EFFECT OF RECLAIMED ASPHALT PAVEMENT ON CEMENT TREATED MATERIALS FOR ROAD BASE LAYER

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ABSTRACT

In the French national research project named "RECYROUTE", a high-performance composite material consisting of reinforced compacted cement concrete (RCC) including reclaimed asphalt pavement (RAP) has been investigated for use in base layers of heavy traffic roads. This composite material, referred to as FRCC®, is used in combination with an asphalt overlay. Steel fibers are included in FRCC® in order to minimize crack width. RAP is added to save material and comply with sustainable development, especially in the case of in-situ treatments. FRCC® performances with different RAP and performances of a reference material ERTALH® "RAP treated with cement" were studied at laboratory. The viscous properties of both bitumen and mixes with RAP are obtained from complex modulus test. It is observed that some viscous properties of the bitumen are still present in the composite studied. The results show that the Time-Temperature Superposition Principle is respected the new composite. Furthermore, a relationship between bitumen and mixes behavior is observed. The ENTPE Transformation, generally used to link the behavior of bitumen to the behavior of mastic and asphalt concrete, is then validated for cement treated materials containing a small part of bitumen (from RAP). In this paper, results and analyses from laboratory tests are presented.

Keywords: Reclaimed Asphalt Pavement, Viscous properties, Roller Compacted Concrete, 2S2P1D model, Complex modulus

1 INTRODUCTION

This research is a part of a French National Research Agency (ANR) project named “Recyroute”. This 2.3 million-euros project intends to propose a new high performance and long-lasting pavement using Steel fiber reinforced roller compacted concrete as a road base layer including reclaimed asphalt pavement (RAP). Pavement design, material properties characterization and road structure calculation are part of the developments to be conducted among the involved teams: Eiffage Travaux Public, University of Lyon/École Nationale des Travaux Publics de l’État (ENTPE), Laboratoire Central des Ponts et Chaussées (LCPC), Laboratoire Régional de l’Ouest Parisien (LROP), Chaussée Technique et Innovation (CTI), Paris City and Autoroutes Paris Rhin Rhône (toll highways company, EIFFAGE subsidiary). Both in situ and laboratory studies are performed. The new aspect introduced in the program is the analysis of the use of different RAP contents (between 0% and 80% of the aggregate mass).
The first step of the program is to characterize the selected formulations to be used on experimental sites by a laboratory study divided into two parts. First part of laboratory study aims at determining the classical mechanical properties were obtained from some standard tests in order to define parameters of composite materials to be placed as a road base layer. These parameters were used for the pavement design. These results made subject of two previous publications. It is shown that the introduction of bitumen present in RAP modify the mechanical performances. All strengths and the stiffness modulus decrease when adding RAP same with a small bitumen content [1,2]. Then a more comprehensive thermo mechanical test (complex modulus) is made to determine the viscous properties of composite mixes and the effect of the RAP content in mixes. First results on complex modulus show that the Time-Temperature Superposition principle is valid for mixes containing RAP. As observed for standard mechanical test a decreasing of stiffness modulus also decrease when using RAP.[2]
The following sections present the tested materials, the testing device and procedure, the obtained results and discussions about visco-elastic properties of cement treated materials with different contents of RAP. Finally a comparison between the bitumen behavior and that observed on mixes containing RAP is made.

2 MATERIALS

Two kind of mixture is used in this study. The first one is a roller compacted concrete reinforced with steel fiber. The hydraulic binder content is fixed at 12% in mass of granular part. It corresponds to about 280kg/m³ of concrete when used with natural aggregate only. The chosen hydraulic binder - is composed of 52% clinker, 21% fly ash, 6% slag and 21% limestone. The plasticizer admixture is fixed at 0.5% in mass of hydraulic binder. Fibers are added to minimize crack opening. The chosen steel fibers are 6cm long and 0.75mm diameter (Dramix 80/60 BN from Beckaert Company, Figure 1). They are added during the final mix process and are not considered for concrete design.

