# RELATIONSHIPS BETWEEN ZERO SHEAR VISCOSITY, LOW SHEAR VISCOSITY AND MSCRT TESTS AND EN 12697-22 RUTTING TEST

*Antonio Paez Dueñas, Antonio Perez Lepe, Emilio Moreno Martinez, Veronica Contreras Ibañez*

*Repsol Technological Center. Móstoles. Spain*

## ABSTRACT

*There is an increasing interest in the Performance related relationships between binder and Asphalt Mixture. One of the most interesting fields is the relationship between technological properties of bitumen and rutting properties of Asphalt.*

*Recently, Zero Shear Viscosity and Equiviscous temperature methods were converted as EU Standards and MSCRT were developed in USA. The three methods were proposed sometimes as key bitumen parameters to control rutting in Asphalt Mixes. However there have not been enough studies to distinguish clearly the contribution of each parameter to the mix property.*

*In this paper a relationship was aimed. By using a conventional, polymer modified and rubber modified bitumen, Asphalt Mixes were formulated and their behavior towards resistance to rutting was established. Zero Shear Viscosity Equiviscous temperature and MSCRT parameters were determined for the binders. Some relationships and parameters trends were proposed for dense-graded asphalt mix.*

**Keywords:** Zero Shear Viscosity, Low Shear Viscosity, MSCRT Tests, rutting, Bitumen Mixes

## 1. INTRODUCTION

Rutting in flexible pavements is in most cases caused by accumulation of permanent deformation in pavement layers. Procedures for evaluation of the resistance or susceptibility of the mixtures to rutting have become an important issue. Several test methods and procedures were proposed over the years for the purpose of evaluating the mixture performance. The rheological properties of the binder must be taken into account in the design of asphalt mixture because the resistance to permanent deformation is strongly dependant on them. However, a simple correlation between binder parameters and rutting properties of Asphalt Mixes is yet to be developed, although many efforts have already been done in this sense.

The focus of this research work is to identify material parameters that are related to the resistance to permanent deformation of asphalt mixtures and evaluate available relationships between them.

The binders evaluated in this study are currently used in Spain, a paving grade bitumen (50/70), a polymer-modified binder (PMB 45/80-60), a highly-polymer-modified binder (hvPMB 45/80-75) and a crumb rubber binder. Zero-Shear Viscosity (prEN 15325), Low-Shear Viscosity (prEN 15324) and MSCRT (ASTM D-7405: multiple-step creep&recovery test) parameters were determined for all the four binders. Master-curves were constructed upon temperature and frequency testing. The upper grade of Superpave PG (performance graded) system was also calculated from DSR tests.

Many studies show that temperature, binder content and void content significantly influence the permanent deformation characteristics. For this reason the asphalt mixes were designed as AC16 with the same binder content, the same void content and mix testing were performed at 60°C. The wheel tracking test (EN 12697-22), the cyclic compression test (EN 12697-25) and creep test were adopted to measure the resistance to permanent deformation of a bituminous mixture.

## 2. TEST PROGRAM AND RESULTS

### 2.1 Binder rhelogical evaluation

#### 2.1.1. Basic properties. Elasticity and Ductility (EN).

In the first place, some basic properties of the four binders selected are presented in table 1. A typical polymer-modified binder (elastomeric) and a highly-modified binder (same polymer in higher proportion) are compared in the study, in order to obtain a different asphalt mix elastic response. With penetration levels between 50 and 70 dmm, a neat bitumen was selected as a background response. This bitumen is not then the bitumen employed for the manufacture of the included PMB's, but a similar penetration-grade non-modified reference. A crumb rubber modified binder (CRMB) was also included in the study in order to translate the elasticity levels of the CRM binder to asphalt mix elastic responses. It is worth noting that in the case of CRMB, the penetration is lower than the rest of the binders (50 dmm). This is important because the stiffness and viscosity of this binder is somewhat higher than what should be expected according to the level of modification. This crumb rubber binder was so selected according to a somewhat general practice or preference of slightly lowering the CRMB penetration, to compensate for the stiffness hold in crumb particles rather than the bituminous matrix. Then, caution must be taken when comparing binders data, in this case.

**Table 1. Properties of binders: neat bitumen, polymer-modified binder (PMB), highly-modified binder (hvPMB), and crumb rubber modified binder (BC).**

| Characteristics | Unit | Test Method | 50/70 | Crumb rubber binder | PMB 45/80-60 | hvPMB 45/80-75 |
|---|---|---|---|---|---|---|
| **Penetration at 25ºC** | 0,1mm | EN 1426 | 59 | 50 | 67 | 66 |
| **Softening Point** | ºC | EN 1427 | 50,2 | 61,8 | 62,8 | 78,2 |
| **Force Ductility** | J/cm$^2$ | EN 13589 | 0,24 | 0,27* | 7,59 | 8,3 |
| | | EN 13703 | at 15ºC | at 25ºC | at 5ºC | at 5ºC |
| **Fraass Breaking Point** | ºC | EN 12593 | -11 | -16 | -17 | -22 |
| **Elastic Recovery at 25˚C (traction)** | % | EN 13398 | 10 | 59** | 88 | 95 |
| **Elastic Recovery at 25˚C (torsion)** | % | NLT-329 | 3 | 25 | 59 | 79 |
| **Resistance to hardening** | | | | | | |
| *Change of mass* | % | EN 12607-1 | 0 | 0,1 | 0 | 0 |
| *Retained Penetration* | % | EN 1426 | 62 | 66 | 68 | 82 |
| *Increase in soft point* | ºC | EN 1427 | 7 | 7,7 | 4,4 | 0 |
| *Drop in soft point after ageing* | ºC | EN 1427 | 0 | 0 | 0 | 0,2 |
| **Dynamic Viscosity** | | | | | | |
| *170 ºC* | *mPa.s* | *EN 13302* | *107* | *301* | *347* | *805* |

*Breaking at 220mm

**Breaking at 110mm

The parameters with a higher influence on the resistance to rutting are the softening point, deformation energy in force-ductility test and elastic recovery. A higher elasticity is obtained for the highly- modified binder. Low ductility values are shown by the crumb rubber binder.

