# Influence of the mastics on the permanent deformation of asphalt pavements

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## ABSTRACT

*The resistance to permanent deformation or rutting of asphalt mix depends on many factors; among them we can mention the type and dosage of bitumen, the aggregate gradation, the nature of the aggregates, the ambient temperature of the pavement, traffic loads and intensity, the degree of compaction, etc. In this study the permanent deformation is evaluated based on a single parameter; the filler/bitumen ratio.*
*The composition of the mastic of a mixture has a significant influence on certain properties, such as fatigue and permanent deformation. Is logical to assume that as the ratio f / b increases the elasticity of the mixture decreases and stiffness increases, bringing its performance against the action of the traffic in terms of rutting be different. Thus, we have evaluated the characteristics related tothe permanent deformation of mixtures and mastics varying the ratio f / b. At the same time it has tried to find relationships between the results of various tests.*

**Keywords:** Mastic Asphalt, Mineral filler, Permanent Deformation, Rheology

## 1. INTRODUCTION

The study was performed with four types of mixtures; AC16D (dense type of continuous aggregate gradation mixture), AC22S (semi-dense mixture of continuous gradation type), BBTM11B (discontinuous mixture for wearing course) and SMA11 (Stone mastic asphalt).

The binders used are; 50/70 and 35/50 (distillation bitumen penetration grade) and PMB 45 / 80-65 (elastomer-modified bitumen) and PMB 45 / 80-75 AV (highly viscous modified bitumen with elastomers).

The aggregates used are from quarries around Madrid; Silicious-calcareous Madrid area and Northern mylonite. The filler used is limestone and is commercially supplied.

As regards the tests conducted were as follows; EN 12697-22 (Wheel Tracking Test) [1] EN 12697-25 (cyclic compression test) [2] made on the asphalt mixes, and ASTM D-7175 (Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer) [3], ASTM D-7405 (Multiple Stress Creep and Recovery (MSCR) of Asphalt Binder Using a Dynamic Shear Rheometer) [4] on the mastics and net bitumen.

## 2. MIXTURE

The gradation curves used are presented table 1 and figure 1, and the dosage of binder for each f/b evaluated in Table 2.

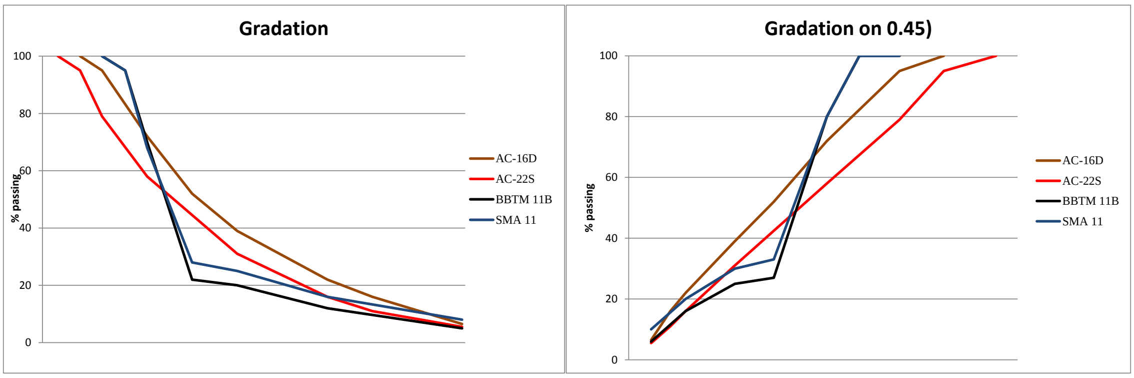



**Figure 1: Gradation of mixtures used**

**Table 1: Particle size of mixes**

| Sieve, mm | AC16 D | AC22 S | BBTM11B | SMA11 |
|---|---|---|---|---|
| 31,5 | | 100 | | |
| 22,4 | 100 | 95 | | |
| 16 | 95 | 79 | 100 | 100 |
| 11,2 | | | 95 | 95 |
| 8 | 72 | 58 | 70 | 68 |
| 4 | 52 | | 22 | 28 |
| 2 | 39 | 31 | 20 | 25 |
| 0,5 | 22 | 16 | 12 | 16 |
| 0,25 | 16 | 11 | | |
| 0,063 | 6,5 | 5,5 | 5 | 8 |

**Table 2. Dosage of binder and relationships f / b**

| AC16 D | | AC22 S | | BBTM11B | | SMA11 | |
|---|---|---|---|---|---|---|---|
| f/b | Binder% | f/b | Binder% | f/b | Binder% | f/b | Binder% |
| 1,1 | 5,91 | 1 | 5,50 | 0,8 | 6,25 | 1,1 | 7,27 |
| 1,2 | 5,42 | 1,1 | 5,00 | 0,95 | 5,26 | 1,2 | 6,67 |
| 1,3 | 5,00 | 1,2 | 4,58 | 1,05 | 4,76 | 1,3 | 6,15 |
| 1,4 | 4,64 | 1,3 | 4,23 | 1,15 | 4,35 | 1,4 | 5,71 |

## 3. TESTS

### 3.1 EN 12697-22 (Wheel Tracking Test)

This test is performed by applying a cyclic load through a wheel loaded on a rectangular asphalt specimen conditioned at 60 ° C. The pressure applied by the wheel is 9 kg / cm$^2$. The main parameters obtained are; WTS (slope of strain produced between 5000 and 10000 cycles in mm /10$^3$ cycles) and RD (total deformation produced in mm) as shown in Figure 2.

