Evaluation of the integration of alternative materials in laboratorial tests of Chip Seals

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ABSTRACT

The application of thin coatings on low volume roads is a typical practice in the northeast of Brazil. Despite this, service specifications in general do not completely address aspects related to: design, performance evaluation and the use of alternative materials. Thus, this paper aims to evaluate the incorporation of RAP and Steel Slag in chip seals, by replacing partially or completely the conventional aggregates in laboratory samples. The chip seals were submitted to an adaptation of the Wet Track Abrasion Test to predict the aggregate loss. In addition, the Performance-Based Uniformity Coefficient (PUC) was used as a tool for predicting chip seal performance. It was noted that the PUC results were related to the abrasion tests performed, in a way that the lower value of PUC reflected proportionally in lower aggregate loss. Alternatively, it was possible to assert that there is potential in the use of alternative materials in chip seals: (i) the RAP was tested as replacement of up to 50% of the conventional aggregate, showing satisfactory results and saving up to 12% of the total service costs; (ii) the steel slag was tested as total replacement of the aggregate and presented viable environmental, economic and technical results. It is also suggested that the criteria specified by the National Department of Transport of Brazil for chip seals services should be updated to include aggregates uniformity requirements or concepts such as the PUC.

Keywords: Chip Seal, Reclaimed Asphalt Pavement, Steel Slag, Aggregate Loss, PUC

1. INTRODUCTION

The insertion of new methodologies of analysis of alternative materials in the conception of new pavements is a general tendency in this area of study that reflects both in less cost and a better performance. Additionally, the study of reused or recycled products promotes less impact to the environment. In this context, this research interconnects elements related to the use of Reclaimed Asphalt Pavement (RAP) and to the application of Chip Seals in Low-Traffic roads. In fact, this kind of service is already pointed as an efficient practice to expand the paved net with reduced costs (Loiola, [1]; Pereira [2]). In Brazil, the initiation of this practice is, however, associated to limitations, since the current methods used to estimate the performance of pavements in laboratory are still not embraced by all kinds of aggregate used in this country.

In other countries, the study of this performance is made by a different approach. In the United States, for example, there is a tendency of using the Performance-Based Uniformity Coefficient (PUC), that is a mean of predicting the performance of chip seals based on the granulometry designed by Lee & Kim [3].

The incorporation of RAP in a layer of chip seal is not a common subject in the Brazilian scientific scenario, neither is considered in manuals. In this perspective, the central objective of this paper was to define a product of the mixture of RAP and mineral aggregate that is acceptable to use in Chip Seals with low susceptibility to failure. It was established to use a local method of surface abrasion applied to the samples, and the granulometric ranges chosen were under the limits of DNIT [4] and DER-CE [5].

2. LITERATURE REVIEW

There are intrinsic properties to the aggregate that affect chip seals performance, such as porosity, surface area, absorption capacity, mineralogy and surface texture (Lee & Kim, [6]). Distresses like raveling may occur due to aggregate in excess, or to a wrong choice of granulometry (very large grains), or by constructive problems (rolling process), or even by lack of bonding in the binder-aggregate set (Lee & Kim, [3]; Gürer *Et Al*., [7]; Aktaş *Et Al*., 2013 [8]; Moraes; Bahia, [9]; Adams *Et Al*., [10]).

Studies focused on the uniformity shows that there is a major tendency to Chip Seals present better performance when executed with uniform grains (Lee & Kim, [3]; Silva, [12]). This subject is directly related to both major problems in the performance of this service: Aggregate loss and bleeding. Based on this perspective and thinking of attributing a numerical value to the uniformity of granulometric ranges applied to Chip Seals, Lee & Kim [3] proposed the Performance-Based Uniformity Coefficient (PUC), a parameter that evaluates in a granulometric curve the percentage of the coat that presents the tendency of developing defects such as aggregate loss and bleeding.

The determination of PUC is made by means of five steps that can be followed in the Figure 1: (i) plotting the granulometric range; (ii) identifying the medians: trace a horizontal line from the mark of 50 in the passing percentage to the curve and this is projected in the x-axis to identify the value M (the grain dimension corresponding to this percentage); (iii) calculation of the interval of good performance: 0,7×M and 1,4×M; (iv) definition of P_{EM} and P_{2EM}: respectively the corresponding terms of the 0,7×M and 1,4×M of the curve in the y-axis and (v) calculation of PUC, using the Eq. (1):

$$PUC = \frac{PEM}{P2EM} \tag{1}$$

In which: *PUC*: value of PUC;

P_{EM}: passing percentage, corresponding to 1,4×M (%) and

P_{2EM}: passing percentage, corresponding to 0,7×M (%).