### 2.1.2. Visco-elastic behaviour

The visco-elastic response of the binders was evaluated through dynamic-shear tests (DSR). Complex, storage and loss moduli as well as phase angle were registered within a temperature range. An attempt to address the visco-elastic character of modified binders is currently being done in Europe by means of two technical standards (CEN/TS15324 and 15325). In particular, a test protocol is depicted in TS15324, by which an equiviscous temperature (EVT) in the low-frequency region is obtained. The test consists of two separate dynamic tests:

Test 1: a 1ºC/min increasing temperature sweep (0,1Hz) is first applied on the binder to get a temperature value at which a complex viscosity of 2kPas is attained, by interpolating within a linear regression fitting.

Test 2: At this temperature (EVT1), a second oscillatory test is applied, by which a decreasing frequency sweep is carried out, and a further extrapolation in dynamic viscosity up to 0,0001Hz is calculated, through a second linear fitting. This second value of complex viscosity is related to EVT1 by means of the first linear fitting with temperature from test 1, obtaining a delivered value of EVT. The higher level of modification the binder has, the higher difference (increase) in temperature between test 2 and test 1 (EVT-EVT1) is obtained.

EVT test was carried out for all the four binders. Results are shown in table 2.

As a reference, the upper grade of Superpave PG (performance graded) system, was also calculated from DSR tests, since both tests follow the same approach: to deliver a temperature at which the binder shows a determined complex viscosity value. Upper PG values are also shown in table 2.

**Table 2. Equiviscous temperatures and upper PG-grade temperatures of binders: neat bitumen 50/70, crumb rubber modified binder, polymer-modified binder (PMB), and highly-modified binder (hvPMB).**

| | Neat bitumen 50/70 | Crum rubber bitumen | PMB | hvPMB |
|---|---|---|---|---|
| **EVT-1** | 53,1 | 62,0 | 60,0 | 66,0 |
| **EVT-2** (0,1-0,0001)log-log | 57,3 | 74,1 | 77,3 | 83,8 |
| **ΔT** | 4,2 | 12,1 | 17,3 | 17,8 |
| | | | | |
| **SHRP_PG upper grade** | 70 | 76 | 82 | 88* |
| *Fresh bitumen conditions G*/sinδ at 1,59Hz* | >1,0 kPa | | | |
| *RTFOT residue conditions G*/sinδ at 1.59Hz* | >2,2 kPa | | | |

*PG 88 not defined as SHRP_PG upper grade, but for hvPMB binder, 88 would be the most correct upper-grade.

The reaction of visco-elastic fluids to sinusoidally imposed shear stresses is related to the mobility of molecules and volume elements within such a sample. This mobility, also characterized by the relaxation time spectrum, is related to the type of the major fluid component but also to the type and percentage of all other components of a particular material. At low temperatures, this mobility is small so that the reaction of such fluid is slow. If the temperature is raised, the molecular mobility is increased so that the effect of rubbery volume elements or particles in the binder can be explored by means of higher and faster responses in the visco-elastic fluid. A strong and fluid-specific correlation between the time of response at the measured frequencies and test temperatures, exists. This time-temperature interdependence was explored in 1955 by researchers Williams, Landel and Ferry, who provided a theoretical understanding of the temperature dependence of the physical structure of fluids.

By the so-called time-temperature superposition principle (TTSP), a master-curve of each material can be obtained from oscillatory measurements at different temperatures and frequencies. For the binders studied, frequency sweeps ($10^{-3}$-$10^{1}$ Hz) within the linear visco-elasticity range, were carried out at 25ºC, 40ºC, 60ºC and 80ºC. The storage modulus (G'), loss modulus (G''), as well as the phase angle (º) can be horizontally and even vertically shifted along the frequency abscissa, by means of a calculus software, so that a master-curve of the binder is obtained along an extended frequency range ($10^{-7}$-$10^{1}$ Hz) .

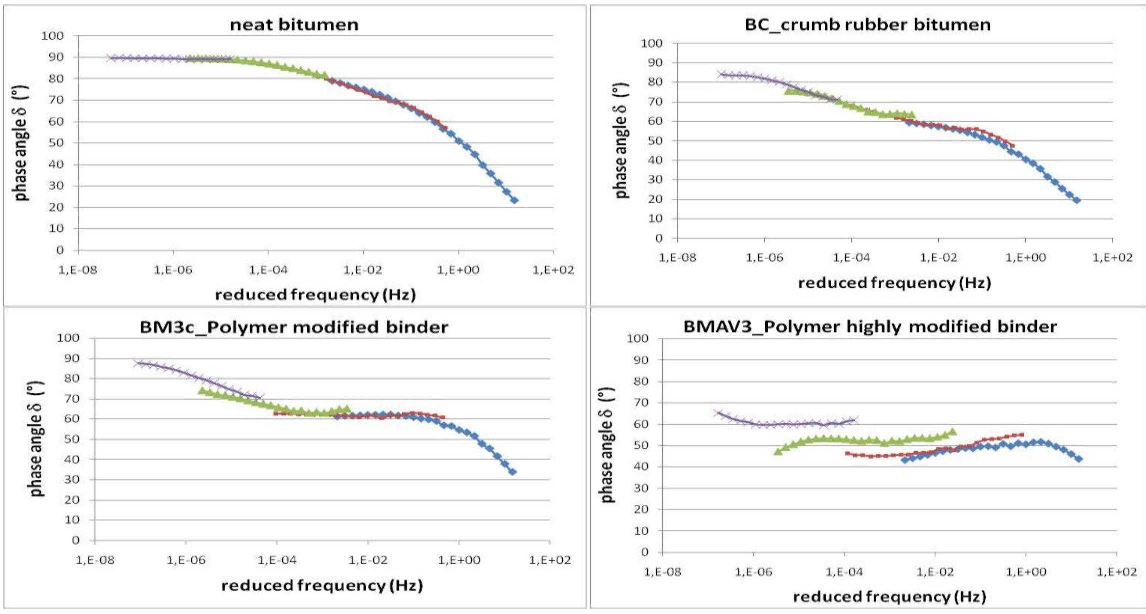



**Figure 1. Master-curves of phase angle for all binders constructed by WLF-software upon frequency sweeps at 25ºC (reference), 40ºC, 60ºC and 80ºC.**

