Evaluation of the behavior of recycled mixes with portland cement addition in-site

Gislaine Luvizão[1], Glicério Trichês[2]
([1] University of the West of Santa Catarina, Joaçaba, Brazil, gislaine.luvizao@unoesc.edu.br)
([2] Federal University of Santa Catarina, Florianópolis, Brazil, glicerio.triches@ufsc.br)

ABSTRACT

The big Brazilian road extension that needs to be restored, not only presents unfavorable conditions of safety and comfort, but low structural condition of the layers. The bearing layer, in the majority of cases, are of asphalt coating. It receives directly the traffic load and dissipates for lower layers. Recycling was one of the main alternatives of restoration that has spread around the world. The research was conducted on the highway SC 355, located between the cities of Jaborá and Concórdia, State of Santa Catarina. For the composition of the recycled mixture was added basaltic aggregate (stone dust) and Portland cement. It was evaluated the performance of the mixture through the resistance to simple compression, resistance to traction by diametrical compression, elasticity and resilience module, as well as the study of fatigue life. The increase in the proportion of cement increases the compressive strength and traction strength by diametrical compression. Similarly, during the curing time, there was an increase of resistance with the most pronounced increase in early age. The adequate control of all processes guarantees the quality of the restored highway.

Key-words: Deep Recycling. Recycling with Cement. Fatigue. Monitored Segments.

1. RECYCLING WITH THE ADDITION OF CEMENT

Brazil currently has 1,720,607 km of roads, of which 12.4% (213,299 kilometers) are paved, 78.6% (1,353,186 km) unpaved and 9.0% (154,192 km) are planned. Besides the reduced paved extension, the roads have serious conservation problems, providing increased operating costs and lack of security to users. Thereby raising the costs to restore the pavement [1].

In the western state of Santa Catarina the flow of industrial and agricultural products is carried out exclusively by road, overloading the structure of the pavement. Much of the roads in the region, that were built in the 80's under budget constraint conditions, currently present unsatisfactory conditions as trafficability and safety to users. These conditions increase the cost of transportation, causing the increase in the price of the final product transported and cause accidents with victims, also increasing spending on the maintenance of vehicles.

This study aimed to evaluate the construction process along with performance of recycling with cement, of the base layer and coating of the highway SC 355, stretch between BR 153 (Concórdia) and Jaborá (SC), which contemplates extension of 22.8 km.

The recycling in situ has the advantage of not requiring transport and storage of materials, which makes it more economical in relation to the recycling in a central plant. However, in a central plant, the advantage is to get mixtures with more quality, but with higher costs [2].

Pavement recycling in situ with the addition of cement, is a form of transforming a road deteriorated in a structure with adequate structural capability, by taking advantage of the materials from the site. Compared to other rehabilitation solutions, recycling with the addition of cement allows the use of damaged layers, obtaining recover and even increase their load capacity [3].

It is recommended to use recycling with the addition of cement when the structure requires more than 20% of its length to be corrected or replaced in its depth [4].

There is need for accurate determination of the thickness to be recycled, in order to know the actual coating thickness, so that it does not exceed the appropriate percentage, ensuring no reduction in the mechanical performance of the mixture after recycling [5].

The thickness of the recycled cemented layer has great influence on the pavement stiffness, interfering in the results of deflection. In Brazil, most executed works used between 2.5 and 3.5% of cement. These low levels are justified by precaution in the emergence of crack of hydraulic retraction at the recycled layer [6].

New materials can be evaluated in the structural performance of the pavement. Predictions are made and empiricism ceases to prevail, but it stays in the right dose.

The backcalculation of deflection basin on the surface of the structure, associated with the module and the thicknesses of the layers is made through a mechanistic analysis, which assumes that the layers are homogeneous, elastic and isotropic [6].

