Bituminous emulsions

Consolidated state of structuring grave-emulsion

Abdeltif Belkahia, Thomas Zanini, Caroline Lévêque, Laura Lioux
COLAS

Abstract

A series of investigations were carried out on structuring grave-emulsion. After 10 years of service, a consolidated state of the grave-emulsion is observed. The modulus values measured are higher than those measured after the usual lab curing protocols. This consolidated state is the ultimate state beyond which a stabilization or a drop by fatigue of the modulus can be observed depending on the structure and the traffic. It is proposed here to make an overview of our knowledge of the mechanical characteristics of the structural graves-emulsion in their consolidated state.

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1. INTRODUCTION

In the 1990s, the Colas Group carried out several research projects on emulsion asphalt mixes which led to the development of new manufacturing processes. This research focused on base and wearing courses and resulted in the setting up of experimental worksites. This article deals with structural grave-emulsion. Two of the worksites have been the subject of an innovation charter. A road condition survey was conducted after 18 and 15 years of service. Core samples were taken and a number of mechanical characteristics were measured.

2. THE PROJECTS ON THE RD42[1] and RD22

2.1. Manufacture and laying

The two grave-emulsion (GE) projects conducted in the framework of an innovation charter are located on two county roads, the RD42 (Département of Allier), built in 1997, and the RD22 (Département of Eure et Loir), built in 2003. In both cases, the structural grave-emulsion mixes were manufactured in a cold mix plant (equipped with the E.S.T. process) in the case of the RD42) and laid with a paver with heavy compaction trains that included a vibrating roll and a heavy tyre roller. Table 1 summarizes the main characteristics of the monitored sections of GE.

Table 1. Main characteristics of the grave-emulsion sections

Site	Substrate	Grading of the GE (mm)	Thickness (cm)	Wearing course	Date of works	Change in traffic level
RD42 (Allier)	Flexible structure surface dressing /unbound gravel	0/14	12	Surface dressing	09/1997	T3**=>T2*
RD22 (Eure et Loir)	5cm asphaltic concrete+25cm unbound gravel	0/14	11	6cm semi-coarse asphaltic concrete	07/2003	T5***=>T3

*T2 = 150-300 HGVs/day/direction
**T3 = 50 - 150 HGVs/day/direction
***T5 = 0 - 25 HGVs/day/direction

Figure 1: Photos of the structural grave-emulsion works on the RD42 (1997)

2.2. Results of mix design study

The main results of mix design are summarised in Table 2. Modulus tests were not performed in the laboratory for the RD42.

Table 2: Main results of the study

	RD42	RD22
Duriez test (NF P98 251-4[2])		
R (MPa)	4.6	7.6
r (MPa)	4.1	4.8
r/R	0.89	0.63
% voids	8.5	10.6
Gyratory shear compactor (NF P 98-252[3])		
% voids after 100 gyrations	14.9	-
% voids after 120 gyrations	-	14.8
UMATTA stiffness modulus (NF EN 12697-26 Annex C[4])		
% voids	-	
Modulus measured at 15°C and 25ms (MPa)	-	5100

2.3. Follow-up

The RD42 project was monitored for 5 years on its completion under the terms of the memorandum of understanding. After this, core samples were taken after 6 years and 13 years of service. A final core sample was taken in February 2015, 18 years after the material was laid.

The RD22 project was only monitored for the first 2 years. A final core sample was taken in December 2017, 15 years after the material was laid.

18 samples were taken at each site, 9 in the lane centres and 9 in the wheel paths, with the aim of assessing any difference in the way the grave-emulsion changed according to the level of stress it was subjected to.

All the 150 mm diameter core samples were removed in the conventional manner with water cooling at both sites.

Figure 2: Structural grave-emulsion on the RD42 (covered by a surface dressing) on the left and on the RD22 (covered by a semi-coarse asphaltic concrete) on the right

Figure 3: Core samples of 0/14 mm structural grave-emulsion: RD42 (on the left) and RD22 (on the right)

3. RESULTS OF THE ANALYSIS OF THE CORE SAMPLES

3.1. Voids content

The densities of all the collected samples were measured on a vertical gamma bench[5] (Table 3). Beforehand, the core samples were washed and dried at 18°C and 50% RH for 15 days.

