

Roller Compacted Concrete for Road Base Layer with RAP and Steel Fibers: Viscous Properties and Description of Experimental Sites

K. Bilodeau¹, C. Sauzéat², H. Di Benedetto³ and F. Olard⁴

Abstract

A high-performance composite material consisting of reinforced compacted cement concrete including Reclaimed Asphalt Pavement (RAP) has been investigated. This composite material is used as a base layer in combination with an asphalt overlay for heavy traffic roads. Steel fibers are used to minimize crack opening. RAP is added to preserve raw material and to comply with sustainable development, especially in the case of in-situ treatments. Composites with different RAP and fiber content and cement content were studied both in laboratory and on site. The laboratory study is divided into two parts. First, classical standard tests for road concrete were carried out: compressive strength, compressive modulus and tensile splitting strength, with a view to the design of pavement structures to be used on site. Secondly, more comprehensive rheological tests, such as complex modulus and fatigue tests, were performed to obtain a better knowledge of material behavior. Then, on-site behavior was studied from two experimental sites. The presence of bitumen in cement-treated composites induces an increase of viscous properties, observed mainly on the phase angle. These composites respect the time-temperature superposition principle and can be fitted by a visco-elastic rheological model.

Introduction

This research is part of a French National Research Agency (ANR) project named "Recyroute". This 2.3 million euro project intends to propose a new high performance and long-lasting pavement using steel Fiber reinforced Roller Compacted Concrete (FRCC) as a road base layer including Reclaimed Asphalt Pavement (RAP). Pavement design, characterization of material properties 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), Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux (IFSTTAR), Laboratoire Régional de l'Ouest Parisien (LROP), Chaussée Technique et Innovation (CTI), Paris City and Autoroutes Paris Rhin Rhône (toll highway 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).

¹ Kevin Bilodeau EIFFAGE Travaux Publics, Research & Development Division, 8 rue du dauphiné BP 357, F-69960 Corbas Cedex, France & Université de Lyon, ENTPE, DGCB (FRE CNRS 3237), Rue Maurice Audin, Vaulx-en-Velin, F-69518, France. Email : kevin.bilodeau@entpe.fr

² Cedric Sauzéat Université de Lyon, ENTPE, DGCB (FRE CNRS 3237), Rue Maurice Audin, Vaulx-en-Velin, F-69518, France. Email : cedric.sauzeat@entpe.fr

³ Herve Di Benedetto Université de Lyon, ENTPE, DGCB (FRE CNRS 3237), Rue Maurice Audin, Vaulx-en-Velin, F-69518, France. Email : herve.dibenedetto@entpe.fr

⁴ François Olard EIFFAGE Travaux Publics, Research & Development Division, 8 rue du dauphiné BP 357, F-69960 Corbas Cedex, France. Email : francois.olard@eiffage.com

The first step of the program is the characterization of the selected mixes to be used on experimental sites by a laboratory study divided into two parts. The first part of the laboratory study aims at determining the classical mechanical properties. They were obtained from standard tests in order to define parameters of the composite materials to be placed as a road base layer. The obtained parameters were used for pavement design. Then, a more comprehensive thermo mechanical test (complex modulus) is performed to determine the viscous properties of mixes and the effect of RAP content in mixes. The second step of this project is the monitoring of two experimental sites. The following sections describe the tested materials, the testing device and the visco-elastic rheological model considered. The rheological model use to analyse experimental data is base on simple combination of physical elements. It is composed of two Springs, two Parabolic elements and 1 Dashpot (2S2P1D) (Di Benedetto et al. 2004 & Olard et al. 2003). This paper also presents visco-elastic properties of cement-treated materials with different RAP contents and a description of the two experimental sites.

Materials

FRCC (Ficheroulle and Henin 2004) components are presented in this section, as well as material design. The hydraulic binder content is fixed at 12% by mass of the granular part. It corresponds to about 280kg/m³ of concrete when used with natural aggregates only. The chosen hydraulic binder (Ligex FPL2, Calcia) is composed of 52% clinker, 21% fly ash, 6% slag and 21% limestone. The plasticizer admixture content is fixed at 0.5% in mass of hydraulic binder. Different fiber contents from 0 to 25 kg/m³ are investigated. The chosen steel fibers are 6cm long and have a 0.75mm diameter (Dramix 80/60 BN from Beckaert Company, Figure 1). Fibers are added during the final mix process and are not considered for the 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. Three RAP contents materials are studied. The contents are fixed at 0%, 40% and 80% by weight of the aggregates (respectively 0%, 36% and 70% of aggregates + hydraulic binder mass). The obtained materials are named F0%, F40% and F80%. Considering the combination of fiber and RAP contents, five different FRCC mixes are studied.

Another well-known material developed by Eiffage Travaux Publics is used as reference to evaluate the properties of FRCC materials. This reference material is composed of reclaimed asphalt pavement treated with a road hydraulic binder (ERTALH®). It is made with the same Ligex FPL2 hydraulic binder (the content of which being fixed at 5% by weight of the aggregates) and contains 70% of the same RAP (by mass of aggregates + hydraulic binder).

Table 1 presents the properties of the 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.

