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MECHANICAL BEHAVIOR OF ASPHALT MIXTURES IN REGIONS OF LOW TEMPERATURE AND ALTITUDE ABOVE 3800 METERS

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ABSTRACT

This work shows the results obtained in laboratory from a mechanical behavior study on asphalt mixtures subjected to the Peruvian altitude climate, for application in pavement construction. A case study was performed at Juliaca airport, Puno, located at an altitude of 3,800 meters and presenting behavior peculiarities in the pavement structure due to the combination of climatic demands and to the high level of water table and soils in the subgrade with low support capacity. Results are presented concerning resilient modulus and rutting in asphalt mixtures with conventional Peruvian asphalt, normally employed at worksites in the region studied; also, a comparison is made with the results obtained with the same asphalt modified by 4% of SBS polymer.

KEY WORDS
Asphalt, low temperature, Polymer, Altitude, Pavement

1. INTRODUCTION

The asphalt behavior at low temperatures has been studied in Peru for quite some time, due to the need of building asphalt pavements in altitude zones, above 3,500 meters. Combined to the problem of low temperatures, the asphalt pavement in these regions is also exposed to a significant daily thermal variation, going from negative to positive temperatures and to saturation of layers very close to load applications. All these factors cause premature deterioration in asphalt wearing courses, with cracking and rutting.

The altitude problem is intensified since, added to the problems of low temperatures and thermal variations – a common occurrence in cold and even temperate climate countries, there is an excessively intense solar radiation, harmful to asphalts in 3,500-meter or higher zones. The solar radiation in the altitude zone has an intensity 4 to 5 times higher than those corresponding to the sea level. Measurements carried out at 4,000 meters indicate a 5.5×10^6 calories/m^2 /day radiation (1). In this context, this research is important for countries having a significant part of their road networks and airports in the altitude regions, typical cases of Peru and Bolivia.

The region in the Peruvian mountains is subjected, all year long, to two well defined seasons: the rainy season and the cold or freezing season. Those between December and March are the rainiest months, sometimes accumulating an average monthly precipitation between 400 and 600 mm in the months with higher incidence. The months between April and July are the ones with the highest intensity in the winter season or “gelada”, period in which minimal temperatures of up to –25 ºC occur during the early hours in the Puna regions; inversely, during the day, relatively high ambient temperatures of up to +20 ºC occur, which determines an important thermal variation in the asphalt layer, going from negative to positive temperatures in a short time span.

High levels in groundwater or of underground waters occur in the plateau zones or in the “Pampas”. For this reason, it is common for the soils to keep significant amounts of water accumulated, causing their saturation in regions close to the surface, which would require a draining project to reduce problems in pavements.

The solution to thermal cracking problems on asphalt wearing courses in cold climates in the altitude regions lies in adopting an asphalt material able to perform well at both negative and positive temperatures; that is, an asphalt with low thermal susceptibility characteristics, tending to reduced aging and sustaining its ductility at low temperatures. The Peruvian asphalts have shown not to comply with such severe demand of climatic requirements. It is believed that the use of asphalts modified by elastomeric polymers may be an alternative for extending the life of asphalt layers, as they are reckoned to act in decreasing thermal susceptibility and accelerated aging (3).

The construction of pavements at low temperatures in the altitude regions is subjected to very severe conditions, demanding a special study. Otherwise, the pavement service life will be considerably reduced, resulting in significant economic losses for the countries with such climatic features.

2. CHARACTERISTICS OF MATERIALS

Laboratory experiments were conducted to study and compare asphalt mixtures to conventional Peruvian asphalts and to asphalts modified by SBS polymer (Styrene-Butadiene-Styrene), so as to seek an indication for a solution that lessens some frequent problems in asphalt wearing courses in the altitude regions. For this, characterization tests were performed for PEN 85/100 asphalt, used in the construction of the Juliaca airport, Puno, Peru and an incorporation of SBS was experimented as an attempt to improve reologic properties. The results of materials characterization essays will be presented next, as well as the aging effects by the SHRP method and by exposure of asphalts in ultra-violet chamber to simulate solar radiation effects in the altitude regions.

