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Monitoring analysis of two pavement sections of highway BR-448/RS included in the Asphalt Thematic Network Project

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ABSTRACT
Highways are the mode of transport used for the transportation of the majority of loads and passengers in Brazil; however, the lack of conservation of pavements has caused several economical losses to the country. Only through suitable pavement management the rehabilitation measures taken might ensure a satisfactory level of service. The present research aimed at evaluating the performance of two pavement sections of the federal highway BR-448/RS, in southern Brazil. For three years, the evolution of the pavement structural capacity and functional condition were followed in order to propose performance trends. Deflections, permanent deformations, and surface defects surveys scarcely varied and were quite low due to the thick asphalt layers used (19 cm). On the other hand, segregation of the asphalt mixture was observed when the final layer was laid. That segregation affected pavement texture, reduced tire-road friction, and caused the formation of surface water films; thus, reducing the road safety. In general, the proposed trend lines predicted quite accurately the pavement performance throughout the period evaluated and will be used in the MeDiNa software database for the creation of a new Brazilian pavement design method.

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1. INTRODUCTION

In Brazil, although the transportation of goods and people is predominantly done through highways, this mode has historically shown remarkable deficiency. The lack of conservation of the road network has caused several economic damages to the country, such as: loss of production, increase of vehicles operational cost, greater risks of accidents, among others.

According to the National Transport Confederation (2017), 57% of all the country's paved network, out of the 107.161 km surveyed in 2017, showed some kind of inadequacy in general condition, including pavement, road signs and track geometry. Regarding exclusively pavements, nearly 51% of the road length presented some type of more severe defects; thus, having their Present Serviceability Rating (PSR) classified as fair, poor or very poor.

The poor quality of highways reflects a history of low investment in the sector, which received a federal investment of only 0.14% of the GDP (CNT, 2017) in transport infrastructure in 2017. For the past 30 years, the quality of Brazilian pavements has decreased due to the increasing traffic volume, climatic and environmental changes, inadequate pavement maintenance, and other factors (Soncim, 2011; Paterson, 1987; Haas *et al*., 1994; Yoder e Witczak, 1975).

In addition, the old national empirical method of asphalt pavement design no longer matches the pavement needs due to the significant increase in commercial traffic and the evolution of vehicles. Nowadays, the availability of more advanced tools (relevant laboratory tests and softwares for mechanistic-empirical design) must also be considered. Such scenario has supported a national effort to develop a new Brazilian flexible pavement design method, which began in 2009 through the Asphalt Thematic Network – RTA (a partnership among PETROBRAS and several universities in Brazil).

One of the first actions of the RTA was to promote standardized follow-up of experimental sections, which are monitored by universities, designed in partnership with road agencies and concessionaires. The objective was to collect systematic data on national pavement behavior, the main gap for the construction of a more modern design method (Santiago e Soares, 2015). Thus, since its inception, several universities have been conducting systematic surveys of functional and structural performance data of typical national pavements on the various section monitored by RTA in Brazil. In the state of Rio Grande do Sul, research studies of the Federal University (UFRGS) have monitored test sections built on two federal highways (BR-290/RS and BR-448/RS), evaluating functional, structural, and safety aspects.

In this context, this paper reports and analyzes the performance of two test sections on the BR-448/RS highway, considering functional, structural, and safety aspects in order to contribute to the MeDiNa software database for the development of this new method flexible pavement design.

2. BACKGROUND

According to AASHTO (1990), pavement performance is related to the ability of the pavement to accomplish its objectives over time. In order to predict this performance, the Restoration Pavement Manual - IPR-720 (2006b) states that it is necessary to quantify the reduction of utility or generation of defects over the life of the pavement through periodic evaluations.

By pavement evaluation it is possible to check whether the pavement needs maintenance or reconstruction, if it has been well constructed or if it meets the specifications for which it was designed. Pavement evaluation is a set of activities that aim to describe qualitatively and quantitatively the condition of pavements (Péres, 2016). There are two types of pavement evaluation to verify its performance: the functional evaluation used to assess comfort and safety; and the structural evaluation, to assess the quality of the pavement to withstand vehicle loads without exceeding the carrying capacity of the structure.