In figure 1, the master-curve of phase angle with the reduced frequency is represented for all the four binders. For neat bitumen, a typical arc-shaped curve with a good overlap between single temperature curves is obtained. In the case of polymer modification (PMB), the overlap is not well-fitted and a plateau region a behavior can be noticed at a phase angle at around 60º, typical for SB rubber chain relaxations. In the case of crumb rubber a behavior between that of PMB and that of neat bitumen is obtained. A higher amount of SB elastomers in the bitumen (highly-modified binder) accounts for non-overlapping single curves, running parallel to each other, which is indicative of a more complex microstructure of the binder.

In addition, material's moduli can also be represented and shifted (25ºC as a reference) by multiplying values by a factor ($a_T$, horizontal shift, and $b_T$, vertical shift if needed), for each temperature. In figure 2, a wider spectrum of binders' dynamic behaviour can be displayed, in terms of the storage and loss moduli. This representation enables us for an evaluation of temperature dependency of the shift factors applied. The superposition of curves is mathematically worked out in two steps: first, it is determined how much the temperature segments must be shifted to form a continuous master-curve at the reference temperature, and second, the shift factors found may be plotted as a function of temperature and fitted by a mathematical equation, being the most common ones those of Arrhenius and WLF.

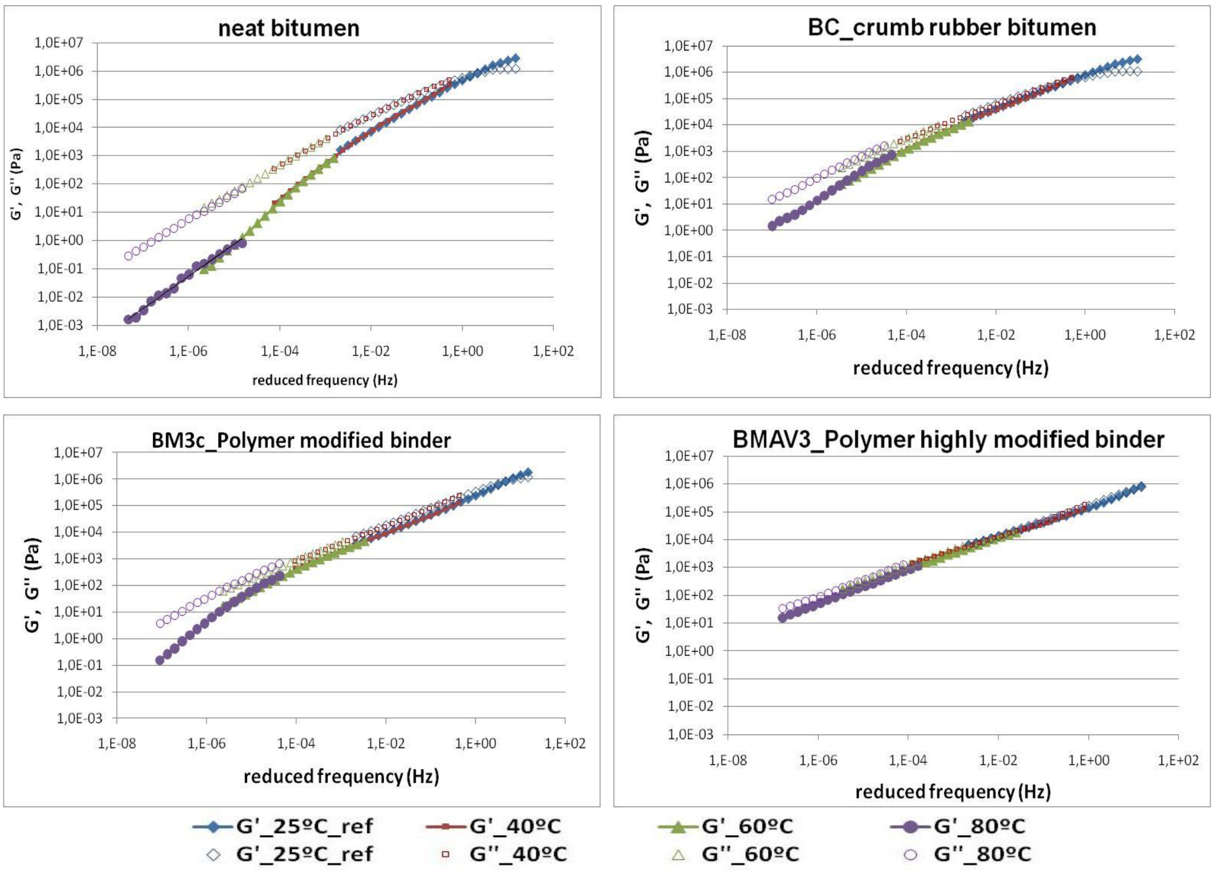



**Figure 2. Master-curves of storage and loss moduli for all binders, constructed by WLF-software upon frequency sweeps at 25ºC (reference), 40ºC, 60ºC and 80ºC.**

The shift factors were found to better correlate with temperature by a WLF-equation [$a_T = \exp(-C1^* (T-T0)/(C2+(T-T0)))$], with constants C1 and C2 for each material. The shift factor found for any particular material accounts mainly for the response time of the dominant matrix material. In table 3, values of $a_T$ at 40ºC and 80ºC are shown for each binder. It can be seen that at 40ºC similar values are obtained for all of them, but at 80ºC, bigger differences are obtained between binders, and higher $a_T$ values are needed to shift data. At this temperature, the bitumen-rich phase of the binders is softened so that the polymeric effect is more apparent. In table 3, values of the constants C1 and C2, obtained by WLF-fitting the $a_T$ parameters evolution with temperature are also shown. Again, higher modification level implies higher C-constant values. In theory, the suitability of application of TTSP to multiphasic or blend materials is somewhat controversial, but in the present work, it was empirically applied in order to have a good insight of the compared binders and to establish a rheological protocol for bituminous binders and performance-related properties.