2.1. Characterization of asphalts

There are two asphalts commercially available in Peru for cold regions: PEN 120/150 and PEN 85/100, classified according to the penetration test. In Table 1 are the characterization results of the PEN 85/100 employed in this study, carried out at CENPES in PETROBRAS, Rio de Janeiro. The tests were performed according SHRP methods (4).

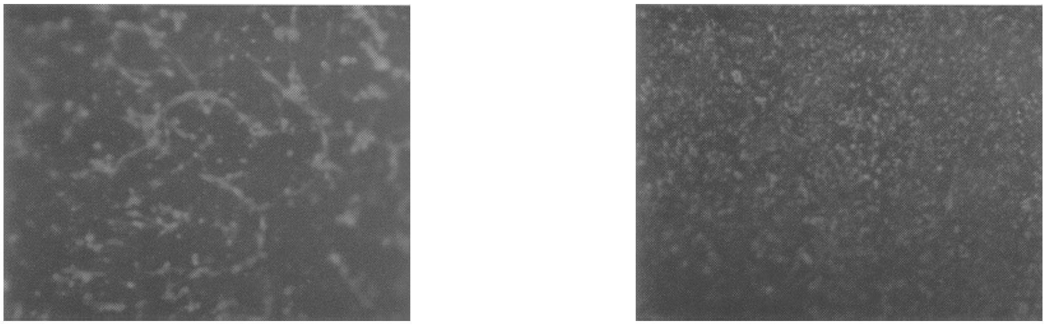
Table 1 - Results of asphalt characterization

ASPHALTS FROM THE CONCHAN REFINERY, PERU	
Type of asphalt - classification	85/100
TESTS	
Penetration at 25ºC, 100 g, 5s, ºC	85
Softening point, ºC	45.3
Absolute Viscosity at 60ºC, P	1375
Brookfield viscosity at 135ºC, 20 rpm, spindle 21, cP	260.3
Temperature corresponding to $G^* / \text{sen}\ \delta \geq$ 1KPa, ºC	58 (1.6)
AFTER RTFOT	
Mass loss, %	0,13
Temperature corresponding to $G^* / \text{sen}\ \delta \geq$ 2.2 KPa, ºC	58 (3.7)
AFTER RTFOT / PAV	
Temperature corresponding to $G^* \text{sen}\ \delta \leq$ 5 MPa, ºC	19
Temperature corresponding to $S \geq$ 300 MPa and $m \geq 0,3$ ºC	- 24
SUPERPAVE Performance Grade (PG)	**58-34**

At IPT-SP, essays were performed to determine the paraffin content, once a high percentage of this component in asphalt was suspected. The paraffin content obtained was 2.18%; in Europe - Germany and Austria, the paraffin limits allowed in asphalt is 2%, according to Agnusdei (1).

2.2. Addition of polymers

The SBS polymer addition was performed in the IPT (Institute for Technological Research) laboratory, in experimental character, due to the fact that polymer-modified asphalts are not produced in Peru. The polymer used was SHELL SBS, at a 4% percentage. The complete incorporation of polymers was obtained after about 3 hours. Figures 1 (a) and 1 (b) show the polymer aspect in asphalt, being that in (a) it can be observed that the polymer is not yet dispersed in the asphalt; whereas in (b) a homogeneous aspect of the mixture can be verified.



(a) after 2 hours **(b)** after 3 hours

Figure 1: Electronic microscope photographs of modified asphalt by SBS (200 times)

2.3. Ultra-violet radiation

Two conventional asphalt samples and two polymer-modified asphalt samples were subjected to seven-day exposure at 50°C in an ultra-violet chamber available at IPT to simulate radiation effects.