The functional evaluation describes the pavement performance for rolling quality and safety from the user's point of view. It is usually determined by measuring surface defects, longitudinal irregularities, and macro- and microtextures (tire-road friction). Structural evaluation, however, encompasses the complete characterization of the pavement structural elements and variables. It provides an objective description of its behavior as a function of traffic loads and environmental factors, as well as determines coating quality indicators and the integrity of the underlying material layers (Balbo, 2007). Structural evaluation is usually done by measuring of wheel path depressions and deflections.

The present and future evaluation of pavement performance involves techniques to obtain parameters of performance in the field, knowledge of the behavior expected for each type of pavement, and use of mathematical models that make it possible to portray the pavement behavior over time (Albuquerque, 2007).

Pavement performance is closely linked to its deterioration mechanisms. In this way, it is important to point out that the main factors that contribute to the beginning and propagation of deterioration are climatic factors, traffic demands, functional and structural behavior, physical and chemical characteristics of building materials, and pavement age (Soncim, 2011; Paterson, 1987). Thus, for the development of a rational method of designing flexible pavements, it is essential to establish design criteria based on adequate performance prediction models.

Performance prediction models for predicting pavement deterioration can be found in the literature (Péres, 2016; Balbo, 2007; Santiago e Soares, 2015; Ferreira, 2016; Santos, 2015; Soares *et al*., 2009; Khaled, 2004; Rosa *et al*., 2017; Solazzo *et al*., 2017; Mahmood *et al*., 2016). Being able to predict pavement behavior is an essential factor for the effective application of any rehabilitation and management model. Performance prediction models developed in Brazil with the highest international recognition were incorporated into the HDM (Highways Design and Maintenance Standards Model), model developed by the World Bank, with some adaptations (Paterson, 1987; Queiroz, 1981). Nationally, the research carried out by Marcon (1996), Yshiba (2003), Benevides (2006), and Albuquerque (2007) stand out when it comes to irregularities, permanent deformations, and deflections.

In southern Brazil, the performance models proposed by Mattos (2009), Victorino (2008), and Vitorello (2008) present good results. Finally, the trend lines presented for the highways monitored by UFRGS (Bock, 2016; Kern, 2017; Mattos, 2014) help in understanding highway performance in the region.

Since the creation of the Asphalt Thematic Network, research projects carried out in various regions of the country have presented pavement response data that contribute to the understanding of the behavior of the materials used to form its layers (Balbo, 2007; Santiago e Soares, 2015; Ferreira, 2016; Santos, 2015; Soares *et al*., 2009). This joint action helps enrich the national database and the decision-making regarding the choice of the type/material to be used in the design.

3. METHODOLOGY

The highway BR-448/RS is located near the metropolitan area of Porto Alegre, in the state of Rio Grande do Sul, and is 23 km long. It was finished in December 2013 and since then two sections have been monitored. Section I is located between km 15+600 and km 15+900 and Section II is located between km 16+760 and km 17+060. The monitoring of the construction of the experimental sections and the analyses of the materials used are presented in Bock (2016).

The two experimental sections were defined according to the geotechnical design solutions adopted. In Section I, vertical drains were implanted to consolidate soils of the subgrade. In Section II, soft soil removal and replacement by sandy soil was performed; thus, forming a drainage mattress. The highway structure has a five-centimeter layer of polymer-modified asphalt concrete (range B), 14 cm of conventional asphalt concrete (range B), in accordance with DNIT (2006a), 19 cm of granular base, and 21 cm of sub-base dry macadam. The structure of the highway is shown in FIGURE 1.