The pavement structure in the monitored segments resulted in the following layers: subgrade (existing material) subbase (dry macadam, existing material), the remaining base (graded gravel, variable thickness depending on the segment), new base (graded gravel recycled, coating, virgin aggregate and cement, totaling 18.00 cm), coating (simple surface treatment, 3 cm of thin crust and 5 cm of asphalt mix.

2. RECYCLING AT SC 355

During the recycling of the coating layer and the base on site, the recycled thickness was measured, the rate of grit and cement application, the humidity of the mixture, the granulometry of the crushed material and the degree of compaction of the layer. Samples were molded for measuring the resistance to simple compression [7] and resistance to traction by diametrical compression [8].

A survey of deflection basins was conducted at different ages after the layer recycling and it was followed the implementation of the thin crust layer and the coating. From the highway restoration project analysis and the geometry of the same, three segments were selected to be monitored the performance of recycling. The segments were located in tangent with the longitudinal slope less than 2%, encompassing several structural conditions of the existing pavement and the thickness of the required reinforcing layer. The segments extend from 1200 meters, ranging from km 2 + 000 to 8 + 800, divided and identified as follows:

- Segment 1: between km 2 + 000 to 3 + 200;
- Segment 2: between km 4 + 300 to 5 + 500;
- Segment 3: between km 7 + 600 to 8 + 800.

2.1 Structural and functional conditions

The deflectometric survey was conducted over the segments with the aid of Benkelman Beam (2:1 ratio). The survey of deflection basins was performed every 100 meters on both sides of the raceway, positioning the beam on the outer wheel track. In each segment twenty-two deflection basin were considered. In each basin 9 reads were obtained, as follows: initial reading (L0), L12.5, L25, L50, L75, L100, L125, L150 and final reading (Lf) [10].

The deflectometric survey showed maximum deflection values average between 60 and 68 x 10-2 mm, while the characteristic deflection was higher than the admissible (68 x 10-2 mm). Figure 1 shows the maximum deflection found in the segments monitored before the intervention.

The structural conditions of the pavement layers were evaluated by backcalculation, using the Elsym5® software. In all the segments there was a significant variability in the layer's thickness. The coating presented thickness between 5 and 16 cm. Because of these high thicknesses, the coating milling was necessary at some points in order to obtain thicknesses consistent with the specified project. The base layer presented thicknesses from 8 to 23 cm, with average thickness of 15 cm for the segments 1 and 3, and 13 cm to the segment 2.

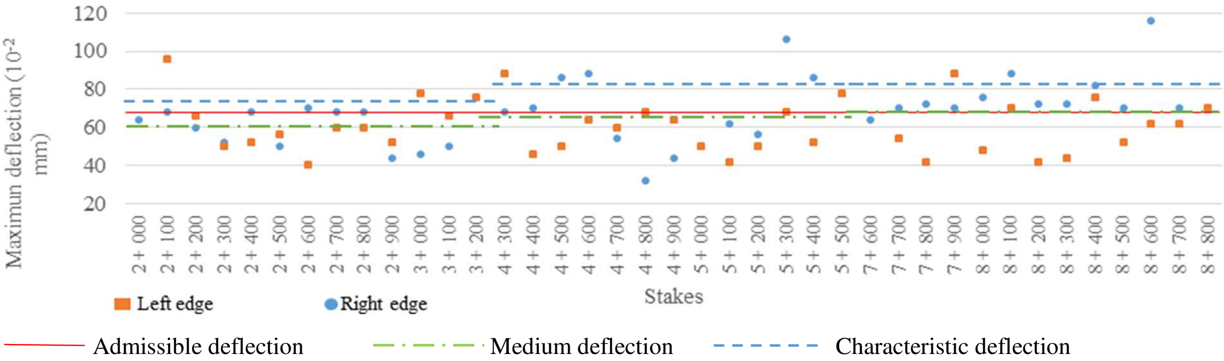

FIGURE 1: Deflection before intervention

For sub-base layer thicknesses have been found from 6 to 27 cm. Locations with very small thickness had total contamination with clay material, originating from fine pumping. The segment 1 showed greater thickness (20.4 cm) and best conditions, as the subgrade material is more granular (decomposed rock), thereby reducing the pumping subgrade. Segment 3 showed the smaller thickness with an average of 16.4 cm. It was also the segment where more problems emerged after recycling. With the thickness and characteristics data of the collected material, modules of the pavement support layers were obtained by backcalculation (Figure 2).