Table 2 – Characteristics of asphalt binders after Ultra-violet radiation

Results of Tests		
Sample	**Before exposure to UV**	**After exposure to UV**
Elastic Recovery		
85/100	5%	5%
85/100 + 4% SBS	77.5%	78.5%
Softening Point		
85/100	45.3° C	51.5° C
85/100 +4% SBS	70.0° C	74.0° C
Absolute Viscosity at 60° C		
85/100	1375 P	2379P

As could be observed through the results obtained, the softening point undergoes an increase after radiation as does the viscosity. These data demonstrate an aging effect deriving from radiation. Nevertheless, the results of the elastic recovery essay were not affected by radiation; according to the technical staff at IPT, the exposure should have lasted at least 15 days to present significant changes between the asphalt not exposed and those exposed to ultra-violet radiation (2), as is the procedure with some asphalt insulators.

2.4. Gradation

The gradient adopted at the Juliaca airport original design was the IVB gradation from the North-American Asphalt Institute (5)(6)(7), with volcanic origin aggregates. Due to the difficulty in transporting about 300 kilograms of Peruvian rocky material to Brazil, Brazilian granite aggregates from the Sao Paulo metropolitan region were used. Table 3 shows the weight percentages of the materials originally employed and the Brazilian ones. Figure 2 shows the North-American A I. band and the gradation adopted in the present study and the ones in the original asphalt wearing courses at the Juliaca airport, Peru.

Table 3- Original gradation and the one adopted in the study

SIEVE (inches)	**SIEVE (mm)**	**Original (% by weight passing sieves)**	**Adopted (% by weight passing sieves)**
¾	**19.5**	**100**	**100**
½	**12.50**	**87.24**	**87.24**
Nº4	**4.76**	**58.40**	**53.84**
Nº10	**2**	**42.30**	**42.30**
Nº40	**0.42**	**18.65**	**22.59**
Nº80	**0.177**	**9.93**	**13.46**
Nº200	**0.074**	**6.57**	**7.95**

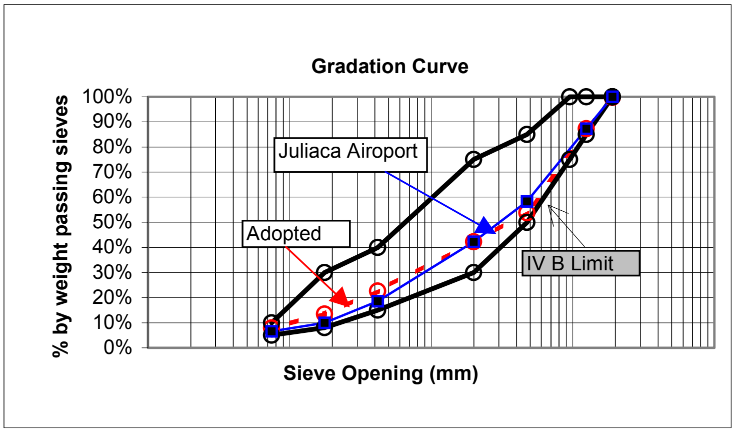


Figure 2: Original gradation and the one adopted in the study

3. MARSHALL METHOD OF MIX DESIGN

The tests related to the Marshall mix design were conducted at the Pavement Technology Laboratory at the University of Sao Paulo. The results obtained for PEN 85/100 asphalt mixtures can be found in Table 4. Figure 3 shows the results of air voids obtained with the conventional asphalt mixture and SBS-modified asphalt for comparison. A very similar characteristic is observed concerning the void volume among the mixtures.

Table 4 – Results of essays by the Marshall method

Asphalt Content (%)	Density (kN/m^3)	Air voids (%)	Voids filled with asphalt (%)	Stability (N)	Flow (0,25 mm)
4.5	23.61	5.28	62,2	10080	4.8
5.0	23.87	3.34	77,63	12640	4.9
5.5	23.98	2.4	84,3	12180	5.4
6.0	24.04	1.05	93,02	11670	6.4
6.5	23.96	1	93,79	10730	6.8