Table 3. In-situ voids content

Section	RD 42	RD22
Mean voids content (%)	11.7 (1 month) 10.3 (6 years) 9.7 (18 years)	13.3 (1 year) 12.7 (2 years) 13.3 (15 years)
Mean voids content (%) – Lane centre - Wheel path	9.4 (18 years) 10.0 (18 years)	13.4 (15 years) 13.1 (15 years)

While the initial voids content after one month was 11.7% for the structural grave-emulsion on the RD42, the mean of the values measured in 2015 was 9.7%, which is very close to the measurements from 2003 (10.3%). On the other hand, the voids content did not change between 1 and 15 years for the RD22. In both cases, it can be seen that the difference in density between the lane centres and the wheel paths remains small. The fairly heavy compaction train allowed this rapid density increase to occur in both the structural grave-emulsion projects.

3.2. Stiffness modulus measured with a UTM

The core samples were sawn to reduce the thickness of the structural grave-emulsion to about 60mm in order to perform the stiffness modulus tests according to the standard NF EN 12697-26 (Appendix C / IT-CY). For the tests, the specimens were conditioned at 10°C and the loading time was 124 ms.

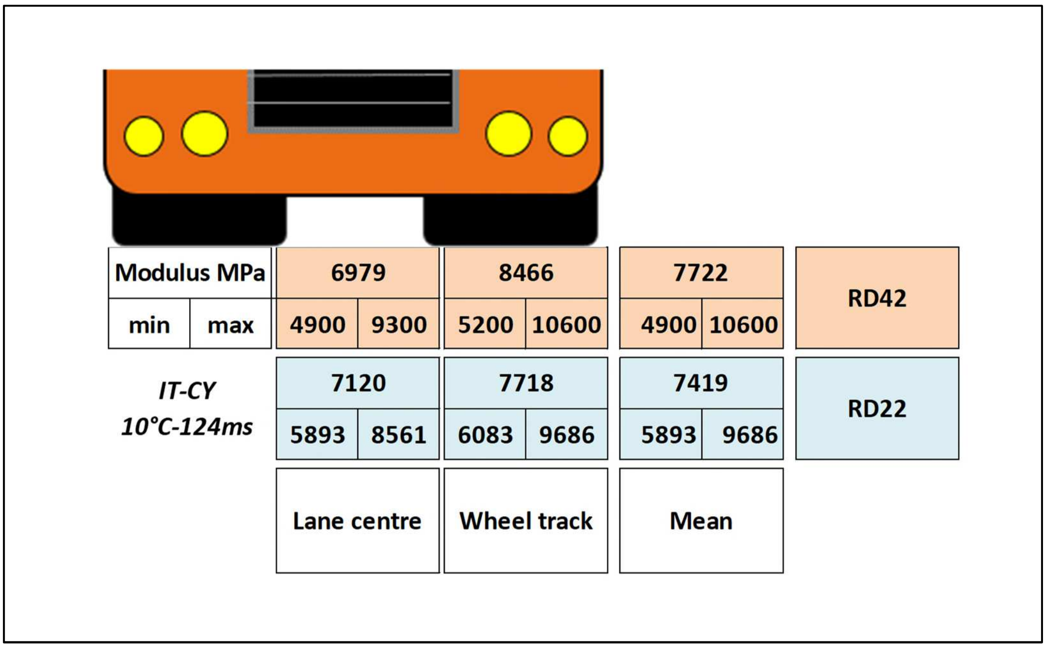

Figure 4: Stiffness modulus of the structural grave-emulsion on the RD42 and the RD22

The stiffness modulus is fairly high for a grave-emulsion. Indeed, it is comparable to that of the former Class 1 road base asphalt (specification > 7000 MPa) and well above the minimum modulus of 2500 MPa required for Class S2 grave- emulsions in the NF P 98-121 standard of October 2014. It is perfectly legitimate to refer to structural grave-emulsion as a structural grave-emulsion. The modulus is higher in the wheel tracks than in the lane centre, with a difference of about 1500 MPa for the RD42, while the 600 MPa difference for the RD22 is negligible. The higher traffic in the wheel tracks has encouraged the curing of the mixture and increased the stiffness of the material. This confirms observations and what we already know about grave-emulsion.

