Performance control of bituminous mixture with a high RAP content

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ABSTRACT

To conserve natural resources and reduce greenhouse gas emissions, the use of Reclaimed Asphalt Pavement (RAP) becomes essential. In order to allow an increase of the RAP content in our bituminous mixtures without affecting either sustainability or the mechanical performance, a lot of research is conducted by the road building companies. A key point lies in a thorough knowledge of the bituminous mix (physico-chemical properties, homogeneity) obtained by blending new and aged bitumen (i.e. recovered bitumen coming from the RAP).These parameters will be affected by the mode of incorporation of RAP and therefore the type of mixing plant.

At the same time, new techniques are being developed to reduce the temperature at which asphalt concretes are produced, from 30 to 50°C. This decrease in temperature directly affects the viscosity of the bitumen and therefore also the kinetic of remobilization (bitumen blending). The simultaneous goal of increasing the rate of RAP and reducing production temperature leads to technical limitations undefined to date.

Through some examples, this paper presents a methodology to describe the remobilization of different bitumen, to predict the mechanical properties of recycled asphalt, to adjust the asphalt concrete parameters more precisely for future production and asphalt design.

The first part presents a new procedure to describe the blending between the aged (RAP) and the new bitumen. It allows a progressive extraction of the bitumen from asphalt with a specific solvent followed by physico-chemical analysis of these samples (leachate).

In the second part, a rheological model of modulus prediction of the asphalt concrete specifically developed from the rheological properties of the bitumen and volume distribution of the constituents of the asphalt concrete will be presented.

Keywords: Asphalt, Leaching, Reclaimed asphalt pavement (RAP) Recycling, Rheology, Stiffness

1. INTRODUCTION

To conserve natural resources and reduce greenhouse gas emissions, the use of Reclaimed Asphalt Pavement (RAP) becomes essential. In order to allow an increase of the RAP content in our bituminous mixtures without affecting either sustainability or the mechanical performance, a lot of research is conducted by the road building companies. A key point lies in a thorough knowledge of the bituminous mix (physico-chemical properties, homogeneity) obtained by blending new and aged bitumen (i.e. recovered bitumen coming from the RAP**)**.These parameters will be affected by the mode of incorporation of RAP and therefore the type of mixing plant.
At the same time, new techniques are being developed to reduce the temperature at which asphalt concretes are produced, from 30 to 50°C. This decrease in temperature directly affects the viscosity of the bitumen and therefore also the kinetic of remobilization (bitumen blending). The simultaneous goal of increasing the rate of RAP and reducing production temperature leads to technical limitations undefined to date.

Through some examples, this paper presents a methodology to describe the remobilization of different bitumen, to predict the mechanical properties of recycled asphalt, to adjust the asphalt concrete parameters more precisely for future production and asphalt design.
The first part presents a new procedure to describe the blending between the aged (RAP) and the new bitumen. It allows a progressive extraction of the bitumen from asphalt with a specific solvent followed by physico-chemical analysis of these samples (leachate).
In the second part, a rheological model of modulus prediction of the asphalt concrete specifically developed from the rheological properties of the bitumen and volume distribution of the constituents of the asphalt concrete will be presented.

2. IMPACT OF THE HIGH RAP CONTENT IN THE ASPHALT

The evolution of the market which is moving towards the use of higher RAP content in asphalts, on the development of warm production processes resulting in energy saving through lower processing temperatures, raises some questions. In fact, a lower temperature tends to increase the viscosity of the bitumen and therefore decrease the kinetic of remobilization. Studies are performed by road companies in order to better understand these asphalts. Figure 1 presents the disparities related to the homogeneity of the asphalt according to process, time, temperature of production, process of adding reclaimed asphalt.

