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DURABILITY PERFORMANCE OF TIRE TREAD RUBBER COMPOUNDS AS A FUNCTION OF ROAD PAVEMENT[1]

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Abstract

The wear resistance of tire tread rubber compounds is fundamental to develop durable products. The tire wear assessment is challenging because can be influenced by several factors, such as the nature of pavement, vehicle, driver and weather conditions. Outdoor tests provide a wear assessment but are expensive and need around 6 months to present results. A scientific and technological partnership between Polytechnic School of Sao Paulo University and Pirelli Tires developed laboratory equipment that uses asphaltic counterface extracted from Brazilian roads. In a previous work the testing machine was validated. The aim of this work is to present the wear analysis of rubber compounds as a function of different pavements found in Brazilian roads. For a pavement with good integrity (absence of holes and irregularities) its microtexture will significantly influence the durability of tire tread rubber compounds.

Keywords: Wear; Rubber compounds; Laboratory test.

DURABILIDADE DE COMPOSTOS DE BORRACHA DA BANDA DE RODAGEM DE PNEUS EM FUNÇÃO DOS PAVIMENTOS DAS RODOVIAS

Resumo

A resistência ao desgaste dos compostos de borracha dos pneus é fundamental para desenvolver produtos duráveis. A avaliação deste desgaste é desafiadora pois pode ser influenciada por vários fatores, tais como o pavimento, veículo, motorista e condições climáticas. Testes de campo em veículos fornecem a avaliação do desgaste, mas são dispendiosos e necessitam por volta de 6 meses para apresentar resultados. Uma parceria científica e tecnológica entre a Escola Politécnica da USP e a Pirelli Pneus desenvolveu equipamento de laboratório que utiliza como contra-corpo amostras de pavimentos extraídas de estradas brasileiras. Em um trabalho anterior a máquina de testes foi validada. O objetivo deste trabalho é apresentar desgaste de composto de borracha em função de diferentes pavimentos encontrados no Brasil. Em um pavimento em boas condições de conservação (ausência de buracos e irregularidades) a sua microtextura terá influência significativa na durabilidade dos compostos de borracha utilizados na banda de rodagem dos pneus automotivos.

Palavras-chave: Desgaste; Compostos de borracha; Teste de laboratório.

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1 INTRODUCTION

The tire wear assessment is challenging because can be influenced by the pavement, the vehicle, the driver and weather conditions. Outdoor tests in vehicles provide a wear assessment but are expensive and need around 6 months to present results.

Laboratory devices were developed to accelerate the data acquisition, some of them are standardized but present a high severity, differently from tires rolling against road pavements. A scientific and technological partnership between Polytechnic School of Sao Paulo University (EPUSP) and Pirelli Tires developed through the *Surface Phenomena Laboratory (LFS)* a testing machine that uses as counterface the pavement coupons, extracted from roads. This equipment, under patent approval process, is able to reproduce the tire wear mechanism. Further information about this equipment and its validation were presented by Cardoso.(1)

The aim of this work is to present the wear analysis of a rubber compound as a function of four different pavement types, found on State of São Paulo roads. These pavements present distinct classifications regarding its microtexture and macrotexture. In conformity with the literature, the results showed that wear is proportional to the counterface microtexture. The pavement with the highest microtexture promoted a wear 2 times higher than the finer microtexture

For a pavement with good integrity (absence of holes and irregularities) its microtexture will significantly influence the durability of tire tread rubber compounds.

1.1 Tire Wear Pattern

According to Gent,(2) when rubber is abraded by sliding a scrape repeatedly in the same direction a characteristic surface pattern appears. It takes the form of a series of ridges, lying at right angles to the sliding direction, with the abrasion occurring mainly at the base of the ridges, as showed at Figure 1. This mode of abrasion is known as Schallamach waves and is strikingly different from the abrasion of hard materials, where long scratches are formed parallel to the sliding direction.