Figure 1 : Dramix 80/60 BN fibers used in FRCC® materials

As mentioned previously, the innovative aspect is the use of RAP as an aggregate. Two RAP contents are studied. The contents are fixed: 40% and 80% by weight of the aggregate (respectively 36% and 70% of aggregates+ hydraulic binder mass). The obtained materials are named F36%RAP and F70%RAP (see Table 2).
Another well known material ERTALH® is used as reference to evaluate the properties of the new composites investigated. This reference material is a reclaimed asphalt pavement treated with a road hydraulic binder. It’s made with the same hydraulic binder (the content of which being fixed at 5% by weight of the aggregate) and contains 70% of the same RAP (in mass of aggregates + hydraulic binder). The obtained material is named E70%RAP (see Table 2).
Table 1 presents the properties of RAP used. RAP bitumen content was obtained following the standard NF EN 12697-1. A penetration test, as well as a ring and ball test were done according to standards NF EN 1426 and NF EN 1427 on the bitumen extracted by distillation NF EN 12697-3. Grading curves of all used aggregates (alluvial sand 0/4 Gurgy, crushed sand 0/6 Crain, crushed gravels 6/14 Crain and RAP) are presented in Figure 2a).
To obtain the final mix design the following procedure is used. First the cement content and grading envelop are fixed. Cement content is fixed at 12% in mass for composite Fx%RAP and at 5% for E70%RAP. Then the aggregate fractions are adjusted to respect the grading envelop specification. The water content is then determined from the modified Proctor test NF EN 13286-2 and immediate bearing ratio (IPI) test NF P 94-078 on materials without steel fiber. Figure 2

presents Proctor and IPI curves and the selected water content of each mixes. Finally Table 2 gives the mix proportions (without fiber) of the tested materials.

Table 1 : Properties Of Used Reclaimed Asphalt Pavement

RAP	Aggregates	Bitumen		
Origin	Size (mm)	Content (%) NF EN 12697-3	Penetration at 25°C (1/10 mm) NF EN 1426	Ring & Ball temperature (°C) NF EN 1427
Yonne	0-14	3.51	12	69.4

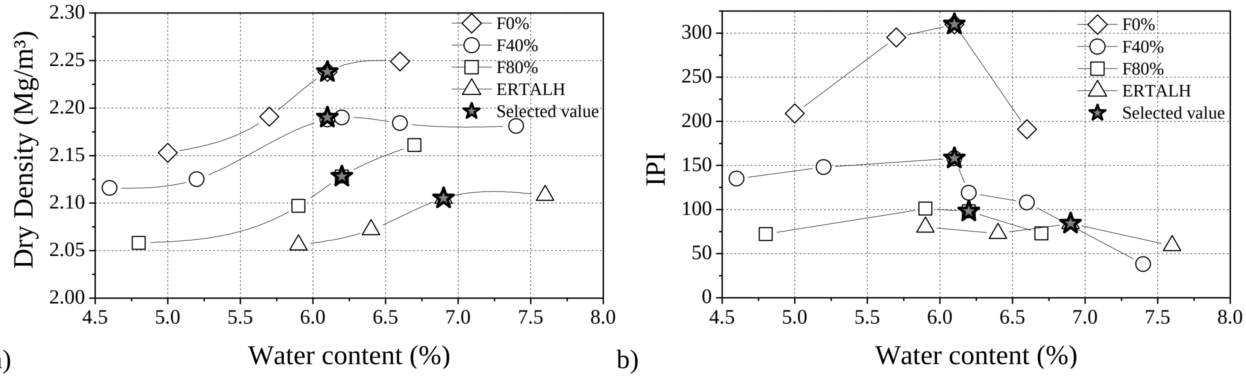

Figure 2 : a) Proctor and b) IPI curves and selected water content values of each mixes [1]

Table 2 : Mixes Component (Without Fiber)

Material or Properties	F36%RAP	F70%RAP	E70%RAP
Alluvial sand 0/4 Gurgy	20.0%	18.0%	0.0%
Crushed sand 0/6.3 Crain	20.0%	0.0%	25.0%
Crushed gravel 6/14 Crain	12.0%	0.0%	0.0%
RAP (0/10 Yonne enrobés)	36.0%	70.0%	70.0%
Hydraulic binder (FPL2)	12.0%	12.0%	5.0%
Total	100.0%	100.0%	100.0%
Additive[1] (Sika)	0.06%	0.06%	None
Water content[2]	6.2%	6.2%	6.9%
Bitumen content (%) from RAP	1.26	2.46	2.46
Dry Density	2.190	2.128	2.105
water/cement ratio	0.516	0.516	1.380