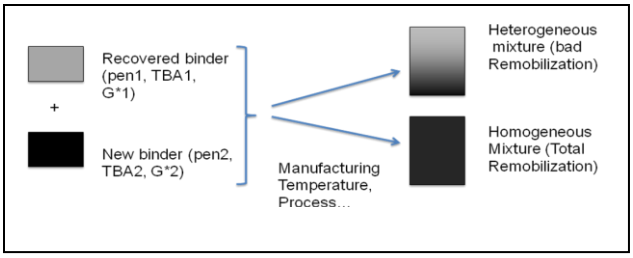


Figure 1: Impact of the RAP introduction in an asphalt concrete on the quality of the mixture

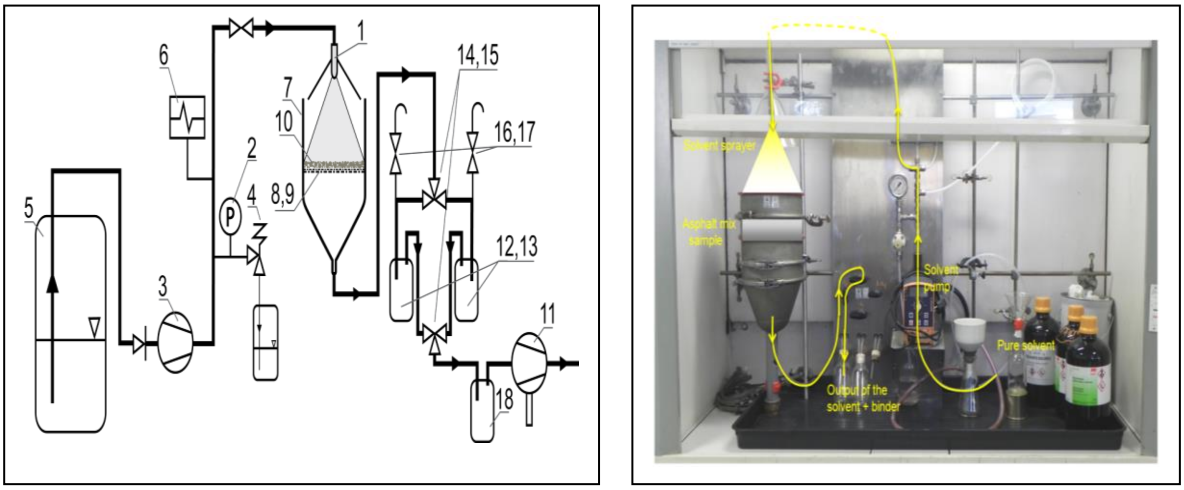
When we increase gradually the ratio of RAP, the physico-chemical properties of the aged bitumen become more and more significant. Aged bitumen has specific characteristics. For its life on the road, the coating bitumen gradually oxidizes according to weather conditions, asphalt concrete design (richness modulus, porosity...). Some compounds of the bitumen oxidize and turn into compounds of higher molecular weight, which significantly modifies its rheological properties [7]. Thus, it is important for the asphalt designer to control the quality of the blending between aged and new bitumen.

3. METHODOLOGY TO QUALIFY THE BITUMEN BLENDING BY INFRARED

An experimental procedure was set up to measure the quality of the asphalt constituents. From studying the available literature on this subject[2,3,4,5], it became clear that we could use an existing method and we proceeded to soak reclaimed asphalt concrete samples in solvent (C_2Cl_4) to obtain several solutions showing the progress of the dissolution. However, because the bitumen dissolved too quickly in the solvents used, this method provided only a limited number of solutions. In addition, the tests used to analyse the solutions required that the solvent be separated by evaporation in order to recover the bitumen, and they also necessitated a large quantity of bitumen.

Having examined various other routes [6] we opted for a test based on spraying solvent over a reclaimed asphalt concrete sample to extract the bitumen more progessively, and hence increase the possible number of solutions. A method of chemical analysis by spectroscopy was also developed which required only a small amount of bitumen to analyse the extracted solutions, without the need to extract solvent by heating [7,8]. The ageing of bitumen typically involves the creation of carboxyl (C=O), a chemical function produced by the interaction between the bitumen and the oxygen in the air. This chemically oxygenated band is detected by infrared spectroscopy at wavenumber 1700 cm^{-1} (figure 4).