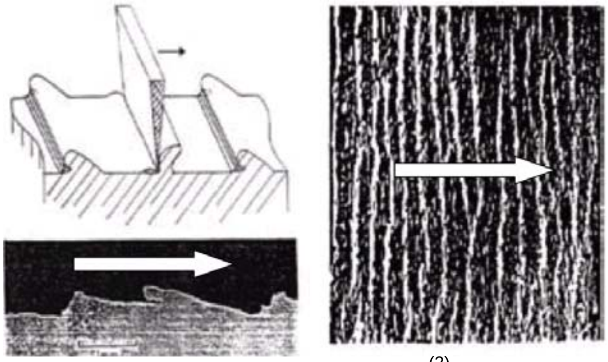


Figure 1: Schallamach waves.(2)

1.2 Pavement Texture Characterization

The pavement is the layer made by one or more materials that are deposited on the ground in order to increase its resistance and to ensure the mobility of people or vehicles.

The pavement texture is influenced by the shape and surface texture of the aggregates. Figure 2 presents the pavement micro and macrotextures.

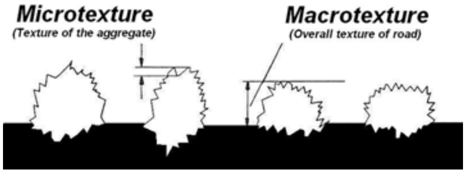


Figure 2: The pavement microtexture and macrotexture.(3)

1.2.1 Pavement macrotexture characterization –sand patch method

This method is used to determine the average texture depth of road surfaces, as specified by ASTM E 965-96(4) Standard. It consists in spreading a given volume of sand into a circle, filling the surface voids. The diameter of this circle is measured at the quarter points and an average diameter for the circle is determined to calculate the mean texture depth, which is an indication of the surface texture, according to Equation 1.1. Figure 3 illustrates the sand patch method.

$$H_m = \frac{V.4}{D_m^2.\pi} \qquad [1.1]$$

Where:
V = sample volume 25,000 ± 150 (mm^3);
D_m = sand patch average diameter (mm);
H_m = sand patch average height (mm).

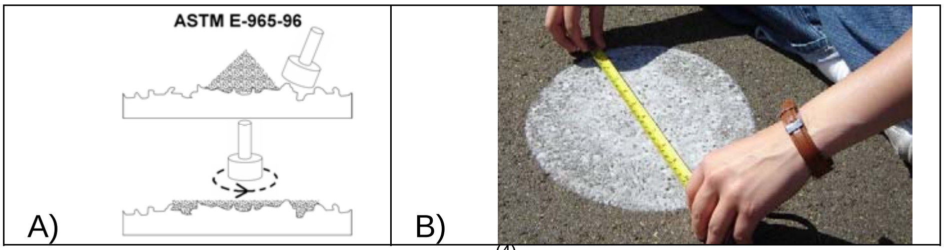


Figure 3: Sand patch test – A) ASTM E-965-96(4). B) Procedure performed by the Pavement Technology Laboratory from EPUSP.

1.2.2 Pavement microtexture characterization – British pendulum method

This method is specified by ASTM E-303-93(5) Standard. It is based on the energy loss by the pendulum's foot when its rubber counterbody slides against a wet pavement. The obtained value is expressed in BPN (*British Pendulum Number*). Figure 4 presents the British Pendulum main components.

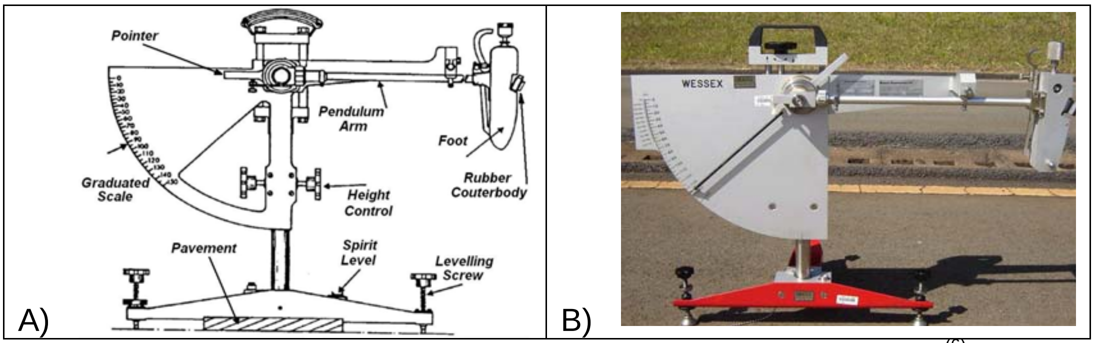


Figure 4: A) British Pendulum main components. (Main Roads Western Austrália(6). B) Equipment from the Pavement Technology Laboratory from EPUSP.