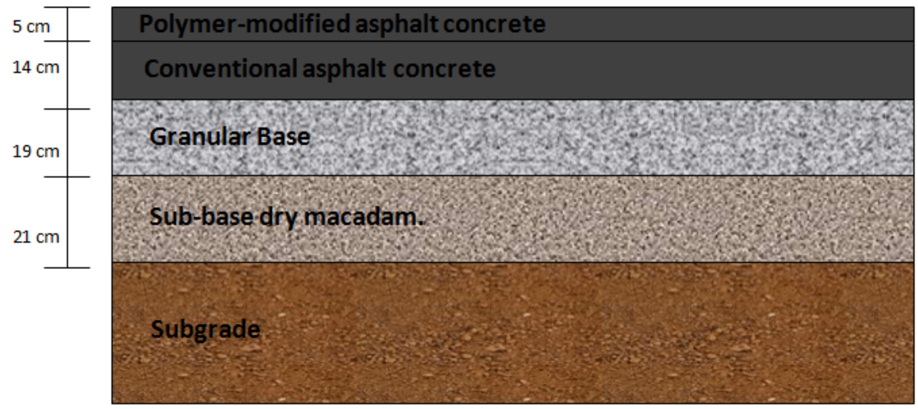

Figure 1. Structure of the highway BR-448/RS

The activities developed to evaluate the studied sections consisted of monitoring the evolution of functional parameters and structural performance. The results correspond to the first years of traffic, from December 20, 2013, when the highway was opened to traffic, to December 15, 2016, date of the last monitoring. TABLE 1 shows the dates of the monitoring carried out together and their respective traffic estimates (N_{AASHTO}).

Table 1 – Dates of monitoring

Date	Monitoring	Traffic
December 15, 2013	0 months	0.00E+00
March 08, 2014	3 months	8.22E+05
September 27, 2014	9 months	2.48E+06
April 18, 2015	16 months	4.45E+06
January 23, 2016	25 months	7.27E+06
December 17, 2016	36 months	1.19E+07

3.1. Field Tests

The structural evaluation of the pavement was performed with the measurement of deflections using the Falling Weight Deflectometer (FWD), following the DNER-PRO 273 standard (1996). The choice of equipment was due to the presence of deflections closer to those that would be caused by a real dynamic load. The FWD simulates the passage of a wheel over the pavement by dropping a set of masses from a certain height onto a shock absorber system capable of transmitting a load pulse similar to the shape of a sinusoid to the pavement. The load is transmitted to the pavement through a thirty-centimeter diameter plate and is measured through a load cell.

The recoverable displacements generated on the pavement surface are measured by 7 geophones (velocity transducers). In the surveys conducted for this paper, distant geophones were used: with 0, 20, 30, 45, 65, 90, 120 cm from the center of loading. The comfort conditions were evaluated by measuring the irregularity associated with the road, determining the International Roughness Index (IRI). The evaluation of the longitudinal irregularity was established by the DNER-PRO 182 standard (1994) and using an Inertial Laser Profiler.

The IRI was determined by measuring both longitudinal profile wheel path depressions with laser sensors installed at the front of a vehicle. In addition to these sensors, the equipment consists of accelerometers and an inertial motion sensor.

The permanent deformations were measured according to the DNIT-PRO 006 (2003b) procedure, which determines the use of a standard aluminum framework with a length of 1.20 m at the base and fitted with a movable ruler. This ruler allows the measurement of the wheel path depressions in millimeters. Permanent deformations of the inner wheel path (IWP) and the outer wheel path (OWP) were measured in millimeters at each stake of the monitored sections. In each of the points, the maximum depression was assessed.

In order to evaluate the tire-road friction, the macro and the microtexture of the pavement were verified. The Sand Patch Test, standardized by ASTM E 965 (2006), was used to determine the roughness of the pavement. This test allows the determination of the macrotexture of the pavement through the height of the sand patch, or in French *Hauteur au Sable* (HS). The Sand Patch test consists of spreading a certain volume of fine calibrated sand over the surface of the pavement using a rubber-based disc. The sand is gradually spread in circular motions until the sand path cannot be further increased. The diameter of the path is measured and, since the initial sand volume is known, it is possible to calculate the average thickness of the sand patch. The resulting sand height is expressed in mm. The macrotexture classification of a surface is also specified in the Rehabilitation Manual for Asphalt Pavements (2006b) and its boundaries are defined as a function of the average sand patch height (HS), which is advised to vary between $0.6<HS<1.2$ mm. Surfaces should have average or thick texture. According to Brosseaud (2006), acceptable macrotexture values for acceptable adhesion would be between 0.4 mm and 0.7mm to ensure good surface drainage.