In Brazil, customarily there are institutions which regulate the standards to each region, in which are defined limits for the granulometric ranges. It is possible to observe by the analysis of each standard that some of them define ranges aiming for uniformity, while others propose intervals in which the aggregates must fit.

Brazilian researchers have developed their own test to evaluate performance of chip seals in laboratory, since there are no national methods defined. Loiola [1] and Pereira [2] adjusted the Wet Track Abrasion Test (WTAT) developed for microsurfacing design to evaluate chip seals performance. Such test was found as a viable alternative of performance evaluation, however it was verified a severity level higher than the field one.

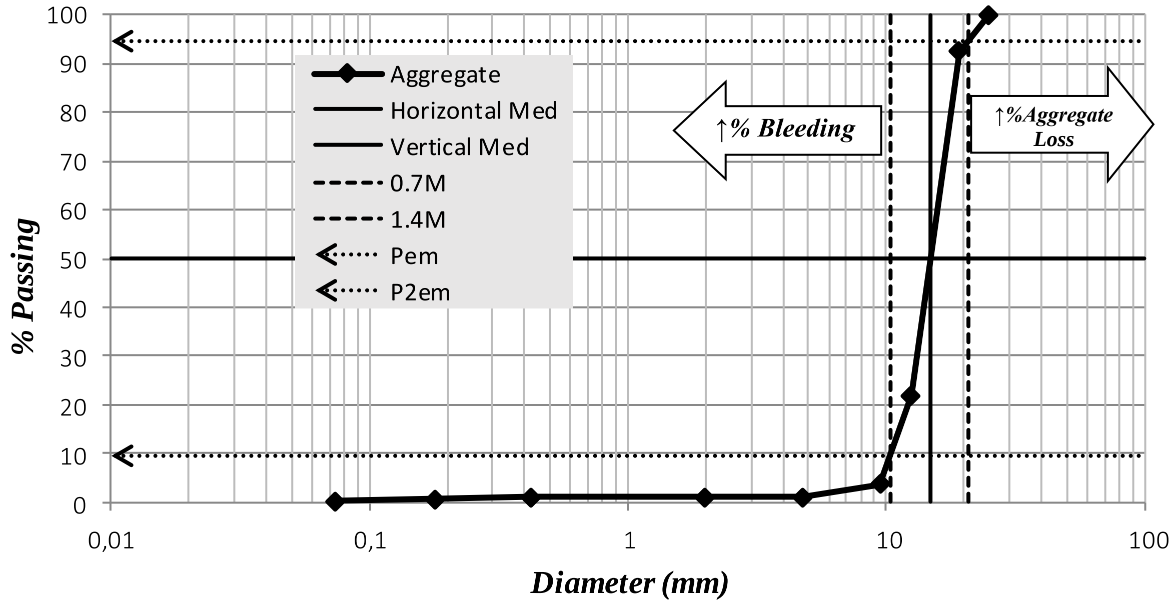


FIGURE 1 Demonstration of PUC's calculation

In an international context, there are already some tests such as Sweep Test (or Flip-over test) for the evaluation of aggregate loss, whose equipment is similar to WTAT. The Flip-over Test is specified in ASTM D7000: *Standard Test Method for Sweep Test of Bituminous Emulsion Surface Treatment Samples*. This test has already been applied by Lee [13] to Lee & Kim [6] for understanding the effects of emulsion and aggregate rates in chip seal performance and by Adams [14] for the development of a design method for chip seals. While the WTAT uses water to predict the worst condition of pavement, this other test uses high temperatures.

3. MATERIALS AND METHODS

Samples of ordinary and alternative aggregates in the Metropolitan Region of Fortaleza were selected and collected. The choice criteria of these materials were the limits of granulometric curves currently present in the reality of that city and the availability in the field. Those aggregates were characterized individually and then specific compositions of gravel and RAP were submitted to the evaluation of PUC, as well as with the Steel Slag. Two lines of analysis of granulometric range were studied: (1) following the standards of National Department of Transport of Brazil DNIT [4]; and (2) following the local standards of DER-CE [5]. As a result of this process one sample of each line was selected to the evaluation of performance along with the gravel in its natural form.