The final mix design was obtained with the following procedure. First the cement content and the grading envelope (Figure 2b and 2c) were fixed. Cement content was fixed in dry mass at 12% for FRCC and at 5% for ERTALH®. Then, the aggregate fractions were adjusted to obtain a grading curve inside the grading envelope specification. Figure 2b and 2c show the selected grading envelopes and grading curves of all mixes. The water content was then determined from the modified Proctor test NF EN 13286-2 and the immediate bearing ratio (IBI) test (NF P 94-078) on materials without steel fibers. Table 2 gives the mix proportions (without fibers) 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

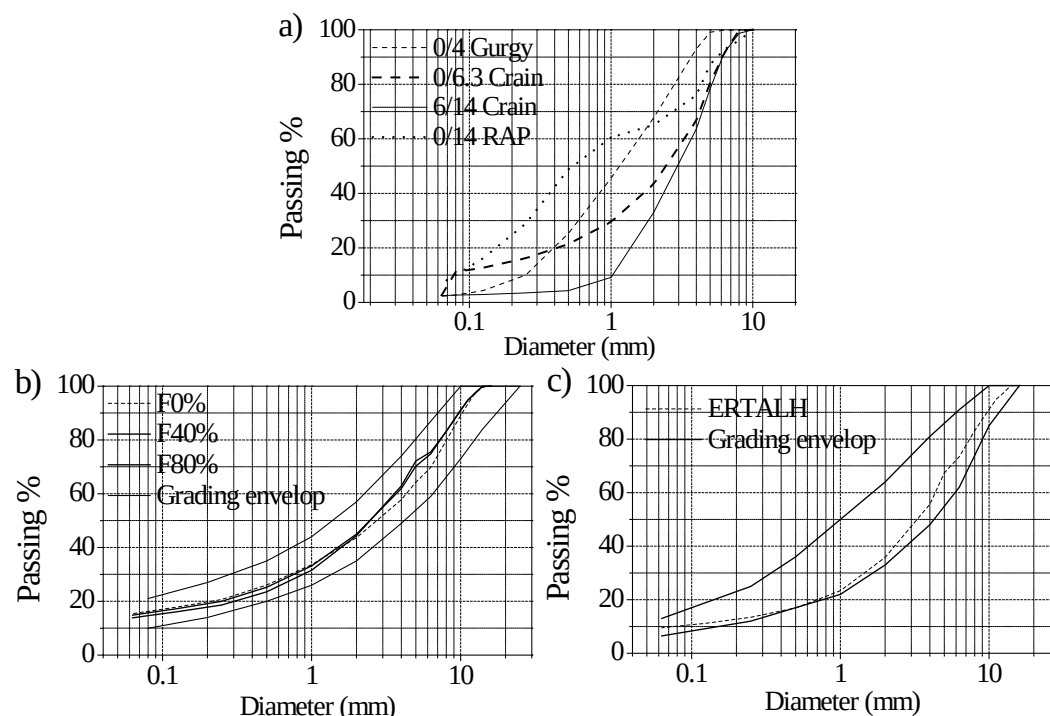


Figure 2 Grading curves and grading envelopes: a) All granular fractions; b) FRCC; c) ERTALH

Table 2 Mixes Component (Without Fibers)

Material or Properties	F0%		F40%	F80%		ERTALH	
Type of RAP	-	-	RAP Yonne	RAP Yonne	RAP Tours	RAP Yonne	RAP Tours
Type of aggregate	AG Crain	AG Ht-Lieu	-	-	-	-	-
Alluvial sand 0/4	23%	20%	20%	18%	18%	-	-
Crushed sand 0/6.3	35%	37%	20%	-	-	25.0%	25%
Crushed gravel 6/14	30%	31%	12%	-	-	-	-
RAP (0/10)	-	-	36%	70%	70%	70%	70%
Hydraulic binder (FPL2)	12%	12%	12%	12%	12%	5%	5%
Total (aggregates + hydraulic binder)	100%	100%	100%	100%	100%	100%	100%
Additive ¹ (Sika)	0.06%	0.06%	0.06%	0.06%	0.06%	None	None
Water content ²	6.1%	5.5%	6.2%	6.2%	6.1%	6.9%	6.1%
Bitumen content (%) from RAP	0.0	0.0	1.26	2.46	2.681	2.46	2.681
Dry Density	2.240	2.320	2.190	2.128	2.210	2.105	2.190
Immediate bearing ratio	215	310	120	101	91	84	65
water/cement ratio	0.508	0.458	0.516	0.516	0.508	1.380	1.220

Aggregate mass

¹ by weight of concrete (Total + water)

² by weight of Total (aggregates + hydraulic binder)

Testing devices

Complex modulus of mixes was measured with tension/compression tests. Binder complex modulus tests were carried out using the Dynamic Shear Rheometer (DSR) device. Complex modulus tests were performed on FRCC & ERTALH containing RAP and on the bitumen extracted from these RAP. Complex modulus was used to determine the influence of bitumen on the behavior of concrete materials containing RAP.

Visco-elastic properties of mixes were obtained by tension/compression complex modulus tests. The principle of this test consists in applying a sinusoidal loading on a cylindrical specimen of cement-treated materials. The tested specimens were 120 mm high, with a 75 mm in diameter. During the test, axial and radial strains as well as axial stress (radial stress is nil) were registered. Axial stress (σ_1) was measured from a load cell, while axial strains (ε_1) were obtained with three extensometers. Radial strain (ε_2) was deduced from two non-contact transducers (Figure 3). For the complex modulus test, cement-treated materials were loaded at 7 different frequencies (from 0.01 to 10 Hz) and 8 temperatures (from -15°C to +45°C). The target axial strain was fixed to 50µdef.