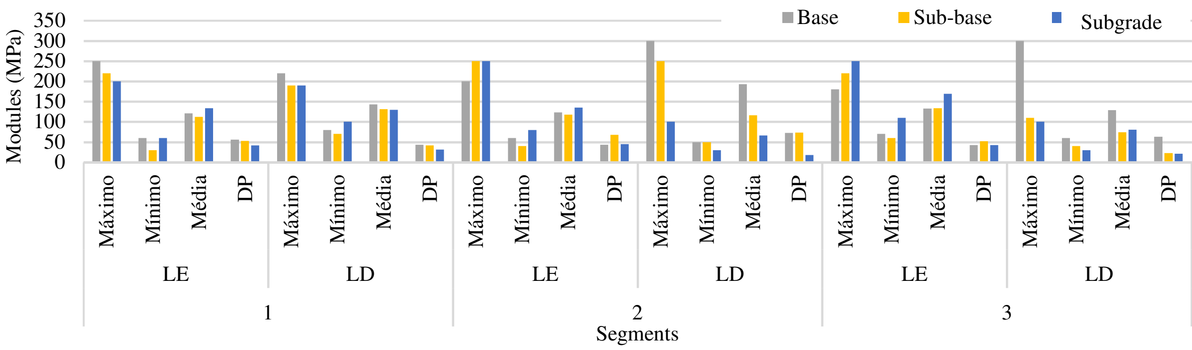

FIGURE 2: Backcalculated modules of the base, subbase and subgrade

2.2 Executive process of recycling

To frame the granulation in range III of DEINFRA/SC, an addition of 15% of virgin aggregate was necessary. The scan rate was done in two ways: first by measuring the spreading thickness and the second, more precise, by the tray method. In all the segments the grit application rate was slightly lower than the specified in the project.

When adding smaller amount of this material, there is a reduction in the percentage of passing material in the thinner sieves (0.425 to 0.0075 mm). The lack of fines in the recycle mixture can provide a reduction of the resistance due to little material to make the connection between coarse aggregates, making the contact grain to grain more prompted by efforts.

The cement used was the type CP II F 32 (Itambé brand). It was distributed with truck, with digital control of the spreading. The control of application rate was performed by the tray method.

In the first two monitored segments, the variation of the cement ratio was around 0.2 percentage points to more and less, while the third segment reached 0.3 percentage points. The cement application rate was always constant, but due to the variation in the thickness of the recycled layer there were differences in the cement percentages. Higher rates, besides increasing the rigidity and strength of the recycled material, increases the cost for execution of the restoration, which may cause cracks in the recycled layer.

Values of the coating/base proportion greater than 1, represent the largest amount of material coating than the base. It is recomended the use of a maximum of 50% coating in relation to the total recycled thickness in order to provide greater strength to the mixture [11].

Some of the points presented humidities above specified, with a maximum variation of 1.5% above and 1.0% below (only 1 point). The humidity of the mixture interfere with the compression of the recycled material and the ultimate strength of the mixture. The cement added "works" as a binding agent, providing greater resistance to mixture. However, to have a suitable performance it requires water to initiate the chemical reactions, acquire consistency and strength. Values of humidities above the specified provide greater workability of the mixture, but high values reduce the efficiency of compression and makes the region susceptible to cracking by hydraulic retraction.

2.3 Mechanical behavior

For the evaluation of the mechanical behavior of the mixture recycled in the site the Compressive Strength tests (RCS) and Tensile Strength by Diametral Compression (RTCD) were made. Were molded 4 test samples per day of work with a diameter of 10 cm and height of 20 cm. The material was compacted in five layers, applying forty-two blows in each one.

