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Road and Rail Infrastructure V

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STIFFNESS AND FATIGUE RESISTANCE OF HOT MIX ASPHALT CONTAINING HIGH RATES OF RECLAIMED ASPHALT PAVEMENT

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Abstract

The present work focuses on the determination of the stiffness and fatigue properties of hot mix asphalt (HMA) containing conventional and rejuvenated reclaimed asphalt pavement (RAP). Different mixtures of High Modulus Asphalt Concrete (HMAC) containing high rates of RAP (40 to 70 %) are characterized from laboratory testing in terms of general properties and mechanical performances: stiffness and fatigue resistance. The RAP mixes are compared to a control mix (without RAP) tested in the same conditions. All the remaining parameters (particle size distribution, binder and void content, mixing time and temperature) are maintained constant. The test results regarding workability, water sensitivity and rutting resistance are in agreement with the French specifications for all mixtures. Compared to the control mix, the use of RAP increases the rutting resistance whereas the rejuvenator improves the workability without negative effects on the rutting resistance. The stiffness modulus and the fatigue resistance are measured on standard trapezoidal specimens, by using a strain-controlled two-point bending test (2PB-TR). The experimental results show that, compared to the control mix, the use of RAP increases the stiffness modulus, reduces the phase angle of the mixes and increases the fatigue resistance. The use of rejuvenator (REGEFALT®) produces a small decrease of the stiffness modulus and an increase of the fatigue resistance.

Keywords: bituminous mixes, rejuvenator, mix workability, stiffness modulus, fatigue resistance

1 Introduction

1.1 Aims of the research

The objective of our research work is to analyse the impact of increasing the rate of reclaimed asphalt pavement (RAP) in hot mix asphalt (HMA) and the effect of adding a rejuvenator (REGEFALT®). An extended set of laboratory tests is performed involving two main steps: (i) production of different mixtures with variable RAP content with and without the rejuvenator; (ii) measurement of the general and thermo-mechanical properties of the mixes. The material considered is a High Modulus Asphalt Concrete, currently used as a base layer in France. The content of reclaimed asphalt pavement (RAP) varies from 0 % (reference mix) to 70 %. For all the mixtures, the grading curve of the aggregates and the total binder content are constant and fit the French standards.

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1.2 State of the art

The addition of RAP in Hot Mix Asphalt faces several limitations. First, the process for mixing RAP and virgin components must be optimized in order to guarantee a correct homogeneity between virgin and aged binders [1-3]. Moreover, differences between laboratory and plant production must be controlled [4]. Then, a sufficient level of mechanical performances like stiffness modulus and fatigue resistance must be guaranteed. Current observations show that high percentages of RAP reduce workability of the mixes and increase rutting resistance and elastic stiffness, due to the ageing of the RAP binder and to the consequent hardening of the final binder [5-10]. The effect of RAP content on the fatigue resistance of the mixes is observed differently, depending on the authors and on the conditions. In some cases, up to a certain content of RAP, the fatigue resistance of the material is improved [11-14]. But when the RAP content increases, the fatigue resistance may deteriorate compared to the mixture without RAP [6, 8].

2 Materials and test program

2.1 Material components

Exhaustive characterization of the different components is performed to reduce the heterogeneity of the final mixtures. The stocks of RAP and virgin aggregates are homogenized mechanically in piles. A second laboratory homogenization is performed for each sample (one control test per ton). All virgin aggregates come from massive rocks (silico-calcarious), while the filler is a limestone. The gradation of the mix is shown in Figure 1.
The main properties of RAP, summarized in Table 1, can be considered as homogeneous according to the RAP classification. Penetration value and softening temperature are representative of an aged binder proceeding from pavement surface layers. Different grades of the virgin binder (penetrations: 10/20, 20/30, 35/50 mm/10) are used to ensure the same penetration class (10/20) of the final binder for all the mixtures. The rejuvenator employed (REGEFALT®) reduces the oxidized hydrocarbon components included in the RAP binder and facilitates the interpenetration of the particles of old and new binders. This leads to a better integration of the components of the composite binder and to an increase in the performances of the mixes [15, 16].