**Table 3. Master-curves construction parameters: shift factors ($a_T$) used for 40ºC and 80ºC curves, WLF-equation parameters (C1, C2), and slopes of G' and G'' in the low-frequency region.**

| | $a_T$ 40ºC | $a_T$ 80ºC | C1 (WLF) | C2 (WLF) | G' SLOPE Terminal | G'' SLOPE Terminal |
|---|---|---|---|---|---|---|
| **neat** | 0,036 | 2,24 E-5 | 34,954 | 142,727 | 1,44 | 0,94 |
| **CRMB** | 0,034 | 3,24 E-5 | 56,625 | 213,633 | 1,05 | 0,83 |
| **PMB** | 0,044 | 4,15 E-5 | 62,840 | 286,551 | 0,98 | 0,85 |
| **hvPMB** | 0,056 | 7,68 E-5 | 77,670 | 388,945 | 0,62 | 0,59 |

The spectrum of the binders obtained by the application of TTSP does not fully cover the so-called terminal region of materials (figure 2). This region is often shown at high temperatures or low frequencies. At low frequencies, a terminal zone can be identified when G'' is a linear function of frequency and G' a quadratic one. In the case of the binders, the different G' and G'' negative slopes in this region accounts for the elastic modification of binders. The non-modified bitumen is closer to the terminal zone than the modified binders. The storage modulus slope is much lower than 2 in the case of the highly-modified binder.

### 2.1.3 Creep mode

In order to predict the behaviour of asphalt mixtures, and particularly their resistance to rutting, another important parameter to take into account is the viscosity of the binder. By applying the technical standard 15325 procedure (stress selected was 50 Pa for neat bitumen and 10 Pa for modified bitumen), the zero-shear viscosity (ZSV) at 60ºC was determined for all the binders. By plotting the compliance, *J* (1/Pa), versus test time (1 h test for neat and 4h test for modified bitumen), a constant evolution slope is attained in all cases (figure 4). In the creep mode, the non-recoverable compliance value is inversely related to the viscosity of fluids at rest. Thus, ZSV values were calculated upon the compliance values at the final 15 minutes of the test, by simply dividing time (900s) by the compliance. Viscosity values are shown in table 4. The viscosity increases with higher modification levels. In the case of crumb rubber binder, a higher than expected viscosity is obtained due to a lower penetration of the binder.

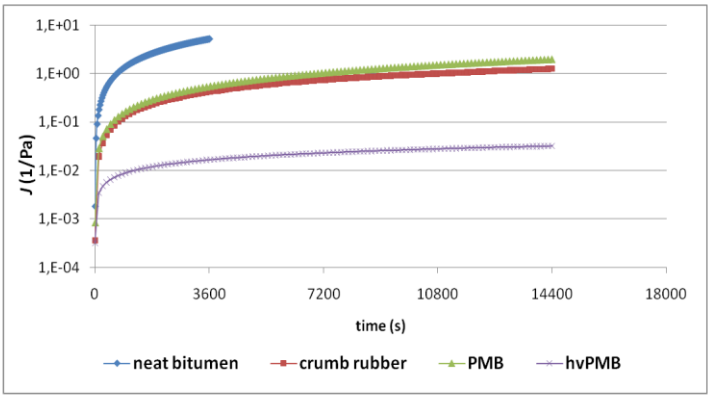


**Figure 4. Evolution of Compliance with time during Creep tests at 60ºC.**

The average viscosity over the last 15 min. was obtained by dividing the change in time (Δt) by the change in compliance (ΔJ) over the last 15 min (900 s) of the test. This can be expressed in mathematical terms as follows:

$$\eta_i = \Delta t / \Delta J = 900 / \left(J_{end} - J_{15\min - before-end}\right)$$

**Table 4. Zero-Shear Viscosity at 60ºC for all binders. Percentage strain and slopes of the Compliance curves for performance-related calculation.**

| | **Neat 50/70** | **CRMB** | **PMB** | **hvPMB** |
|---|---|---|---|---|
| **Viscosity, Pa** | **698** | **15252** | **8489** | **999900** |
| $J_{end}$,Compliance (1/Pa) | 5.148 | 1.254 | 1.952 | 0.032 |
| Compliance slope $_{2000\text{-}3600s}$ | 14.25E-04 | 3.44E-04 | 5.37E-04 | 0.08E-04 |

## 2.1.4 MSCRT: Multiple-step creep and Recovery test.

At high service temperatures is where the asphalt is prone to sustain rutting phenomena. Then, it is important to evaluate the rheological behaviour of binders and asphalts in the region around 60ºC. It is also a region where the bituminous matrix softens letting the elastomeric effect become apparent.

The permanent component of the dissipated energy is believed to better contribute to the resistance to rutting of asphalt pavements. Some reversible cyclic-stress tests on mixes are sometimes not able to clearly distinguish between the two mechanisms present in the dissipated energy. For this purpose, a test on the binders was developed at the DSR, by applying a repeated-creep test, with recovery steps after each stress cycle. By this protocol, the capacity of the binder to recover under a given strain is detected (more reliably than in the case of the Superpave rutting parameter G*/sinδ).