A diagram of the equipment is shown in figures 2 and 3. The system basically consists of a circuit supplying the solvent, a leaching cell where the dissolution takes place and a system for sampling the solutions produced by leaching. “n” samples are recovered over time (“n” will depend on the accuracy expected to evaluate the remobilization) and will be analyzed after adjusting the concentration in each sample.



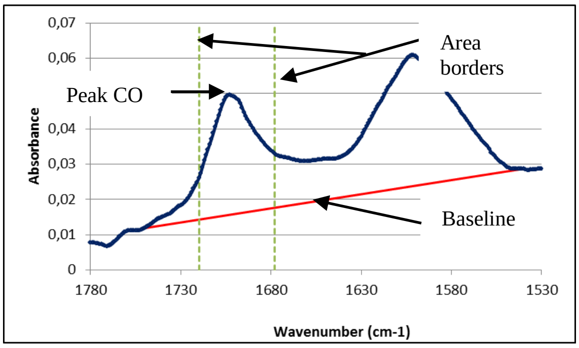
Figures 2 and 3: Experimental extraction system by leaching

(**1**) An air atomising nozzle with a conical screen to protect the user. Solvent flow from this nozzle is controlled by means of a needle gauge (**2**), a single piston pump (**3**) which draws liquid solvent into a tank (**5**). A discharge valve (**4**) and an expansion tank (**6**) ensure the correct load behind the nozzle and a properly adjusted and regular flow rate. The leaching cell consists of a vertical tube (**7**), closed at the bottom in a funnel shape which channels the leach, and covered above by the spray system (**1**) and a steel woven wire mesh screen (**8**) placed on a supporting grid (**9**). The reclaimed asphalt concrete sample (**10**) is placed on this screen. The system for sampling the channelled leach consists of a vacuum pump (**11**) which creates a depression under the screen and draws the collected leach to a sampling station with two storage units (**12** and **13**); filling is controlled by two 3-way valves (**14**, **15**) so that the flasks can be filled in situ. Each flask is associated with a vent-valve device (**16**, **17**) to return it to atmospheric pressure so that it can be easily replaced during the leaching process. A container (**18**) upstream from the vacuum pump acts as a safety device in case the leach should be drawn up accidentally.

The CO Index (carboxyl index) is based on a ratio between the area under 2 references peaks (Methyl and Ethyl function wavenumber 1460 cm^{-1} and 1376 cm^{-1}) and the area under the studying peak -CO (Figure 4). As methyl and ethyl groups are not influenced by oxidation of the bitumen, this CO index can easily characterize the bitumen ageing. The higher is the bitumen oxidation (bitumen aged) the higher is the CO Index.

For asphalt containing aged bitumen from RAP, this CO Index will depend on the remobilization. If the ICO of “n” leachates (obtained by progressive extraction) stays constant, then the bitumen around the aggregates is homogeneous [9]. For each leachate, the conversion degree is determined by the recovered bitumen content / total bitumen content.

Figure 5 shows an analysis of asphalt with 8 samples.



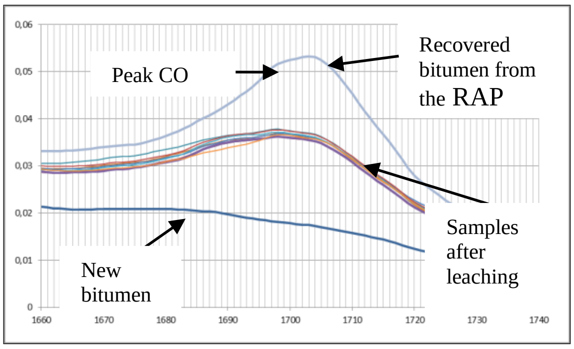


Figure 4: Determination of the peak CO area.

Figure 5: Infrared spectra on samples after leaching.

To compare the "n" leachates, it is important to fix for all the samples, the same limits and the same baseline of each studied peaks (Figure 4).