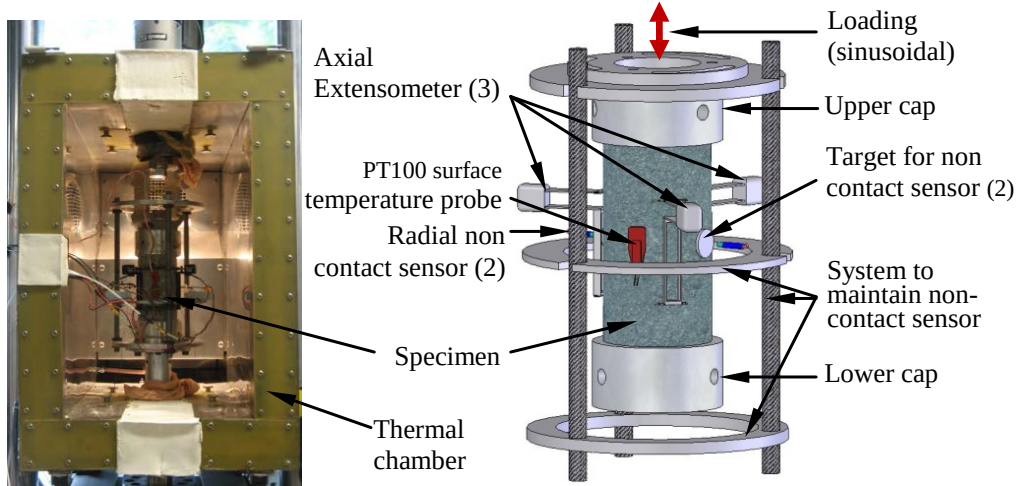


Figure 3 Experimental device used for tension-compression test, in the linear domain.

2S2P1D visco-elastic rheological model

Before showing the results and the analysis, the authors present an alternative general rheological model 2S2P1D, generalization of the Huet-Sayegh model, valid for bituminous binders and mixtures. This general model is based on a simple combination of physical elements (two springs, one dashpot and two parabolic elements) (Figure 4).

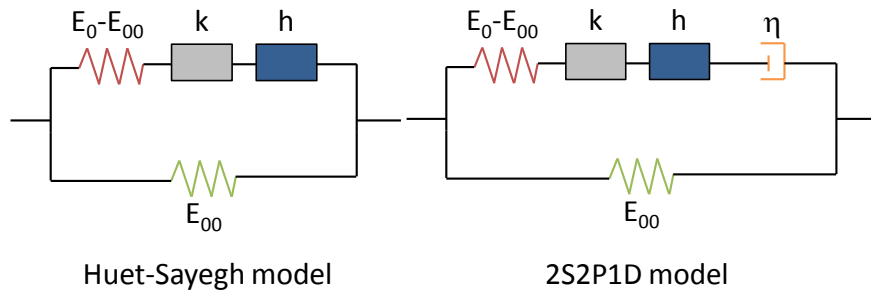


Figure 4 Representation of the Huet-Sayegh and general 2S2P1D for bituminous binders and mixes, h and k refer to two parabolic creep elements.

The Huet-Sayegh model (Sayegh 1965) has been adapted by adding a linear dashpot in series with the two parabolic elements and the spring of rigidity $E_0 - E_{00}$ (Figure 4). Thus, in particular for binders, for which $E_0 = 0$, the model is equivalent to a linear dashpot at very low frequencies. At a given temperature, the 2S2P1D model has 7 constants and the 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 $0 < k < h < 1$ and 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.

It has to be emphasized that only 7 constants (δ , k , h , E_{00} , E_0 , β and τ_0) are needed to entirely determine the linear viscoelastic behavior of the considered material, at a given temperature. For binders, the experimental static modulus E_{00} is very close to zero. Thus, in equation 1, E_{00} 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 (TTSP) holds), only the τ parameter depends on temperature. τ evolution may be approximated by a WLF type law (Williams et al. 1955) (equation 2) in the range of temperatures observed in laboratory (Olard et al. 2003 & Neifar et al. 2001). If 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 (8 for binders, since $E_{00}=0$). 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.

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

Visco-Elastic properties

Visco-elastic properties of cement-treated materials containing reclaimed asphalt pavement were obtained from complex modulus tests under tensile-compressive cyclic loading. Experimental results of complex modulus tests on the studied composite materials are presented in Figures 5 and 6. The 2S2P1D rheological model is also fitted to experimental data. Figure 5 presents complex modulus results in Cole-Cole and Black representations. Each group of materials (ERTALH, F80% and F40%) is plotted separately.

Results for F80% materials with the same range of curing time but with different fiber contents are similar to each other (same range of stiffness modulus and phase angle). Furthermore increasing the cement content between ERTALH and F80% causes a higher complex modulus without significant changes for the phase angle. The effect of curing time (60 days and 772 days) was studied for F40%. The phase angle of mixes with fibers decreases when curing time increases. Results presented in Black space shows that RAP content influences viscous properties. As observed by some authors (Bilodeau et al. 2011, Mathias 2004, Delwar et al. 1997 & Kolias 1996 (1&2)), complex modulus decreases as RAP content increases. Results for phase angles show small viscous properties. The studied composites materials have a unique curve in Black, therefore the hypothesis of TTSP is hold.

For each studied material, master curves of the norm of complex modulus and the phase angle are plotted (Figure 8) at a reference temperature of 15°C. Adding RAP to FRCC decreases the norm of the complex stiffness modulus ($|E^*|$) and increases the phase angle. At same RAP content (80%) and with lower cement content (F80% and ERTALH) the norm of complex modulus decreases. Compared to the behavior generally observed on bituminous materials (Olard 2003), the maximum phase angle of cement-treated materials including RAP is very low. It reaches about 3°-7°. But curves obtained for mixes and the bitumen have the same shape regardless of the representation. ERTALH materials tested at different curing times show similar results, such as the minimum asymptotic E_{00} modulus ranging between 4500 and 5500 MPa. The same tendency is observed on the maximum asymptotic E_0 modulus (14000 MPa). The maximum and minimum ratio (E_0/E_{00}) of composites tested is about 1.5 to 3, depending on the considered mixes. This value is very low compared to asphalt concrete mixes for which obtained E_0/E_{00} is about 1000 (Olard 2003).