Test protocol: a 100Pa stress is applied over 1s, followed by a 9s rest step (0Pa). Right after 10 cycles of repetition, a second sequence of 10 cycles is applied, with 3200Pa as the imposed stress for 1s and the same 9s recovery steps. Test temperature is 60ºC, selected in all cases as a reference temperature region where the binder may be prone to accumulate strain. This method is adapted from the multiple-stress creep-and-recovery test (MSCR) proposed by AASHTO for bituminous binders.

The outlined protocol was applied over the four binders.  In figure 5, the results of the tests are represented as the evolution of shear strain (%) with time. The Compliance is usually referred as the opposite to Viscosity or Stiffness modulus, since it represents the easiness of a material to flow or deform under stress. For the first 100Pa alternate sequence, most of the strain is elastically recovered in a similar way for all the binders. However, for the following 3200Pa sequence, a clear difference in the way the strain is recovered is observed for each binder. Thus, for neat bitumen, a high deformation is attained upon the creep step, most of which is lost during the recovery periods. Polymer-modified binders deform less than neat bitumen and are able to partially recover the strain, with a really elastic performance for the highly-modified binder.

Quantitative information was extracted for the sequences: for each creep cycle, $\varepsilon_0$ and $\varepsilon_c$ are selected as the initial and final strain values, respectively (and $\varepsilon_1$ as the difference between both values), and $\varepsilon_r$ as the strain after each recovery cycle (being $\varepsilon_{10}$ the difference between $\varepsilon_r$ and $\varepsilon_0$). An average strain recovery percentage (RE) value can be calculated through the 10-step sequence, according to equation 1:

$$RE = \frac{\left(\varepsilon_1 - \varepsilon_{10}\right) * 100}{\varepsilon_1} \qquad \text{(Eq. 1)}$$

Similarly, a value of the non-recovered compliance, *Jnr*, can be calculated from the recovery periods, by dividing $\varepsilon_{10}$ by the applied stress of the creep step. *Jnr* is the parameter that relates to rutting potential, meanwhile RE provides an indication of the delayed elastic response of the binder. A high delayed elastic response is an indication that the asphalt binder has a significant elastic component at the test temperature. By this two values from the MSCR test, information on the elastic recovery, force ductility and toughness-tenacity of binders is inferred.

Following this simple calculations, a strain recovery value, *RE*, for the 3200Pa test, and a non-recoverable compliance *Jnr* value, are obtained for each binder (see table 10). Values of elastic recovery of the binders at 25ºC, from the torsion NLT-test, are also shown for the sake of comparison, as a good correlation can in most cases be inferred between both tests.

**Table 5. Recovery for all binders**

| | 50/70 | CRMB | PMB | hvPMB |
|---|---|---|---|---|
| **Elastic Recovery at 25˚C (torsion), %** | 3 | 25 | 59 | 79 |
| **MSCR Recovery %** | 1 | 15 | 40 | 82 |

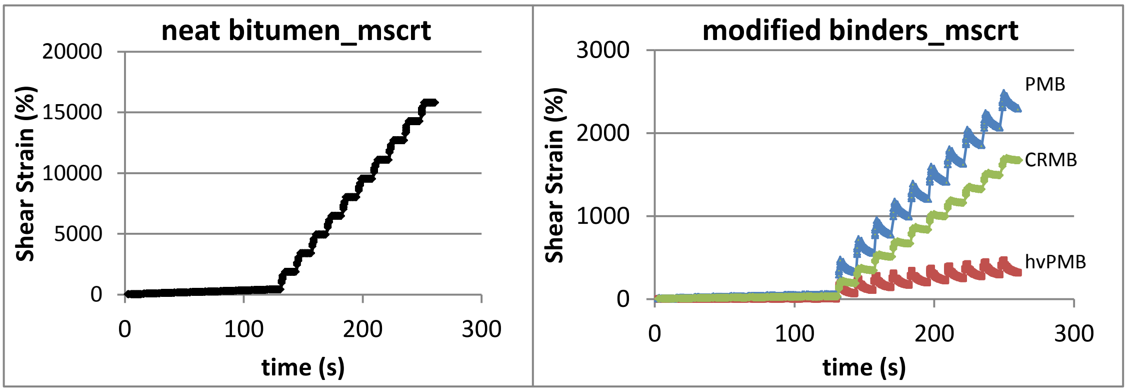



**Figure 5. MSCRT: Multiple-step Creep and Recovery test for neat bitumen (left) and modified binders (right).**

## 2.2 Mixture characteristics

An AC16 dense mixture was chosen for the performance evaluation. To do that, an aggregate (siliceous-calcareous nature) from the area of Madrid was used. The sieving and binder content were optimised for a dense-grade mixture.

**Table 6.- Gradation of the mixture.**

| Sieve, mm | % Passing | AC16D | Binder content |
|---|---|---|---|
| 22 | **100** | 100 | 5.20% on aggregate |
| 16 | **100** | 90-100 | |
| 8 | **73** | 64-79 | |
| 4 | **54** | 44-59 | |
| 2 | **39** | 31-46 | |
| 0,5 | **21** | 16-27 | |
| 0,25 | **15** | 11-20 | |
| 0,063 | **6,0** | 4-8 | |

### 2.2.1 Wheel tracking test EN 12697-22

This test followed the EN 12697-22 method. The test temperature used was 60 ºC. In table 7, parameters from the WT test are shown, which will be discussed later: WTS $_{AIR}$ wheel-tracking slope, $RD_{AIR}$ Rut depth, and PRD $_{AIR}$ proportional rut depth at 10000 cycles.