[1] by weight of concrete
[2] by weight of aggregates

For each material, a rectangular plate (15cm x 40cm x 60cm) is compacted with the French asphalt concrete MLPC compactor. Specimens used for complex modulus tests are cored under direction of compaction (Figure 3). All specimens are stored in regulated thermal room at 20°C before test.

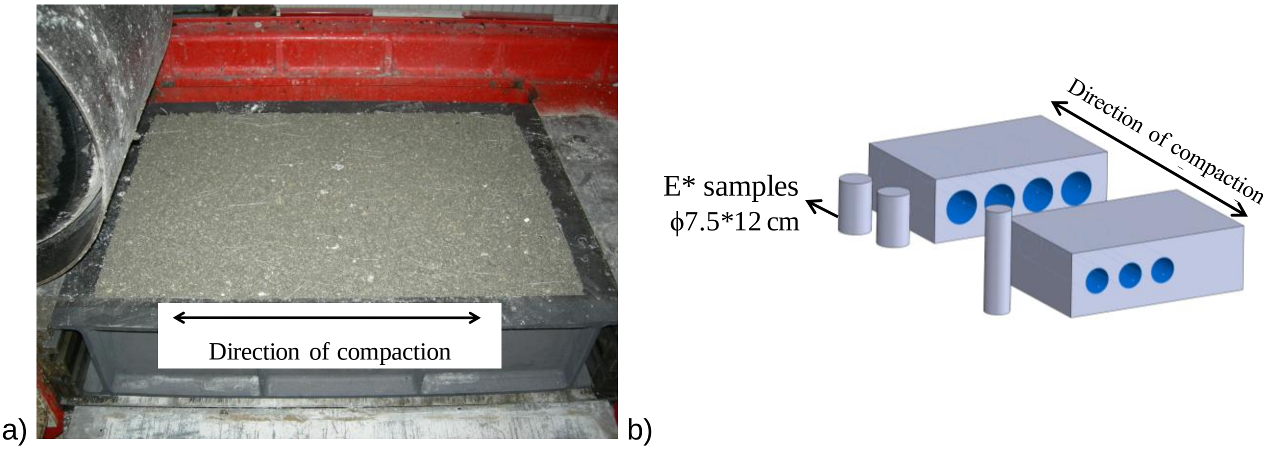

Figure 3 : a) MLPC Compactor with mixes and b) Sampling pattern

3 TESTING DEVICES

Complex modulus of mixtures was measured with tension/compression test. Binder complex modulus tests were carried out by using the Dynamic Shear Rheometer (DSR). All tests procedures are described in this section. Both complex modulus tests are performed on mixes containing RAP and the bitumen extracted from these RAP to determine which part of the bitumen behavior is present in the composite material studied. Visco-elastic properties are obtained from two different tests.

Visco-elastic properties of mixes were obtained by a tension/compression (or push/pull) complex modulus test. The principle of this test consists in measuring axial and radial strains as well as axial stress (radial stress is nil), when sinusoidal loading is applied on a cylindrical specimen of cement treated materials. The tested specimens are 120 mm high and 75 mm in diameter. Axial stress (σ_1) is obtained from a load cell, while axial strain in direction 1 (ε_1) are obtained by three extensometers and radial strain in direction 2 (ε_2) are deduced from non-contact transducers (Fig. 4). For the complex modulus test, cement treated materials are loaded at 7 different frequencies (from 0.01 to 10 Hz) and 8 temperatures (from -15°C to 45°C).