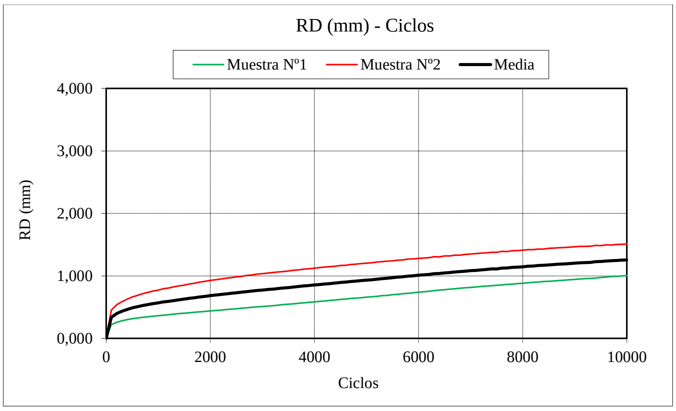



**Figure 2: Testing Wheel Tracking, EN 12697-22**

Not all asphalts have been used for all mixtures, for example in dense or semi-dense blends modified bitumen mixtures of high viscosity is rarely used, while in discontinuous blends generally are used only modified bitumen. The results obtained by varying the ratio f / b are reflected in Table 3 and Figure 2:

**Table 3: Wheel Tracking Test Results**

| **AC16D** | **50/70** | | **35/50** | | **PMB 45/80-65** | |
|---|---|---|---|---|---|---|
| f/b | WTS | RD | WTS | RD | WTS | RD |
| 1,1 | 0,321 | 7,269 | 0,145 | 4,943 | 0,061 | 4,62 |
| 1,2 | 0,134 | 3,865 | 0,058 | 2,544 | 0,034 | 2,935 |
| 1,3 | 0,06 | 2,246 | 0,046 | 1,933 | 0,026 | 2,22 |
| 1,4 | 0,059 | 1,856 | 0,036 | 1,723 | 0,028 | 2,03 |
| **AC22S** | **50/70** | | **35/50** | | **PMB 45/80-65** | |
| f/b | WTS | RD | WTS | RD | WTS | RD |
| 1.0 | 0,191 | 5,145 | 0,105 | 3,615 | 0,041 | 2,665 |
| 1,1 | 0,107 | 3,890 | 0,073 | 2,942 | 0,031 | 1,946 |
| 1,2 | 0,076 | 2,392 | 0,058 | 2,37 | 0,030 | 1,462 |
| 1,3 | 0,070 | 2,312 | 0,050 | 2,208 | 0,025 | 1,227 |

| **BBTM11** | **PMB 45/80-65** | | **PMB 45/80-75** | |
|---|---|---|---|---|
| f/b | WTS | RD | WTS | RD |
| 0,8 | 0,059 | 3,500 | 0,050 | 1,727 |
| 0,95 | 0,047 | 1,906 | 0,042 | 1,732 |
| 1,05 | 0,039 | 1,745 | 0,039 | 1,495 |
| 1,15 | 0,028 | 1,782 | 0,033 | 1,540 |
| **SMA11** | **PMB 45/80-65** | | **PMB 45/80-75** | |
| f/b | WTS | RD | WTS | RD |
| 1,1 | 0,042 | 2,973 | 0,035 | 1,837 |
| 1,2 | 0,025 | 1,850 | 0,025 | 1,830 |
| 1,3 | 0,023 | 1,670 | 0,023 | 1,329 |
| 1,4 | 0,019 | 1,425 | 0,018 | 1,279 |