Lower resistance values in segment 1 may be due to the execution process, where daily production and the rate of recycling increased, also by changing the equipment operator. The recycling speed interfere with the granulometry of the mixture, due to the impact and number of times that the drum rotates mixing the sample.

The segments 2 and 3 showed values above the minimum prescribed, even in segment 2 containing 2.7% of cement. Low resistance may initiate a premature rupture of the layer, as well as lead to increases cracking more than the estimated in project. The thickness of the recycled layer will also influence at the performance. In segment 1 it was higher than in the other segments, resulting in rate of cement and grit below the calculated.

Figure 3 shows the correlation between the strength of simple compression of the recycled layer obtained after 7 and 28 days of curing.

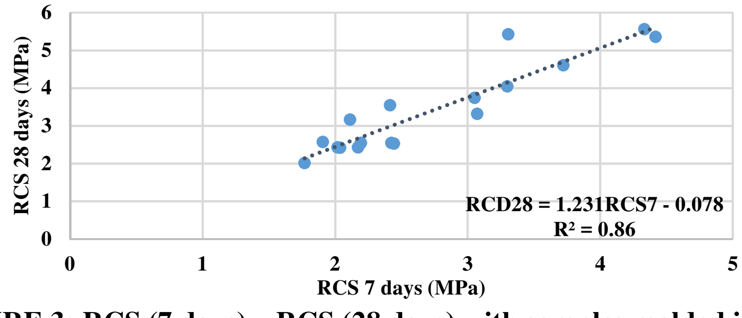

FIGURE 3: RCS (7 days) x RCS (28 days) with samples molded in site

For the RTDC testing were molded 2 samples per day of work, using the same molding and curing process that the test samples for determining the RCS [12]. According to the executive process, the track was opened to traffic after 3 days of curing, after checking the resistance to simple compression, being necessary to obtain at least 70% of expected resistance at 7 days old. Thus, should get at least 1.47 MPa.

Correlations between the ages of cure, can assist in estimating the strength with 28 days and in the liberation of services that depend on these values.

Segment 2 showed less dispersion in the results, with standard deviation of 0.04 and 0.08 for 7 and 28 days of curing, respectively. After 7 days of curing the recycled mixture reached 82%, 79% and 76% of resistance compared with the resistance at 28 days, very close to percentages obtained in the RCS tests. Therefore, it can be said that the behavior of tensile strength gain with curing time follows the same pattern for the RCS test.

Therefore, it is essential the strictly control of the amount of asphalt material in the recycle mixture, as humidity, cement and grit application rate, besides the speed of grinding the layers (displacement speed of the recycling machine), which interferes directly on the particle size and amount of fines. Figure 4 shows the relation of tensile strength by diametrical compression between 7 and 28 days.

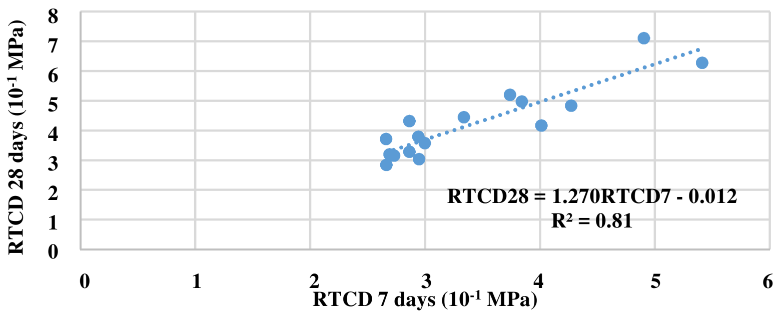

FIGURE 4: RTD (7 days) x CD (28 days) with test samples molded in site

With this correlation is possible to estimate the tensile strength by diametrical compression at 28 days, from the knowledge of resistance to seven days of curing. It is interesting for the field control and liberation of subsequent recycling services, and to check if the dimensioned layer is consistent with the actual behavior in the field, since their dimensioning is based on the tensile strength in the lower face of the recycled layer.