The British Pendulum, standardized by ASTM E303 (2013), was used to check the microtexture. It determines the surface slip resistance by simulating the passing of a low speed vehicle tire on a wet pavement with the measured friction value expressed in BPN (British Pendulum Number). The microtexture of a surface is classified according to the test and specified in the Rehabilitation Manual for Asphalt Pavements (2006b), which recommends BPN values ≥ 55 and that surfaces should have rough to very rough characteristics.

The survey of defects followed the identification guidelines established by the DNIT-TER 005 standard (2003a). An objective evaluation of the surface of the pavement was carried out according to the DNIT-PRO 006 standard (2003b) to establish the Global Severity Index (GSI). The Global Severity Index is a numerical value obtained through the evaluation of defects on the surface of flexible pavements which aims to reflect the state of the pavement. It is classified according to the concepts presented in TABLE 2.

Table 2 – Concepts of pavement degradation according to the GSI

Concept	Limits
Excellent	$0 < GSI \leq 20$
Good	$20 < GSI \leq 40$
Fair	$40 < GSI \leq 80$
Poor	$80 < GSI \leq 160$
Very poor	$GSI > 160$

4. RESULTS

4.1. Deflections (FWD)

Structural evaluation is an important parameter that verifies the evolution of deflections on the top of the pavement due to traffic. FIGURE 2 shows the trend lines of the maximum deflections of each section after being corrected according to the temperature.

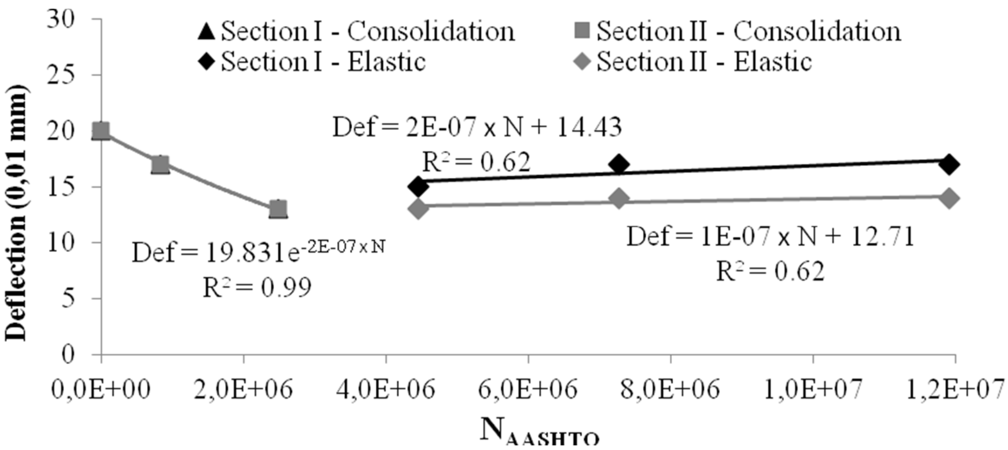

Figure 2. Trend lines of the deflections measured in the two sections

The maximum deflection values obtained were low (close to common values for concrete pavements), which may be related to the robustness of the pavement structure, which has a nineteen-centimeter thick coating layer. It was possible to observe a very similar evolution of the deflection through time for the two sections. In the first months after being opened to traffic, there was a strong reduction of deflections, which corresponds to consolidation due to traffic. The values of deflections obtained in the initial six months (pavement consolidation) were the same for both sections, resulting in the same trend line. Only after traffic of 2.48×10^6, Section I began to present deflections greater than Section II, entering the elastic phase.

This initial consolidation stage and the elastic phase stage are common on asphalt pavements, as seen in FIGURA 3 (DNER-PRO 011, 1979).