**Table 7.- Wheel-tracking parameters for all four mixtures.**

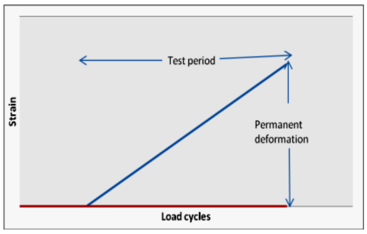
| Procedure | Small device. Procedure B, 60 ° C, 10000 cycles | | | |
|---|---|---|---|---|
| Mix Identification | **Neat 50/70** | **CRMB** | **PMB** | **hvPMB** |
| $WTS_{AIR}$ | 0,255 mm/$10^3$ cycles | 0,068 mm/$10^3$ cycles | 0,035 mm/$10^3$ cycles | 0,022 mm/$10^3$ cycles |
| $RD_{AIR}$ 10000 cycles | 4.436 mm | 2.519 mm | 1.571 mm | 1.165 mm |
| $PRD_{AIR}$ 10000 cycles | 10.99 % | 5.038 % | 3.914 % | 2.608 % |

### 2.2.2 Cyclic compression test

For this test the standard EN 12697-25 was followed. Laboratory-made specimens were tested. The laboratory specimens were compacted using a gyratory compactor. The applied load had a haversine shape with 1sec of loading time and 1sec of rest time. The test duration was 3600 cycles and the test temperature was 60 ºC. The maximum axial stress was 100 kPa.

**Table 8- Test conditions and results (Strain at cycle 2000 and 3600) for cyclic-compression test for all four mixtures.**

| | |
|---|---|
| **Preparation Method of the specimens** | Gyratory Compactor, EN 12697-31 |
| **Test temperature** | 60ºC |
| **Pre-conditioning Strength** | 10kPa |
| **Pre-conditioning time** | 600s. |
| **Test Strength** | 100kPa |
| **Test cycles** | 3600 |




| Mix Identification | **Neat 50/70** | **CRMB** | **PMB** | **hvPMB** |
|---|---|---|---|---|
| Strain 3600 cycles, microstrain | **>40.000** | **11709** | **4417** | **3092** |
| Strain 2000 cycles, microstrain | 35427 | 9479 | 3874 | 2837 |
| Flow cycle 400-1000, microstrain/cycles | 10.40 | 2.84 | 1.06 | 0.65 |
| Flow cycle 2000-3600, microstrain/cycles | Broken | 1.39 | 0.34 | 0.16 |

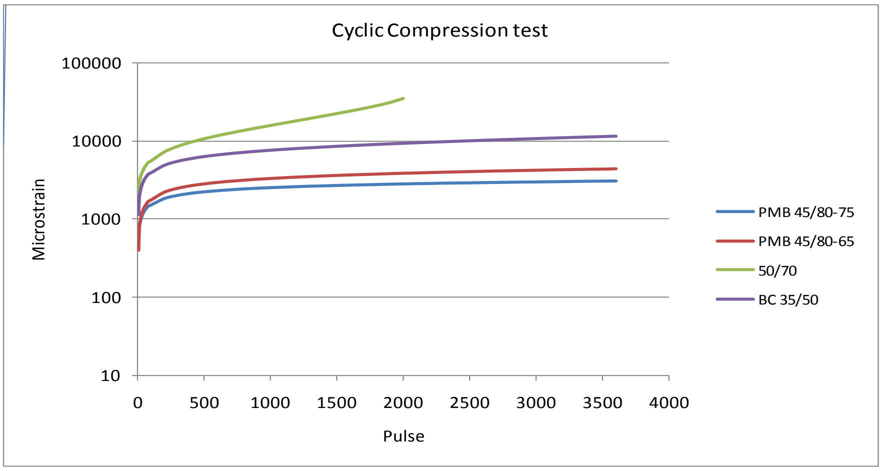


**Figure 6. Cyclic-compression test curves for all four binders (microstrain versus pulses).**

### 2.2.3 Creep test.

The creep test was conducted under unconfined conditions on gyratory-compacted specimens. The test was conducted at 60°C. A creep load of 100kPa was applied during 3600s, followed by a 900s relaxation period. Test results are shown in table 9.

**Table 9- Test conditions and results (maximum strain at 3600s, slope of the curve between 2000 and 3600s) for the creep test for all four mixtures.**

| | |
|---|---|
| **Preparation Method of the specimens** | Gyratory Compactor, EN 12697-31 |
| **Test temperature** | 60ºC |
| **Pre-conditioning Strength** | 10kPa |
| **Pre-conditioning time** | 600s. |
| **Test Strength** | 100kPa |
| **Test time** | 3600 seconds |
| **Relaxation period** | 900 seconds |

| **Mix Identification** | **Neat 50/70** | **CRMB** | **PMB** | **hvPMB** |
|---|---|---|---|---|
| **Max. strain 3600 seconds, %** | **0.362** | **0.3** | **0.213** | **0.187** |
| **Slope 2000-3600 seconds** | 0.367 | 0.304 | 0.136 | 0.067 |

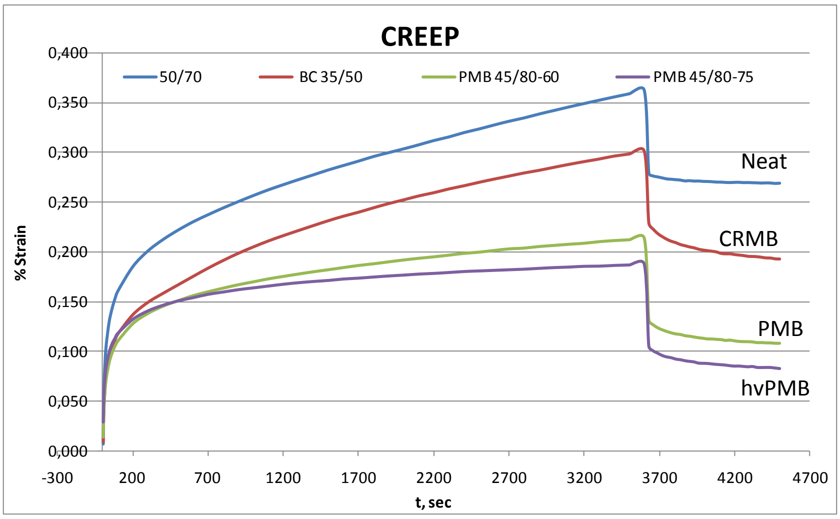



**Figure 7. Evolution of Percentage Strain with time from Creep mixture test for all four mixtures.**

## 3. ANALISYS OF CORRELATION

### 3.1 Relation between Wheel tracking test and cyclic compression test

Both tests measure the resistance of bituminous mixtures to permanent deformation caused by applying a given load. The conditions of application of load, both in time and quantity are different, but it is obvious that at least more resistant mixtures sill obtain better results in the two trials than poorer strength mixtures. In this sense, we have represented various parameters obtained from tests, such as deformation of both pending and on the other hand, total and partial deformation.