3.3. Change in the stiffness modulus

The modulus of the structural grave-emulsion on the RD 42 has been regularly monitored since it was laid. However, the modulus measurements were made with different test equipment and in different laboratories. It is difficult to compare the stiffness modulus results obtained since 1997, since some tests were carried out with the MAER rheological testing machine at the Lyon C.E.T.E., others with a UMATTA, UTM or 2-point bending machine (CST Colas), as there is no established correlation between these tests for asphalt emulsion mixes.

On the other hand, when the same equipment is used, it is clear that performance improves over time, even after several years of trafficking:

- With the MAER (15°C and 0.02s), there was an increase from the initial value of 2200 MPa after 1 month (1997) to 4600 MPa (2002).
  ⇨ **The modulus doubled in the first five years**
- With the UMATTA and the UTM (10°C-124ms), the modulus increased from 4200 MPa (2003) to 8500 MPa (2015).
  ⇨ **The modulus doubled again in the next ten years**

It is also possible to plot a trend curve. Even if it is not totally rigorous, it was considered of interest to position some points on the same graph in order to have an idea of how the stiffness modulus changes over the entire period of service. The modulus value for a Type S2 grave-emulsion (2500MPa) was reached rapidly, in about one year. This value tripled after 18 years.

Consolidation of the GE is observed in the first 15 years, after which it seems to stabilize.

As far as the RD22 is concerned, structural grave-emulsion already exhibited a very high stiffness modulus for a GE (5100 MPa) in the laboratory study. But this nevertheless continued to increase over time until it reached 7419 in 2018 (+45%), attaining a stiffness level similar to that on the RD42 after 18 years.

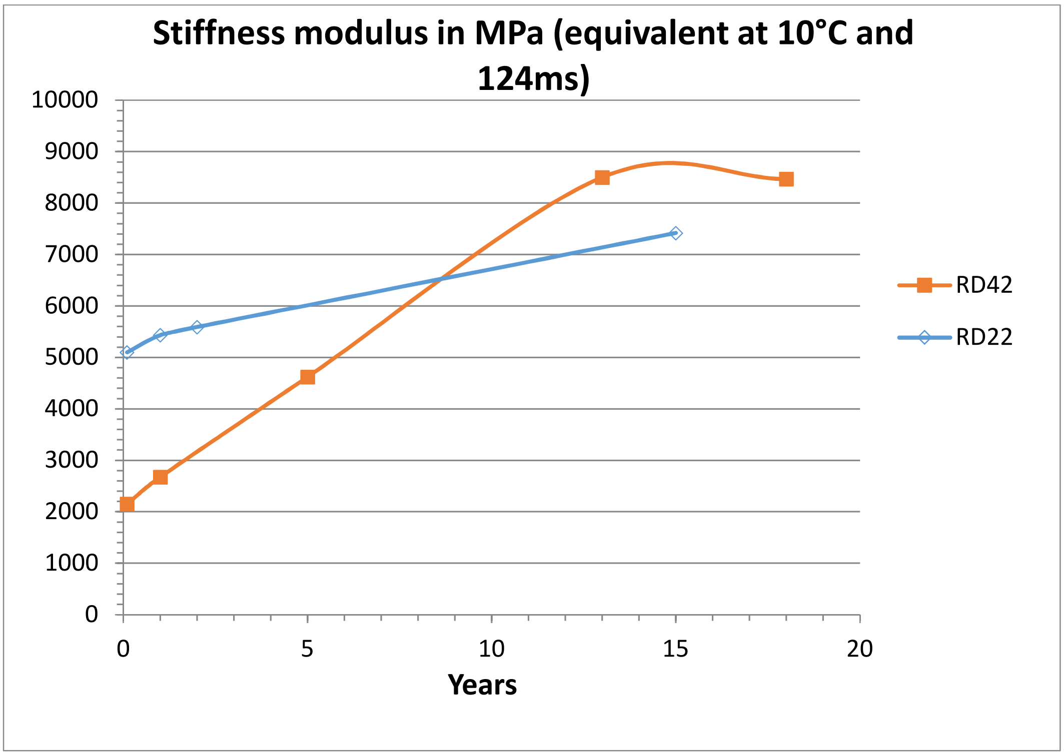

Figure 5: Change in the stiffness modulus of the structural grave-emulsion over time

4. CHARACTERISTICS OF THE RECOVERED BINDERS

4.1. Penetration[6], Softening point[7] ($T_{R\&B}$) and G*[8] measurements on the recovered binder

Binder was recovered in the lane centres and wheel tracks. It should be noted that the asphalt was not dried in an oven at 105°C but at a moderate temperature in a dry atmosphere (18°C/50%). The binder was recovered from the Asphalt Analysator machine. The results obtained for the recovered binders are shown in Figure 6.