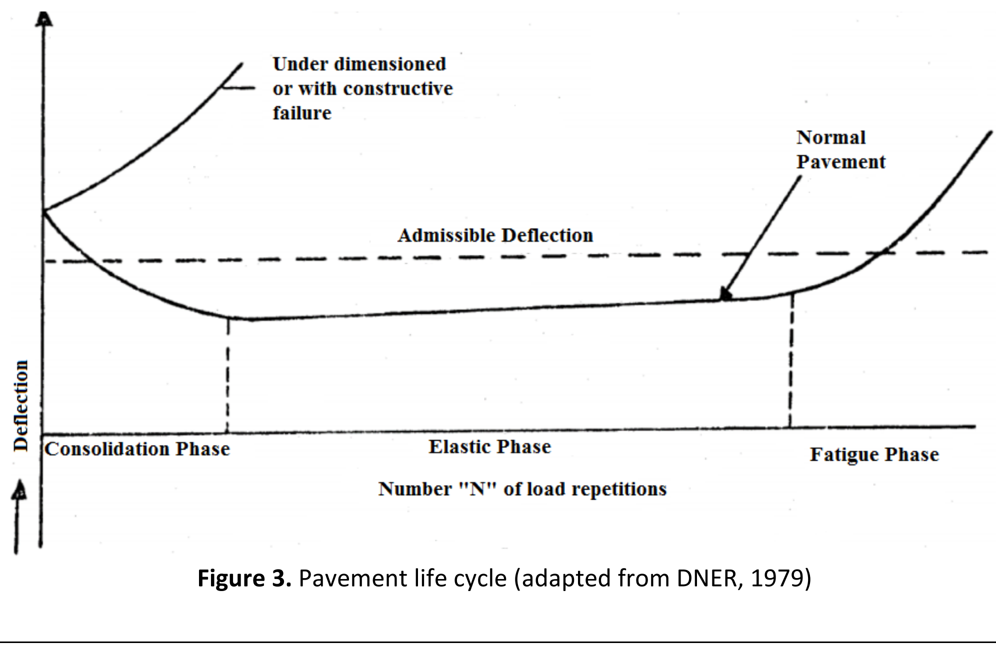

Figure 3. Pavement life cycle (adapted from DNER, 1979)

Regarding the last monitoring, there was already a tendency to increase in deflections, which indicates that the pavement will enter the fatigue phase with time.

4.2. Longitudinal Irregularity

The International Roughness Index (IRI) of BR-448/RS highway was also evaluated, and is presented through trend lines in FIGURE 4.