Table 1 RAP properties

Property		Test result
Type	–	12.5 RA 0/10
Petrography	–	Silico-calcarious
Mix density	kg/m³	2483
Soluble binder content	%	5.26
Category [17]		$TL_1 - B_2/B_1 - G_{NS} - R_{NS}$
Penetration (25 °C)	mm/10	6.0
Softening point	°C	93.1
Saturates	%	3.3
Aromatics	%	31.5
Resins	%	31.1
Asphaltenes	%	34.1

2.2 Mix composition

Three RAP contents are considered: 40 %, 55 % and 70 %, "rejuvenated" and "conventional" (without rejuvenator), compared to a control mixture containing only virgin aggregates and binder, leading to a total of seven mixtures (Table 2).

Table 2 Mix properties

		Mix Id						
Item	**Unit**	**0R**	**40R**	**40R'**	**55R**	**55R'**	**70R**	**70R'**
RAP	%	0	40		55		70	
Rejuvenator	‰	–	–	0.8	–	1.0	–	1.3
Binder Penetration (25 °C)	mm/10	12	10	11	8	9	8	10
Binder Softening point	°C	75.1	85.5	86.5	90.1	89.1	88.9	89.1
Soluble binder content	%	5.45						
Binder composition :	%							
Saturates		4.4	6.5	6.6	5.2	5.6	4.6	4.5
Aromatics		52.7	45.4	44.7	40.5	42.9	40.5	40.4
Resins		20.7	20.1	22.5	25.8	24.0	26.3	27.9
Asphaltenes		22.3	28.0	26.2	28.5	27.6	28.5	27.2

By first mixing the 70 % RAP formula with different proportions of the elementary fractions of virgin aggregates a conventional 0/14 grading curve is obtained for all the mixtures (Figure 1). A constant total binder content of 5.45 % is fixed by modifying the amount of the virgin binder content. The rejuvenator content Q (‰) is determined from the proportion of RAP (R) in the mixture and the RAP binder content (X) by the following empirical relation: Q = 36 R X.

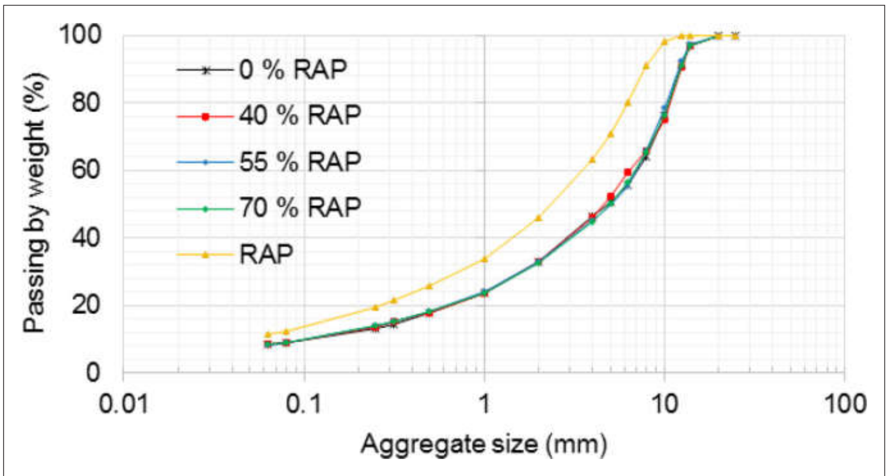

Figure 1 Grading curves of RAP and mix aggregates

3 Mix general properties

3.1 Workability and sensitivity to water

The workability tests are performed with the Gyratory Shear Press (GSP type 2) on specimens of 160 mm diameter at a temperature of 185 °C. The results are shown in Figure 2a for the different mixtures in terms of voids content at 100 gyrations. All mixtures are in large agreement with the French specifications (voids content at 100 gyrations V100 $\leq$ 6 %). Compared to the control mix (0R), a slightly smaller workability is observed on the mixtures containing RAP (higher voids content). However, the rejuvenator increases the workability of the mixes, especially for the mix with the highest rates of RAP (55R' and 70R'), producing a voids content equal to that of the control mix.

Sensitivity to water is determined using the Duriez test which measures the ratio i/C of the compressive strength in dry and saturated conditions at a temperature of 18 °C. The Duriez specimens, of 120 mm diameter, are compacted statically with application of a vertical force of 180 kN during 5 mn. A reduction in the i/C ratio of the mixtures is observed while increasing the RAP content from 40 to 70 % (Figure 2b). Nevertheless, except for the highest RAP content (mix 70R) the i/C ratio of the RAP mixes remains above the one of the control mix and far higher than the French specifications (i/C > 70 %). In any case the rejuvenator produces an increase in the i/C ratio, especially comparing the mixes 70R (i/C = 90 %) and 70R' (i/C = 97 %).