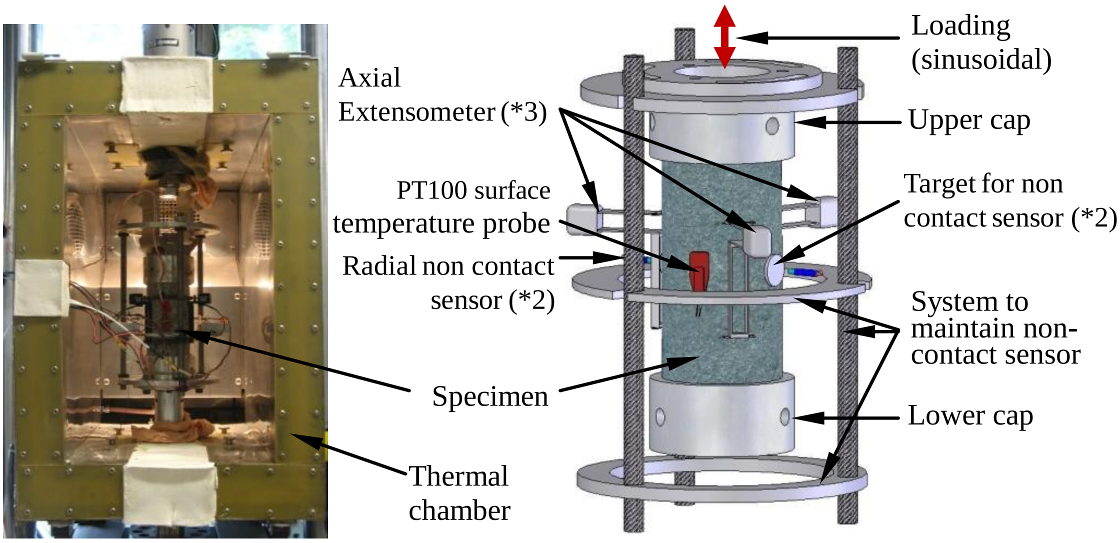

Figure 4 : Experimental device used for tension-compression (push-pull) test, in the linear domain [2].

The Dynamic Shear Rheometer (DSR) (Fig.5) device is used to test the bitumen extracted from RAP under cyclic loads. Complex modulus test is made according the standard NF EN 14770, 2006. It gives the shear complex modulus and the phase angle. During test, a fixed sinusoidal shear stress is applied and the response of the material is measured. Solicitations are made at a range of frequencies (from 0.01Hz to 30Hz) and a range of temperature (from -30°C to +70°C).

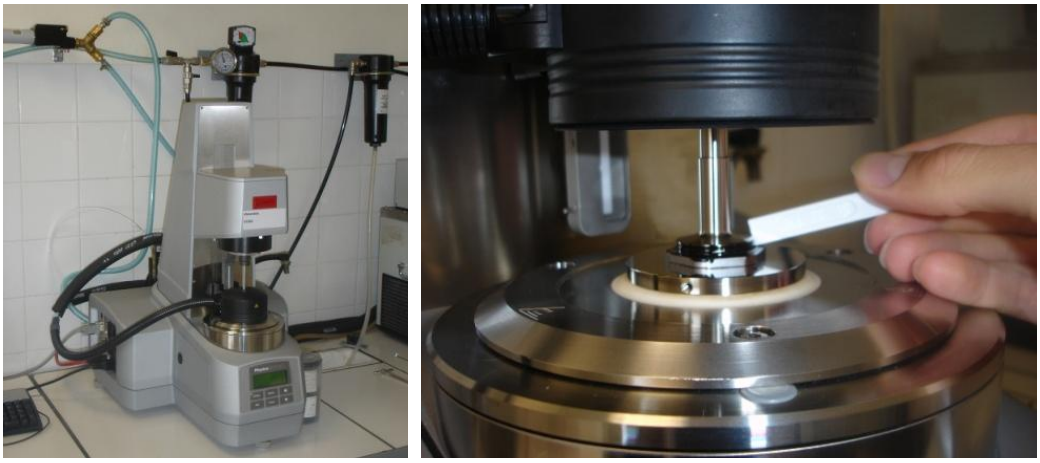

Figure 5 : Dynamic Shear Rheometer device used for shear complex modulus tests on bitumen

4 2S2P1D VISCO-ELASTIC RHEOLOGICAL MODEL

Before giving the results and analysis, the authors present an alternative general rheological model 2S2P1D (generalization of the Huet-Sayegh model) valid for both the bituminous binders and mixtures. This general model is based on a simple combination of physical elements (spring, dashpot and parabolic element) (Figure 6).