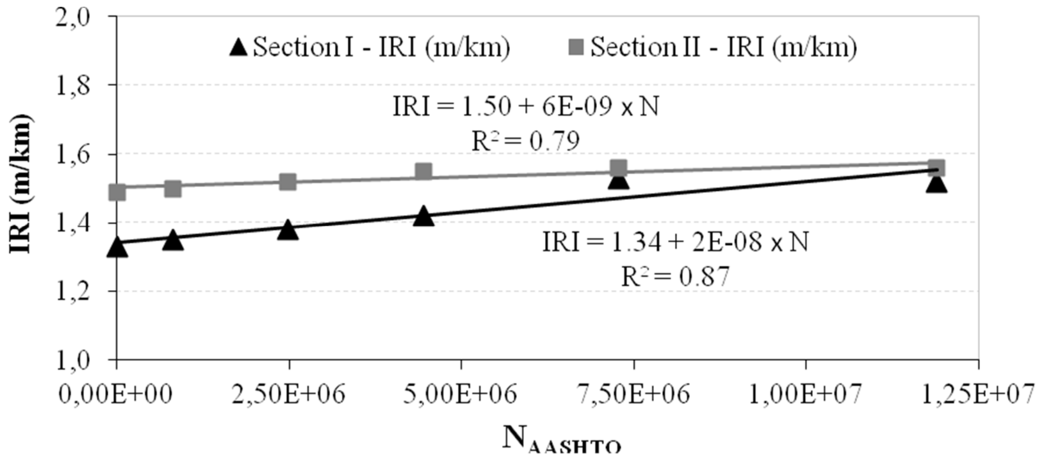

Figure 4. Trend lines of the IRI in the two sections

Immediately after the construction of the highway, Section I presented a lower IRI than Section II, being 1.33 m/km and 1.49 m/km, respectively. However, by observing the evolution of the parameter during the first months, an approximation of the values was noticed. Section I presented a higher rate of evolution than Section II, and this factor may be associated to the different solutions adopted in the subgrade of each section. Currently, the two sections have IRI values of 1.56 m/km (Section I) and 1.52 m/km (Section II).

According to Bock (2016), the executive project of this highway specifies that the top layer of the pavement should have a maximum IRI of 2.5 m/km. IRI values above 2.5m/km indicate that the section needs maintenance to avoid accidents. According to the Asphalt Pavements Rehabilitation Manual (2006b), pavements with IRI values lower than 2 m/km are considered excellent.

4.3. Wheel Path Depressions

Permanent deformation is an important parameter for the safety of road users. Depression limits depend on the road width and slope, where the greater the road width, the greater the slope and the permissible wheel road depth. The evolution of the permanent deformation of the two sections can be seen in FIGURE 5.

As traffic demand increased, deformations increased gradually, with maximum values of 4.8mm. In the last survey (36th month) a decrease in deformation was observed for the two sections. According to the Asphalt Pavements Rehabilitation Manual (2006b), rutting values greater than 120mm are indicative of structural compromise of the pavement, which, thus, requires intervention.

This result was not expected as normally with increasing traffic, measured rutting values tend to gradually increase or stabilize. Such a result can be attributed to the use of the standard aluminum framework, which measures only the selected arrow, and to some operator subjectivity when selecting the exact location for arrow measurement on the wheel path (Bastos *et al.*, 2015). Another hypothesis is the difference in pavement temperature at the time of collection.

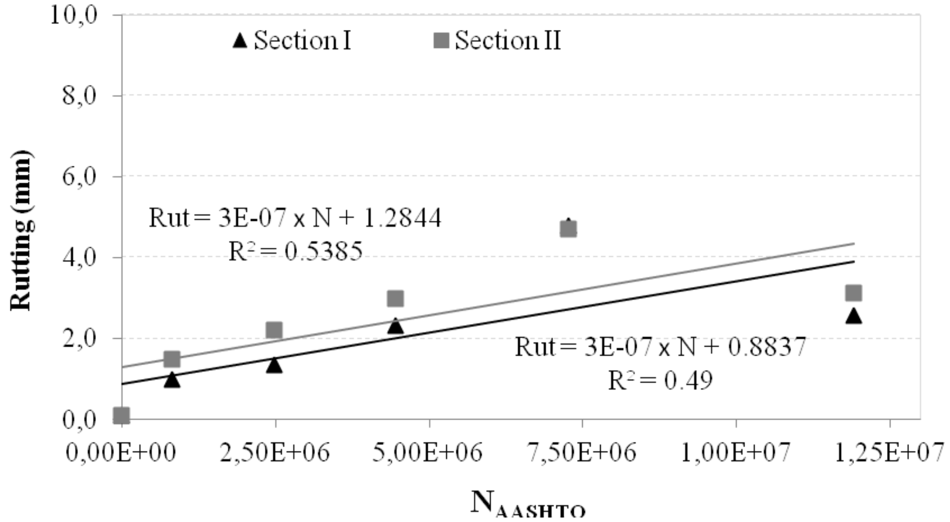

Figure 5. Trend lines of the evolution of the rutting

4.4. Tire-road Friction

The data collected from the wheel path for the evaluation of the macro- (Sand Patch Test) and micro-textures (mean BPN value) are presented in trend lines in FIGURE 6 and FIGURE 7.

