Full-depth Reclamation of Asphalt Pavements with Portland Cement: Mechanical Behaviour of Cement-treated Mixtures of RAP and Lateritic Soil

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ABSTRACT

This paper aims to evaluate the mechanical behaviour of cement-treated mixtures of reclaimed asphalt pavement (RAP) and lateritic soil, resulting from full-depth reclamation with Portland cement (FDR-PC). Therefore, an experimental programme was developed in order to measure the indirect tensile strength (ITS) and the resilient modulus (RM) of different mixtures and to analyse the effects of RAP percentage, cement content and curing time. An experimental matrix considering several levels for the independent variables was designed using a statistical software. Models with statistically significant effects and acceptable coefficients of determination were obtained, given the heterogeneity of the studied materials. In summary, the studied mixtures presented satisfactory results for ITS, considering the minimum value of 0.25 MPa adopted by the most recent Brazilian standards. The range of ITS values obtained was also close to those found in other experimental studies on FDR-PC mixtures. Regarding the RM results, the wide range of values achieved showed that the mixtures can generate recycled layers with different levels of stiffness. Moreover, it was identified that cement content and RAP percentage strongly affect the strength and the stiffness of the mixtures, increasing both of them.

Keywords: pavement recycling; full-depth reclamation with Portland cement; mechanical behaviour; reclaimed asphalt pavement; lateritic soil.

1. INTRODUCTION

In the context of roads maintenance, there are several intervention possibilities to solve the existing problems in distressed pavements. For example, it may vary from simple rehabilitation techniques to the total reconstruction of the pavement structure. However, most options have a high cost, not only monetary, but also environmental. These costs are related to the consumption of non-renewable raw material, the transportation of materials and the need of specific places to dispose the waste from the works.

Considering this, full-depth reclamation with Portland cement (FDR-PC) is more economic and environmental friend option than the practices commonly applied. These advantages are obtained through the reuse and cement stabilization of the original pavement materials, allowing a quick execution of a new strong and durable base [1].

FDR-PC has been used as a solution in pavement rehabilitation for decades in many countries, including Brazil [2-4]. Despite this, there are still few Brazilian standards addressing this technique and the existing ones are incomplete in several factors, such as the lack of appropriated mix design methods. This lack of references results in the use of different procedures and criteria in recycling projects, often compromising their effectiveness. Therefore, it is clear the need to provide more information and experimental data about FDR-PC.

The research reported here aimed to contribute to the study of FDR-PC, more specifically, for asphalt pavements with the base layer made of lateritic soil (LS), as there are only few researches on this topic [5]. Therefore, the main objective of this work was to evaluate the mechanical behaviour (strength and stiffness) of cement-treated mixtures of reclaimed asphalt pavement (RAP) and LS, identifying the effects of cement content, RAP percentage and curing time.

2. EXPERIMENTAL PROGRAMME

In order to achieve the research objective, tests were carried out to measure the indirect tensile strength (ITS) and the resilient modulus (RM) of cement-treated mixtures of RAP and LS, using different RAP percentages, cement contents and curing times. Among the analysed variables, the cement content and the RAP percentage were defined from a central composite design (CCD), proper for fitting second-order response surfaces [6].

The experimental matrix, designed using Minitab 17 statistical software, is shown in Table 1. The mixtures are identified by codes, in which the first number represents the cement content and the second represents the RAP percentage. It is pointed out that the central point (4-50) were measured six times, while the other points were measured only once (14 tests per curing time). This fact is due to the CCD applied, which uses the central part as a parameter of reliability. Schreinert [7] details the experimental planning used in this research.

The adopted curing times were 3, 7 and 14 days and the compaction effort applied was the AASHTO Modified (described in Section 2.1). Fedrigo [4] recommended this compaction effort, since it enables a great increase in the strength and stiffness of mixtures, allowing a reduction of cement content.

2.1 Materials

The studied FDR-PC mixtures were made of LS, RAP and cement. The LS was sampled from a section of the SP-425 highway, located in the State of São Paulo, southeastern of Brazil. The RAP was sampled from streets of Porto Alegre, located in the State of Rio Grande do Sul, southern of Brazil. These source options were chosen in order to obtain laboratory mixtures containing original pavement materials (only recycled materials). It is pointed out that in a real situation the materials must be obtained from closer sources, avoiding great transport distances.

LS was classified as a clayey lateritic soil (LG'), according to the MCT (Miniature, Compacted, Tropical) methodology [8]. 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. Portland cement with ground-granulated blast-furnace slag addition (Brazilian type CP II E 32) was used.