Simulation curves with the 2S2P1D rheological model are also plotted with

our experimental results. These simulations are very close to the experimental results. 2S2P1D parameters used for each mixes are reported in Table 3.

Figure 7 presents shift factors as a function of temperature. They were used to build the master curve of all materials. These experimental values are fitted with a unique set of the classical Williams-Landel-Ferry (WLF) law parameters (C1, C2) for the chosen reference temperature. Shift factors used for all mixes containing RAP are very close to those for the bitumen.

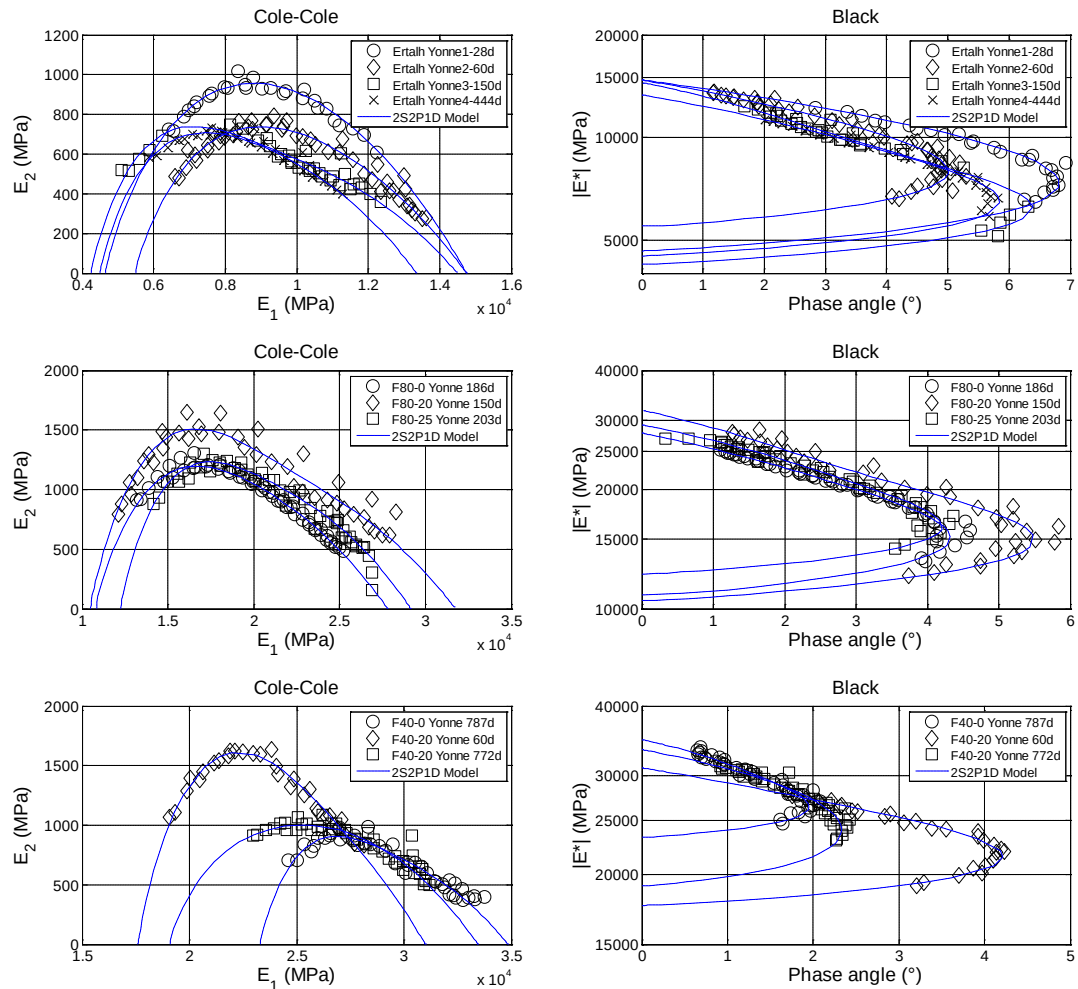
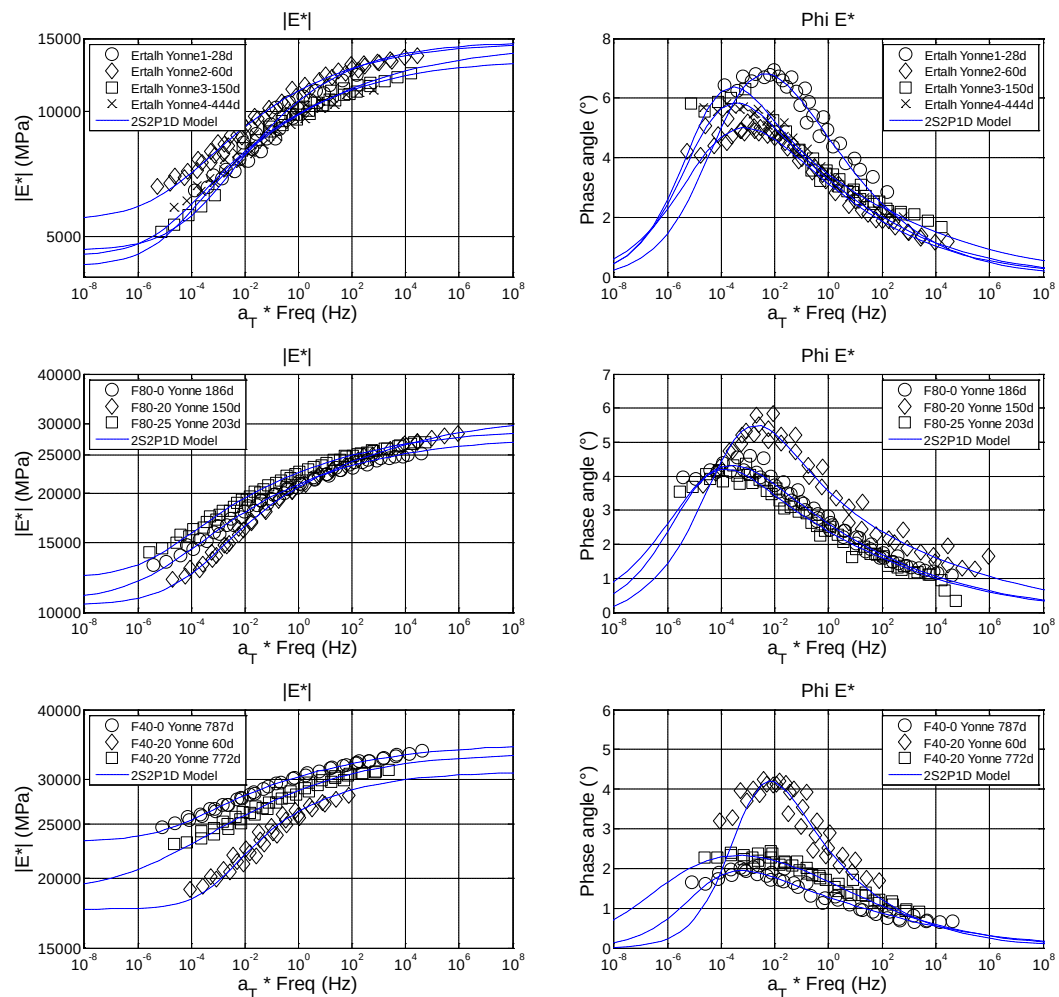