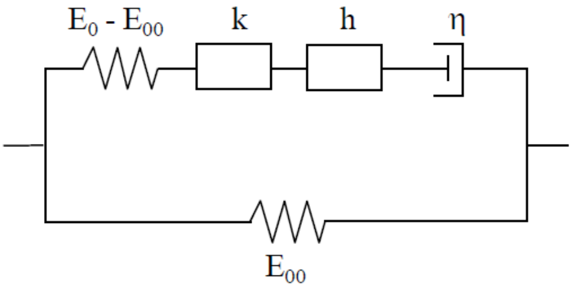

Figure 6 : Representation of the general 2S2P1D for both bituminous binder and mixes, h and k are two parabolic creep elements.

The Huet-Sayegh model [3] has been adapted by adding a linear dashpot in series with the two parabolic elements and the spring of rigidity E_0-E_{00}. Thus, in particular for binders, for which E_0=0, the model is equivalent to a linear dashpot at very low frequency. At a given temperature, the 2S2P1D [4; 5] model has 7 constants and its complex modulus is given by the following expression:

$$E^{*}_{2S2P1D}(\omega) = E_{00} + \frac{E_0 - E_{00}}{1+\delta(i\omega\tau_E)^{-k} + (i\omega\tau_E)^{-h} + (i\omega\beta\tau_E)^{-1}} \quad (1)$$

with i : complex number defined by i2 = -1,
ω: the pulsation = 2π.fr, (fr is the frequency)
k, h : exponents such as 0<k<h<1,
δ : constant
E_{00} the static modulus when $\omega \rightarrow 0$,
E_0 the glassy modulus when $\omega \rightarrow \infty$,
with the notations (0<k<h<1) and also with a Newtonian viscosity $\eta=(E_{00}-E_0)\beta\tau$. When $\omega\tau \rightarrow 0$, then $E^*(i\omega\tau) \rightarrow E_0 + i\omega(E_{00}-E_0)\beta\tau$. β is dimensionless.
τ : characteristic time, which value varies only with temperature.

It has to be emphasized that only 7 constants (δ, k, h, E_∞, E_0, β and τ_0 (equation 1)) are needed to entirely determine the linear viscoelastic behavior of the considered material, at a given temperature. For binders, the experimental static modulus is very close to zero. Thus, in equation 1, E_0 can be taken equal to zero for binders and the number of constants of the model can be reduced to six.

Furthermore, if the hypothesis of a linear viscoelastic thermorheologically simple behavior can be applied to the considered material (i.e. the Time-Temperature Superposition Principle holds (TTSP)), only the τ parameter depends on temperature. τ evolution may be approximated by a WLF type law [6] (equation 2) in the range of temperature observed in laboratory [5; 7]. If the TTSP holds, the two additional constants C_1 and C_2 (calculated at the reference temperature T_{ref}) of the WLF equation are needed. The number of constants of the model amounts to 9 (and 8 for binders since E_0=0).

Unlike the Huet model and like the Huet-Sayegh model, no analytical expression of the creep function of this model is available in the time domain. Some simulations are shown in the next paragraph.

$$\log(a_T) = -\frac{C_1(T - T_{ref})}{C_2 + T - T_{ref}} \qquad (2)$$

5 RESULTS AND ANALYSIS

First results presented in this section are the complex modulus results of the bitumen extracted from the reclaimed asphalt pavement studied. Complex modulus results (|G*|) are presented at figure 7 a) in the Cole-Cole axes. Where G1 is associated to the real or elastic part of the complex modulus and G2 is the associated to the imaginary of viscous part. As these are a single curve in the Cole-Cole axes, a single master curve can be plot (Fig.7b) for a reference temperature (15°C). The associate shift factor for each temperature is also plotted at figure 7 b) as secondary axis. It is adequately fitted with the WLF law. For the reference temperature, WLF parameters are C1 = 29 and C2 = 214.6. The bitumen studied respect the Time-Temperature-Superposition-Principle (TTSP). This material can be fitting by the visco-elastic model 2S2P1D presented in section 4. The 2S2P1D constants are reported in table 3.