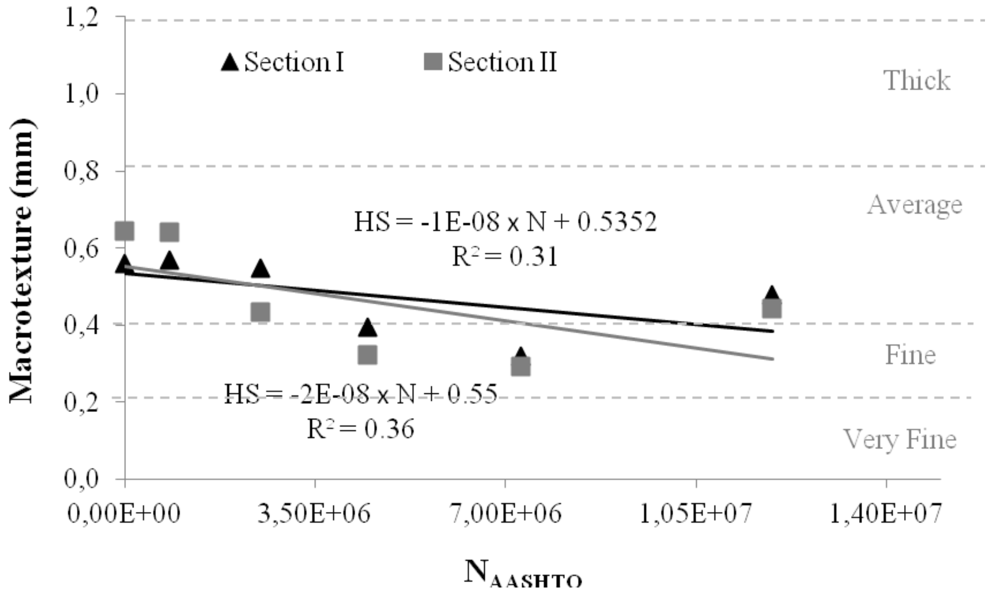

Figure 6. Trend lines for the evolution of macrotexture

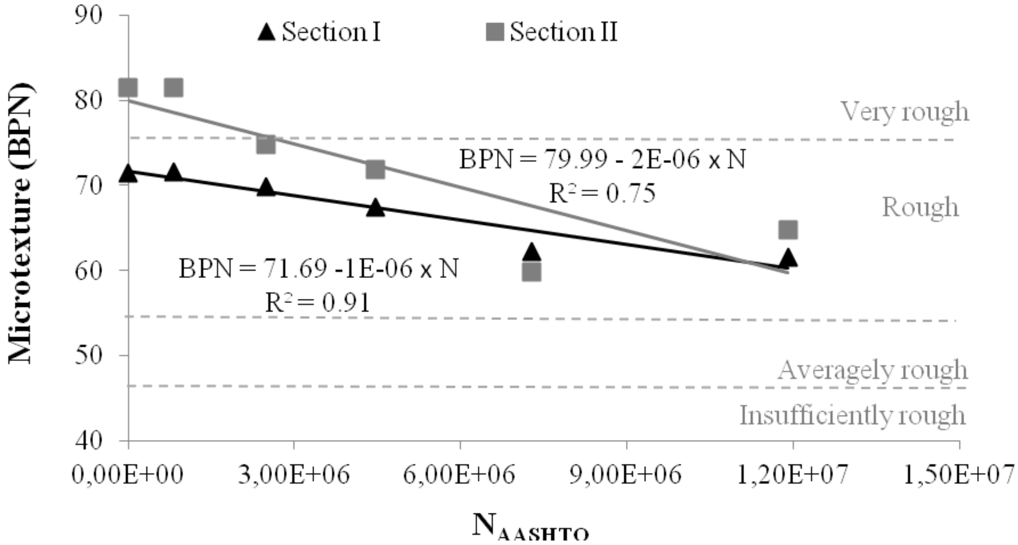

Figure 7. Trend lines for the evolution of microtexture.

Considering the macrotexture of the pavement, during the first two years of monitoring there was a marked drop in the condition of the texture, which went from an average to a fine condition. In the last inspection, an increase in the macrotexture of the pavement was observed, which was again classified as average.