Since the cyclic compression test, the binder 50/70 does not reach the end of the trial due to rupture of the mixture, slopes are shown in two sections: 400/1000 cycles (where the mix is not broken yet) and

2000/3600. The deformations have been taken also compared at two points, 2000 and 4600 cycles. The results are shown in the following two graphs:

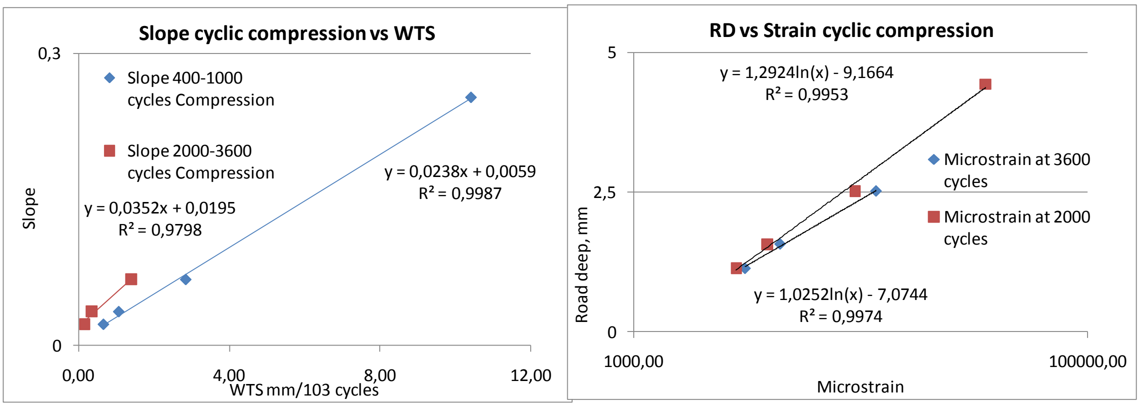


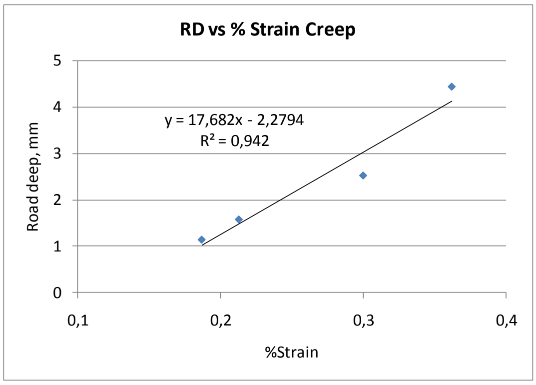

**Figure 8. Relations between Wheel tracking test (WTT) and cyclic compression test (CCT).**

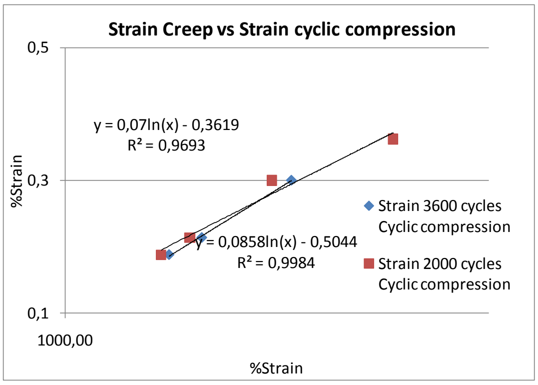
The slope from the cyclic compression test and the slope from the Wheel-Tracking Test (Figure 8. Left), as well as the Rut depth from WTT and the microstrain from CCT (Figure 8. Right), have been represented in order to get an influence over the parameters. It is observed that both the slope and strain values can be related to each other, even for trials under different conditions.

### 3.2 Relation between Wheel tracking test, cyclic compression test and Creep test

Although the three tests measure permanent deformation, the wheel tracking test and cyclic compression test apply a cyclic load, while the Creep testing applies a maintained stress in time.

To compare the results, it was not taken into account the relaxation period of the Creep testing (only the strain), calculating the total deformation and its slope.



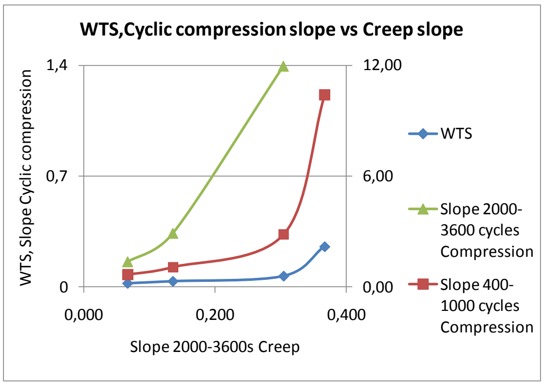



**Figure 9. Relations between Wheel tracking test (WTT), Creep test and cyclic compression test (CCT).**

It is noted that there is a linear relationship between the permanent deformation of the three trials, but there is no linear correlation with the slopes.