	Lane centre	Wheel track	Binder
Pen (1/10 mm)	30	19	RD42
T R&B (°C)	56	62	RD42
Class[t] (EN12591)	20/30	20/30	RD42
G* (DSR) Mpa	34	67	RD42
Pen (1/10 mm)	19	23	RD22
T R&B (°C)	61	59	RD22
Class[t] (EN12591)	20/30	20/30	RD22
G* (DSR) Mpa	57	47	RD22

Figure 6: Characteristics of the recovered binders

The recovered binders have the same characteristics as the binders recovered from Recycled Asphalt Pavement (RAP). Their grade was 20/30 pen. Although the base bitumens used to manufacture the emulsions used in structural grave-emulsions are softer than those used in hot mix asphalt, the in-situ ageing process seems ultimately to result in the same level of hardness.

The bitumen in the emulsion used for the RD42 project in 1997 was sourced from Shell's Berre refinery. Since we did not have a conservatory sample, we used a 2011 sample from the same refinery for comparison in order to assess the ageing of the recovered binder. However, we did not have a sample of an equivalent bitumen for the emulsion used for the RD22.

4.2. Infrared spectrum[9]

Ageing leads to an increase in the presence of molecules resulting from oxidation (sulfoxides, carbonyls), which can be observed by analysing the area of different peaks in the infrared spectrum (Table 4).

Table 4: Analysis of the peaks in the infrared spectrum

	Recovered binder upper part	Recovered binder lower part	Fresh binder (70/100)
Peak area in the band at 1700cm^{-1} (carbonyls)	0.3	0.3	0
Peak area in the band at 1030cm^{-1} (sulfoxides)	3.6	3.0	0.6

As can be seen in Figure 7, the fresh binder plot (70/100 pen from Berre) does not show a carbonyl peak while there is one on the aged binder plots (recovered GE binder from the RD42). In addition, the sulfoxide peak is much more marked on the recovered binder spectrum. Based on the sulfoxide peak, ageing is slightly more intense in the upper part of the GE.

The infrared ageing study confirms the advanced state of ageing of the binder recovered from GE core samples.