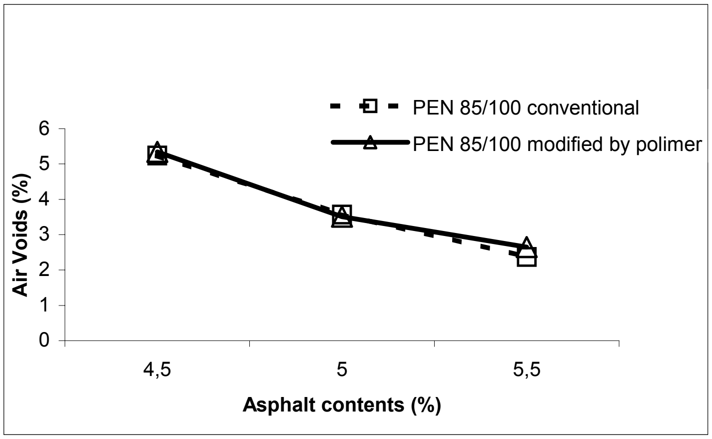


Figure 3 - Comparison between air voids of PEN 85/100 and SBS polymer-modified PEN 85/100 asphalt mixtures

4. MECHANICAL PROPERTIES

The resilient modulus tests were conducted in Marshall specimens submitted to diametrical compression by repeated loads with conventional PEN 85/100 Peruvian asphalt and SBS-modified Peruvian asphalt, in three different contents: 4.5%, 5.0% and 5.5%.

Different test temperatures were used for evaluating the thermal susceptibility of mixtures depending on the asphalt type. As a result of the low temperatures in altitude regions, essays were conducted at 5°C and 15^{o}C. Due to a rise in temperature during the day, essays were equally conducted at 25^{o}C and at 35°C. The essays were conducted by applying 0.1-second load and 0.9-second rest.

Figure 4 shows the resilient modulus results in function of the temperature obtained for the PEN 85/100 asphalt mixture, for the three asphalt contents tested; Figure 5 shows the results for polymer-modified asphalt for the three asphalt contents tested and, finally, Figure 6 shows the comparative results for the 5% content with the conventional asphalt mixtures and with the polymer-modified asphalt one.

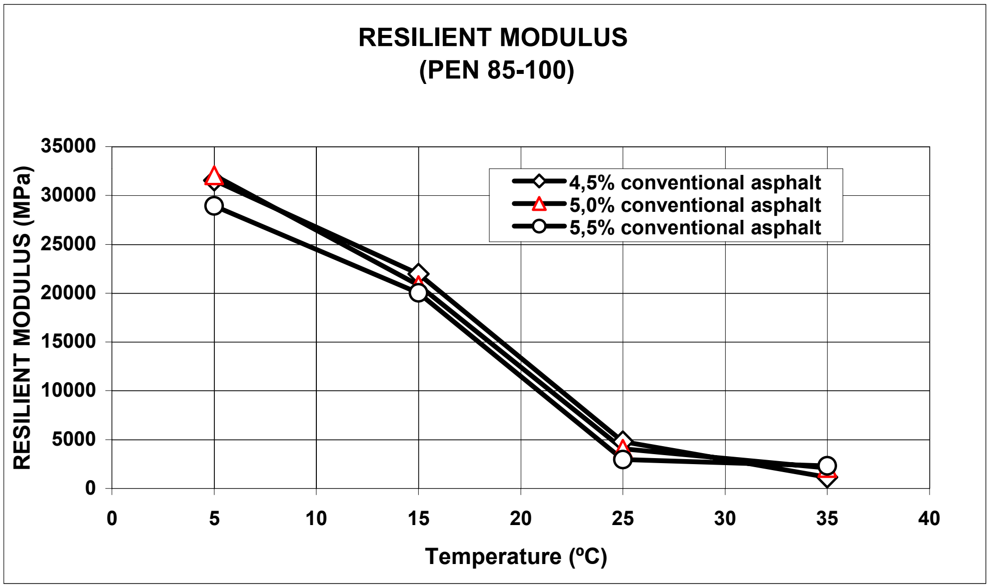


Figure 4 - Resilient Modulus in function of temperature with conventional PEN 85/100 asphalt mixture