The analysis of aggregate loss by means of the (WTAT) was defined as the kind of performance evaluation for the samples defined in this study. For each sample, it was constructed 9 specimens. The construction of each specimen was made as shown in the Figure 3: steps (a),

(b) and (c) are related to the montage of the frame of support; step (d) is the compaction that in this research was made by the use of a concreted roller. The performance was measured by the percentage of aggregates pulled out of the specimen in the execution of WTAT.

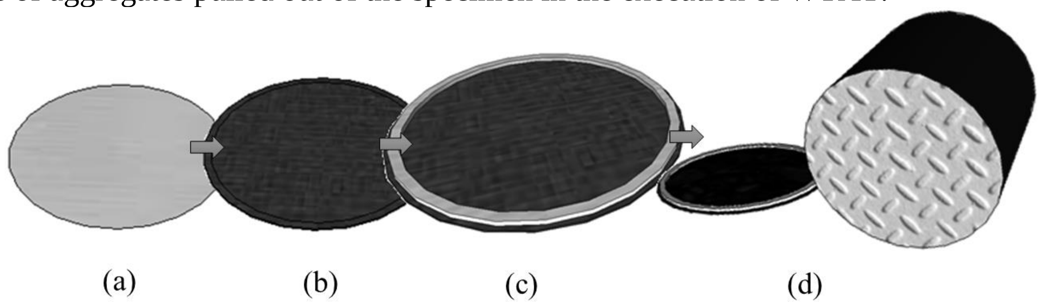


FIGURE 1 Design of the specimens

4. RESULTS AND DISCUSSION

4.1 PUC

The RAP was submitted to a process of separation of grains, aiming both to achieve a better uniformity of grains and less waste of grains. This process was made twice. (a) Firstly, it was intended to achieve a granulometric curve within the ranges specified by DNIT [4] The percentage of utilization of the material at the end of this process was 42%. (b) Secondly, the material was sized in a higher uniformity, with the utilization of 12%, and within the ranges specified by DER-CE [5]. The Steel Slag was used as it was collected aiming to use the maximum of this material, rejecting only bigger grains.

After process (a), the PUC of different combinations of RAP and mineral aggregate were calculated, and the best one between them (33% RAP) was chosen to be submitted to the posterior tests. The mineral aggregate and RAP resulted of process (b) was mixed with the mineral aggregate in the percentage of 50%, due to the availability of this material. Table 1 presents the process of calculation of PUC for all the cited materials. Samples selected for posterior tests were identified by the following abbreviation in this paper: MA – Mineral Aggregate in its natural state; MIXa – Mixture of RAP (33%) and Mineral Aggregate (67%); MIXb – Mixture of RAP (50%) and Mineral Aggregate (50%); SS – Steel Slag in its natural state.

TABLE 1 Summary of PUC calculation

	RAP			***GRAVEL***	***DNIT [4{***			***DER-CE [5]***	***Steel Slag***
	Natural	*(a)*	*(b)*	*3/4''*	*67% RAP*	*50% RAP*	*33% RAP*	*50% RAP*	*Natural*
M	3,4	8,0	12,0	15,4	10,3	12,5	13,8	13,8	17,8
0,7 M	2,3	5,6	8,4	10,7	7,2	8,7	9,6	9,6	12,5
1,4 M	4,7	11,1	16,8	21,5	14,4	17,4	19,3	19,3	25,0
P_{EM} (%)	41,3	15,5	0,0	7,2	27,5	31,2	24,8	4,1	5,5
P_{2EM} (%)	59,3	79,8	88,3	94,3	73,5	85,0	92,8	95,0	87,5
100 - P_{2EM} (%)	40,8	20,3	11,8	5,8	26,5	15,0	7,3	5,0	12,5
PUC	0,696	0,194	0,000	0,076	0,374	0,366	0,267	0,043	0,063

4.3 Analysis of Performance

It is noticeable that there is considerable variability associated to the use of WTAT for evaluation of Chip Seals. This is mainly related to the different combination of arrangement that aggregates can form. In order to guarantee that the value of abrasion is correctly estimated, and point conclusions, general statistics parameters in the analysis of each sample were used. In cases in which the test had to be interrupted the abrasion was calculated but not considered in the calculus of the parameters. Table 2 presents the percentage of abrasion for each specimen. It is possible to notice that the average abrasion was low in sample MIXb (8%), contrasting to MIXa, that presented the highest between the samples (30%). Alternatively, the Steel Slag was the sample with the lowest average abrasion (4%). In general, Pereira [2] pointed out that values of abrasion lower than 20% represents a good performance in the field.