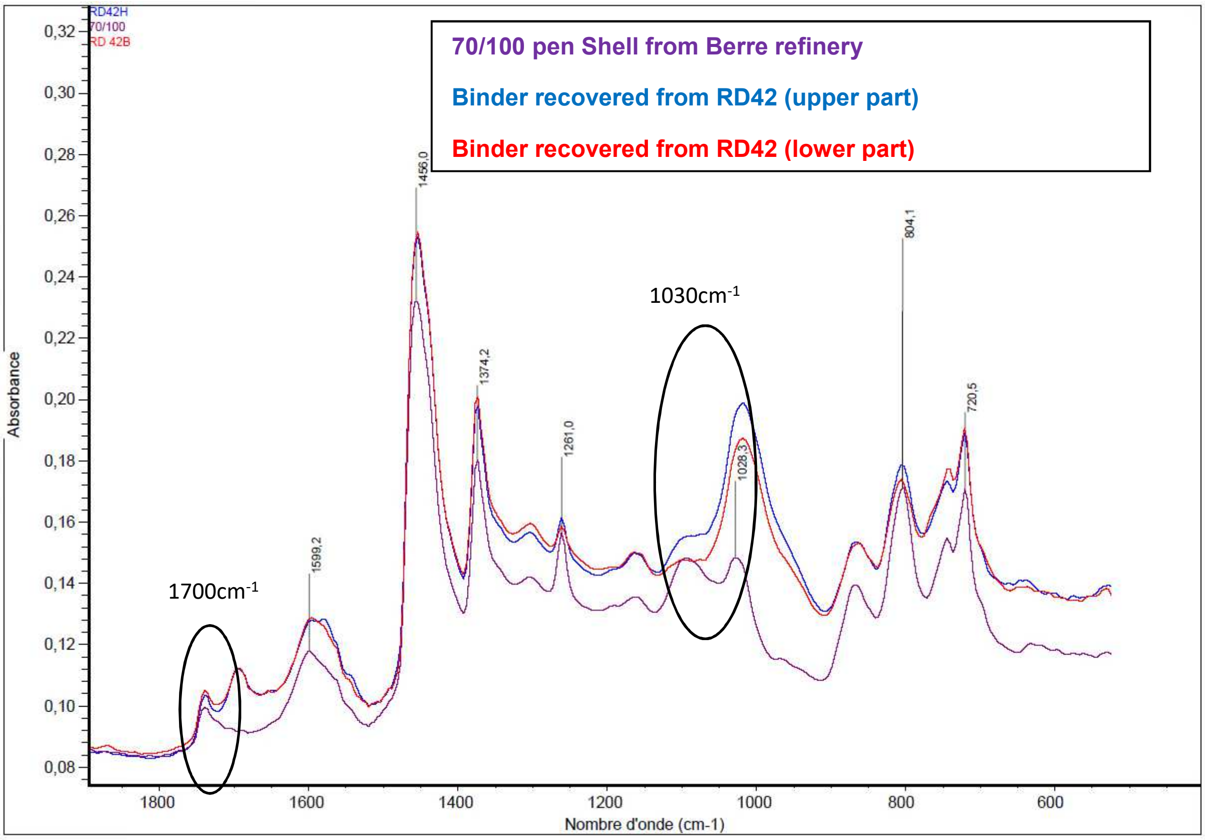

Figure 7: Infrared spectrum of the recovered binders

4.3. Iatroscan chemical composition

Bitumen is made up of two main chemical families, asphaltenes and maltenes, which are in turn made up of saturated and aromatic oils, and resins.

The Iatroscan test involves separating the asphaltenes by dissolving the maltenes in heptane and then determining their chemical composition by thin layer chromatography and flame ionization detection (FID).

Table 5. Chemical composition of the recovered binders

	Binder recovered from the RD42	Fresh binder (70/100)
Saturates (%)	8.3	15.2
Aromatics (%)	45.0	59.8
Resins (%)	23.4	14.3
Asphaltenes (%)	**23.4**	**10.6**
Colloidal index	0.46	0.35

The Iatroscan chemical composition results also show very advanced ageing of the recovered binder with a significant increase in the percentage of asphaltenes compared to the base bitumen. There is also a similar increase in the amount of resins.

The substantial decrease in saturated oils is surprising given that they are deemed to be un-changing.

In the accepted ageing mechanism (aromatics → resins → asphaltenes), the second stage is slower than the first.

5. PAVEMENT CONDITION SURVEYS

5.1. Pavement condition survey on the RD42

To supplement the monitoring of mechanical performance in the laboratory, a pavement condition survey campaign was carried out in 2015 using the Road Eagle Colas (REC) and the Super Heavy Weight Deflectometer (SHWD).

The REC (Figure 8) is a high-speed measuring device for evaluating transverse pavement deformations using a LASER profilometer and for detecting the presence of cracks using a high definition imager. Post-processing of the HD images is conducted to classify cracks into different categories (longitudinal, transverse, crazing) and according to their position.

Figure 8: The Road Eagle Colas

The survey conducted on the RD42 shows that the pavement is in good general condition: cracking has only been detected over a length of 500m and the small radius ruts are still of limited size (≤ 8 mm) (Figure 9).

Figure 9 part of the route condition survey diagram provided by the REC on RD42.

The SHWD, a falling weight deflectometer, replicates a load that is representative of the passage of a heavy vehicle and measures the deflection basin generated by this load over a length of over 2m. Analysis of the deflection basins using the Alizé LCPC software permits the evaluation of the bearing capacity of the subgrade level and the modulus of each of the pavement layers (see Figure 10). It should be noted that in this analysis, the load exerted by the SHWD is modelled as a static, circular load, applying uniform pressure on the pavement.