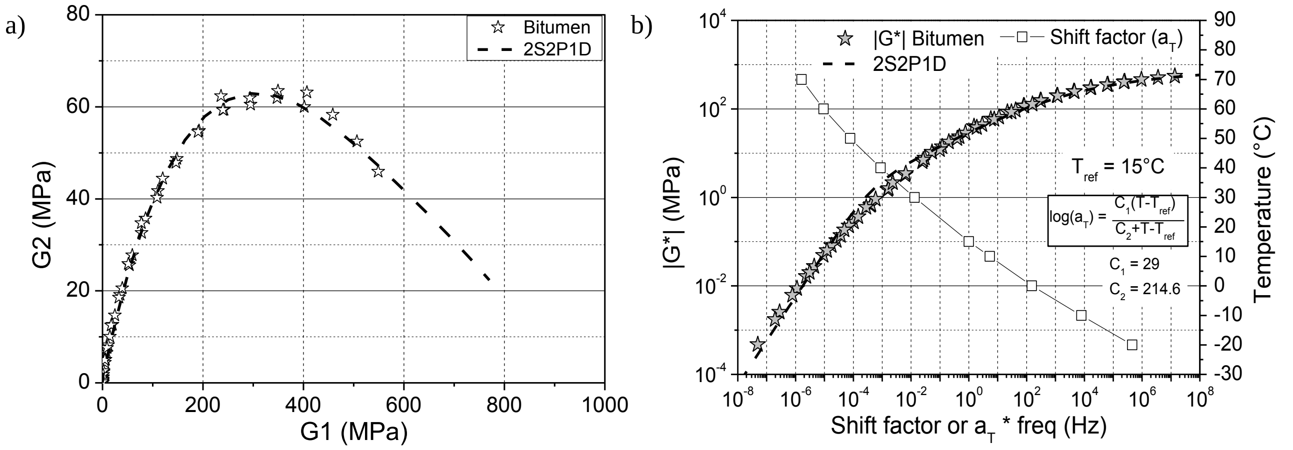

Figure 7 : Complex modulus result of the bitumen extracted from RAP a) Cole-Cole b) Master curve and Shift factor curve used to translate isotherms.

TABLE 3 : 2S2P1D model constants for the bitumen extracted from RAP

Materials	G_{00} (MPa)	G_0 (MPa)	k	h	δ	τ	β	T_{ref} (°C)
Binder extracted (Yonne)	1E-7	920	0.11	0.34	1.4	0.00001	100000	15

Experimental results of complex modulus tests of composite materials studied are presented at figure 8a. Results presented in Black space shows that using more or less RAP content have a role on the viscous properties. As observed by some authors [8; 9; 10; 11; 12], stiffness complex modulus decrease at a higher RAP content. Higher viscous properties are observed on the phase angle. Composites studied have a unique curve in Black space and show that like for the bitumen, the hypothesis of TTSP is hold. For the three mixes studied, a unique master curve for a reference temperature (i.e. Tref = 15°C) can be plot (figure 8b). Adding RAP to F RCC® decreases the norm of the complex stiffness modulus (|E*|). For the same RAP content (80%), the same conclusion can be drawn with a used of lowered cement content. Compared to the behavior generally observed on the bitumen [13] , the maximum phase angle of mixes is very low. It reaches about 3-6 degrees. But curves obtained for mixes and the bitumen have the same shape whatever the representation.

