EFFECT OF RECLAIMED ASPHALT PAVEMENT ON COMPLEX MODULUS AND FATIGUE RESISTANCE OF BITUMENS AND ASPHALTS

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ABSTRACT

Use of Reclaimed Asphalt Pavement (RAP) material in road construction industry is a very common practice, allowing for significant environmental and economical cost saving. Recently, evolution in field practice allows producing asphalts containing up to 60% of RAP material. However, most of the literature on the subject is based on studies involving lower RAP percentages.
The presented study is part of a wider ongoing research project in the framework of a PhD thesis, in collaboration between Université de Lyon/Ecole Nationale des Travaux Publics de l'Etat (ENTPE), EIFFAGE Travaux Publics and Beyond Petroleum (BP). The paper focuses on the influence of the percentage of RAP material on mechanical response of asphalts. Particularly, effects of high contents of RAP are observed. Mixtures are produced by mixing a well known RAP material (provided by EIFFAGE Travaux Publics) with pure bitumens (provided by BP) and aggregates. Typical sets of RAP contents and virgin bitumen penetration grades were adopted.
Complex modulus and fatigue tests were performed and experimental results discussed. Typical test methods (types, temperatures and frequencies) commonly used by construction industry were chosen for the experimental campaign. Complex modulus of bitumens and asphalts shows an increase with RAP material content: moreover, stiffness growth trends of both materials exhibit a linear relationship. Fatigue resistance of asphalts containing 60% of RAP appears satisfactory. Material performance evaluations based on DSR tests for bitumens and two-point bending tests for asphalts are not coherent.

Keywords: bitumen, asphalt, complex modulus, fatigue, RAP

1. INTRODUCTION

Use of Reclaimed Asphalt Pavement (RAP) material in road construction industry is a very common practice, allowing for significant environmental and economical cost saving. Research has shown that the use of RAP material in the production of new asphalt mixtures can also improve mechanical performances with respect to conventional asphalts. For a fixed aggregate curve mix design, the main factors influencing final response of asphalt mixtures are RAP content and characteristics of bitumen contained in it [1,2,3]. In general, increasing the amount of recycled material in asphalts causes a stiffness increase and a better rutting resistance, given the same neat bitumen used in the production of the mixture [4,5]. Recently, evolution in field practice allows producing asphalts containing up to 60% of RAP material [6,7]. However, most of the literature on the subject is built upon studies involving RAP percentages ranging from 0% to 40%.
The presented study is part of a wider ongoing research project in the framework of a PhD thesis, in collaboration between Université de Lyon/Ecole Nationale des Travaux Publics de l'Etat (ENTPE), EIFFAGE Travaux Publics and Beyond Petroleum (BP). The paper focuses on the influence of the percentage of RAP material on mechanical response of asphalts. Particularly, effects of high contents of RAP are observed. Mixtures are produced by mixing a well known RAP material (provided by EIFFAGE Travaux Publics) with pure bitumens (provided by BP) and aggregates. Typical sets of RAP contents and virgin bitumen penetration grades were adopted.
Complex modulus and fatigue tests were performed and experimental results discussed. Typical test methods (types temperatures and frequencies) commonly used by construction industry were chosen for the experimental campaign.

2. MATERIALS AND METHODS

2.1. Materials

The experimental plan consisted of different asphalts produced by mixing a well known RAP material in different proportions with granular aggregates (mainly silicates and limestone) and three distinct base bitumens:
- a 15/25 penetration hard paving grade bitumen;
- a 35/50 penetration paving grade bitumen;
- a 70/100 penetration paving grade bitumen.

Penetration and Ring-Ball Temperature (T_{RB}) tests were performed on the RAP-extracted bitumen in order to characterize it. Characteristic penetration and T_{RB} values were, respectively, 10.3 dmm and 71.2 °C.
Blending proportions of RAP material were approximately equal to 20%, 40% and 60% by weight of the final mixture.
Mix design of all asphalts was carried out so that all final materials had a bitumen content of 5.35% by total weight of the mixture. The same continuous 0/14 aggregate gradation was used for the production of all asphalts.
For each asphalt, a bitumen blend of the corresponding base bitumen with the RAP-extracted bitumen was prepared, by maintaining the same proportions.
Therefore, a total number of twelve asphalts and thirteen bitumens were tested (Table 1).