For segment 2 the tensile strength by diametrical compression is on average 0.12 of the resistance to simple compression. While for the segment 3 is around 0.11. Figure 5 shows the correlation between RCS and RTCD with all the results of the segments 2 and 3 (including resistances determined at 7 and 28 days of curing).

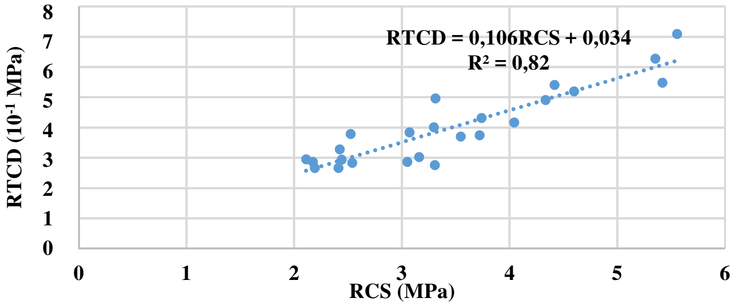

FIGURE 5: RCS x RTCD - Segment 2 and 3, with all sample tests molded in site

2.2 Estimated useful lives

With the values obtained in backcalculation of the deflection basin, a mechanistic analysis of the pavement structure after recycling was made, in order to estimate the lifespan of the structure. For this analysis it was taken as the main parameter estimated the tensile stress in the lower face of the recycled layer, because the coating present strain to traction in very low levels. The simulations were conducted employing the Elsym5® software with default loading shaft of 82 kN and pressure of contact tire equal to 0.56 MPa.

Traffic forecast for the project period is 9,98x106 according to USACE method. Thus, according to the results obtained in the field and models of recycled [13] and CCR [14] , it is expected that the action performed to the restoration will meet the road traffic designed for 10 years.

Table 2 shows the Poisson's coefficient, thicknesses and modules used to verify the lifespan of the recycled pavement using the modulus values found in backcalculation of the deflection basin.

TABLE 2: Characteristics of the final structure with modules backcalculated

Segment		1		2		3	
Layer	Coef. Poisson	Thickness cm	Mod. MPa	Thickness Cm	Mod. MPa	Thickness cm	Mod. MPa
Coating	0.27	9.1	3096	9.5	2760	8.5	2896
recycled base	0.20	17.8	871	17.4	1462	17.5	866
remaining base	0.35	5.0	140	4.4	156	6.4	120
Subfloor	0.45	21.4	148	19.4	130	16.4	100
subgrade	0.45		142		132		120

For the conditions shown and considering the mean values of backcalculated modules, tensile strength obtained in the lower face of the recycled layer is 0.165 MPa and the maximum deflection of the structure is 28.3×10^{-2} mm. Considering that the tensile strength at 28 days of the recycled layer is 0.38 MPa, the SR ratio is equal to 0.43.

Thus, the estimated lifespan of the recycled pavement shall be $1{,}81 \times 10^{8}$ requests of 82 kN. Similarly to segment 1, for segment 2 and 3 it was estimated the lifespan of the restored structure. Table 3 shows the results obtained for the three segments. Taking into account the RTCD values obtained in the field, the segment 2 would not meet the expected traffic in the 10 years considered in design.

TABLE 3: Life estimates (backcalculation)

Model	Recycled			CCR		
Segment	1	2	3	1	2	3
Tensile strength (MPa)	0.17	0.24	0.20	0.17	0.24	0.20
Def. calculated (10^{-2} mm)	28.30	27.10	33.40	28.30	27.10	33.40
Deflection field (10^{-2} mm)	30.80	33.50	37.00	30.80	33.50	37.00
RTCD (MPa)	0.38	0.43	0.45	0.38	0.43	0.45
SR	0.43	0.56	0.44	0.43	0.56	0.44
N	1.8E+08	1.4E+06	1.2E+08	3.2E+08	4.0E+06	2.4E+08

3. CONCLUSION

From the monitoring of the enforcement proceedings and trials in the field, it is possible to draw some conclusions regarding the behavior and performance of recycled pavement structure. The proper characterization of materials to be used in the recycled layer, ensures a coherent project work. During the implementation of the monitored segments, it was visible the difference in the behavior of layers, since they showed different particle sizes, amount of different coating for each segment, maximum dry density varied, great compression humidities varying from day to day.