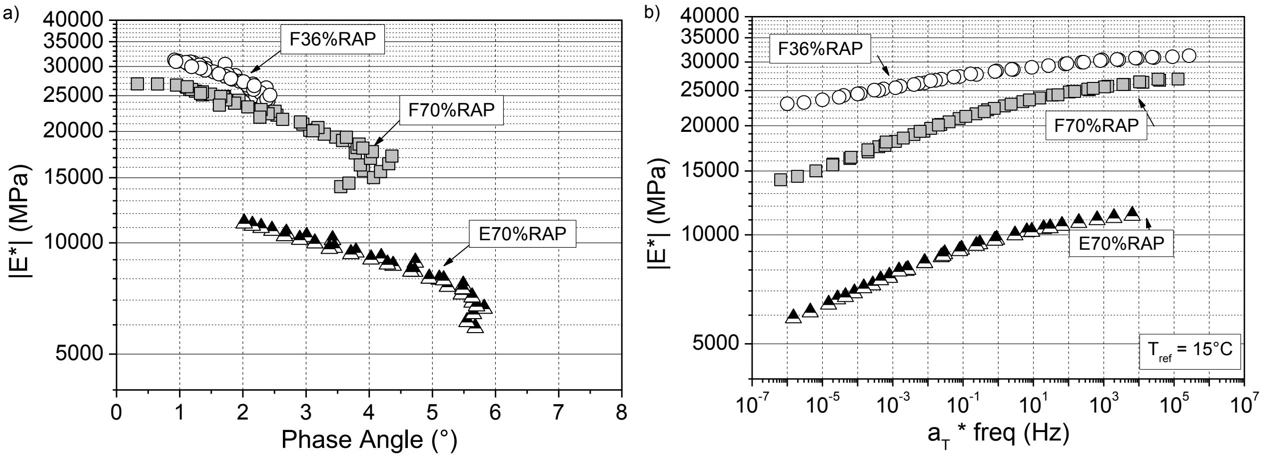

Figure 8 : Complex modulus results a)Black space b) Master curves

Figure 9 presents shift factors as a function of the temperature. These shift factors are used to build master curve for all materials. This figure shows that the shift factors used for all mixes containing RAP are very close to those for the bitumen. These experimental shift factors can be fitted with a unique set of the classical Williams-Landel-Ferry (WLF) law parameters (C1; C2) for the reference temperature.

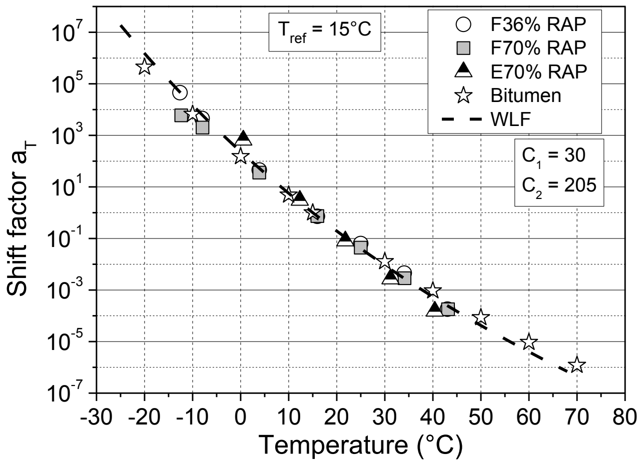

Figure 9 : Shift factors to translate isotherms of mixes and the bitumen extracted from RAP.

6 VALIDATION OF NORMALIZED CURVES CONSIDERING ENTPE TRANSFORMATION

As already shown in Section 5, TTSP is verified for both binders and mixes; particularly, time-temperature dependency of a cement concrete with RAP relies on the behavior of the bituminous binder used to produce the material, independently of the aggregate fraction. Another point of view to examine this concept is given by normalized complex moduli, as proposed by the ENTPE research team. These parameters are expressed by the following equations:

$$E^*_{norm} = \frac{E^* - E_{00}}{E_0 - E_{00}} \tag{3}$$

$$G^*_{norm} = \frac{G^* - G_{00}}{G_0 - G_{00}} \tag{4}$$

where E_0 and G_0 are the minimum asymptotic values of the norm of, respectively, Young's and shear complex moduli at very low frequencies/high temperatures; E_∞ and G_∞ are the maximum asymptotic values of the norm of, respectively, Young's and shear complex moduli at high frequencies/low temperatures.
When plotted in a Cole-Cole or Black diagram, normalized moduli of materials derived from the same binder originate curve that superimpose with each other. This confirms that time and temperature dependency of these materials (which underlies the concept of TTSP) originates from the binder behavior, regardless of the aggregate skeleton. A visual representation is shown in Figure 10, which reports normalized Cole-Cole diagrams for materials studied.