The grain size distributions of the materials and mixtures are presented in Figure 1. It is verified that the increase of RAP percentage led to denser and well graded mixtures, while the increase of LS percentage led to poorly graded mixtures.

Compaction tests were carried out using a rammer with 4.54 kg mass and 457 mm drop height, applying AASHTO T180 [9] Modified effort (approximately 2.7 N.mm/mm^3; five layers compacted with 56 blows). Table 1 presents the values of optimum moisture content (OMC) and maximum dry unit weight (MDUW) obtained for each mixture.

TABLE 1 Experimental matrix and compaction parameters obtained for the mixtures

Code	Cement content (%)	RAP percentage (%)	OMC (%)	MDUW (kN/m³)
1.17-50	1.17	50	8.6	19.30
2-20	2	20	14.2	17.10
2-80	2	80	7.1	20.73
4-7.57	4	7.57	18.0	17.57
4-50	4	50	10.9	19.59
4-50	4	50	10.9	19.59
4-50	4	50	10.9	19.59
4-50	4	50	10.9	19.59
4-50	4	50	10.9	19.59
4-50	4	50	10.9	19.59
4-92.43	4	92.43	5.8	21.64
6-20	6	20	12.7	18.11
6-80	6	80	8.2	21.03
6.83-50	6.83	50	12.8	19.43

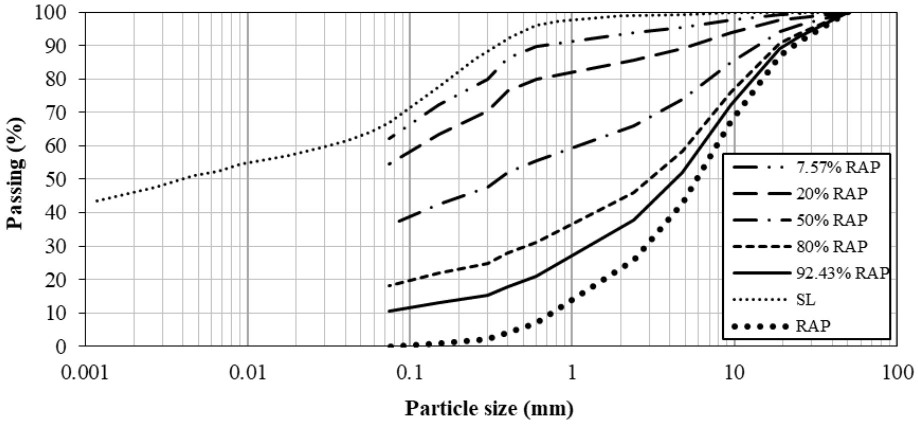


FIGURE 1 Grain size distributions of the materials and mixtures

2.2 Methods

The mixtures were manually produced; initially, the dry materials were mixed and then water was added to reach OMC while continuing the mixing process. Marshall cylindrical moulds were used, with an inside internal diameter of 10.2 cm and a height of 6.5 cm. The specimens were compacted on both sides of a single layer. The amount of material added and the number of blows given were adjusted to reach MDUW.

The specimens were cured in sealed plastic bags, avoiding contact with external moisture. A wet curing could not be used, since the specimens disaggregated when submitted to an environment with high moisture, making it impossible to perform the tests.

2.2.1 Indirect Tensile Strength (ITS) Test

The test was performed in accordance with ASTM D6931 [10]. The specimen was placed in the automatic loading machine with its cylindrical surface between the metal stripes and the load was applied, with a constant displacement rate of 0.8 mm/s (Figure 2-a). The test was finalised as soon as the rupture occurred (Figure 2-b) and the load value was noted. From this result and the measures of diameter and height of the specimen, the ITS was determined. For each mixture and curing time (3, 7 and 14 days), two specimens were prepared, totalling 84 specimens.

2.2.2 Resilient Modulus (RM) Test

The adopted testing procedures were based on ASTM D7369 [11]. For this test, it is necessary to know the tensile strength and the Poisson's ratio of the material to be tested. Thus, before the test, the ITS of all the mixtures was determined. As the Poisson's ratio was not determined for the mixtures analysed in this study, the value of 0.17 was adopted. Kleinert [12] found this value for cement-treated mixtures of RAP and soil-cement.

The test was performed by applying one load cycle per second (frequency of 1 Hz). The load duration was 0.1 second and the vertical load magnitude was equal to 30% of the rupture load obtained in the ITS test. A linear variable differential transformer (LVDT) transducer was used to measure the horizontal displacements. The test configuration is shown in Figure 2-c.