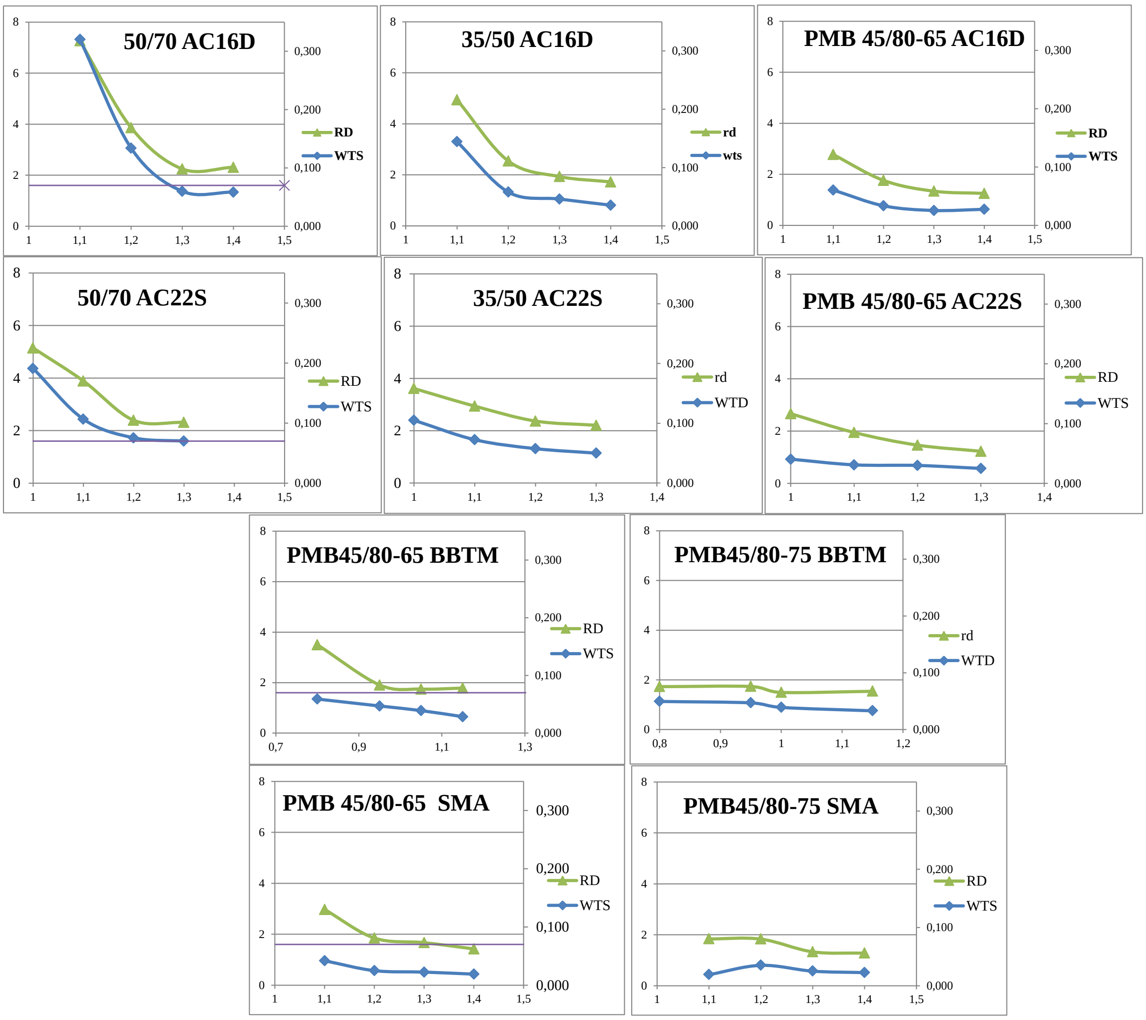



**Figure 3: Wheel Tracking test**

As can be seen from these data, the permanent deformation assessed with this test, varies greatly with the relationship f/b and the type of bitumen. If we assimilate the bitumen softening point as a parameter which measures the resistance to permanent deformation; for bitumen softening point lower (50/70) values, both WTS slope deformation and permanent deformation, RD are the highest and its dependence on f/b is greater. As the softening point increases, and this decreases dependence curves are flatter. Furthermore, depending on the type of mixture, the values are different; The denser mixture has greater inclination towards the semi-dense deformation. Discontinuous mixtures still have less propensity to permanent deformation. Therefore, playing with the relationship f/b and the softening point of the binder, it is possible to change resistance to rutting.

In Spain the values specified for the value of the slope deformation, depending on the traffic intensity and the layer in which the mixture is placed, ranging from 0.07 to 0.15 mm/$10^3$cicles. If we represent the value for each mixture WTS and the softening point, by extrapolating the limits of the specification. Maps obtained are shown in Figure 4 (AC16D mixture):

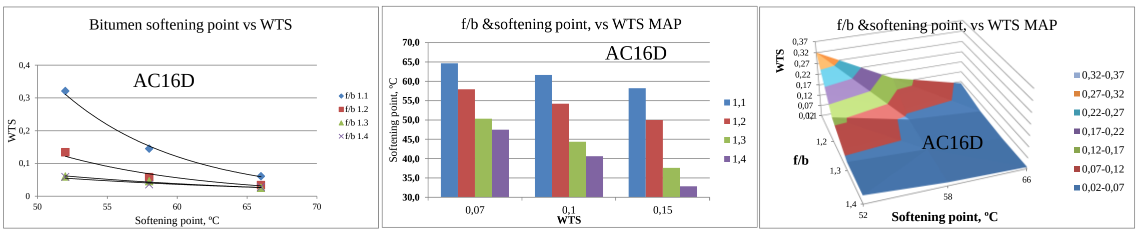



**Figure 4: Wheel Tracking slope-softening point AC16D Map**

Thus, in the AC16D mixture, if specification value was 0.1 and have a bitumen with a softening point around 50°C, we should work with f/b more than 1.2 to meet the limit value.

In the case of the AC22S mixture the same operation obtains similar maps, although the sensitivity of the strain to the variation of the ratio f/b is lower (Figure 5).

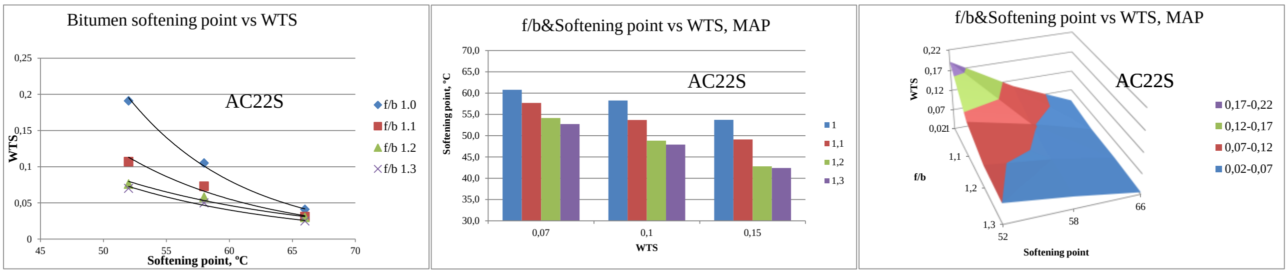



**Figure 5: Map Wheel Tracking slope-softening point AC16S**

In the case of discontinuous mixtures, the obtained values meet the specification values with the modified bitumens employed, the variation of slopes and deformations with the relationship f/b is quite low, so it has no sense to create a map, as in the case of dense or semi-dense mixture.

### 3.2 EN 12697-25 (Cyclic Compression test)

This test applies repeated loads on cylindrical specimens conditioned at 60°C through a piston supported on a flat face, and driven by pulses in an Servo pneumatic equipment. After each cycle is a short relaxation time in the same manner as in Wheel tracking test between each step of the wheel. The parameters evaluated are the slope of the deformation obtained between 2000-3600 cycles, as well as the total strain. Obtained results are presented in Table 4 and Figure 6.