2.2 Methods

Complex modulus tests were performed on all bitumens using a Dynamic Shear Rheometer apparatus (DSR), at a 15 °C temperature and 10 Hz frequency (Figure 1). E^* values were obtained from G^* measured values by applying an arbitrary Poisson's ratio equal to 0.5.

Figure 1: Detail of DSR apparatus with bitumen sample (before trimming)

Fatigue tests on bitumens were also run as DSR time sweeps: materials were subjected to continuous oscillating loading at a 25 Hz frequency, in strain-control mode, at 10 °C. Strain levels ranging from 4000 μstrain (0.4%) to 20000 μstrain (2.0%) were adopted. Plan-plan configuration was used; initially 8 mm polished plates were used which were later replaced by roughed plates (50 μm average roughness) in order to improve bitumen-plate adhesion.
Complex modulus two-point bending tests on mixtures were performed on trapezoidal samples cut from compacted slabs (Figure 2): test temperature and frequency were, respectively, equal to 15 °C and 10 Hz. An identical type of tests was performed to investigate fatigue properties of mixes, at a 10 °C temperature and 25 Hz frequency.

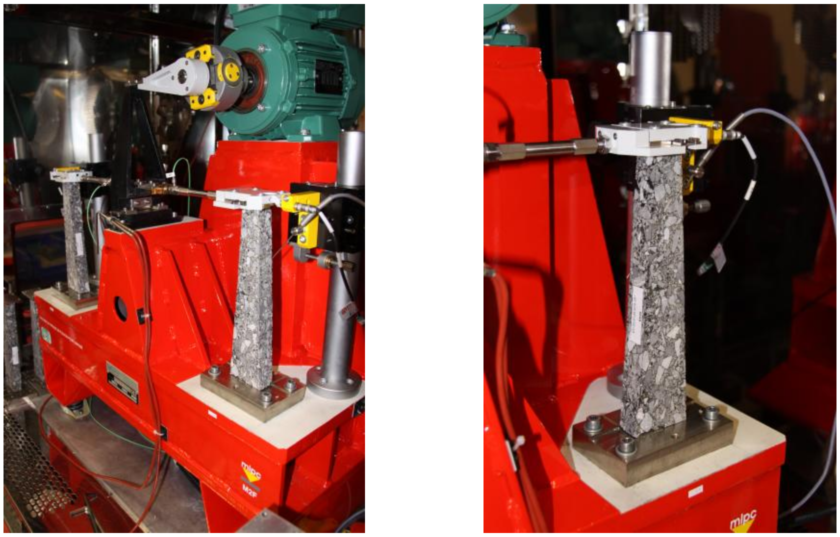

Figure 2: (a, left) Two-point bending test apparatus used for asphalt tests at the EIFFAGE Travaux Publics laboratory in Ciry-Salsogne (France); (b, right) Close-up on a test sample

For fatigue tests on both bitumens and mixes, fatigue life was arbitrarily determined as the number of loading cycles corresponding to a 50% reduction of initial complex modulus value. Fatigue life data were plotted against related strain levels and fitted by Equation 1,

$$\log\left(\frac{N}{10^6}\right) = \log\left(\frac{\varepsilon}{\varepsilon_6}\right)^{\frac{1}{b}} \qquad (1)$$

where:
N is fatigue life;
ε is the strain level associated with fatigue life N;
ε_6 is the strain level corresponding to a fatigue life of one million cycles..
Complex modulus tests were performed on all materials. Fatigue tests were carried out on all asphalts and on the three base bitumens (15/25, 35/50 and 70/100). The experimental campaign is still ongoing.

3. RESULTS

Table 1 shows data obtained from complex modulus tests on all materials. Results are illustrated in Figures 3 and 4. Figure 5 reports measured void contents of all asphalt samples used for complex modulus tests.