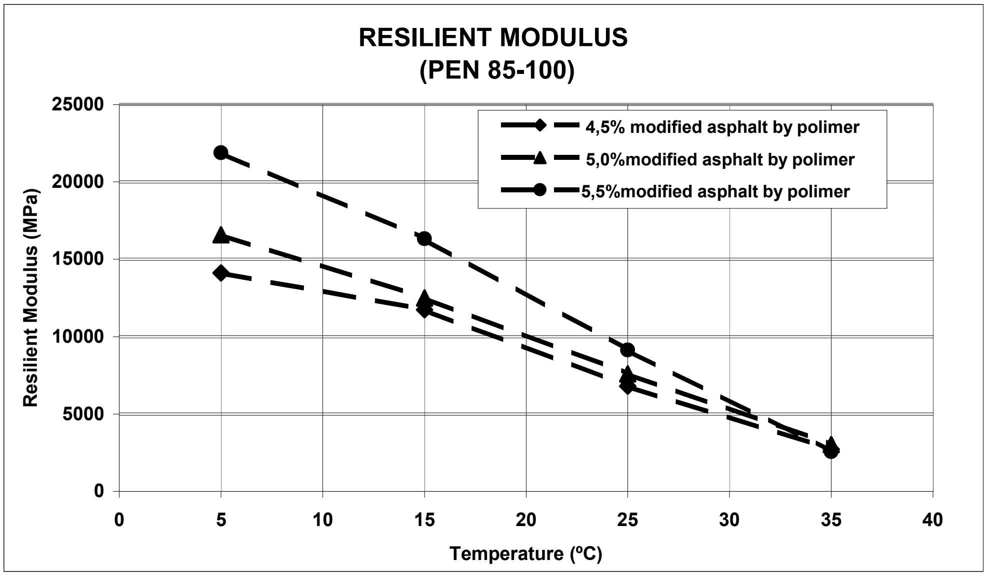


Figure 5 - Resilient Modulus in function of temperature with PEN 85/100 asphalt modified by SBS polymer

It should be observed that the resilient modulus is very high at 5°C, sharply reducing the values at higher temperatures. The polymer-modified asphalt presents reduction in the modulus at low temperatures demonstrating that it maintains a certain flexibility, reducing the probability of early fatigue by load repetition. Likewise, in temperatures above 25ºC, the mixture with the polymer-modified asphalt shows higher Resilient Modulus than that with conventional asphalt, demonstrating not to lose rigidity so markedly at these temperatures, which is favorable for the pavement mechanical behavior.

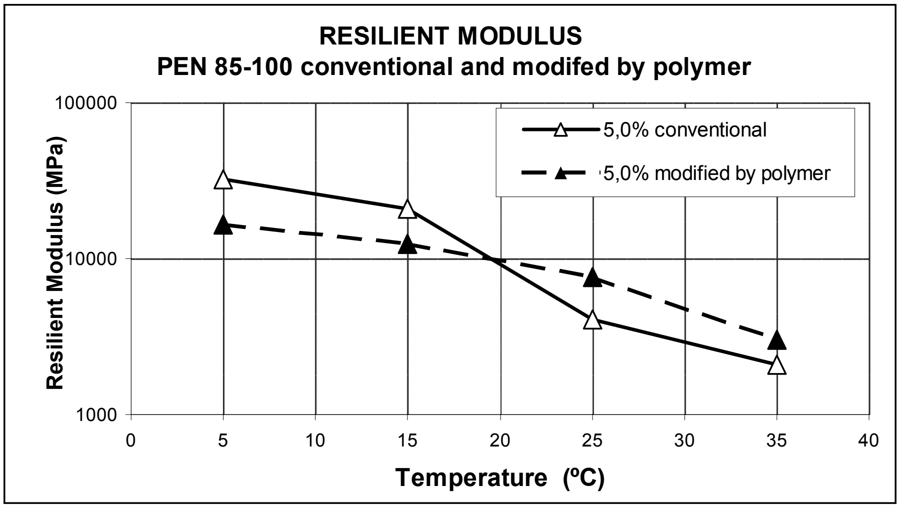


Figure 6 - Comparative Resilient Modulus in function of temperature with PEN 85/100 conventional asphalt and with PEN 85/100 asphalt modified by SBS polymer