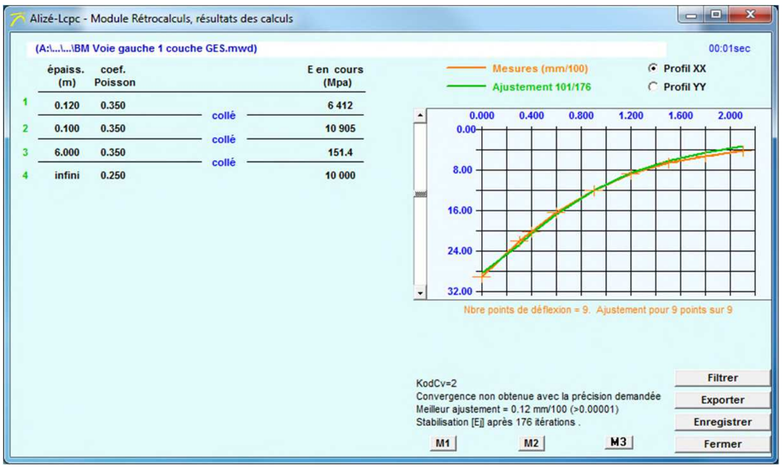

Figure 10: Example of results obtained by back-calculation from the SHWD measurements on the median strip

The measurements on the RD 42 were made on both lanes, alternately on the centre lines and on the right-hand traffic lane. The modulus values at 9°C and 30 Hz (the measurement conditions) obtained for each layer of material are shown in Figure 11.

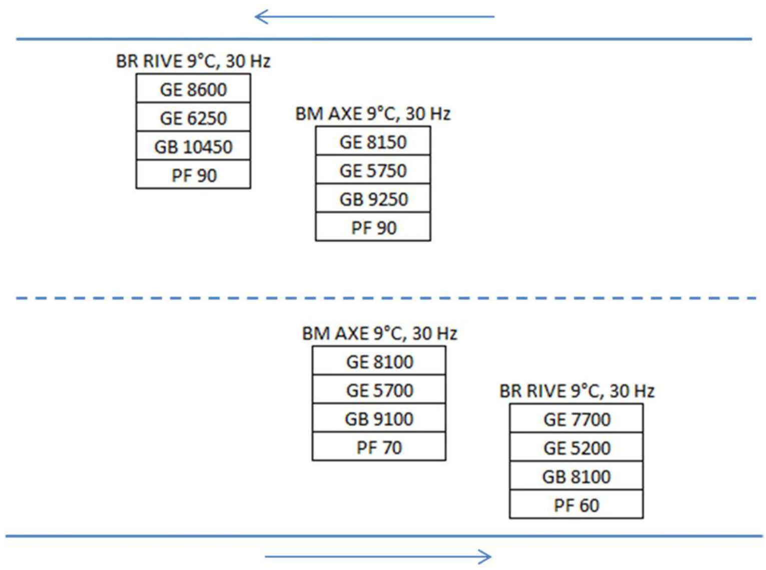

Figure 11: Mean moduli at 9°C and 30 Hz based on the SHWD tests according to the layer of material and the position on the road.

Assuming that the master curve of the structural grave-emulsion is similar to that of a road base asphalt, the pavement materials have moduli at 15°C and 10 Hz varying from:
5,100 MPa to 6,600 MPa for the road base asphalt.
4,800 MPa to 5,400 MPa for the structural grave-emulsion in the upper part of the pavement.
3,300 MPa to 3,900 MPa for the structural grave-emulsion in the lower part of the pavement.

When comparing the moduli after 18 years at 15°C and 10Hz measured by the UTM and the SHWD tests, the laboratory values are about 1,000 MPa higher. However, this difference is not significant in view of the difference in the methods applied.
The results of the SHWD measurements confirm that the modulus of structural grave-emulsion is considerably higher in the upper than in the lower part of the pavement. This observation supports the view that the curing of grave-emulsion is favoured by the compressive stresses generated by heavy traffic in the upper part of the pavement.
We can also note that the modulus of the structural grave-emulsion in the upper part of the pavement is tangential to that of the Road base asphalt in situ.

A long-lasting technology
The results from this study, based on the monitoring of the site over time and a sophisticated analysis after 18 years, demonstrate the durability of structural grave-emulsion over a period of 18 years and probably even longer, under the conditions at the RD 42 site.