TABLE 2 Abrasion obtained

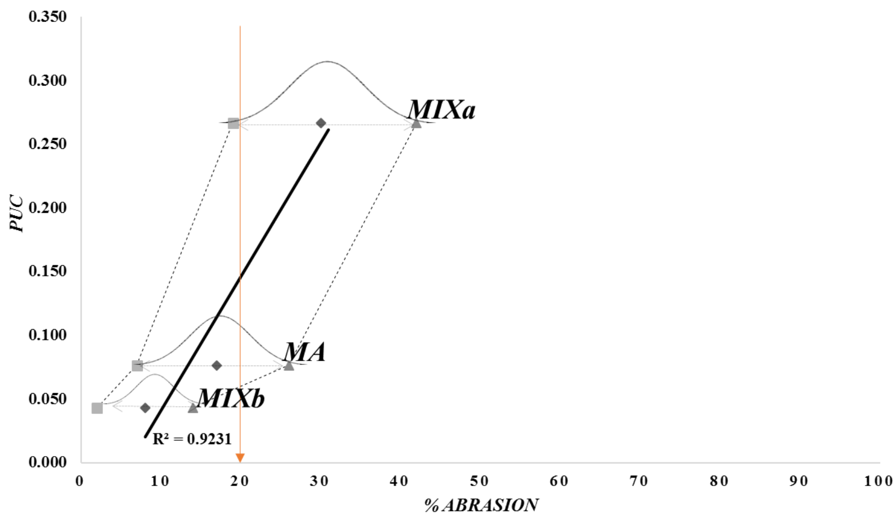
SAMPLE	***MA***	***MIXa***	***MIXb***	***SS***
Sp 1	33%	48%	*	5%
Sp 2	*	42%	*	0%
Sp 3	17%	*	18%	5%
Sp 4	5%	31%	2%	5%
Sp 5	10%	15%	4%	*
Sp 6	5%	26%	5%	1%
Sp 7	20%	28%	10%	0%
Sp 8	21%	6%	4%	6%
Sp 9	24%	22%	14%	4%
Mean	17%	30%	8%	4%
Median	18%	27%	5%	4%
Stand. Deriv.	10%	14%	6%	3%
Variance	0.01	0.02	0.00	0.00
Max	33%	48%	18%	6%
Min	5%	6%	2%	0%

* - Specimens in which the abrasion test was interrupted

It was not obtained evidence that increasing the use of RAP in the samples represents reduction in the resistance of specimens. Additionally, the investigation of the first three samples (materials with mineral origins) it is possible to associate the average abrasion to the PUC, allowing the analysis of this correlation. The linear regression pointed a $R^2 = 0{,}9231$ (Figure 2), suggesting the relation between the two variables.

It is also noticeable that the amplitude of the variation of abrasion itself contains essential information for understanding this variable in a way better than the simple punctual analysis of its central tendency. For instance, considering that the abrasion can be represented by a Gaussian distribution, it is possible to picture "intervals of abrasion" of one standard deviation to each extremity of the interval. In this perspective, it is possible to assume that 68,3% of the abrasion expected for this test is inside the interval of abrasion. Figure 2 demonstrates samples MA, MIXa and MIXb in a graphic associating each PUC to the interval of abrasion.

FIGURE 2 PUC and Abrasion for samples MA, MIXa and MIXb



4. CONCLUSIONS

In what concerns all things to be considered, it is reasonable to take conclusions about this study that both confirm expectations about what was said before and guide studies which are going to be started in the future. Among the main conclusions it is possible to highlight:

- The Reclaimed Asphalt Pavement was successfully inserted in tests performed for Chip Seals, pointing that there is potential for the use of this material in percentage inferior or equal to 50%;
- There is an economic benefit of up to 12% in the final price of the service with the addition of the RAP;
- The RAP naturally presents a tendency to the rupture superior to the mineral aggregate, suggesting that part of the abrasion obtained in the test with this material could be resulted of the crash of aggregate itself;
- The variable PUC exhibited a good correlation to the abrasion obtained in the tests with WTAT;
- Granulometric ranges specified by DNIT [4] standards present a lower performance than the ones specified by local organs, such as DER-CE [5];
- The Steel Slag can be inserted integrated in the practice of Chip Seals in its natural form depending on its granulometric curve.

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