showed similar moduli under both loading conditions, which is useful for design by allowing estimating resilient modulus through static results. Strain based fatigue relationships were obtained, but cement content and RAP percentage effects on the fatigue life parameters did not show a well-defined trend. The mixtures fatigue life showed to be highly dependent on the tensile strain at the bottom of the recycled layer, a fact that highlights the importance of mechanistic-empirical design.

Keywords: pavement recycling; full-depth reclamation with cement; fatigue; flexural behaviour; lateritic soil

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]. Although the resulting CTB initially shows little distress, 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 [2].

The materials obtained through FDR-PC differ from regular CTM, 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 [3-8], its effects on the fatigue behaviour 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. However, only one study on that subject was reported [9] and a few other focused on the fatigue behaviour of recycled pavement materials simultaneously stabilized with cementitious and bituminous binders, such as emulsion or foamed asphalt [10-12]. Besides, lateritic soils (LS) are often used as base materials in some regions and may ending up being a constituent of FDR-PC layers. However, literature searches for the flexural behaviour and/or fatigue behaviour of cement-treated mixtures of RAP and LS were unsuccessful, as authors have only studied the unconfined compressive strength of such mixtures [13].

The research here reported aimed on measuring flexural strength, strain at break and flexural modulus (static and resilient) and obtaining fatigue relationships of cement-treated mixtures of RAP and LS, as well as verifying the effects of cement content and RAP percentage.

2. EXPERIMENTAL PROGRAMME

2.1 Materials and Specimens

Laboratory tests were performed on samples made of cement, LS and different percentages of RAP (20%, 50% and 70%). LS was classified as a clayey lateritic soil (LG’), according to the MCT (Miniature, Compacted, Tropical) methodology [14]. LS liquid limit and plasticity index were, respectively, 44.3% and 12.4%. The studied RAP had 5.71% of asphalt binder on its composition. The grain size distributions of the materials and mixtures are presented in Figure 1. Two contents (2% and 4%, based on the dry mass of LS+RAP mixtures) of portland cement with ground-granulated blast-furnace slag addition (Brazilian type CP II E 32) were used. Modified Proctor compaction tests were undertaken to determine the optimum moisture content (OMC) and maximum dry unit weight (MDUW) of each mixture.

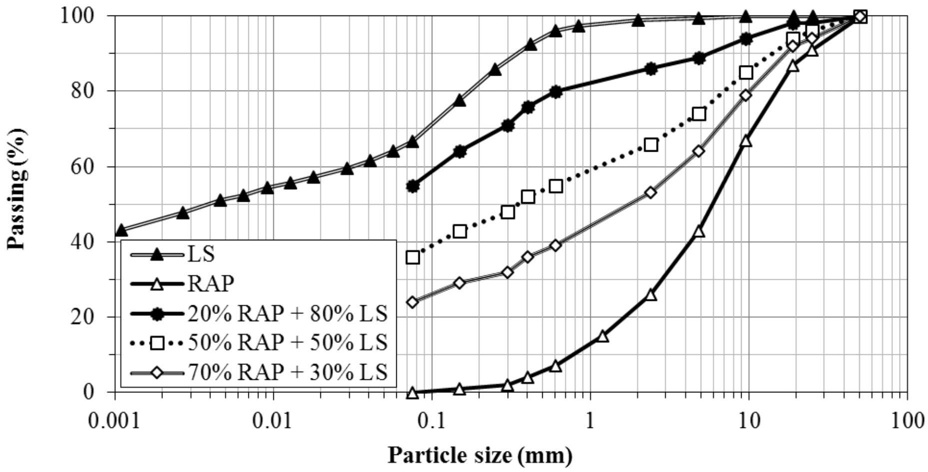

FIGURE 1 Grain size distributions of the mixtures of RAP and LS

Prismatic beams, with dimensions of 100 mm x100 mm x 400 mm, were prepared from the mixtures of LS+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 to a depth of at least one-tenth of the thickness of the layer. The specimens were cured for 28 days in sealed plastic bags in order to maintain the mixtures moisture content. For each mixture, three specimens were prepared for static tests (18 specimens) and nine were prepared for fatigue (cyclic) tests (54 specimens). In order to reduce variability factors, the specimens were discarded and remoulded according to the following conditions: (a) dry unit weight less than 95% of the MDUW; (b) effective moisture content deviating by more than 1% of the OMC, and; (c) variations of beams dimensions higher than 3%.