5.2. Pavement condition survey on the RD22

The RD 22 was tested after 15 years of service in 2017. This site included 2 areas on which the structural grave-emulsion had been used. The first zone, covered with 4 cm of cold asphaltic concrete, was in poor condition at the time of testing. The second, covered with a 6 cm layer of semi-coarse asphaltic concrete, showed no external signs of damage. Below, we will focus in particular on the results obtained in the second zone.

The core samples taken from Zone 2 revealed an 8.5 cm layer of structural grave-emulsion resting on old cracked asphalt. Analysis of the deflection bowls measured with an SHWD on this structure was done by artificially incorporating this old asphalt into the subgrade. As the results of the measurements were not differentiated according to their position, it would be impossible to analyse the possible difference in behaviour between the lane centres and the wheel tracks. The modulus values at 8°C and 30 Hz (measurement conditions) obtained for each material layer are shown in Figure 12.

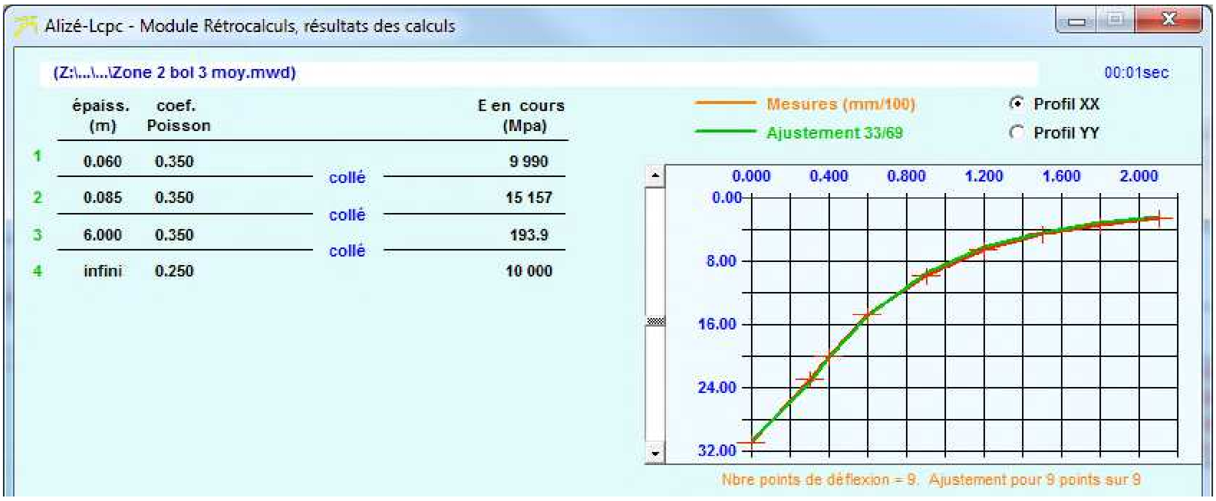

Figure 12: Modulus values at 8°C and 30 Hz (measurement conditions) obtained for each material layer

If we assume that the master curve of the Structural grave-emulsion is similar to that of a road base asphalt, the moduli of the pavement materials at 15°C and 10 Hz vary from:
5,100 MPa to 6,600 MPa for the Road Base Asphalt.
4,800 MPa to 5,400 MPa for the structural grave-emulsion in the upper part of the pavement.
3,300 MPa to 3,900 MPa for the structural grave-emulsion in the lower part of the pavement.

The back-calculated modulus based on the SHWD tests for structural grave-emulsion matches the highest values measured in the laboratory after 15 years. These results confirm the high mechanical performance and durability that Structural grave-emulsion can achieve.

A long-lasting technology
It should be noted that on this site the structural grave-emulsion was laid directly on a substrate with moderate bearing capacity in the framework of pavement strengthening (110 MPa after deduction of the modulus value of the substrate to take account of the frequency of loading). This means that the grave-emulsion has been subjected to tensile stress during its service life (see Figure 13).