Table 1: Complex modulus test results on all materials

material	complex modulus @ 15 °C, 10 Hz		
	E* [MPa]		asphalt % void [-]
	bitumen	asphalt	
RAP	229	-	-
15/25	103	14910	3.3%
15/25 + 20% RAP	136	15282	4.2%
15/25 + 40% RAP	140	16281	3.2%
15/25 + 60% RAP	161	18193	3.4%
35/50	64	11268	4.1%
35/50 + 20% RAP	85	13640	4.0%
35/50 + 40% RAP	114	15765	2.5%
35/50 + 60% RAP	141	17129	3.9%
70/100	24	8425	3.6%
70/100 + 20% RAP	41	10733	2.9%
70/100 + 40% RAP	62	12506	2.7%
70/100 + 60% RAP	100	16083	2.7%

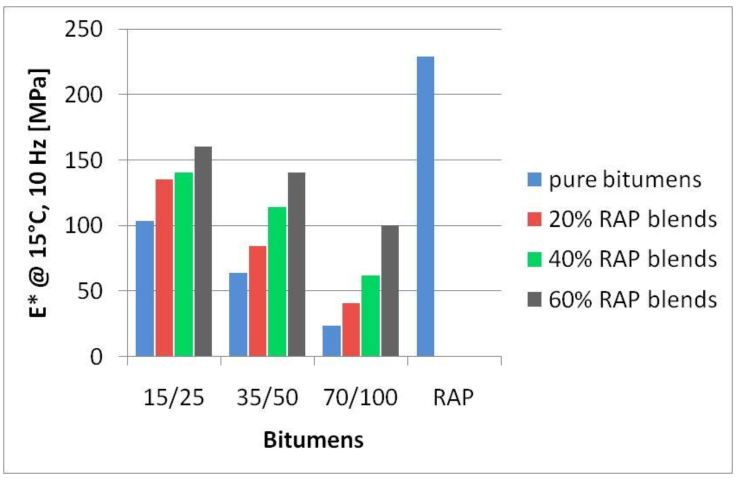

Figure 3: Complex modulus values at 15°C, 10 Hz for all bitumens

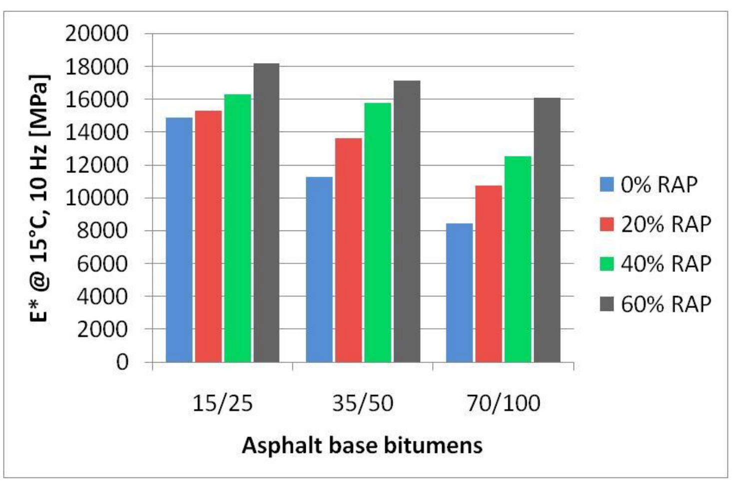

Figure 4: Complex modulus values at 15°C, 10 Hz for all asphalts

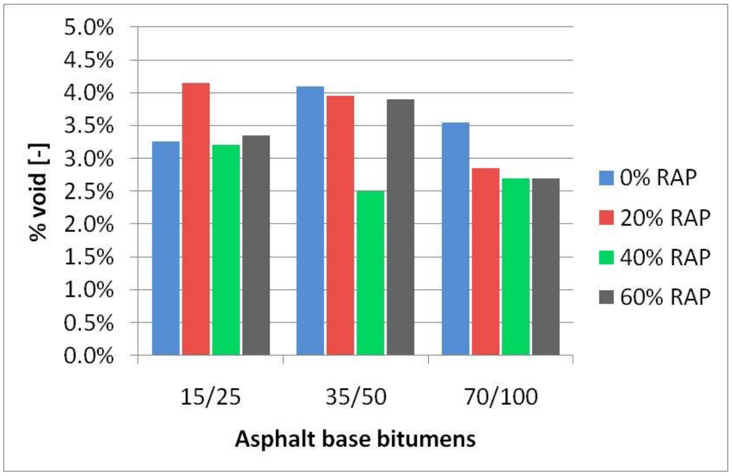

Figure 5: Void contents of all asphalt samples used for complex modulus tests

As expected, complex modulus values increase with the percentage of RAP material (resp. RAP-extracted bitumen) included in the final asphalt mix (resp. bitumen blend).
In order to compare different materials, complex modulus values of all bitumens (with the exception of RAP-extracted bitumen) and asphalts have been normalized with respect to the value measured for, respectively, pure bitumens and asphalt mixes produced without including RAP material. Results are listed in Table 2 and shown in Figures 6 and 7.