Figure 5 Complex modulus results: a) Cole-Cole; b) Black space

Table 3 2S1P1D parameters of all mixes at $T_{ref} = 15^\circ\text{C}$.

Mixes	E_{00}	E_0	k	h	δ	β	τ
Ertalh 28d	4650	14750	0.195	0.45	1.95	2000	47.3
Ertalh 60d	5500	14750	0.156	0.4	1.8	2000	230.7
Ertalh 150d	4250	14500	0.13	0.45	1.95	2000	144.7
Ertalh 441d	4500	13350	0.153	0.45	1.9	2000	243.3
F80-0 186d	10850	27800	0.13	0.37	1.7	2000	409.0
F80-20 150d	10500	31750	0.118	0.41	1.7	2000	20.0
F80-25 203d	12250	29150	0.135	0.41	1.9	2000	64.1
F40-0 787d	23300	34800	0.141	0.45	1.8	2000	325.5
F40-20 60d	17600	31000	0.193	0.55	1.3	2000	22.3
F40-20 772d	19100	33450	0.16	0.4	2.9	2000	10090.0


 Figure 6 Master curves for all materials ($T_{ref} = 15^\circ\text{C}$) : left) Norm of complex modulus; right) Phase angle

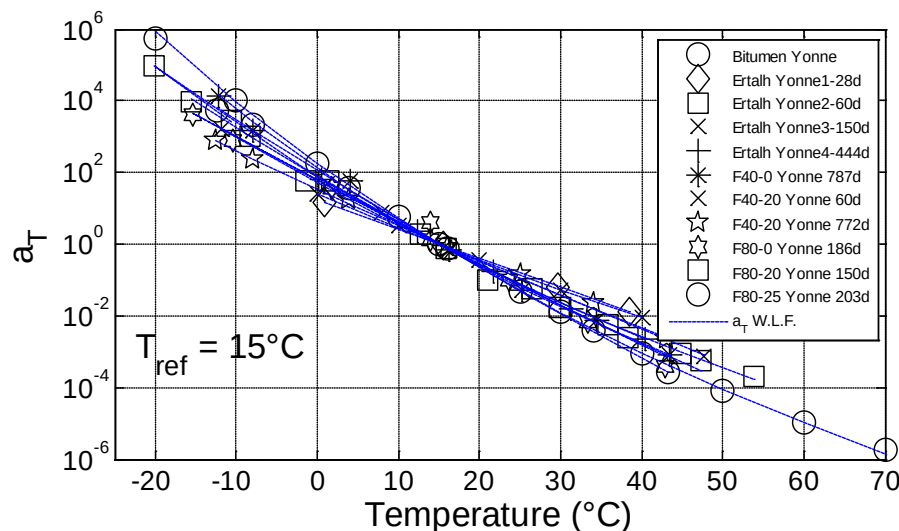


Figure 7 Shift factors used to translate isotherms of mixes and RAP-extracted bitumen.

Description of the two experimental sites

A6 Venoy Service Area. This experimental site is a rehabilitation of a part of the Venoy truck service area on highway A6 near Auxerre, France. Figure 8a shows the details of this experimental site finished in October 2009. The site is divided in two lanes and four sections. Trucks come from Lyon and enter by the access lane (Figure 8b). They leave the site through the exit lanes after passing the parking zone. The selected mixes to be placed on site are F0% (30), F40% (25), F80% (25) and ERTALH[®]. Due to actual limitation of fiber and cement materials used, the fiber content of FRCC[™] with RAP is higher than initially planned and is fixed to 25kg/m³.