**Table 4: Results cyclic compression test**

| **AC16D** | **50/70** | | **35/50** | | **PMB 45/80-65** | |
|---|---|---|---|---|---|---|
| f/b | Slope | Deformation | Slope | Deformation | Slope | Deformation |
| 1,1 | 1,439 | 16313 | 0,770 | 11812 | 0,235 | 8074 |
| 1,2 | 0,658 | 10774 | 0,418 | 9680 | 0,203 | 8090 |
| 1,3 | 0,509 | 9734 | 0,406 | 6760 | 0,166 | 5982 |
| 1,4 | 0,500 | 7698 | 0,401 | 6629 | 0,156 | 2653 |
| **AC22S** | **50/70** | | **35/50** | | **PMB 45/80-65** | |
| f/b | Slope | Deformation | Slope | Deformation | Slope | Deformation |
| 1,0 | 1,352 | 11231 | 0,801 | 10089 | 0,301 | 6992 |
| 1,1 | 0,658 | 10774 | 0,354 | 7999 | 0,189 | 4522 |
| 1,2 | 0,509 | 9734 | 0,288 | 5834 | 0,149 | 3690 |
| 1,3 | 0,500 | 8943 | 0,247 | 4615 | 0,122 | 2001 |

| **BBTM11** | **PMB 45/80-65** | | **PMB 45/80-75** | |
|---|---|---|---|---|
| f/b | Slope | Deformation | Slope | Deformation |
| 0,8 | 0,447 | 7116 | 0,329 | 5984 |
| 0,95 | 0,340 | 5001 | 0,242 | 4001 |
| 1,05 | 0,233 | 2763 | 0,180 | 2001 |
| 1,15 | 0,169 | 1855 | 0,162 | 1699 |
| **SMA11** | **PMB 45/80-65** | | **PMB 45/80-75** | |
| f/b | Slope | Deformation | Slope | Deformation |
| 1,1 | 0,253 | 6224 | 0,231 | 5090 |
| 1,2 | 0,182 | 4567 | 0,188 | 3101 |
| 1,3 | 0,147 | 2608 | 0,126 | 1823 |
| 1,4 | 0,126 | 1795 | 0,119 | 1257 |

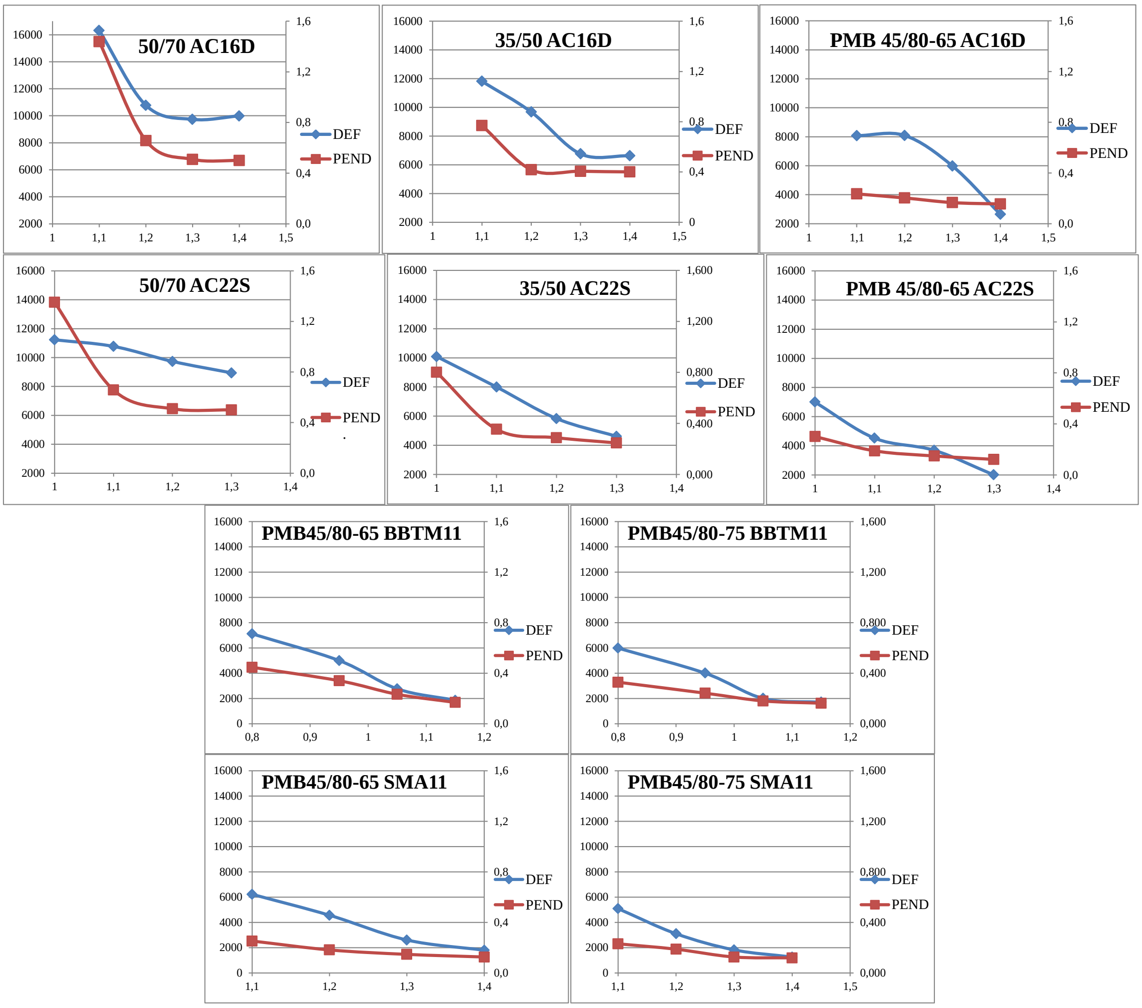



**Figure 6: Cyclic Compression tests**

In the same manner as in Wheel tracking test, the values obtained follow similar trends; bitumens with lower softening point show higher slopes and deformations. There is not values specified for this test currently in Spain.