1.2.3 Influence of pavement texture on tire wear

There is sparse literature available about the tire wear as a function of pavement texture. An important contribution is the work of Lowne,(7) where the vehicle tire tread wear is assessed by tests with different pavements. It was concluded that the pavement microtexture is the main factor to determine the tire tread wear.

In posterior works, Veith(8) and Le Maitre et al.(9) also observed the tire wear as a function of pavement. They concluded that pavement microtexture is significant for the wear and pavement abrasiveness is influenced by weather conditions.

1.3 Laboratory Rubber Wear Machines

Some laboratory equipments are standardized and broadly spread, as the device described in DIN 53516 (known as "*DIN abrasion*") Standard, on the other hand there are equipments developed through continuous research and development, becoming standards for the industry, as the "*Grosch abrader*".

According to Brown,(10) the functioning of DIN abrasion can be described by Figure 5 A) where a cylindrical rubber counterbody is dragged across a rotating drum. The drum surface is covered with abrasive material, usually sandpaper. According to Costa,(11) this test presents high severity because it consists in a continuous slippage against an very abrasive surface, differently from what happens to a tire rolling over road pavements, where it is observed simultaneous rolling and localized slippage.

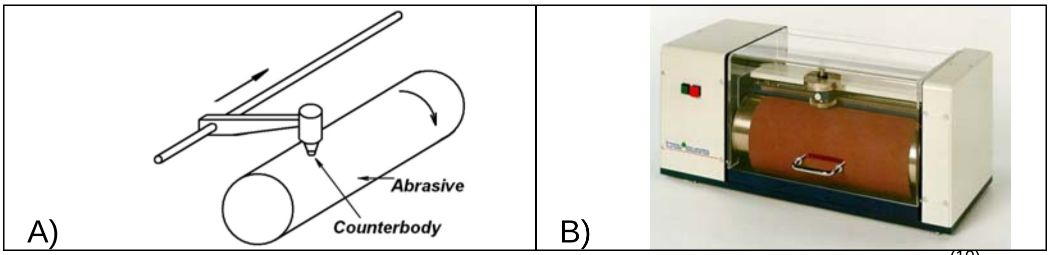


Figure 5: Rubber wear equipment according to DIN 53516. A) Main components.(10) B) General view.(11)

The equipment of Figure 6 was developed by the researcher K. A. Grosch with the aim of improving the deficiencies observed on the DIN 53516.(12) This device presents a rubber wheel that is pressed by the wheel's load and rolls over an abrasive disc (aluminum oxide). A slip angle is imposed to the rubber wheel that presents localized slippage. Thus the test wheel is loaded similarly to a tire.

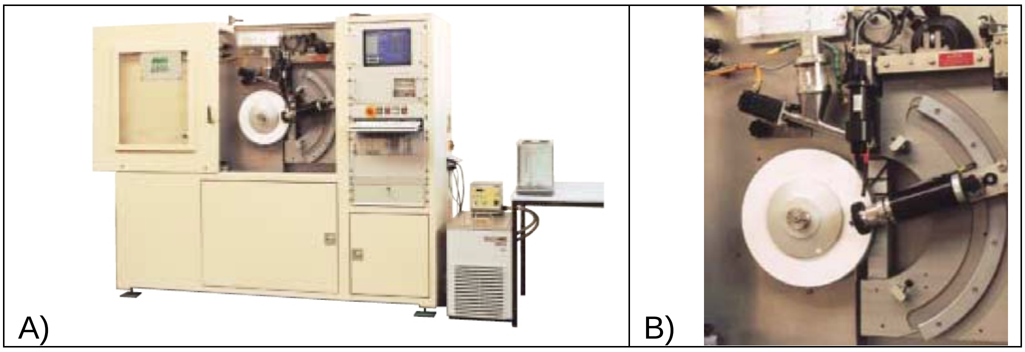


Figure 6: LAT 100 rubber wear machine. A) General view B) rubber wheel and abrasive disc detail.(11)

According to Costa,(11) apart from the advances achieved with the "Grosch abrader", until nowadays there is no laboratory test able to simulate and assess in a efficient way the low severity tire wear, observed on real road pavement wear of ruber compound, able to rank the rubber compounds durability. It is important to state that the tire wear does not depend only on the involved materials but is also influenced by operational and environmental conditions that compose the tribosystem. Considering the tire wear, the tribosystem is influenced by pavement characteristics, vehicle, driver and weather.