2.2 Apparatus and Testing Procedures

A 250 kN capacity load testing machine was used for static tests and a pneumatic testing machine capable of applying haversine load pulses was used for 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), mounted using a yoke arrangement based on JCI SF-4 [15]. The experimental setting was the same for both static and fatigue tests, as shown in Figure 2.

FIGURE 2 Flexural tests: (a) 4-point bending configuration and (b) specimen after test

2.1.1 Static Tests

Flexural strength tests were performed in accordance with NCHRP test method for CTM [16]. Monotonic increase of load was applied at a rate of 0.69 MPa/min. Eq. (1) was used to calculate the flexural stress. The tensile strain was calculated using Eq. (2). Strain at break (ε_b) corresponds to 95% of the ultimate load. Flexural static modulus was determined from the stress-strain relationships (secant modulus corresponding to 40% of flexural strength).

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

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

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

2.1.2 Fatigue Tests

The procedures used for flexural fatigue tests were based on Austroads experience [17-19]. Specimens were subjected to 5 Hz haversine cyclic loading without rest period. The magnitude of the load pulses varied within a range of 10% to 40% of the peak load, accordingly to each mixture (Table 1, Section 4). The tests were terminated either after failure of the specimen or after 1,000,000 loading cycles. The flexural resilient modulus was calculated based on the resilient strain corresponding to a flexural stress. Initial resilient modulus and initial strain (ε_i) were defined as the average values between the 50th and 100th load pulses.

3. STATIC TESTS RESULTS

Figure 3 shows the effects of cement content and RAP percentage on flexural strength and strain at break. The results are the average of three specimens and the standard deviation is also shown. Strain at break increased with RAP percentage, so 20% RAP mixtures were more brittle than 70% RAP mixtures. On the other hand, strain at break decreased with cement content, increasing brittleness. Flexural strength increased with cement content and RAP percentage. Strength increasing with RAP percentage diverge from the literature, which shows that cement-treated recycled pavement materials tends to lose strength with RAP addition [3-6, 8, 9, 13]. As the dry unit weight of RAP inherently exceeds that of soils, the higher the RAP percentage, the denser the mixture, resulting in a stronger material. It may be seen in Figure 1 that 70% RAP mixtures have denser grain size distribution than 20% RAP mixtures. Flexural static modulus results are presented in Figure 4 and discussed in Section 4.

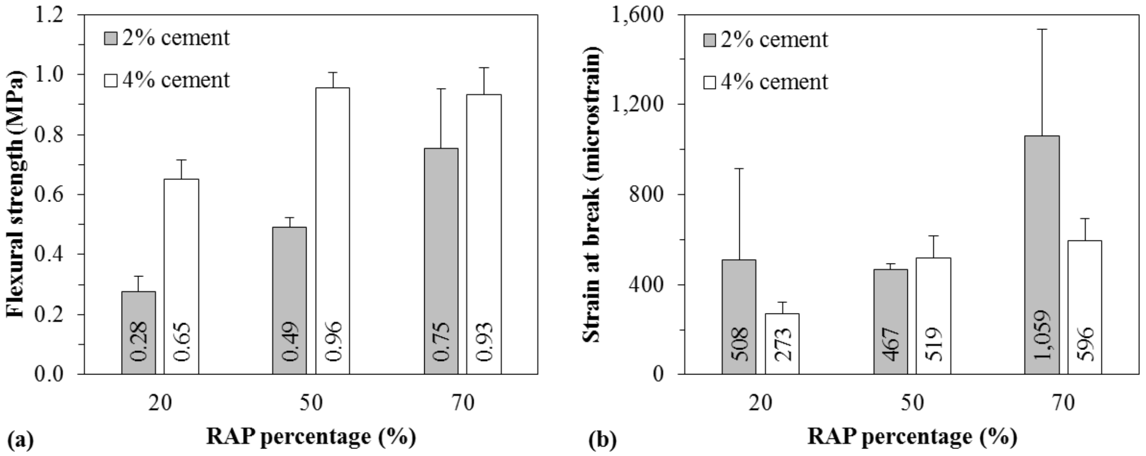

FIGURE 3 Cement content and RAP percentage effects on (a) flexural strength and (b) ε_b

4. FATIGUE TESTS RESULTS

Table 1 summarizes the results of fatigue tests. The number of beams tested for each mixture is presented, as well as the ranges of: stress level applied for testing (% of the peak stress), number of cycles to failure, initial resilient modulus and initial strain.