First operations on site are the milling of current asphalt layer to the desired thickness and off-site storage. The RAP mills from this operation are not the RAP used in our project. Ours RAP is already recrushed and sieved to create a new RAP aggregate (0-14 mm). Afterwards a thin layer of asphalt emulsion (800g/m²) with gravel is applied between the existing layer after milling and the new base layer (ERTALH[®] or FRCC[™]). Base layer mixes are produced from a mobile plant (Figure 8c) installed near (about 25km) the experimental site. They are placed by means of paver that is similar to the one used for asphalt concrete or a roller-compacted concrete. Afterwards the targeted density is obtained with both vibratory asphalt compactor and a pneumatic tire compactor. At last another asphalt emulsion layer (400g/m²) with gravel is applied before surfacing with asphalt concrete.

During construction, strain gages were placed in the longitudinal and transverse directions below ERTALH[®] and FRCC to monitor strain (Figure 8d) under static and mobile loads. Measurements with these gages and visual characterization of this high potential composite material will be realized at specific times during 3 years.

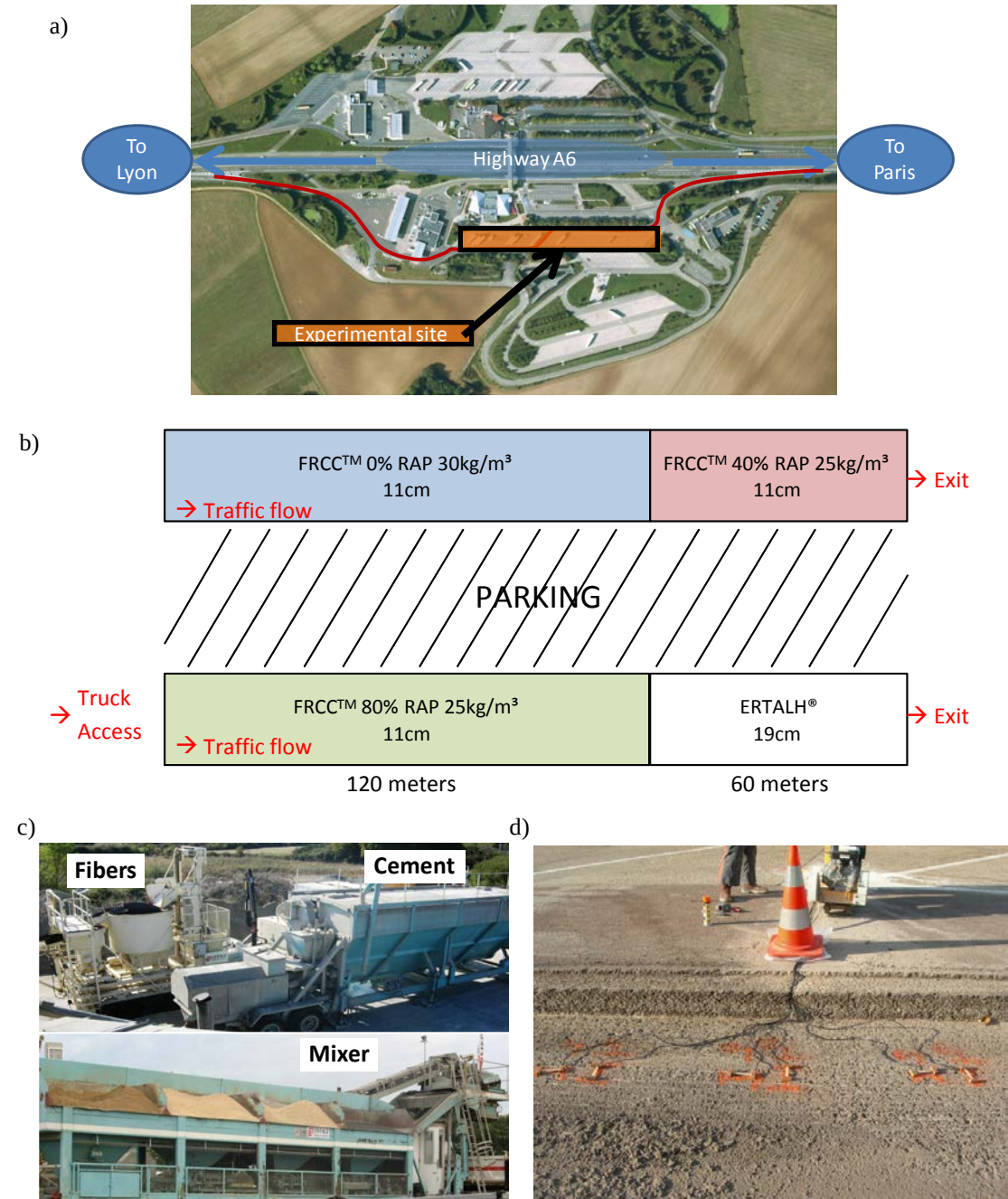


Figure 8 Description of on-site experimentation: a) Aerial view of the site; b) Top view of the site; c) View of mobile plan; d) Strain gages below the base layer

IFSTTAR'S accelerated pavement testing facility. The IFSTTAR's Accelerated Load Testing (ALT) facility, in Nantes, is an outdoor circular carousel dedicated to full-scale pavement experiments, carried out with public and/or private partners. The carousel is composed of a central tower and four arms (20 m long each) equipped with wheels, running on a circular test track. The experimental circular pavement has an average radius of 17.5 m and a width of 6 m, thus a total length of approximately 110 m (Kerzreho et al. 2008). The position of the loading module can be modified and adjusted at a different radius on each arm. The effect of different loading configurations can be observed simultaneously. During loading, a lateral offset of the load can be applied to simulate the lateral distribution of loads of real traffic (Autret 1988).