### 3.3 Relationship between cyclic compression test and Wheel tracking test

Representing the WTS and slope values from the two trials, graphs obtained show a clear relationship between both (Figure 7), which results in the equivalence table 5.

**Table 5. Correlation between WTS and cyclic compression slope**

| Specification limits WTS Wheel tracking | Cyclic compresión slope |
|---|---|
| 0,07 | 0,420 |
| 0,10 | 0,570 |
| 0,15 | 0,820 |

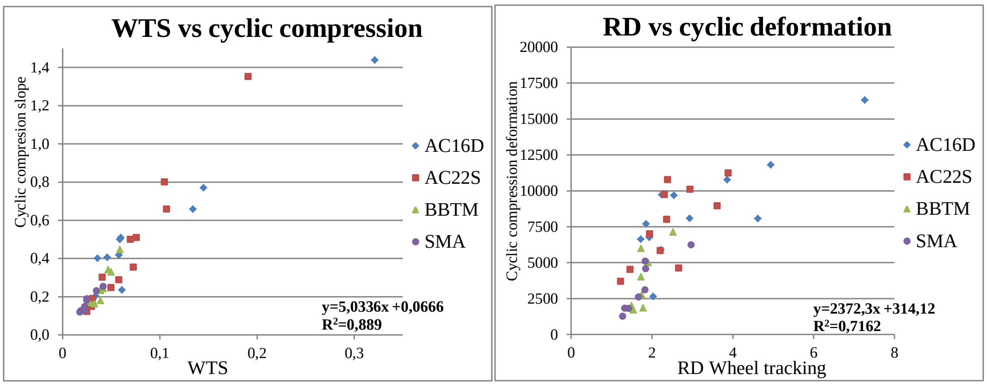



**Figure 7: Correlation between Wheel Tracking test and Cyclic Compression test**

This relationship can be used as an alternative to the realization of the Wheel Tracking test, not as a specification, but how assessment, in a test that has the advantage of handling smaller quantities of asphalt material.

In the case of deformation, there is greater dispersion, probably caused by the difference in thickness of the test specimens of Wheel tracking test (the thickness of the test specimens AC16D and AC22S mixtures is greater than the BBTM11 and SMA11mixtures) and the fixed thickness of the permanent deformation test.

### 3.4 ASTM D-7175 (Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer)

The tests performed with rheometers are always carried out on bitumen or mastic for obvious reasons. In the case of study, it has been attempted to evaluate the variation of the complex modulus with varying the ratio f/b. The mastics were manufactured by mixing at high temperature, different binders with the filler used in the above mixtures with the exception of filler of mylonite for discontinuous mixtures. Is necessary to maintain the samples under constant stirring to prevent settling of the filler and get homogeneous and representative subsamples and avoid experimental errors.

This method covers the determination of the modulus and phase angle, specifically the module divided by the sine of the phase angle, known as rutting parameter, or the ability of the binder to resist permanent deformations. As is larger, the resistance is better. This value has been measured at 60ºC, like in the case of the above tests. Complex modulus results are in Table 6 and shown in Figure 8.

**Table 6: Module complex mastics**

| **Bitumen** | Filler/bitumen rate | | | | |
|---|---|---|---|---|---|
| | Net bitumen | 0,95 | 1,1 | 1,25 | 1,4 |
| 50/70 | 9800 | 10800 | 12250 | 13400 | 18850 |
| 35/50 | 12550 | 20800 | 25600 | 31800 | 37250 |
| PMB 45/80-65 | 13121 | 23000 | 31700 | 46000 | 62900 |
| PMB 45/80-75 | 14000 | 40200 | 67100 | 72400 | 109500 |

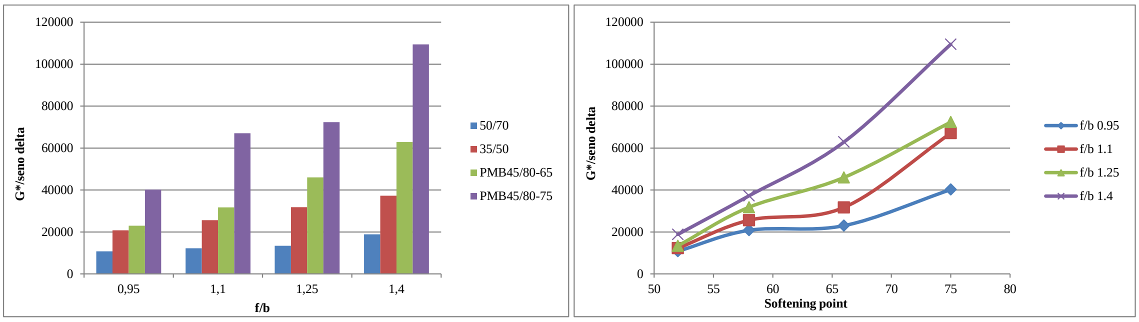



**Figure 8: Complex modulus of mastics**

It is noted that the larger the f/b, the greater the complex modulus and therefore resistance to rutting. Depending on the bitumen, the influence of increasing the ratio f/b is larger or smaller; for example, bitumen with lower softening point show a lower increase of modulus with the f/b ratio. In the case of 50/70 bitumen the modulus increase 92% from the original bitumen, in a ratio f/b 1.4, while in the case of PMB 45/80-75 the increase is 680%. This increased resistance to deformation may involve, for example, excessive stiffness which might prove detrimental to the fatigue performance.