2 MATERIALS AND METHODS

2.1 Design and Construction of Testing Machine

This equipment performs wear tests against asphaltic discs, extracted from roads. The test coupon is a solid rubber wheel that rolls over the asphaltic disc under controlled conditions of speed and load. The slippage is defined by the slip angle between counterbody and the trajectory.

Once defined the testing parameters, test coupon and counterface, a wear machine prototype was built in order to perform laboratory tests. Figure 7 shows the wear machine general view, its results validation were presented by Cardoso.(1)

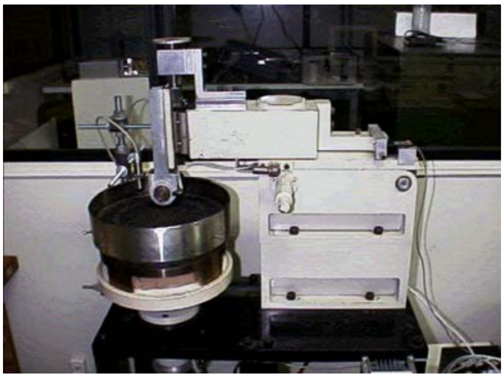


Figure 7: Rubber wear machine using asphaltic discs as counterfaces.

2.2 Testing Machine Characteristics

The testing machine characteristics are presented on Table 1.

Table 1: Testing machine characteristics

Parameter	Range
Speed (km/h)	0 a 10
Load (N)	15 a 500
Slip Angle (degrees)	0 a 20

The machine configuration also provides the possibility to vary the caster and camber angles and perform tests under dry or wet pavement conditions.

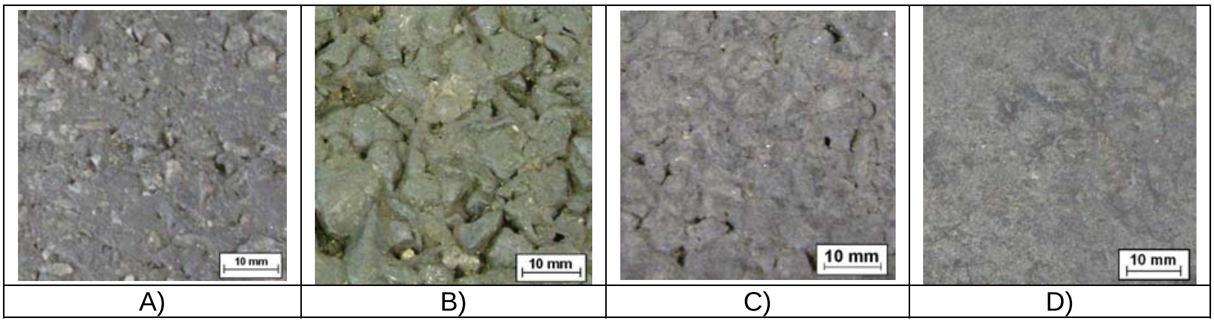
The test coupon were moulded with tire tread rubber compound, made by Pirelli Tires (Pirelli- Brazil). The counterfaces were extracted from Santos Dumont SP-75 road.

The test coupon is presented on Figure 8.

Figure 8: Counterbody used on the testing machine (diameter 80 mm, thickness 20 mm).

The counterface is presented in Figure 9 and surface details in Figure 10.

Figure 9: Counterface used on the testing machine (diameter 250 mm, thickness 50 mm).



A) B) C) D)

Figure 10: surface aspect of the asphalt counterface: A) Micro Seal, B) Double Seal, C) Stone Matrix Asphalt (SMA), D) Hot Mix Asphalt (HMA).

Table 2 presents the counterface textures.