The arms can be equipped with various load configurations: single or dual wheel; single, tandem or triple axles. A large range of loads can be applied: from 45 to 80 kN on a single half axle, up to 135 kN with multiple axles. The maximum speed in classical load configuration (65kN twin-wheels) is 100 km/h. A low-stiffness suspension system allows controlling the loads applied to the experimental pavement during the entire test, regardless of the degradation of the pavement is. Pavement structures are built by private construction firms, using ordinary road building equipment.

Concept of experimental pavement structures. Eight different structures were tested simultaneously, on two different radiuses (respectively 16 m and 19 m, with 4 structures each) of 3m of width. This experiment focuses mainly on the evaluation of new pavement structures produced with new base layer materials. Tested structures include: one reference structure made with a French standard high modulus bituminous material (EME2) with a well known behavior; one structure made of RAP aggregates treated with hydraulic binder (ERTALH[®]); six structures using FRCC materials; three including RAP and three without RAP. Two kinds of new aggregates are used for structures without RAP: the “Crain” (soft limestone) and the “Haut-Lieu” (hard limestone).

These structures were preliminarily designed using the French official design method. Some additional design parameters were taken into account for the innovative structures not considered by the official method. Final structures and carousel compositions are described in Figure 8.

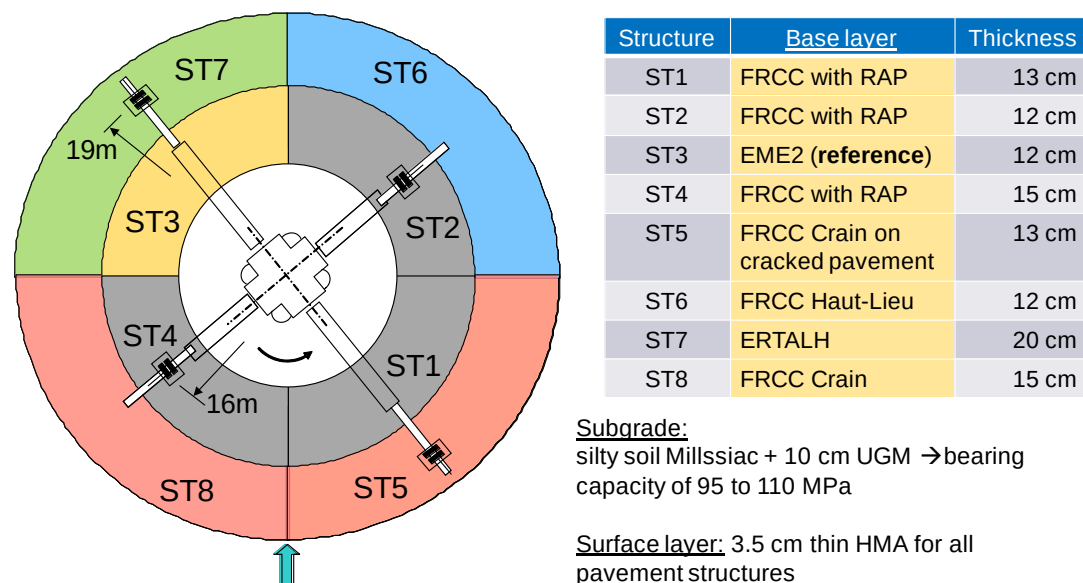


Figure 8 Schematic of tested structures at the IFSTTAR's ALT facility.

For the entire carousel, the same subgrade soil and unbound granular material is used as a support layer. Materials used for base layers and surface layers are described below. As shown in Figure 8, five different materials were used for the base layer of the eight experimental pavement structures. Except for the high modulus asphalt material EME2, which was produced and transported from a bituminous material production plant, all other materials were produced by an on-site production

plant. Two kinds of bituminous materials were used as a surface layer for these pavement structures:

- a 0/10 HMA with a 35/50 penetration grade ordinary bituminous binder is used on all inner radius structures and on structure 7 (outer radius);
- on structures 5, 6 and 8, on the outer radius, the surface layer consisted of a 0/10 HMA with an SBS-modified binder, called Orthoprene®, developed by EIFFAGE.

A total traffic of more than 2.15 million heavy load passages was applied over nine months. It should be noted that the loading started three months after construction of the pavement structures, so that the cementitious materials used in seven innovative structures reached their full resistance. In addition, the first 100,000 loads were carried out with the dual wheels of 45 kN (50,000 loads) and of 55 kN (50,000 loads). Later, the reference French standard dual wheel of 65 kN was used until 2 million passes. At the end of the experiment, about 21,000 and 150,000 additional dual wheel load passings of respectively 70 kN and 75 kN, were applied to study the overload effect on the tested pavement structures. According to the French rational design method, the aggressiveness of the loading on each structure depends on the slope of the fatigue law of the material used in the base layer, as follows:

$$NE = NP \left(\frac{P}{P_{ref}} \right)^{-1/b} \quad \text{with } P_{ref} = 65 \text{ kN} \quad (3)$$

Where NP is the number of passes of the load P and NE is the number of reference loads (65kN) equivalent to the NP passes of the load P. Table 4 shows the cumulated equivalent traffic (standard load of 65 kN) for each tested structure corresponding to a given base layer material, according to equation 3.