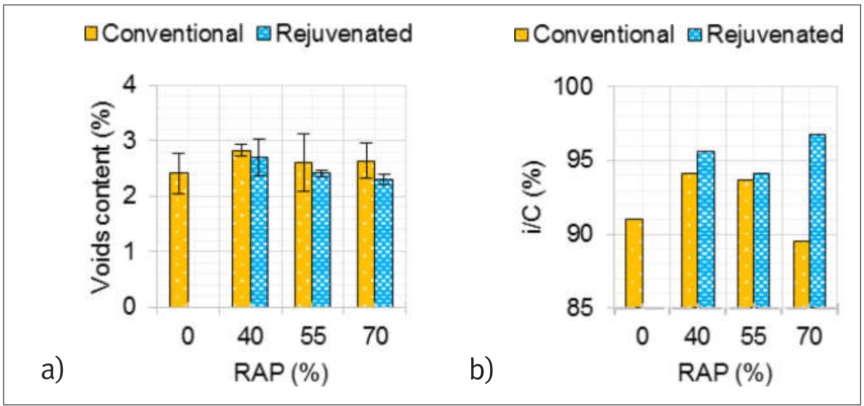

Figure 2 a) Workability of the mixes at 100 gyrations (GSP test) and b) compressive strength ratio (i/C)

3.2 Rutting resistance

The rutting resistance is measured with the mlpc® wheel tracking device at a temperature of 60 °C. Compaction of the specimens is performed with a plate compactor in rectangular moulds 500 mm long and 180 mm wide, with the same energy. As observed in Figure 3a, the initial voids content V of the RAP mixes is higher than the one of the control mix, but remains in agreement with the French specifications (3 % < V < 6 %). Again, as above, the rejuvenator facilitates the compaction leading to a slightly smaller voids content. The rut depth at 30,000 cycles decreases significantly when increasing the RAP content (Figure 3b) due to the hardening of the RAP binder. Using the rejuvenator produces a very slight increase of the rut depth but in all cases, the measured rut depth remains below the allowable value (7.5 %).

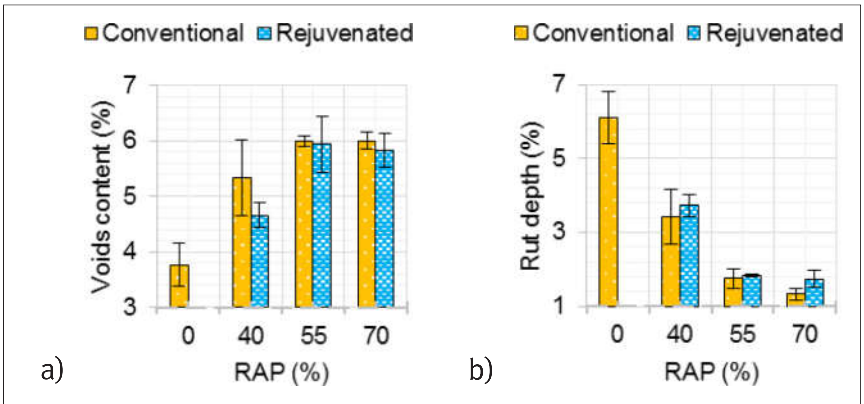

Figure 3 Rutting tests: a) initial voids content and b) rut depth at 30,000 cycles

4 Stiffness and fatigue resistance

The stiffness and the fatigue resistance of the mixes are measured on standard trapezoidal specimens at 3 % voids content, using strain-controlled two-point bending tests (2PB-TR). Stiffness tests are performed on four samples at temperatures of 10 °C and 15 °C, at a frequency of 10 Hz and imposing a cyclic strain of 39 μm/m. Fatigue tests are carried out according to the standards (temperature 10 °C; frequency 25 Hz) imposing three cyclic strain levels and testing six samples per strain level. The fatigue parameters (ε_6 value and slope b) are determined when the sample stiffness is reduced to 50 %.

4.1 Complex modulus and phase angle

Due to the hardening of the aged binder, the mixes exhibit a complex modulus that increases with the RAP content and which is significantly higher than the one of the control mix (Figure 4a). Moreover, all the mixes considered show complex modulus values higher than the conventional value adopted in the standards for this type of material (mix "St"). Inversely, the phase angle decreases with the RAP content (Figure 4b). Similar results have been obtained in [5], [13] and [14] signifying that the RAP content increases the elastic component of the stiffness and reduces the viscous one. On the other hand, the rejuvenator reduces very slightly the complex modulus and increases slightly the phase angle.