Table 2: Counterface texture classification

Counterface	**Sand Patch**	**British Pendulum**
	Average height [mm]	[BPN]
Micro Seal	0,73	53,70
Double Seal	1,52	60,60
SMA	0,52	35,00
HMA	0,21	50,80

2.3 Test Methodology

The tests were performed under ambient temperature and dry pavement. The test parameters are speed, vertical load and slip angle imposed to the rubber wheel coupon. The test parameters were determined after the realization of preliminary tests. Table 3 presents the test parameters.

Table 3:Test parameters

Factor	**Slip angle [degree]**	**Load [kgf]**	**Speed [km/h]**
Level	2	8	2

Each test condition was performed twice, in a random way. After a specified time interval the weight loss was measured using an analytical scale.

2.4 Wear Pattern Analysis

Correlation between outdoor and laboratory results is only possible when the observed phenomena are the same, in other words, the same wear mechanism. The boundary conditions can be different to the same observed phenomena.

The first result analysis will be related to the wear mechanism that must be the same found on tire wear and must present Schallamach waves.

2.5 Statistical Data Analysis

It is necessary verify the statistical significance of the experimental results, according to Box et al.(13) this task is possible through an analysis of variance table (ANOVA).

A ratio that represents the experimental results is compared with a distribution $F(k-1, N-k)$ in a chosen significance level. Where $\boldsymbol{k}$ is the number of treatments and $\boldsymbol{N}$ is the total number of observations.

If the ratio is higher than its respective $\boldsymbol{F}$ distribution value, there are evidences that the differences between results can be associated with differences between treatments. In other words, for the example of rubber compound wear test using different pavements means that each pavement wears the rubber compound in a different way.

This work will use a significance level of 95%. Table 4 presents the method to construct the analysis of variance table

Table 4: Method to construct the analysis of variance table (ANOVA)

Source of Variation	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**	**Ratio**
Between Treatments	$S_T = \sum_{t=1}^{k} n_t(\bar{y}_t - \bar{y})^2$	$k-1$	$S_T^2 = \frac{\sum_{t=1}^{k} n_t(\bar{y}_t - \bar{y})^2}{k-1}$	S_T^2 / S_R^2
Residuals	$S_R = \sum_{t=1}^{k} \sum_{i=1}^{n_t} (y_{ti} - \bar{y}_t)^2$	$N-k$	$S_R^2 = \sum_{t=1}^{k} \sum_{i=1}^{n_t} \frac{(y_{ti} - \bar{y}_t)^2}{N-k}$	

3 RESULTS AND DISCUSSION

It were analyzed the rubber coupon wear pattern and its wear rates obtained for each pavement. The pavements wear rates were compared with the texture classification.

3.1 Wear Pattern Analysis

Figures from 11 to 14 present the wear pattern observed on the rubber coupon edges, region where localized slippage occurs.

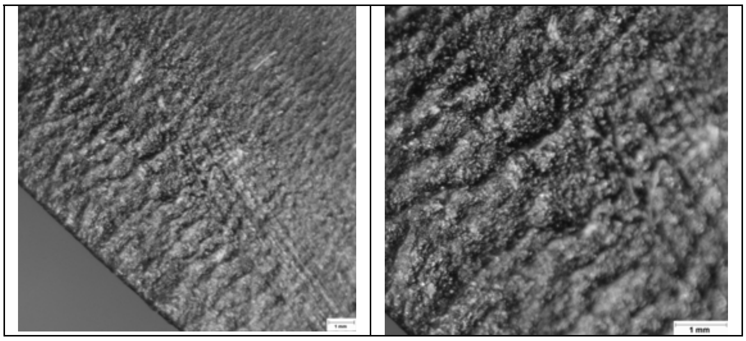


Figure 11: Wear pattern observed on rubber coupon tested with pavement HMA, conditions: 2 degrees slip angle, load 8 kgf, speed 2 km/h.(14)