It is apparent increase in the RCS and RTCD with increasing cement content added and over time. The increase of the cement content and the passing of cure time, provided the recycled mixture increased compression strength and tensile strength by diametrical compression. The estimate of the lifespan of the pavement, was evaluated by the fatigue model previously used (CCR) and the specific model developed to mix recycling with cement, at were only segment 2 will not meet the expected traffic during the project period.

4. REFERENCES

[1] Pesquisa CNT de rodovias 2015: relatório gerencial. – Brasília: CNT : SEST : SENAT, 2015. 420 p

[2] Maria da Conceição Azevedo e Mario Carsoso. Reciclagem a quente em central betuminosa. II Jornadas técnicas de pavimentação rodoviários. Faculdade de Engenharia da Universidade do Porto, Porto, 2003.

[3] José Abascal. Reciclado de firmes in situ con cemento. Instituto Español del Cemento y sus Aplicaciones, Madrid, 2013.

[4] Ashley Vannoy Brown. Cement stabilization of aggregate base material blend with reclaimed asphalt pavement. Department of civil and environmental engineering, Brigham Young University. 2006.

[5] Dane A. Cooley. Effects of reclaimed asphalt pavement on mechanical properties of base materials. Tese submetida ao Department of Civil and Environmental Engineering, Brigham Young University, 2005.

[6] Ana Luisa Aranha. Avaliação laboratorial e em campo da tecnologia de reciclagem de base com cimento para a reabilitação de pavimentos. Escola Politécnica da Universidade de São Paulo, São Paulo, 2013 127p.

[7] Departamento Nacional de Infraestrutura de Transporte .DNER 201 ME. Solo-cimento – Compressão axial de corpos de prova cilíndricos. Rio de Janeiro, Brasil, 1994.

[8] Departamento Nacional de Infraestrutura de Transporte. DNIT 136 ME. Pavimentação asfáltica - Misturas asfálticas – Determinação da resistência à tração por compressão diametral. Rio de Janeiro, Brasil, 2010.

[9] Departamento Nacional de Infraestrutura de Transporte. DNIT TER 005. Defeitos nos pavimentos flexíveis e semirrígidos – terminologia. Rio de Janeiro, Brasil, 2003.

[10] Departamento Nacional de Infraestrutura de Transporte. DNER ME 024. Pavimento – Determinação das deflexões pela viga Benkelan. Rio de Janeiro, Brasil, 2006.

[11] Paulo Cesar Arrieiro de Oliveira. Contribuição ao Estudo da Técnica de Reciclagem Profunda na Recuperação de Pavimentos Flexíveis. Dissertação (Mestrado). Universidade Estadual de Campinas. Campinas/SP, 2003.

[12] Departamento Nacional de Infraestrutura de Transporte. DNER 181 ME. Solos estabilizados com cinza volante e cal hidratada – Determinação da resistência à tração por compressão diametral. Rio de Janeiro, Brasil, 1994

[13] Gislaine Luvizão. Avaliação do Desempenho da Reciclagem na Rodovia SC 355: Caracterização da Mistura Reciclada e Avaliação Estrutural de Segmentos Monitorados Executados. Dissertação (Mestrado). Universidade Federal de Santa Catarina. Florianópolis/SC, 2014.

[14] Glicério Trichês. Concreto compactado a rolo para a aplicação em pavimentação: estudo do comportamento na fadiga e proposição de metodologia de dimensionamento. ITA, São José dos Campos, SP, 1993.