### 3.5 ASTM D-7405 (Multiple Stress Creep and Recovery Test (MSCRT) of Asphalt Binder Using a Dynamic Shear Rheometer)

Multiple testing creep and recovery is applied to a material constant effort (3.2kPa) causing this deformation (creep). After a certain period (1s), the applied stress is removed, leaving the structure of the material to recover from deformation caused by the applied stress for 9 s (recovery). This process is performed for 10 consecutive cycles, it is possible to evaluate the deformation accumulated by the application of repeated loads. Previously ten cycles of conditioning with an effort of 0.1kPa are applied. It is comparable to the effect of Wheel tracking test. Various parameters are measured; unrecovered deformation (Compliance Jnr), the percent recovery (% R). See Figure 9.

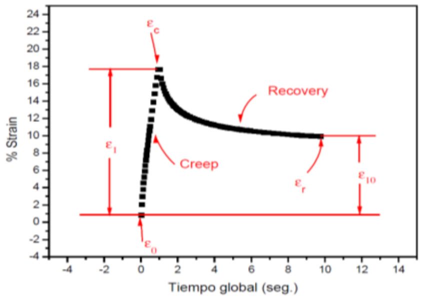
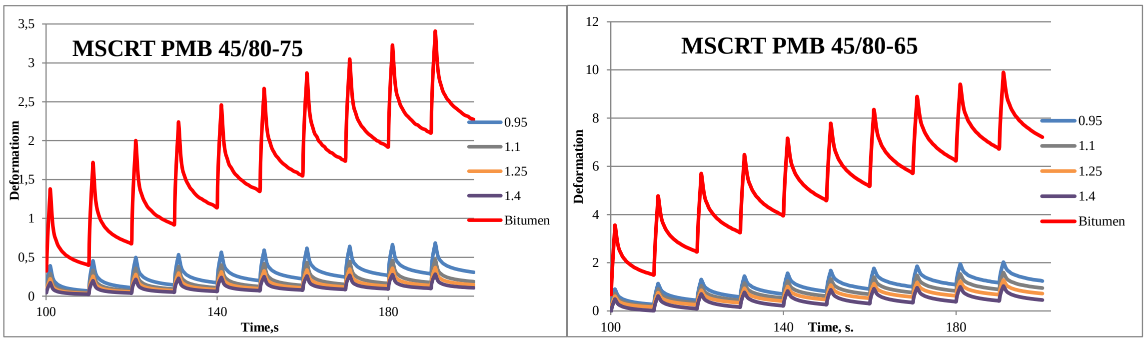



**Figure 9: MSCRT test**

These tests are performed at 60°C. From these graphs it shows that the degree of recovery in each cycle for unmodified bitumen is very low while for modified is very high. Furthermore the deformation in each cycle, or total deformation after 10 cycles for the conventional binders is higher than the modified binders. Table 7 and Figure 10 shows the results.

**Table 7: Test results MSCRT, unrecovered deformation and% recovery**

| | 50/70 | | 35/50 | | PMB 45/80-65 | | PMB 45/80-75 | |
|---|---|---|---|---|---|---|---|---|
| | Jnr | %R | Jnr | %R | Jnr | %R | Jnr | %R |
| Net bitumen | 2,529 | 0,0 | 1,590 | 0,1 | 0,219 | 78,3 | 0,069 | 83,1 |
| Mastic 0,95 | 0,786 | 0,0 | 0,386 | 1,7 | 0,038 | 85,9 | 0,009 | 93,2 |
| Mastic 1,1 | 0,574 | 0,0 | 0,322 | 2,4 | 0,029 | 86,9 | 0,006 | 93,8 |
| Mastic 1,25 | 0,482 | 0,3 | 0,249 | 3,0 | 0,022 | 88,2 | 0,004 | 94,6 |
| Mastic 1,4 | 0,395 | 0,6 | 0,202 | 4,2 | 0,018 | 90,6 | 0,003 | 94,9 |