To qualify the bitumen blending with this methodology, four steps are needed as explained hereafter:

(1) Determination of the CO Index (ICO) : ICO = $A_{CO} / A_{Methyl+Ethyl}$ ($A_{Methyl+Ethyl} = A_{1376cm-1} + A_{1460cm-1}$)
This measure is performed on each leachate. (Figure 6)

(2) A ICO_{ref} is then calculated from the average result of the first samples of leaching, which have a conversion degree inferior to 0,1(Figure 6).

$$ICO_{ref} = \text{Average (ICO)}_{\text{conversion degree}<0.1}$$

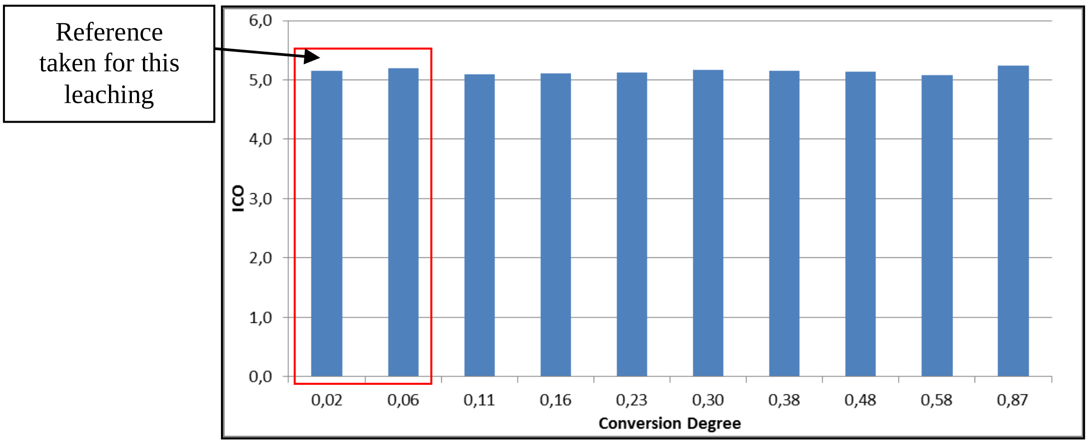
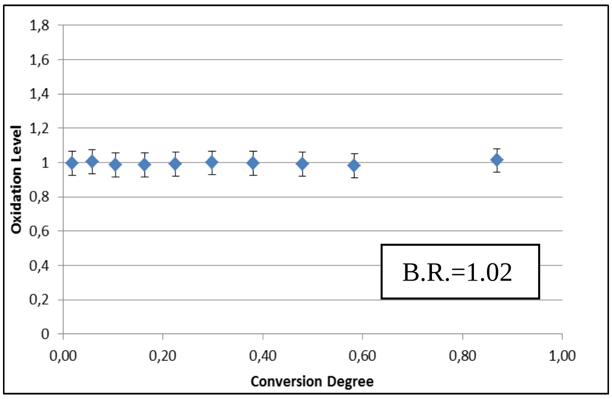


Figure 6: Determination of the ICO for each leachate

(3) For each leachate, the ICO (step 1) is normalized from the ICO_{ref} (step 2) which indicates an oxidation level.

$$\text{Oxidation Level} = ICO / ICO_{ref}$$

All those values are plotted versus the conversion degree (Figures 7 and 8).



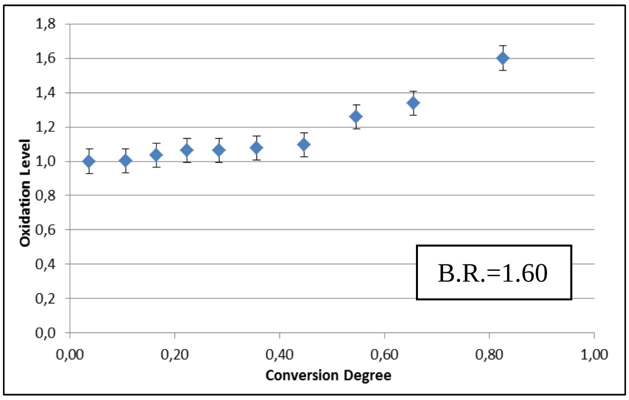


Figure 7: Example of a good remobilization

Figure 8: Example of a poor remobilization

(4) In order to qualify the remobilization between aged and new bitumen of the asphalt, a last index (Blending Ratio, B.R.) is defined as follow :

(5)

B.R.= (Last Oxidation Level)/ (First Oxidation Level)

Taking into account the uncertainty in the measurement, we would consider a Blending Ratio - B.R. >1.30 as a poor remobilization.