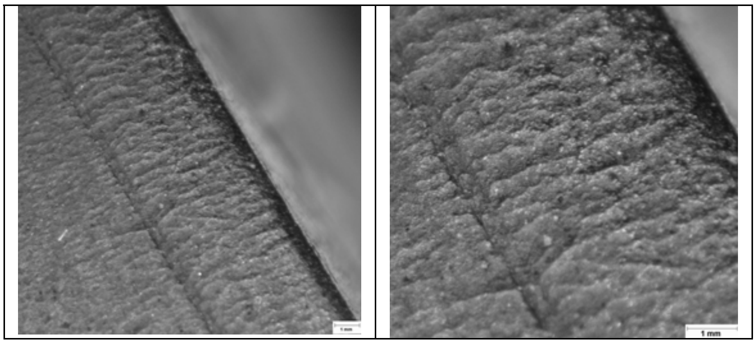


Figure 12: Wear pattern observed on rubber coupon tested with pavement SMA, conditions: 2 degrees slip angle, load 8 kgf, speed 2 km/h.(14)

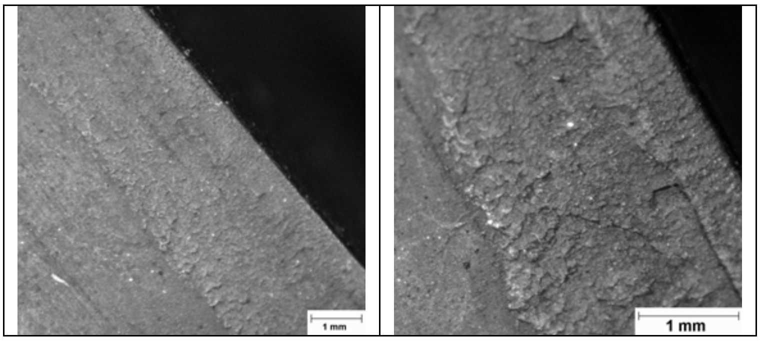


Figure 13: Wear pattern observed on rubber coupon tested with pavement Micro Seal, conditions: 2 degrees slip angle, load 8 kgf, speed 2 km/h.(14)

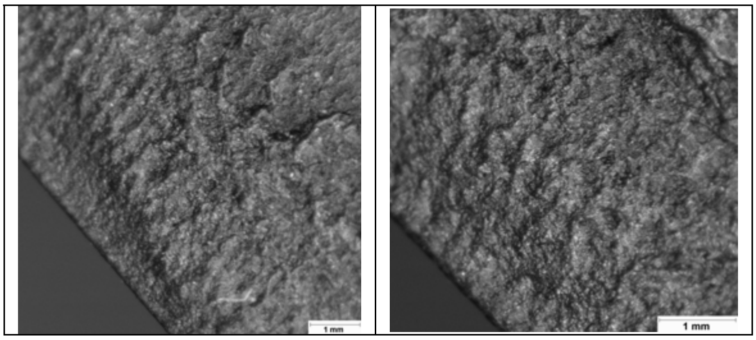


Figure 14: Wear pattern observed on rubber coupon tested with pavement Double Seal, conditions: 2 degrees slip angle, load 8 kgf, speed 2 km/h.(14)

According to these Figures from 11 to 14 it is observed that the rubber coupon wear pattern presents Schallamach waves, therefore the wear machine test conditions can reproduce the wear mechanism found on tires.

3.2 Laboratory Results

The wear test results are presented on Tables 5 and 6.

Table 5: Test results, 2 degrees slip angle, load 8 kgf, speed 2 km/h. Pavements Micro Seal and Double Seal

Pavement	**Micro Seal**		**Double Seal**	
Sample	**Sample1**	**Sample2**	**Sample3**	**Sample4**
Cycles	**Loss [mg]**	**Loss [mg]**	**Loss [mg]**	**Loss [mg]**
0	0	0	0	0
15000	9,8	7,1	17,4	15,4
30000	16,6	22,4	28,0	26,1
45000	28,2	32,7	43,2	38,3

Table 6: Test results, 2 degrees slip angle, load 8 kgf, speed 2 km/h. Pavements SMA and HMA

Pavement	**SMA**		**HMA**	
Sample	**Sample5**	**Sample6**	**Sample7**	**Sample8**
Cycles	**Loss [mg]**	**Loss [mg]**	**Loss [mg]**	**Loss [mg]**
0	0	0	0	0
15000	8,8	8,8	9,6	9,8
30000	16,6	20,4	20,8	19,3
45000	24,4	30,4	30,3	25,7

The wear rate was determined for the tangent of curves presented at Figures 15 and 16.