In relation to the microtexture, initially the mean values in Section II were significantly higher than in Section I. Section II, which presented a very rough surface until traffic of $2.48x10^6$, soon passed to a rough surface. Section I presented from the beginning a decreasing rate lower than that of Section II.

A high loss of texture in the first monitoring can also be explained by the fact that the aggregate lost the asphalt binder film that covered it and started to suffer wear due to traffic demand (Kern, 2017). This aspect was verified in both monitored sections. Furthermore, the quality of the execution of the asphalt mixture was not satisfactory, presenting segregation in both sections (Bock, 2016).

This increase in macro and microtexture values in the last survey may come from several factors, such as:

- The pavement and air temperature were not taken into account at the time of the test, and the general trend shows skid resistance values being higher in autumn and winter and lower during spring and summer (Wilson e Dunn, 2005). This variability of tire-road friction grip over the year can reach approximately 30% of the average value. However, there is no general agreement on the magnitude of these effects (TNZ, 2002; Vaiana *et al*., 2012; Masad *et al*., 2009);
- The high variation of the values collected at the reading points of the sections, that is, some points presented different wear on the pavement surface. This factor was also verified by Santos (2015);
- The verification of a higher incidence of aggregate tearing in the last survey, which may contribute to the texture variations found in some places.

4.5. Surface Defects

In the two monitored sections, visual defect surveys were performed to determine the onset of pathologies from the beginning of the monitoring. As previously reported, an apparent segregation of the asphalt mixture applied on the road was observed after road construction, which generated a non-homogeneous quality of the bearing surface.

Excessive segregation of the asphalt mixture can adversely affect the performance of the coating in two different ways: it may be more closed, compromising safety with reduced friction for braking; or it may be more open, favoring the accumulation of water. The latter, along with the application of loading of commercial vehicles, will lead to premature degradation of the coating. The different coating surface finishes of the two evaluated sections can be seen in FIGURE 8, being more open (a) and more closed (b).

(a) (b)

Figure 8. Differences in finishing of the bearing surface due to the segregation of the asphalt mixture during the execution process

During the three years of monitoring, no critical defects were observed, only surface wearing (affecting roughness), aggregate tearing, and bleeding. The Global Severity Index (GSI) confirms this low incidence of defects. Section I obtained a GSI of 15.3 and Section II a GSI of 12.6, being the pavement of the two monitored sections classified as excellent. FIGURE 9 shows the current surface appearance of the two monitored sections, Section I (a) and Section II (b), after 36 months.

(a) (b)

Figure 9. Appearance of the coating layer after three years of monitoring

5. CONCLUSIONS

The surveys carried out in three years on the BR-448/RS highway allowed us to follow the evolution of pavement degradations, making the evaluation of its performance possible. The measured deflections scarcely varied from the beginning of the traffic loads between ($20x10^{-2}$mm and $14x10^{-2}$mm) up to this date. In the same way, IRI and permanent deformation values were also low, as specified by current standards.

Significant segregation of the asphalt mixture was observed when the final layer was laid, which later affected the pavement texture, reducing tire-road friction. The macrotexture of Section II, initially classified as average (HS = 0.64mm), reached the texture limits of fine (HS = 0.4mm) after N_{AASHTO} equal to $3x10^6$ (only 10 months of traffic). In comparison, in Section I that limit was reached later (after 16 months), after traffic accumulation N_{AASHTO} of $4.45x10^6$. Similarly, the reduction in microtexture was also significant in the first two years of traffic. The increase in pavement roughness evidenced in the third year was justified by the presence of aggregate tearing, variability of the readings made, and the non-consideration of temperature variation. In literature, these factors were seen to affect the tire-road friction.

The data presented and analyzed in this study are helping in the development of a preliminary version of the new Brazilian pavement design method, which will be done using the MeDiNa software. The data presented were entered into the software database and represent typical structures from southern Brazil. The insertion of this monitoring data will lead to the correct design of typical structures in the state of Rio Grande do Sul, which consequently improve the useful life of the pavements.

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