Table 4 Cumulated equivalent traffic for each tested structure

Structure	S2-S1-S4	S3	S5-S8	S6	S7
Material	FRCC with RAP	EME2	FRCC Crain	FRCC Ht-Lieu	ERTALH
-1/b	9.9 (*)	6.6 (**)	16 (*)	16 (*)	10.7 (*)
NE (65 kN)	2.6×10^6	2.4×10^6	3.5×10^6	3.5×10^6	2.7×10^6

(*) slope of the fatigue law to preliminary design of pavements

(**) slope of the fatigue law according to fatigue tests on EME2

For almost all applied loads, the rotational speed is 10 rotations/min, which corresponds to a linear speed of 71.6 and 60.3 km/h for the radius of 19m and 16m respectively. Moreover, during a specific measurement (deformation and dynamic deflection measurements), the rotational speed of the carousel can be set at different values, from 0.6 to 10 rotations/min. Lateral offset of the loads is also applied during the experiment. For this experiment, the wheel path resulted of a lateral range of 1.6m wide, distributed according to an approximated normal law.

In each structure, ten horizontal strain sensors were placed at the bottom of the base layer for the measurement of longitudinal (5 sensors) and transversal (5 sensors)

reversible strains. These sensors were positioned in the middle of the outer and the inner wheel-paths. In the middle of each structure, an anchored deflectometer was placed inside the pavement for dynamic deflection measurement. Thermocouples were also placed inside three pavement structures made of bituminous material (ST3 – EME2) or including RAP (ST4 – FRCC with RAP, ST7 – ERTALH) at different depths in order to monitor the temperature in each layer of these structures. Two other thermocouples were also used to measure air temperature in sunlight and in shade. Measurements of deflections and transversal profiles were also performed after different levels of traffic, and visual surveys of the surface of the pavement were carried out every day.

Conclusions

From the presented experimental study, the following conclusions can be drawn:

Cement-based materials produced with the addition of RAP material, such as materials, showed light viscous properties. A unique normalized Black (or Cole-Cole) curve can be obtained for materials having very different stiffness, provided they contain the same bitumen, even in very small quantity. TTSP was verified for these materials.

Master curves were built for complex modulus. Shift factors used are close, showing that a unique set of shift factors, in first approximation, describes the behavior of the material with respect to the Time-Temperature Superposition Principle. Shift factors are adequately fitted by the Williams-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. The temperature dependency of a bituminous material is driven by the binder, regardless of the aggregates skeleton.

Two experimental sites were described in this paper. The first one, a rehabilitation of A6 Venoy serviced area. It shows the possibility to use these kinds of composites as pavement structure reinforcement. The second one is an accelerated pavement testing to the IFSTTAR alt Facility. First results show that all pavement structure had resisted to all. Further investigation of these two experimental sites will provided conclusions about pavement design parameters to be used for these composites.

Acknowledgement

Authors would like to thank Jean-Maurice BALAY, Jean-Pierre KERZREHO and Mai-Lan NGUYEN from IFSTTAR to their contribution to this research and particularly for the IFSTTAR'S accelerated pavement testing facility section.

References

Autret P., Baucheron de Boissoudy, A., and Gramsammer, J. C. (1988) “Le manège de fatigue du Laboratoire Central des Ponts et Chaussées: Premiers résultats”. Bulletin de liaison des Laboratoires des Ponts et Chaussées, 155, 33–45. In French.

Bilodeau, K., Sauzeat, C., et al., (2011). “Laboratory and in situ investigations of steel fiber reinforced compacted concrete containing reclaimed asphalt pavement.” Transportation Research Board Annual Meeting, Washington DC.

Delwar, M., Fahmy, M., et al. (1997). “Use of reclaimed asphalt pavement as an aggregate in portland cement concrete.” *Aci Materials Journal* 94(3), 251-256.

Di Benedetto, H., Olard, F., et al. (2004). "Linear viscoelastic behavior of bituminous materials: from binders to mixes." *Road Materials and Pavement Design* (Special Issue EATA), 5(1), 163-202.

Ficherouille, B. and Henin, M. (2004). "Compacted rolled fibre-reinforced concrete composition and method for producing a pavement based on same composition", *Chaussees, Techniques Innovation* (67, rue Saint Jacques, Paris, 75005, FR) Patent EP1278925B1.

Kerzreho, J., Balay, J., et al. (2008). "The LCPC's ALT facility contribution to pavement cracking knowledge." *Pavement Cracking*, CRC Press.

Kolias, S. (1996). "Mechanical properties of cement-treated mixtures of milled bituminous concrete and crushed aggregates." *Materials and Structures* 29(7), 411-417.

Kolias, S. (1996). "The influence of the type of loading and temperature on the modulus of elasticity of cement-bound mixes of milled bituminous concrete and crushed aggregates." *Materials and Structures* 29(9), 543-551.

Mathias, V., (2004). "Recyclage des fraisats d'enrobés dans les bétons routiers." Département de génie civil. Nantes, École Centrale de Nantes et l'Université de Nantes. PhD Thesis: 221p. in French.

Neifar, M. and Di Benedetto, H. "Thermo-viscoplastic law for bituminous mixes." *Road Materials and Pavement Design* 2(1), 71-95.

Olard, F. and Di Benedetto, H. (2003). "General "2S2P1D" model and relation between the linear viscoelastic behaviors of bituminous binders and mixes." *Road Materials and Pavement Design*, 4(2). 185-224.

Olard, F., Di Benedetto, H., et al. (2003). "Linear viscoelastic properties of bituminous binders and mixtures at low and intermediate temperatures" *Road Materials and Pavement Design*, 4(1), 77-107.

Sayegh, G., (1965). "Contribution à l'étude des propriétés viscoélastiques des bitumes purs et des bétons bitumineux" *Faculté des sciences. Paris, Université de Paris*. 74p. In French.

Williams, M. L., Landel, R.F. & Ferry, J.D. (1955). "The Temperature Dependence of Relaxation Mechanisms in Amorphous Polymers and Other Glass-forming Liquids1." *Journal of the American Chemical Society* 77(12), 3701-3707.