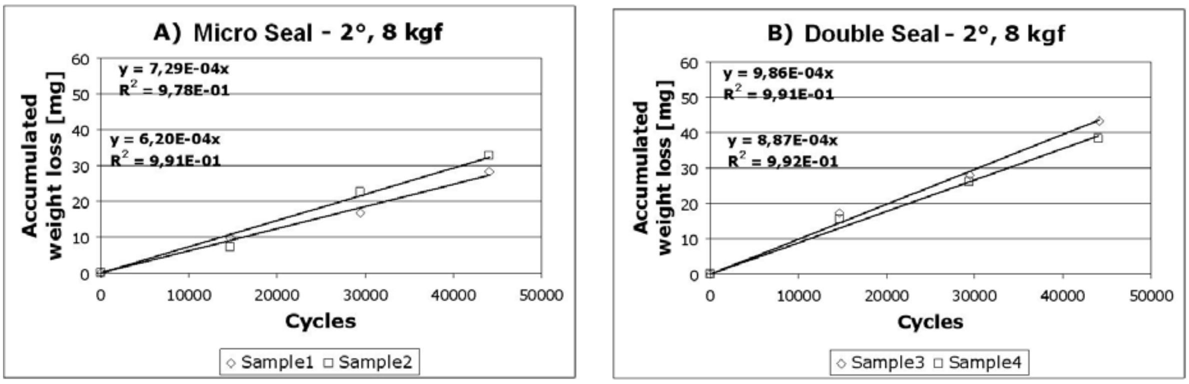


Figure 15: Accumulated weight loss. Slip angle 2 degrees, load 8 kgf, speed 2 km/h. Pavements A) Micro Seal, B) Double Seal (Table 5).

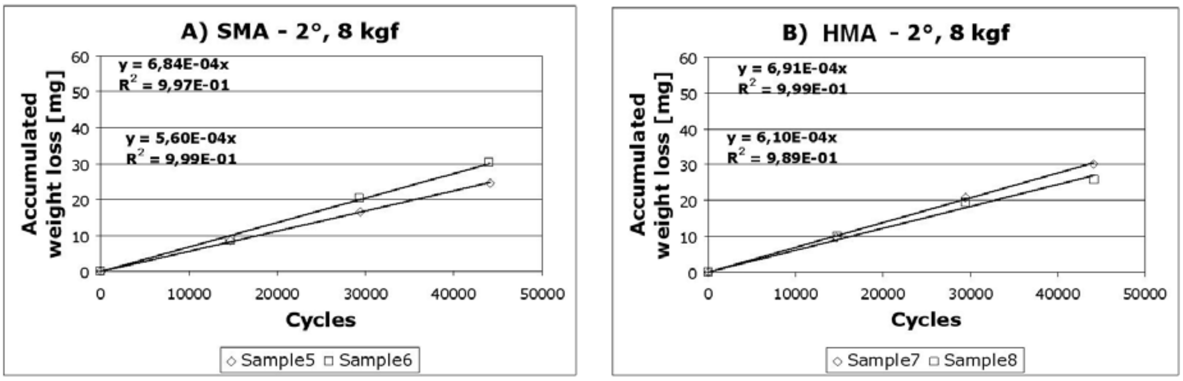


Figure 16: Accumulated weight loss. Slip angle 2 degrees, load 8 kgf, speed 2 km/h. Pavements A) SMA, B) HMA (Table 6).

Table 7 presents a summary of the wear test results obtained from Figures 15 and 16.

Table 7: Wear rates as a function of pavement speed of 2 km/h, load of 8 kgf and angle of 2°

Pavement	Sample	Wear rate [mg/cycle]
Micro Seal	Sample1	6,20E-04
	Sample2	7,29E-04
Double Seal	Sample3	9,86E-04
	Sample4	8,87E-04
SMA	Sample5	6,84E-04
	Sample6	5,60E-04
HMA	Sample7	6,10E-04
	Sample8	6,91E-04

3.3 Statistical Data Analysis

It was performed an analysis of variance table using a distribution F(3,4) 95%. Table 8 presents the results.

Hypothesis: The rubber compound presented a variable durability that depends on each tested pavement.