The values retained at the first and last oxidation level for the B.R have to be checked with respect to the conversion degree on which they have been obtained.
The first oxidation level should be chosen at a conversion degree far below the percentage of added new binder in the mix and at the lowest oxidation level represented in the beginning of the leaching.
The last oxidation level should be chosen at a conversion degree high enough relatively to the percentage of binder coming from the RAP in the global mix. And if the method is used to compare different B.R of samples from a study the conversion degrees retained for the last oxidation levels in the B.R have to be similar.
Special care on the values is important in the case of asphalt mixes coming from asphalt plants or jobsites because we sometime note an external oxidation at the very low level of conversion due to the storage at high temperature in the industrial process.

4. RHEOLOGICAL MODEL AND MODULUS PREDICTION

To complete our expertise and predict the asphalt concrete properties from the recovered bitumen, a rheological model was established.

4.1 Description

Since the 60s, many articles have proposed model to predict the modulus of asphalt concrete from the bitumen characteristics by introducing the volume distribution of the components in the asphalt [10,11,12,13]. Several articles have re-evaluated these models [14].
T. Bennert [15] proposes a new and innovative method to determine the RAP influences on the mechanical properties of asphalt concrete. This procedure uses the Hirsch model to compare the backcalculated modulus and the measured modulus with the recovered bitumen. The Hirsh model correlates the asphalt dynamic modulus data (E*) to the VMA (voids in the mineral aggregate), the VFA (voids filled with binder) of the asphalt (figure 9) and the recovered bitumen shear complex modulus (G*). According to this theoretical model, if the degree of RAP blending with the new bitumen is homogeneous the calculated dynamic modulus (E* cal.) and the measured dynamic modulus (E* mea.) should be in good accordance with one another.

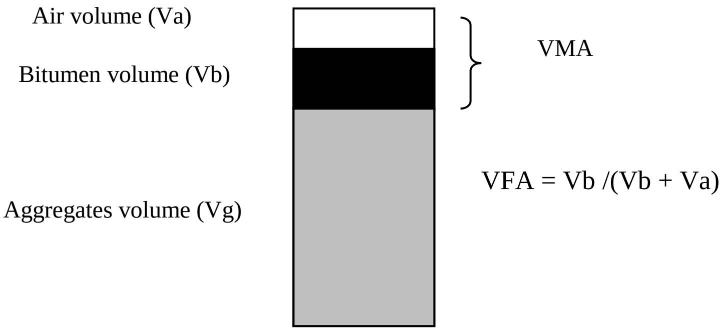


Figure 9: Volume distribution in the asphalt

At the beginning, initial tests were conducted with pure bitumen, to evaluate the Hirsch model. Christensen [13] examined four different models based on the law of asphalt parallel model and chose the model that incorporates the bitumen modulus, VMA, and VFA because it provides accurate results in the simplest form. The suggested model for $|E^*|$ estimation is provided in equations 1 and 2 as follows:

$$|E^*|_m = P_c\left[4,200,000\left(1-\frac{VMA}{100}\right)+3|G^*|_b\left(\frac{VFA*VMA}{10,000}\right)\right]+\frac{(1-P_c)}{\dfrac{\left(1-VMA/100\right)}{4,200,000}+\dfrac{VMA}{3|G^*|_b\,(VFA)}} \quad (1)$$

$$P_c=\frac{\left(20+3|G^*|_b\,(VFA)/(VMA)\right)^{0.58}}{650+\left(3|G^*|_b\,(VFA)/(VMA)\right)^{0.58}} \quad (2)$$

$E^*|_m$ = Dynamic modulus of Asphalt (pounds per square inch).

P_c = Aggregate contact volume.