The RM was determined based on the ratio of vertical load to horizontal resilient strain, as well as on the specimen dimensions. Six values of RM were measured for each specimen. For each mixture and curing time, one specimen was prepared, totalling 42 specimens.

(a) (b) (c)

FIGURE 2 Tests procedures: (a) configuration of ITS test, (b) specimen after tensile rupture and (c) configuration of RM test

3. TEST RESULTS

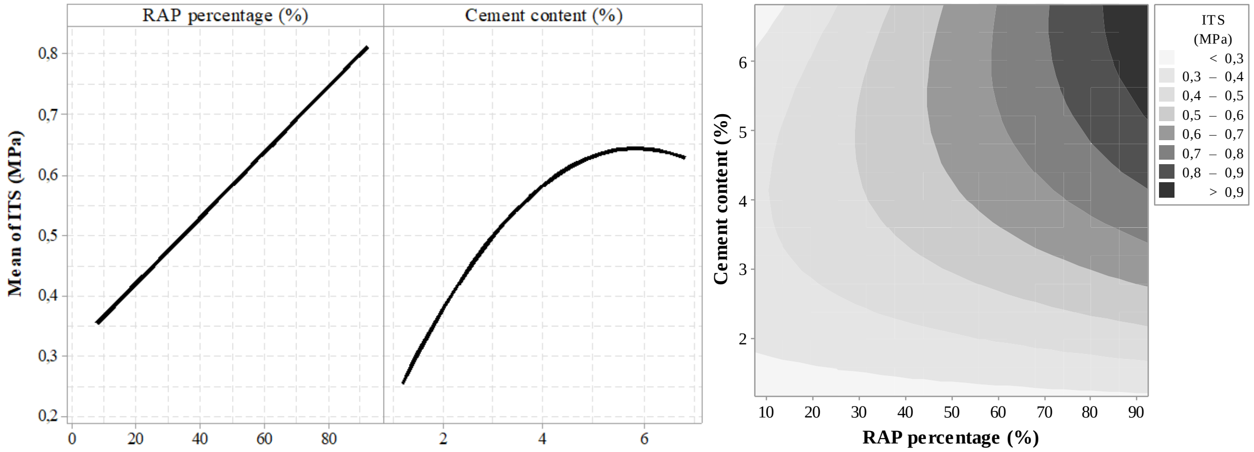
The statistical analysis of the obtained results was carried out using Minitab 17 statistical software. The obtained results for each test were provided to the software and the influence of each variable was evaluated by means of numerical parameters, models and graphs. Non-significant terms (p-value greater than 0.05) were not considered in the regression models.

3.1 Indirect Tensile Strength (ITS) Results

The regression model obtained for ITS, shown in Eq.(1), presented a coefficient of determination (R^2) of 76%, which proves the statistical significance of the results. Figure 3-a shows the effects of the independent variables (RAP percentage and cement content) on the ITS (curing time was a non-significant variable). Figure 3-b shows a contour plot, in which the ITS is presented as a function of cement content and RAP percentage (curing time fixed at 7 days). It is verified that strength increased with cement content and RAP percentage, both presenting great influence in the determination of ITS.

$$ITS(MPa) = 0.236 - 0.00453 * Rp + 0.1071 * Cc - 0.01783 * Cc * Cc - 0.002378 * Ct * Ct \\ + 0.001455 * Rp * Cc + 0.000485 * Rp * Ct + 0.0034 * Cc * Ct \qquad (1)$$

Where *Rp* (%) is the RAP percentage; *Cc* (%) is the cement content; and *Ct* (number of days) is the curing time.



(a) (b)

FIGURE 3 ITS results: (a) influence of RAP percentage and cement content on the mean of ITS and (b) contour plot for ITS at curing time of 7 days