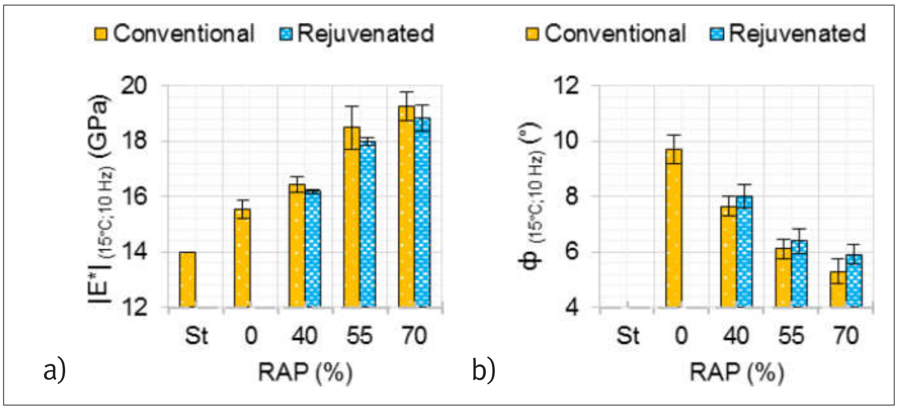

Figure 4 Mixes (2PB-TR): a) Complex modulus, b) phase angle

4.2 Fatigue resistance

The fatigue results (Figure 5) show that for all the mixtures considered, the range of the fatigue parameter ε_6 is significantly high (149 μm/m $\leq \varepsilon_6 \leq$ 173 μm/m) and bigger than the standard value (ε_6 = 130 μm/m). Moreover it may be observed that the RAP mixes exhibit higher ε_6 values than the control mix 0R and that the rejuvenator enhances the fatigue performances [5]. In terms of the slope b of the Wöhler fatigue curve, it is observed that the range of b values of the mixtures containing RAP, with or without rejuvenator (–0.14 ≤ b ≤ –11) is above the values of the control mix (b = –0.18) and of the standard value (b = –0.20). In other words, the RAP mixtures flatten the fatigue curve.

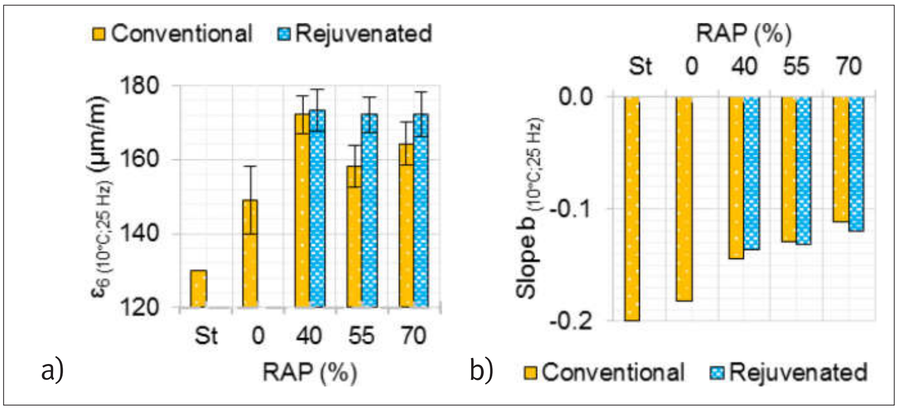

Figure 5 Fatigue resistance parameters (2PB-TR): a) ε_6 and b) slope b

5 Conclusions

Different mixtures of High Modulus Asphalt Concrete containing 40 to 70 % RAP have been characterized and compared to a control mix without RAP. Due to the hardening of the aged binder, the use of RAP increases the rutting resistance whereas the rejuvenator improves slightly the workability and the sensitivity to water, without impacting significantly the rutting resistance. In terms of stiffness, the experimental results show that, compared to the control mix, the use of RAP increases the complex modulus and its elastic component and reduces the phase angle and the viscous component of the mixes. The rejuvenator produces a small decrease of the complex modulus and a small increase of the phase angle. The fatigue performances of the mixes increase with the RAP content and with the rejuvenator; moreover, in all cases they are higher than those of the standard material and of the control mixture.

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