Figure 4 presents the flexural (initial) resilient and static moduli as a function of cement content and RAP percentage. The results of initial resilient modulus correspond to the average value of nine specimens and the static modulus is the average of three specimens. Resilient and static moduli increased with cement content, a trend also observed in other studies on cement-treated recycled pavement materials [3-5]. The resilient modulus also increased with RAP percentage, which could be related to the same reason that was highlighted for flexural strength, that is, the achievement of a denser matrix. However, the static modulus was similar for different RAP percentages and, consequently, the effect of RAP percentage was not well defined. Some mixtures also showed similar modulus under static and cyclic loading, which could be useful for design purposes, since static tests are easier to carry out than cyclic ones.

TABLE 1 Summary of fatigue tests results

	Range of								No. of beams	
Cement (%) + RAP (%)	**stress level applied for testing (%)**		**number of cycles to failure**		**initial resilient modulus (MPa)**		**initial strain (microstrain)**		**Tested**	**Did not fail**
	Low	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**		
2 + 20	15	25	99	1,000,000	862	1,508	29	77	9	1
2 + 50	10	40	99	1,000,000	1,111	2,010	25	99	9	1
2 + 70	10	25	99	325,299	1,714	3,382	34	83	9	0
4 + 20	10	20	99	1,000,000	1,777	2,538	25	65	9	1
4 + 50	10	20	199	1,000,000	3,083	4,143	23	55	9	1
4 + 70	13	25	299	407,299	3,620	5,054	29	43	9	0

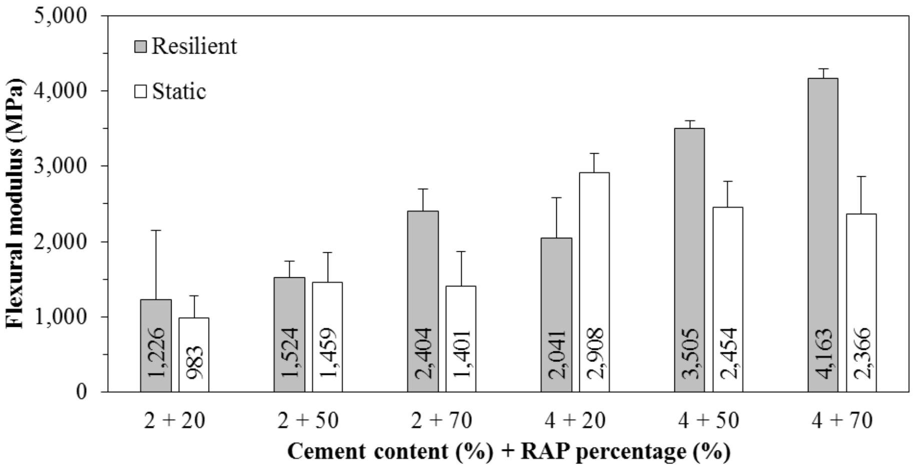

FIGURE 4 Resilient and static moduli as a function of cement content and RAP percentage

Regression analysis was done to derive fatigue relationships according to Eq. (3). The fatigue life parameters *a* and *SDE* (strain damage exponent) and the coefficient of determination (R^2) are shown in Table 2. The strain based fatigue relationships ($\varepsilon_i/\varepsilon_b$) are shown in Figure 5. Cement content and RAP percentage effects on the fatigue life parameters did not show a well-defined trend. The mixtures showed to be highly strain sensitive; that is, a small increase in the initial strain may greatly reduce the mixtures fatigue life. *SDE* values are close to those used by Austroads when designing conventional cement-treated layers (without RAP addition), which have varied from 8 to 21 over the years [17-19].

$$N = a(\varepsilon_i/\varepsilon_b)^{-SDE} \qquad (3)$$

TABLE 2 Fatigue relationships parameters

	Cement content (%) + RAP percentage (%)					
	2 + 20	**2 + 50**	**2 + 70**	**4 + 20**	**4 + 50**	**4 + 70**
a	2×10^{-8}	1×10^{-3}	6×10^{-8}	1×10^{-4}	6×10^{-9}	1×10^{-22}
SDE	11.1	6.7	7.9	9.4	10.7	21.2
R²	0.88	0.89	0.57	0.68	0.71	0.66