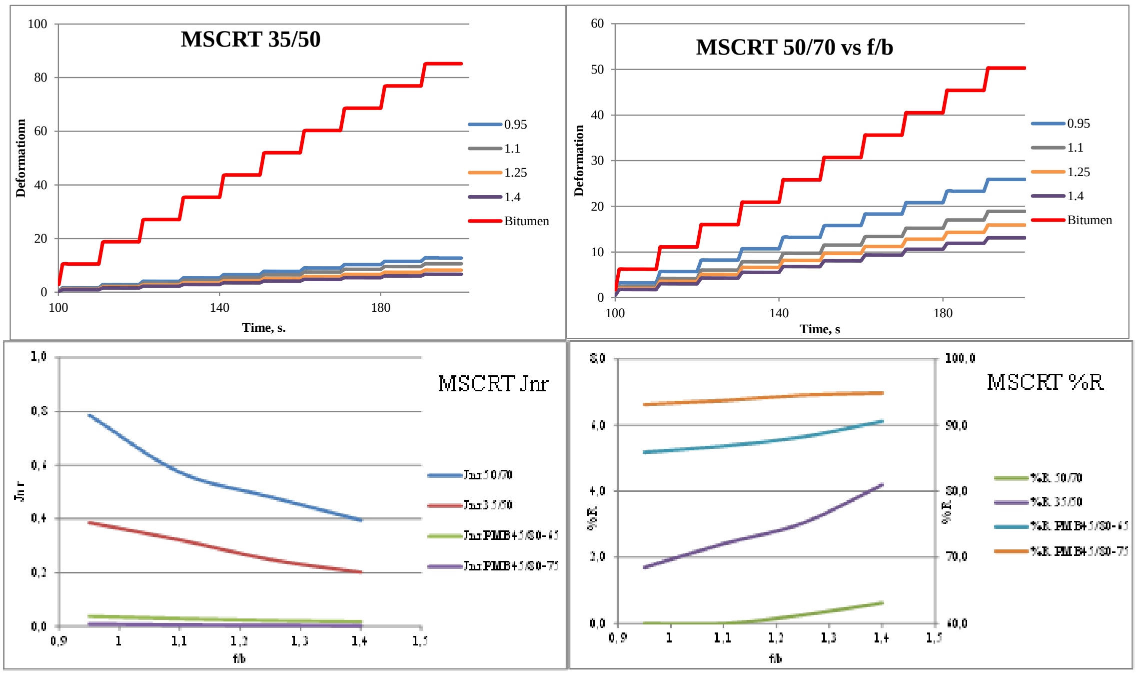



**Figure 10: Test results MSCRT, unrecovered deformation and% recovery**

If we include the value "0" of pure bitumen and place it in semi-logarithmic and normal scale graphs, Figure 11 is obtained:

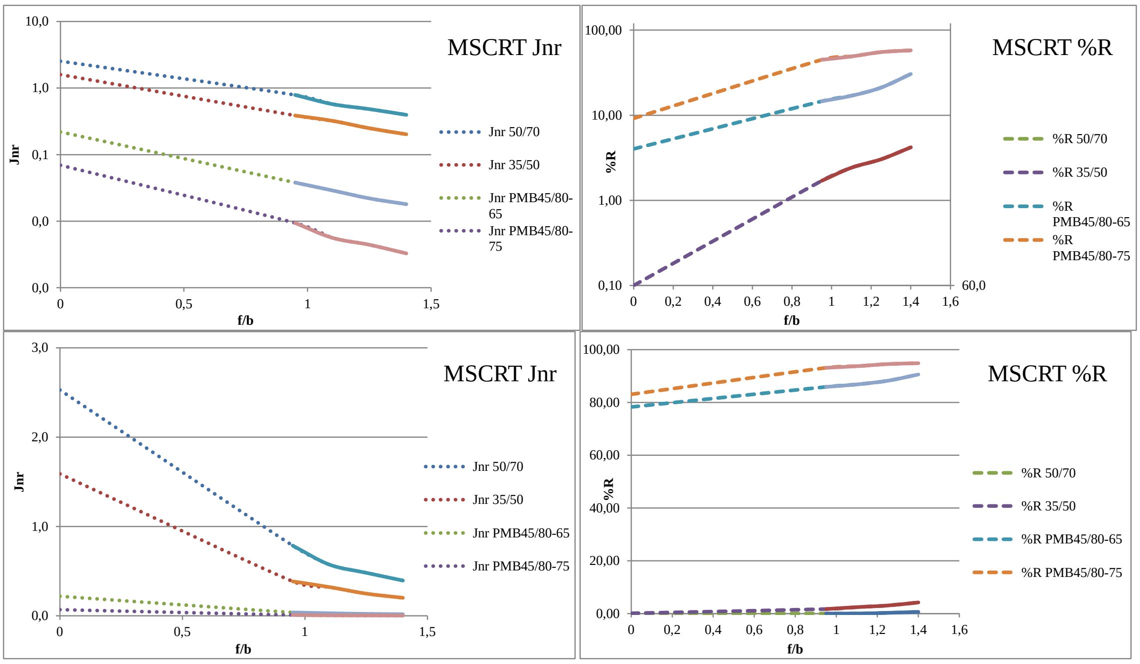



**Figure 11: Jnr and %R across the range of f/b**

As shown, the deformation is more pronounced for non-modified bitumen and decreases significantly for all when we measure the mastics. In the modified bitumen, the variation of Jnr, with the ratio f / b is minimal, which corresponds to most of the results obtained so far. Bitumen 50/70 presents the bigger variation and even has an inflection point around the 1.1 f/b ratio.

### 3.6 Relations between module and compliance MSCRT

Have been represented values Jnr and G*/senδ for all bitumen separately and jointly. There is a tendency for all but discrete correlation coefficient, whereas if we represent each separately mastics (excluding pure bitumen) for each there is good correlation. See Figure 12.

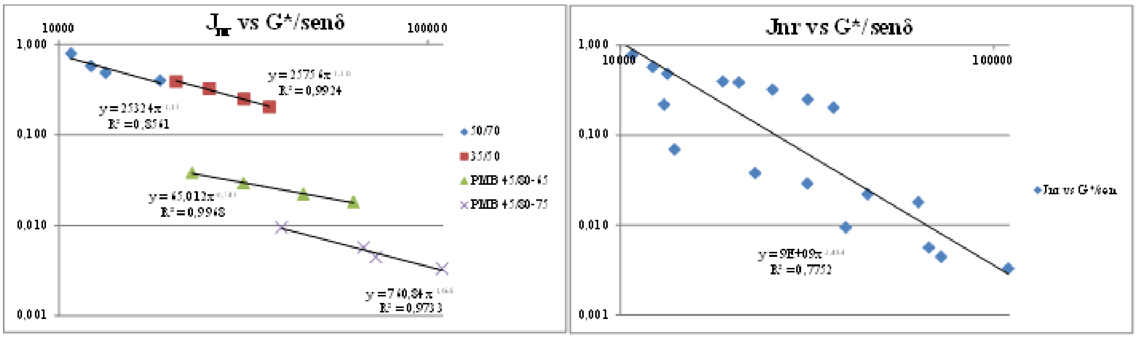



**Figure 12: Correlation Module and MSCRT**

### 3.7 Relationships between rheological tests of mastic and mixtures

Such relationships are complicated because for the same composition of mastic, we have four different asphalt compositions, with different mineral skeleton and exhibiting different deformations. Take for example the deformation DR Wheel tracking test and compared with the value of the deformation not recovered from MSCRT trial. The values for the same ratios f/b, are show in Table 8 and represented in Figure 13.