Weaknesses of the model include a lack of strong dependence on volumetric parameters, particularly at low V_a and VFA conditions. The results obtained show that beyond a dynamic modulus value of about 12000 MPa, the model tends to minimize the modulus values of the asphalt concrete (Figure 10a).

For determined VMA and VFA values, Figure 10b shows the theoretical evolution of the asphalt concrete modulus for different values of G*and confirms the model evolution when the dynamic modulus is superior to 12000 MPa.

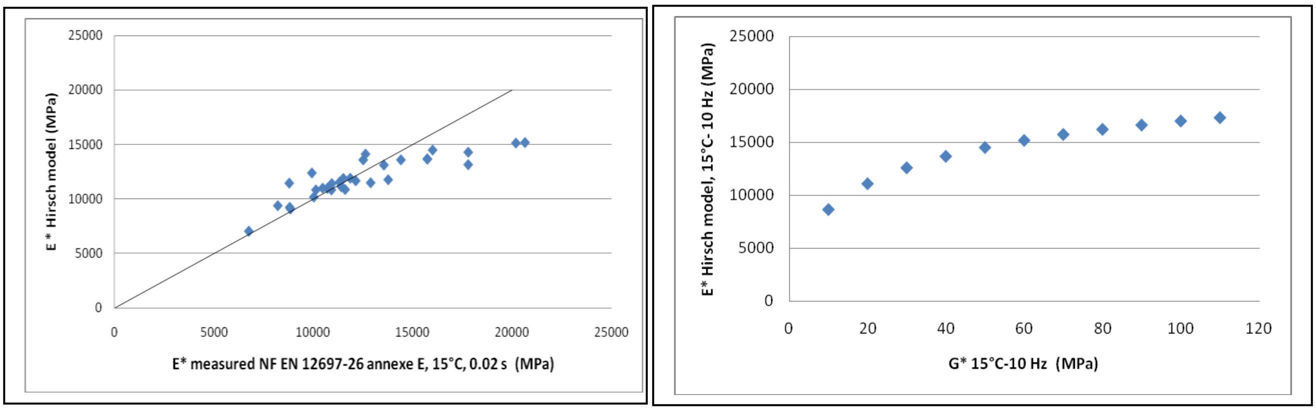


Figure 10 a and b: - Evaluation of Hirsch model

From this approach, and extensive experimental data, a model has been developed by the Eurovia Research Center. Thus, this model allows us to predict the asphalt stiffness modulus (E) from the volume distribution of each component, the bitumen complex modulus (G* neat or recovered) and a coefficient to take more into account the aggregates contribution.

4.2 Model validation from complex modulus of neat bitumen

To validate this model and to evaluate the impact of measurement methods for characterizing the stiffness modulus of asphalt, a complementary study was performed.

Eight bitumen (all unmodified) have been selected: B1 to B8. With these bitumens, 12 asphalts were manufactured (8 with diorite and 4 with limestone aggregates). Each asphalt had a 4.9% bitumen content.

The table 1 presents the main characteristics of these bitumen and the different asphalt mix designs.

	B1	B2	B3	B4	B5	B6	B7	B8
Penetration (1/10 mm) : NF EN 1426	40	37	40	22	26	28	55	57
Rind and Ball Temperature (°C) : NF EN 1427	53.4	53	52	59	57.2	61	49	49.2
Superpave performance grading (PG)	70-22	70-16	70-16	76-16	76-16	76-10	64-22	64-16
HMA with diorite	X	X	X	X	X	X	X	X
HMA with limestone	X		X	X			X	

Table 1: Bitumen characteristics and type of aggregates

Stiffness modulus of asphalts have been performed according to 2 tests:

- NF EN 12697-26 C : Test applying indirect tension to cylindrical specimens (IT-CY) -10°C 124 ms
- NF EN 12697-26 E : Test applying direct tension to cylindrical specimens (DT-CY) – 15 °C, 0.02 s

Figures 11 and 12 present correlations between the complex modulus of bitumen (G*, 15°C/10 Hz) and asphalt stiffness modulus measured according to IT-CY and DT-CY tests.