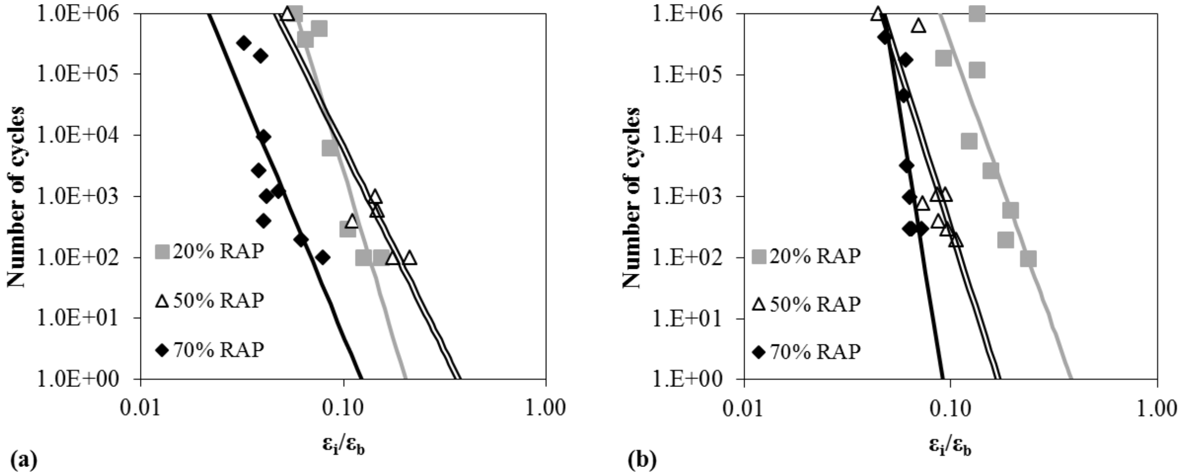

FIGURE 5 Fatigue relationships for mixtures with (a) 2% of cement and (b) 4% of cement

5. CONCLUSIONS

The flexural strength of cement-treated mixtures of RAP and LS depends on cement content and RAP percentage; the higher the cement and RAP amounts, the stronger the mixture. The ε_b is highly influenced by RAP percentage; increasing about twice when RAP varies from 20% to 70%. On the other hand, ε_b decreases with cement content, increasing brittleness.

The mixtures flexural static and resilient moduli increase with cement content. Although RAP effect on the static modulus was not clear, resilient modulus increases with RAP percentage. This is explained by the fact that the dry unit weight of RAP inherently exceeds that of soils; the higher the RAP percentage, the denser the mixture, resulting in stronger and stiffer materials. Some mixtures showed similar moduli under both loading conditions, which is useful for design by allowing estimating resilient modulus through static results.

Strain based fatigue relationships were obtained and the *SDE* were within the reported by Austroads for conventional CTM (without RAP addition). Cement content and RAP percentage effects on the fatigue life parameters did not show a well-defined trend. The mixtures fatigue life showed to be highly dependent on the tensile strain at the bottom of the recycled layer, a fact that highlights the importance of mechanistic-empirical design for FDR-PC.

ACKNOWLEDGEMENTS

The authors would like to thank the CCR Highway Concessionary Group for providing financial assistance to carry out this research. The authors would also like to thank the Brazilian government agencies CAPES and CNPq for the granted scholarships.

REFERENCES

[1] Portland Cement Association. Guide to Full Depth Reclamation (FDR) with Cement, Illinois, USA. 2005.