Table 8: Statistic data analysis using a distribution F(3,4) 95%

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Ratio	F(3,4) 95%
Between Treatments ST	1,27E-07	3	4,22E-08	7,7	6,6
Residuals SR	2,18E-08	4	5,45E-09		

Table 8 presents a ratio greater than the distribution F(3,4) 95%, therefore, there are evidences (95%) that corroborate the hypothesis, that is, the differences between results can be associated to differences between treatments.

Once confirmed the data statistic relevance, the rubber compound wear behavior was analyzed.

3.4 Pavement Classification as a Function of Wear

The pavements were classified according to the rubber compound wear, using the results presented at Table 7; these consolidated in Figure 17

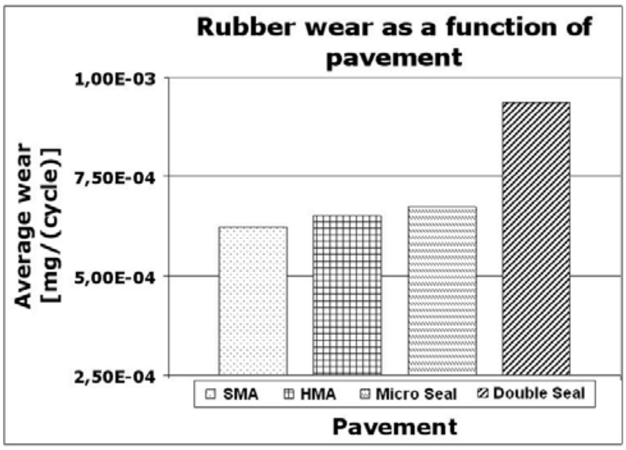


Figure 17: Wear rate as a function of pavement, 2 degrees slip angle, load 8 kgf, speed 2 km/h (Table 7).

3.5 Pavement Classification as a Function of Texture

The pavements texture classification obtained from Table 1 are presented on Figure 18.

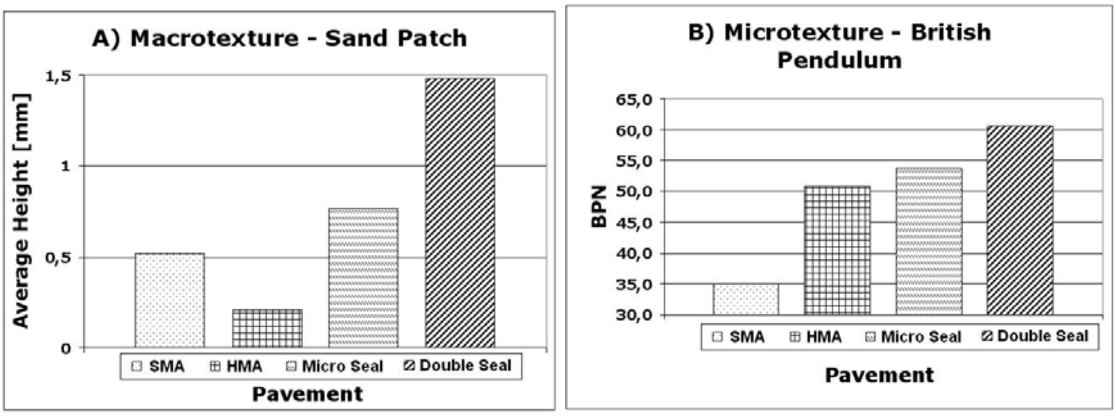


Figure 18: Pavement texture classification. A) Macrotexture assessed by Sand Patch. B) Microtexture assessed by British Pendulum (Table 2).

The results of Figure 18 show that pavements classifications for both texture scales are similar, apart from the SMA pavement that presents an intermediate macrotexture and also the lowest microtexture.

Comparing the texture measurements of Figure 18 with the laboratory wear results of Figure 17 it can be observed that the rubber compound wear is directly proportional to the pavement microtexture.

4 CONCLUSIONS

The wear study of a rubber compound tested against different pavements showed that the wear is directly proportional to the pavement microtexture, in agreement with the literature. The SMA pavement, with the lowest microtexture promoted the lowest wear rate. On the other hand, the Double Seal pavement with the highest microtexture promoted a wear rate that is almost twice that of SMA.

For a pavement with good integrity (absence of holes and irregularities) its microtexture will significantly influence the durability of tire tread rubber compounds.

Acknowledgments

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