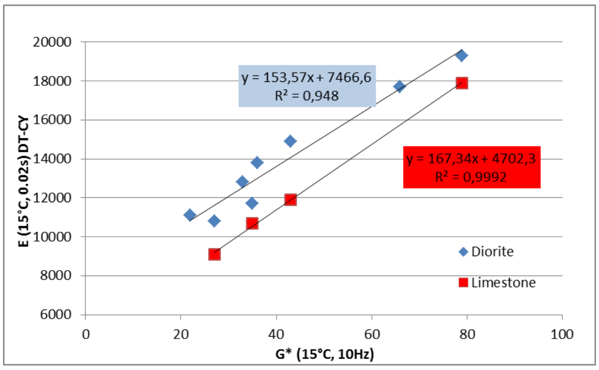


Figure 11: **E (DT-CY) vs G* (15°C, 0.02Hz)**

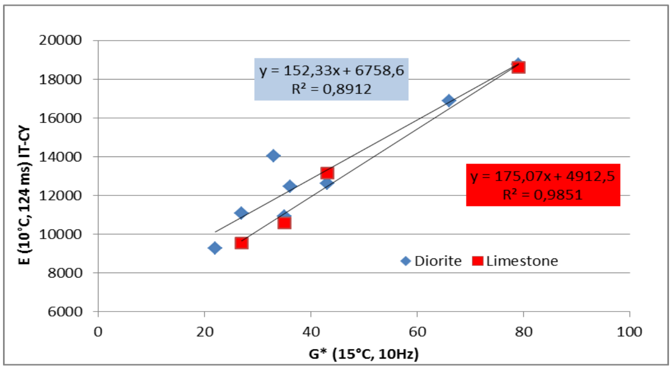


Figure 12: **E (IT-CY) vs G* (15°C, 10Hz)**

Correlation between complex modulus G* (15°C/10 Hz) of neat bitumen and measured stiffness modulus are relevant (R^2 > 0.85) whatever the tests. Nevertheless, we observe especially with DT-CY test, a significant impact on the aggregates'nature. Stiffness modulus measured with limestone aggregates are lower than diorite aggregates.

In order to consider this shift, a specific coefficient has been included in the model the DT-CY to take into account the aggregate nature.

Thus, by calculating stiffness modulus of the 12 asphalts from the improved DT-CY model, figure 13 shows a good correlation with the measured stiffness modulus whatever the type of aggregates.

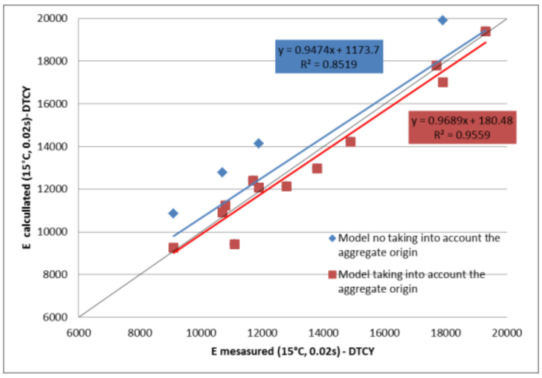
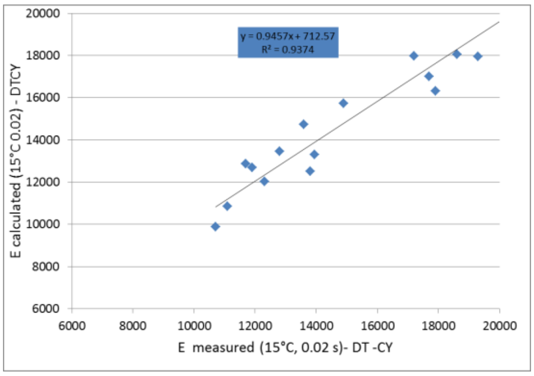


Figure 13: **E calculated (DT-CY) vs E measured according to the model**

4.3 Model validation from complex modulus of recovered bitumen

These rheological models (DT-CY and IT-CY) were modified to fit these correlations from the complex modulus G* of recovered bitumen, VMA and VFA.