This observation is a consequence of the relationship between binder and mix complex moduli, recently presented by the ENTPE research team, which takes into account both the norm and the phase angle. This relationship is independent of any rheological model and it allows calculating the mix complex modulus at temperature T if binder modulus is known (and vice-versa) at the same temperature [5]. Hereinafter, it will be referred to as the “ENTPE transformation”. The equation describing the relationship is:

$$E^*_{mix}(\omega,T) = E_{0,mix} + \left[E^*_{binder}(10^{\alpha}\omega,T) - E_{0,binder}\right]\frac{E_{0,mix} - E_{00,mix}}{E_{0,binder} - E_{00,binder}} \quad (5)$$

where the parameter α depends on the considered mix design. If the TTSP is verified for binders, the following property can be added for both binders and mixes:

$$E^*_{binder}(10^{\alpha}\omega,T) = E^*_{binder}(10^{\alpha}\omega a_T(T),T_{ref}) \quad (6)$$

where $a_T(T)$ is the shift factor at temperature T and T_{ref} is the reference temperature. For more details about the ENTPE transformation, the reader may refer to [5; 14].

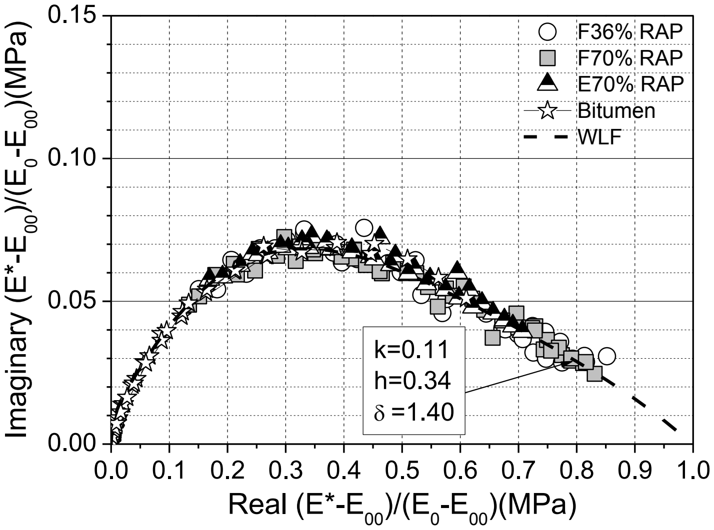

Figure 10 : Normalized Cole-Cole diagrams for materials

Table 4 presents the asymptotic values (E_{00} and E_0) selected. Figure 10 confirm that regardless of the RAP content and the aggregate skeleton, viscous properties for mixes containing RAP are driven by the bitumen same for a very low bitumen content (F40%RAP).

Table 4 : E00 and E0 of all material model constants to obtain Normalized curve

Materials	E_{00} (MPa)	E_0 (MPa)
Bitumen	0.0000003	2760
F40% (20)	20125	35300
F80% (25)	11750	29750
ERTALH	4150	14250

7 CONCLUSION

From the presented experimental study, the following conclusions can be drawn:
Master curves were built for complex modulus. Shift factors used are close, showing that a unique set of shift factors describes the behavior of the material with respect to the Time-Temperature Superposition Principle. Shift factors are adequately fitted by the Wililams-Landel-Ferry (WLF) law (eq. 2).
WLF curves for bitumen and FRCC® or ERTALH® mix produced from the same binder were almost coincident with the WLF curve of the binder itself: this proves the initial hypothesis of the study, that is the temperature dependency of a bituminous material is driven by the binder, regardless of the aggregates skeleton. This concept is further proven by the observation that normalized Cole-Cole curves for these sets of materials are approximately superimposing.
Cement-based materials produced with the addition of RAP material, such as materials, showed light viscous properties. TTSP was verified for these materials.
A unique normalized Cole-Cole (or Black) curve (Eqs 3-4) can be obtained for materials having very different stiffness, provided they contain the same bitumen, even in very small quantity.

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