In this work, the permanent deformation test was conducted in the LCPC wheel tracking test for comparing the behavior of mixtures with PEN 85/100 and those modified by polymer – Figure 7. Such mechanical characteristic is fundamental for analyzing the asphalt mixtures dosages and to forecast behavior, mainly on roads or in channeled traffic situations.

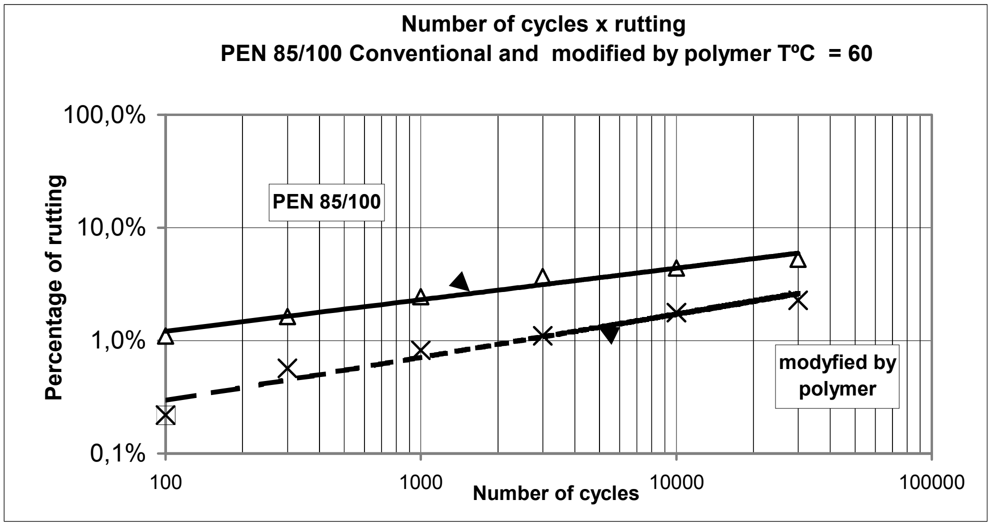


Figure 7 –Rutting deriving from the number of repetitions in LCPC wheel tracking test

The laboratory test results demonstrate the reduction in permanent deformation with the addition of polymers. The deformations observed are not generally high due to IVB gradation stability. Some observations must be made concerning the aggregates shape: the Brazilian aggregates used are cubic, whereas the Peruvian ones employed in the original design are usually rounded, which would result in an increase in permanent deformations. The rutting observed at the Juliaca airport are mainly due to the lack of subgrade support capacity, added to the presence of high groundwater level, with draining deficiencies.

5. CONCLUSIONS

The characterization of Peruvian asphalt materials by the SHRP system demonstrates the possibility of employing these binders in low temperatures as a result of the Performance Grade 58-34. However, cracking problems deriving from thermal retraction have been observed in the very first year after the restoration at the Juliaca airport, Puno, Peru. It was verified that problems with the lack of support in the subgrade and presence of water near the surface are some of the factors responsible for the occurrence of cracking and rutting. In the characterization tests, after ultra-violet radiation, it was observed that the asphalts present aging, with an increase in the softening point and increase in viscosity, losing flexibility. The results of essays performed on asphalt mixtures show that the addition of polymer is an interesting solution for reducing the unwanted hardening of the asphalt wearing courses at low temperatures. In temperatures between 25°C to 35°C, the resilient modulus values also stress the gain in hardness in the polymer-modified asphalt mixtures, desirable structural behavior in this climatic situation. Finally, it is observed that there is a reduction in rutting due to the addition of polymer to the asphalt.

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