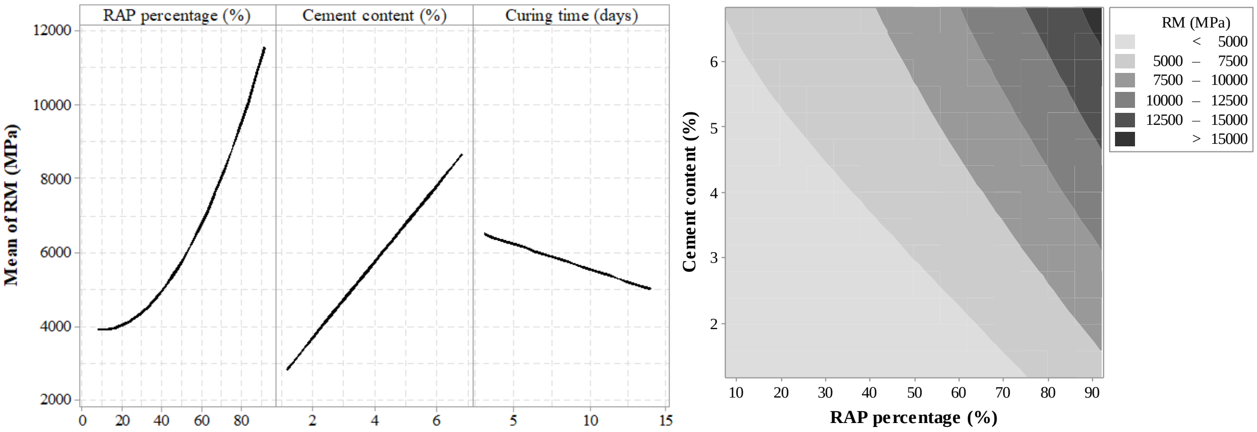
The mixtures presented satisfactory ITS results; most of the values were higher than 0.25 MPa, which is the minimum 7-day ITS proposed by Brazilian standards [13, 14]. Moreover, the range of ITS values obtained is close to those found in other experimental studies on FDR-PC mixtures [4, 12, 15-17]. However, the curing process used in this research, avoiding high moisture condition, was different from the wet curing commonly applied in other studies.

3.2 Resilient Modulus (RM) Results

The regression model for RM, shown in Eq.(2), reached a R^2 of 62%. Although it is a low value, it may be acceptable due to the inherently variability of the used materials. Figure 4-a shows the effects of the independent variables (RAP percentage, cement content and curing time) on the RM. Figure 4-b shows a contour plot of RM as a function of cement content and RAP percentage (curing time fixed at 7 days). As observed for ITS, the mixtures stiffness increased with cement content and RAP percentage; both variables showed a strong influence on the RM. On the other hand, RM slightly decreased with curing time, possibly due to the generation of shrinkage microcracks during the curing process, then reducing the material stiffness.

$$RM(MPa) = 8802 - 126.8 * Rp - 408 * Cc - 664 * Ct + 1.107 * Rp * Rp + 16.49 * Rp * Cc \\ + 4.76 * Rp * Ct + 72.5 * Cc * Ct \qquad (2)$$

The observed increase of strength and stiffness with RAP percentage diverges from the behaviour generally described in the literature, which shows that recycled pavement materials tend to lose strength and stiffness with the RAP addition [4, 12, 16-18]. This is possibly due to the fact that the dry unit weight of RAP exceeds that of soils. Therefore, the higher the RAP percentage, the denser the mixture, resulting in stronger and stiffer materials. It may be confirmed by analysing the grain size distributions in Figure 1. As stated before, the grain size distributions of high RAP mixtures are denser and well graded, while low RAP mixtures are poorly graded.



(a) (b)

FIGURE 4 RM results: (a) influence of RAP percentage, cement content and curing time on the mean of RM and (b) contour plot for RM with curing time of 7 days

4. SUMMARY AND CONCLUSIONS

It was not possible to cure the analysed specimens in high wet conditions, as they disintegrated when subjected to such environments. It can be concluded that the presence of LS makes the recycled mixtures, even after compacted, quite susceptible to moisture. Thus, projects of FDR-PC in pavements with base layers made of LS should include detailed studies on the water effects, in order to find possible solutions to this problem.

The analysed mixtures showed acceptable ITS results, not only considering the minimum values of the most recent Brazilian standards, but also when compared to those obtained in other studies on cement-treated recycled mixtures. Regarding the RM results, the wide range of values demonstrated that the mixtures could generate recycled layers with different levels of stiffness.

Cement content and RAP percentage have strong and significant effects on the mechanical behaviour of cement-treated mixtures of RAP and LS. Conversely, curing time has non-significant effect on strength and slightly affects stiffness. This may be due to shrinkage microcracks generated during the curing process, which was not done in high wet conditions.

As expected, higher cement contents increase strength and stiffness. However, the increase of RAP percentage leads to similar effects, a fact not commonly addressed to FDR-PC materials. This behaviour may be due to changes on the grain size distribution caused by the RAP aggregate addition, which is denser than LS, resulting in stronger and stiffer materials.

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