Figures 14 and 15 present different correlations between measured and calculated modulus, without RAP, from rheological properties of recovered bitumen and show interesting correlations.



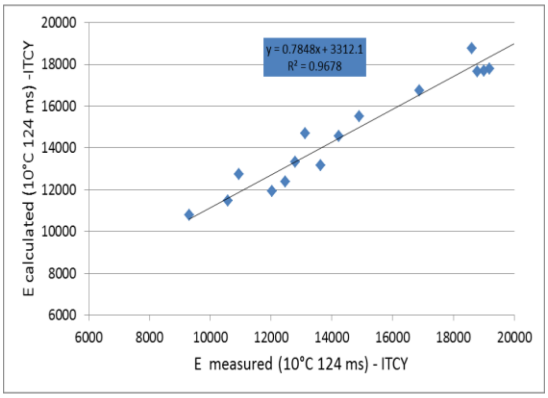


Figure 14: **E calculated vs E measured (DT-CY)** **Figure 15**: **E calculated vs E measured (IT-CY)**

5. COMPARISON BETWEEN BOTH RHEOLOGICAL MODEL AND INFRARED METHOD

These two models (from recovered bitumen) will enable by backcalculation to qualify the asphalt homogeneity.
In fact, complex modulus G* measured on a recovered bitumen involves a good homogeneity between aged and new bitumen : so, if the calculated stiffness modulus E of the asphalt is the same as measured, we can also consider that the bitumen around aggregates is homogeneous.
In order to check rheological model with results of remobilization, the following table presents 5 examples from different jobsites (asphalts with RAP). The table summarizes on the one hand, measured and calculated stiffness modulus by backcalculation, on the other hand, Blending Ratio defined by Infra-Red as seen in §3.

Asphalt Design	B.R.	G* rec. 15°C, 10Hz (MPa)	E measured (MPa)	E calculated (MPa)	Δ (E*$_{\text{mea.}}$-E*$_{\text{cal.}}$)/E*$_{\text{mea.}}$*100 (%)
WMA (20% RAP +4% PmB)	1.04	30.3	7090 (IT-CY)	7700	-8.5
HMA (35% RAP +4% PmB)	0.92	55.7	12665 (IT-CY)	13000	-3
HMA (20% RAP +3% 10/20)	1.02	65.4	14140 (DTCY)	13930	-4.5
WMA (40% RAP +4% 35/50)	1.06	80	11990 (IT-CY)	13770	15
WMA (50% RAP +2.9% 50/70)	1.12	56	12280 (IT-CY)	12600	-2.5
WMA (70% RAP + 35/50)	1.66	59	10025 (IT-CY)	14600	-45

Table 2: Evaluation of the quality of remobilization homogeneity of blending by backcalculation

The results lead to the following comments:

- With B.R. values inferior to 1.15, no significant difference are noted between E measured and E calculated from the Eurovia model.
- The last example with B.R = 1.66 (70% RAP) shows a significant gap between E measured and E calculated > 40%.

The results show a correct matching between both Infra-Red (via Blending Rate) method and backcalculation rheological model to check the quality of a remobilization of an asphalt with RAP. However, more data is needed to improve models, especially data with poor remobilization.

6. CONCLUSION

To improve the proficiency of asphalt production with high RAP content (>20%) for all processes and designs, Eurovia proposes 2 innovated technics, which allows us to qualify bitumen blending between aged (RAP) and new bitumen.
The first one: “leaching blending test” is based on a progressive bitumen recovering. Through IR analyses of leachates, a Carboxyl index (ICO) is calculated. The ICO of the first and the last leaching leads to the determination of the blending ratio (B.R.).
The second methodology: “Modulus backcalculation” is based on a mathematical model which correlates the asphalt stiffness modulus to the recovered bitumen complex modulus. For determined volumetric parameters (VFA, VMA, etc.) and known aggregates, a modulus is calculated and then compared to the jobsite modulus. Good match means good remobilization.
This calculation approach opens a new perspective for asphalt design and for jobsite monitoring.

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