### 3.3 Relationship between Wheel tracking test, cyclic compression test, Creep test, and Zero Shear Viscosity.

The results obtained show that there is a certain linearity between different data, in both strain and slope, although there are some points, especially the crumb rubber binder with significant deviations. However, it is quite possible that working with a population of sufficient data, it could obtain better correlations.

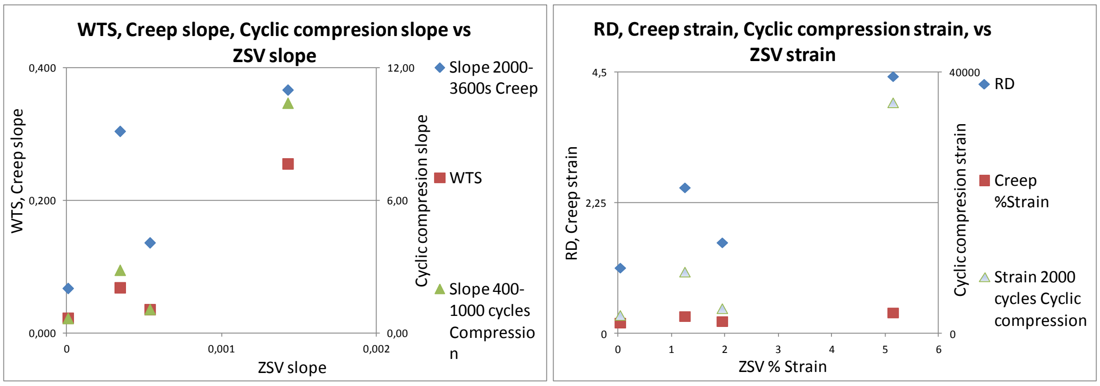



**Figure 10. Relations between Wheel tracking mix test (WTT), cyclic compression mix test (CCT) Creep test, and binder creep test.**

### 3.4 Relationship between MSCR binder test and creep mix test.

A linear dependency between the elastic recovery of the binder, measured as a recovered strain percentage upon MSCR test, and the mixture elastic recovery from the Creep tests, has been found, with a good correlation. Furthermore, the rut depth parameter from the wheel-tracking test decreases exponentially with the elastic recovery of the mixture. Then a higher elastic character of the binder provides for a better resistance to rutting. Nevertheless, with respect to the non-recovered part of the Compliance, which could be envisaged as responsible for the accumulation of strain, a good agreement was found for the binders and the mixtures, except for the crumb rubber case. This could be explained by the lower penetration of this binder. Thus, the elastic recovery is ascertained to better correlate binders and mixtures rutting performance (see table 10 and figure 11).

**Table 10- Mix properties: Creep test calculated Recovery (%), non-recovered Compliance and WTT Rut depth. Binder properties: MSCR recovery RE (%) and non-recovered Compliance.**

| | Neat 50/70 | CRMB | PMB | hvPMB |
|---|---|---|---|---|
| **Creep Test Recovery %** | 26,3 | 37,0 | 52,7 | 66,1 |
| **Creep Test Jnr*10^5, 1/Pa** | 2,620 | 1,838 | 0,943 | 0,535 |
| **RD WTT, mm** | 4,436 | 2,519 | 1,571 | 1,165 |
| **MSCR Recovery %** | 1 | 15 | 40 | 82 |
| **MSCR Jnr, 1/Pa** | 4,524 | 0,396 | 0,618 | 0,084 |

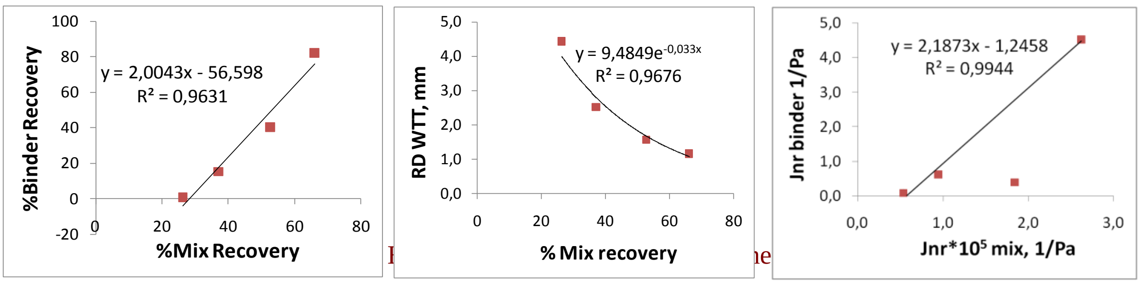


**Figure 11. Representation of Mix properties (Creep test calculated Recovery (%), non-recovered Compliance and WTT Rut depth) versus binder properties (MSCR recovery RE (%) and non-recovered Compliance).**

## 4. CONCLUSIONS

Under the conditions of tests performed and the type of mix chosen and binders used, a relation has been found between wheel tracking tests cyclic compression and Creep test. Obviously, it is necessary to extend the study to more mixes and conditions to check if this correlation is valid and enforceable.
Although the wheel tracking is running in the current specification of asphalt mixes, the cyclic compression test is perfectly valid to evaluate the resistance to permanent deformation of a mixture, which is very useful in research work and development of new binders and mixtures, because of the simplicity of the test.
The creep test also maintains a certain relation in permanent deformation with the other trials, although the test conditions vary significantly, at least for the stress application.
Within the tests, it can be clearly seen that the polymer modified binders and crumb rubber binder have a better resistance to permanent deformation than the conventional binder.
Linear relationships are emerging between permanent deformation testing of mixtures and binders, but a deeper work has to be done in order to consolidate this knowledge.
Of all the observed properties, it follows that there is some relationship between tests of asphalt mixes with bituminous binder tests, but also there are a few conflicting points, especially concerning the crumb rubber binder, possibly due to the internal structure of this product, where a portion of the solid rubber particles are not fully incorporated into the bitumen, and to a lower penetration of this binder, which is also responsible for a better resistance to rutting.

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