**Table 8: Correlation between Wheel Tracking (RD) and MSCRT**

| | F/B | Compliance | AC16D | AC16S | BBTM | SMA |
|---|---|---|---|---|---|---|
| 50/70 | 1,1 | 0,574 | 7,2685 | 3,89 | | |
| | 1,4 | 0,395 | 2,2455 | | | |
| 35/50 | 1,1 | 0,322 | 4,943 | 2,9415 | | |
| | 1,4 | 0,177 | 1,9325 | | | |
| PMB 45/80-65 | 0,95 | 0,038 | | | 1,906 | |
| | 1,1 | 0,029 | 2,7755 | 1,9465 | | 2,973 |
| | 1,4 | 0,018 | 1,3385 | | | 1,425 |
| PMB 45/80-75 | 0,95 | 0,009 | | | 1,727 | |
| | 1,1 | 0,006 | | | | 1,837 |
| | 1,4 | 0,003 | | | | 1,279 |

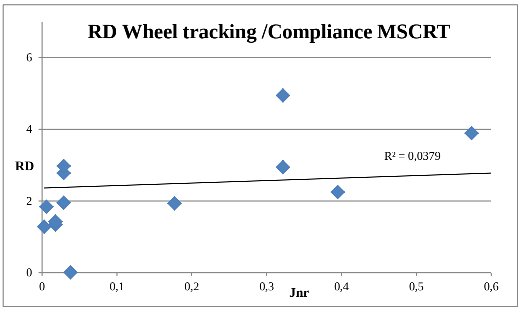



**Figure 13: Correlation between Wheel Tracking (RD) and MSCRT**

Same behaviour occurs with other studied relationships, due to the same reason, the influence of the mineral skeleton and composition of the various asphalt mixes.

### 3.8 Relations between rheological tests of mastic and Softening Point

Values representing softening point of bitumen mastics and opposite values of MSCRT compliance and rutting parameter G*/Senδ each obtain relationships of Figure 14.

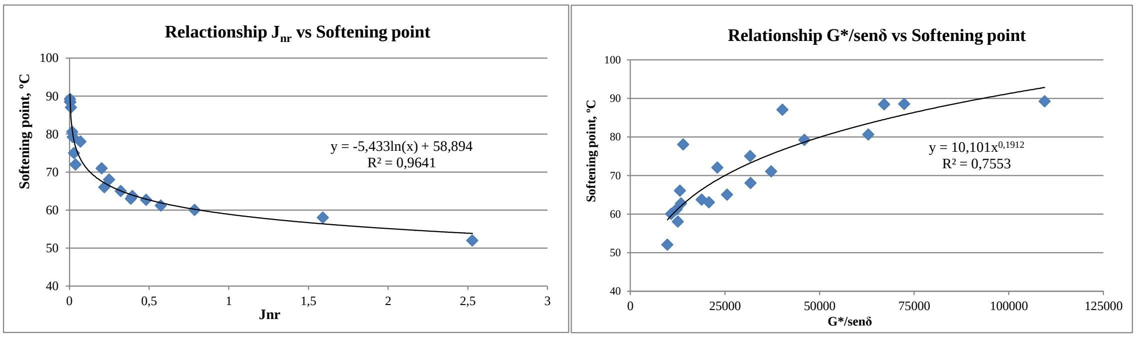



**Figure 14: Correlation between rheological tests and Softening Point**

There is a clear trend among Jnr and the softening point and acceptable initial correlation, which can provide valuable preliminary estimate on the behavior of the joint filler/bitumen system. In the case of modulus the correlation is not so clear.

## 4. CONCLUSIONS

Along the work has been shown the influence of the ratio f/b in the resistance to permanent deformation. A simple and easily adjustable parameter can strongly influence in this property. Are also proven high resistance to deformation of the polymer modified bitumen, which also present it in a wide range of f/b.

Although it may seem otherwise, for the same content of the same binder, the mixture worst performing deformation is the semi-dense mix. Thus, containing 5.0% of 50/70, the dense mixture has a ratio f/b of 1.3 and semi-dense 1.1 due each gradation. The results in the Wheel Tracking test are 0.06 and 0.107 respectively. This clearly shows the difference in results with f/b ratio.

On the other hand we found some relationships between tests, the most representative among the Wheel Tracking test and cyclic compression. The correlation between mixtures and mastic test is not good, due to the influence of the mineral skeleton of each type of mixture, an equal f/b ratio. We have also found a good relationship between compliance and softening point, which opens the range of initial estimates with a simple test.

It it possible to correct the behavior of a mixture to permanent deformation by varying the ratio f/b and/or choosing another binder, but must take into account other factors such as voids, stiffness, fatigue, etc, which should be checked, but generally 0.1-0.15 variations in f/b ratio can substantially improve creep resistance without altering other properties excessively.

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[3] ASTM D7175-08, "Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer".

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