[2] Jitsangiam, P., Nusit, K., Chummuneerat, S., Chindaprasirt, P., and Pichayapan, P. Fatigue assessment of cement-treated base for roads: An examination of beam-fatigue tests, Journal of Materials in Civil Engineering, 28(10). pp. 1-11. 2016. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001601

[3] Kolias, S. Mechanical properties of cement-treated mixtures of milled bituminous concrete and crushed aggregates, Materials and Structures, 29, pp. 411-417. 1996. https://doi.org/10.1007/BF02485991

[4] Kolias, S. The influence of the type of loading and temperature on the modulus of elasticity of cement-bound mixes of milled bituminous concrete and crushed aggregates, Materials and Structures, 29, pp. 543-551. 1996. https://doi.org/10.1007/BF02485954

[5] Grilli, A., Bocci, E., and Graziani, A. Influence of reclaimed asphalt content on the mechanical behaviour of cement-treated mixtures, Road Materials and Pavement Design, 14(3), pp. 666-678. 2013. https://doi.org/10.1080/14680629.2013.794367

[6] Isola, M., Betti, G., Marradi, A., and Tebaldi, G. Evaluation of cement treated mixtures with high percentage of reclaimed asphalt pavement, Construction and Building Materials, 48, pp. 238-247. 2013. https://doi.org/10.1016/j.conbuildmat.2013.06.042

[7] Jones, D., Wu, R. and Louw, S. Comparison of full depth reclamation with portland cement and full depth reclamation with no stabilizer in an accelerated loading test, Transportation Research Record, 2524, pp. 133-142. 2015. https://doi.org/10.3141/2524-13

[8] Fedrigo, W., Núñez, W. P., Kleinert, T. R., Matuella, M. F. and Ceratti, J. A. P. Strength, shrinkage, erodibility and capillary flow characteristics of cement-treated recycled pavement materials, International Journal of Pavement Research and Technology, 10(5), pp. 393-402. 2017. https://doi.org/10.1016/j.ijprt.2017.06.001

[9] Castañeda López, M. A., Fedrigo, Kleinert, T. R., Matuella, M. F., W., Núñez, W. P., Ceratti, J. A. P. Flexural fatigue evaluation of cement-treated mixtures of reclaimed asphalt pavement and crushed aggregates, Construction and Building Materials, 158, pp. 320-325. 2018. https://doi.org/10.1016/j.conbuildmat.2017.10.003

[10] Bocci, M., Canestrari, F., Grilli, A., Pasquini, E., and Lioi, D. Recycling techniques and environmental issues relating to the widening of a high traffic volume Italian motorway, International Journal of Pavement Research and Technology, 3(4), pp. 171-177. 2010.

[11] Bocci, M., Grilli, A., Cardone, F. and Graziani, A. A study on the mechanical behaviour of cement–bitumen treated materials, Construction and Building Materials, 25(2), pp. 773-778. 2011. https://doi.org/10.1016/j.conbuildmat.2010.07.007

[12] Bocci, M., Grilli, A., Cardone, F. and Ferrotti, G. Full-depth reclamation for rehabilitation of local roads: a case study, International Journal of Pavement Engineering, 15(3), pp. 191-201. 2012. https://doi.org/10.1080/10298436.2012.657196

[13] Suebsuk, J., Horpibulsuk, S., Suksan, A., Suksiripattanapong, C., Phoo-Ngernkham, T. and Arulrajah, A. Strength prediction of cement-stabilised reclaimed asphalt pavement and lateritic soil blends, International Journal of Pavement Engineering. 2017. https://doi.org/10.1080/10298436.2017.1293265

[14] Nogami, J. S. and Villibor, D. F. A new soil classification system for pavement applications. In: Proceedings of the Brazilian Symposium of Tropical Soils in Engineering, Rio de Janeiro: COPPE/CNPq/ABMS. 1981. (in Portuguese)

[15] Japan Concrete Institute. Method of Test for Flexural Strength and Flexural Toughness of Steel Fiber Reinforced Concrete, Publication JSCE SF4, Japan. 1984.

[16] National Cooperative Highway Research Program. Characterization of Cementitiously Stabilized Layers for Use in Pavement Design and Analysis, Report 789, Washington DC, USA. 2014.

[17] Austroads. The development and evaluation of protocols for the laboratory characterisation of cemented materials, Publication AP-T101/08, Sydney, Australia. 2008.

[18] Austroads. Preliminary Investigation of the Influence of Micro-cracking on Fatigue Life of Cemented Materials, Publication AP-T198/12, Sydney, Australia. 2012.

[19] González, A, Jameson, G., Carteret, R., and Yeo, R. Laboratory fatigue life of cemented materials in Australia, Road Materials and Pavement Design, 14(3), pp. 518-536. 2013. https://doi.org/10.1080/14680629.2013.779300