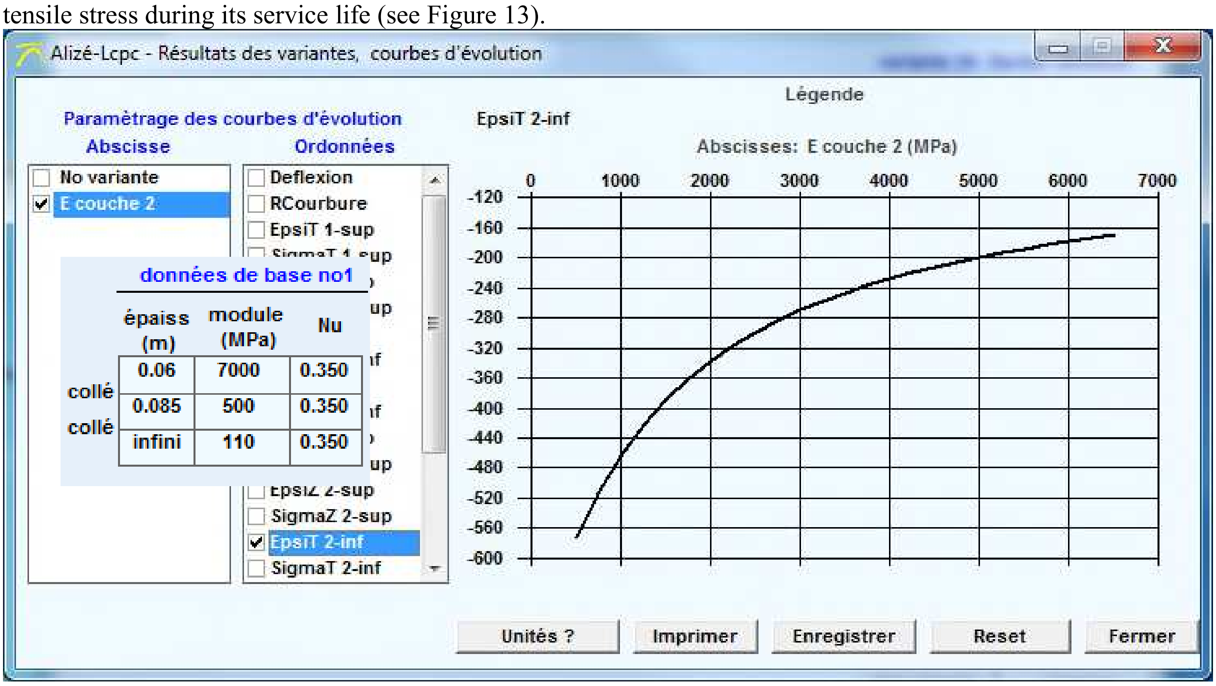

Figure 13: Tensile deformation at the base of the structural grave-emulsion versus its modulus.

After 15 years of repeated tensile loading, the structural grave-emulsion is still in good condition. Thus, in addition to exhibiting high moduli relatively quickly, it is obvious that Structural Grave-Emulsions are also capable of withstanding fatigue even if their fatigue strength has yet to be quantified.

5.3. Conclusions from the pavement condition surveys

The main lessons learned are:
The density increases in early years even between the wheel paths
There is a substantial and progressive increase in the modulus of structural grave-emulsion in the first twelve years after which the values become stable.
In the long term, the behaviour under repeated loading of structural grave-emulsion is similar to that of conventional grave-bitumen.
The characteristics of the binder change as a result of ageing in a similar way to those of a hot mix.
Mechanical loading increases the stiffness of the mixture.
The product exhibits very good performance t when covered just with surface dressings for eighteen years: no cracking, subsidence or significant rutting.

These very positive results confirm the value of these products for maintenance or structural strengthening. Modelling needs to take better account of damage laws in order to optimise the design of structural grave-emulsions. Gaining an understanding of the damage laws in question is still an ongoing topic of research.

6. CONCLUSION

This review of the behaviour of structural grave-emulsions has been highly instructive. After 15 or 18 years of service, structural grave-emulsion is in a consolidated state that has the mechanical characteristics of a road base asphalt. This cold emulsion road base layer has perfectly performed its maintenance and strengthening role. Structural grave-emulsions currently account for a small proportion of the total volume of grave-emulsions produced, most of which is used for reprofiling. This feedback should convince us of their suitability for use as a road base layer. The current design method, which treats them as an unbound gravel, does not reflect the performance of the structure on the RD 42. A suitable design method could help the development of structural emulsion mixes.

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