Table 2: Normalized complex modulus test results on all materials

material	complex modulus @ 15 °C, 10 Hz		
	E* [MPa]		asphalt % void [-]
	bitumen	asphalt	
RAP	-	-	-
15/25	1.00	1.00	3.3%
15/25 + 20% RAP	1.31	1.02	4.2%
15/25 + 40% RAP	1.36	1.09	3.2%
15/25 + 60% RAP	1.56	1.22	3.4%
35/50	1.00	1.00	4.1%
35/50 + 20% RAP	1.32	1.21	4.0%
35/50 + 40% RAP	1.79	1.40	2.5%
35/50 + 60% RAP	2.20	1.52	3.9%
70/100	1.00	1.00	3.6%
70/100 + 20% RAP	1.71	1.27	2.9%
70/100 + 40% RAP	2.61	1.48	2.7%
70/100 + 60% RAP	4.21	1.91	2.7%

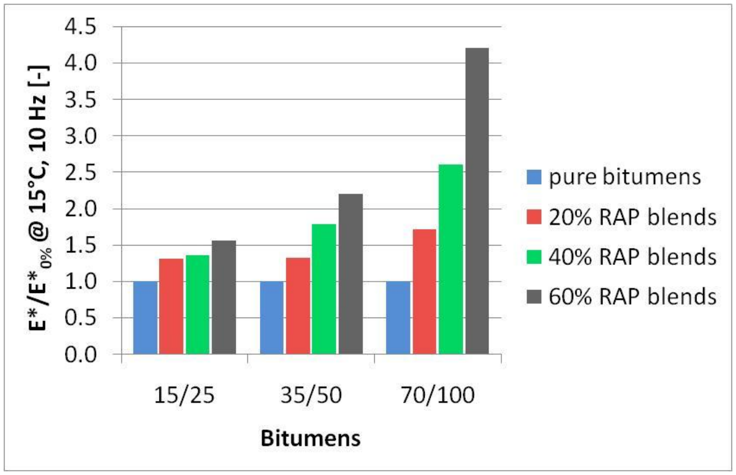

Figure 6: Normalized complex modulus values at 15°C, 10 Hz for all bitumens

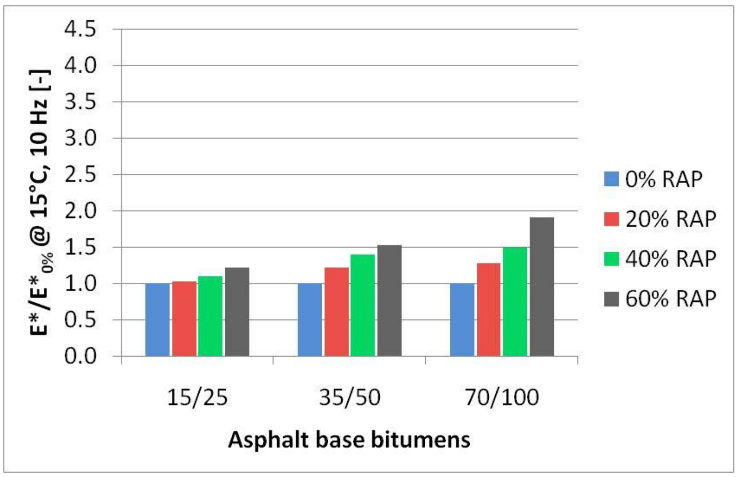

Figure 7: Normalized complex modulus values at 15°C, 10 Hz for all asphalts

It can be observed that complex modulus exhibits a more important increase with RAP content for bitumens than asphalts: this is a largely expected result, given the large influence of the aggregate skeleton on the response of asphalt mixtures. Also, the influence of RAP content on complex modulus is different for asphalts and bitumen blends produced from various asphalt base bitumens. However, normalized complex modulus values of all bitumens and asphalts show a linear trend (Figure 8).

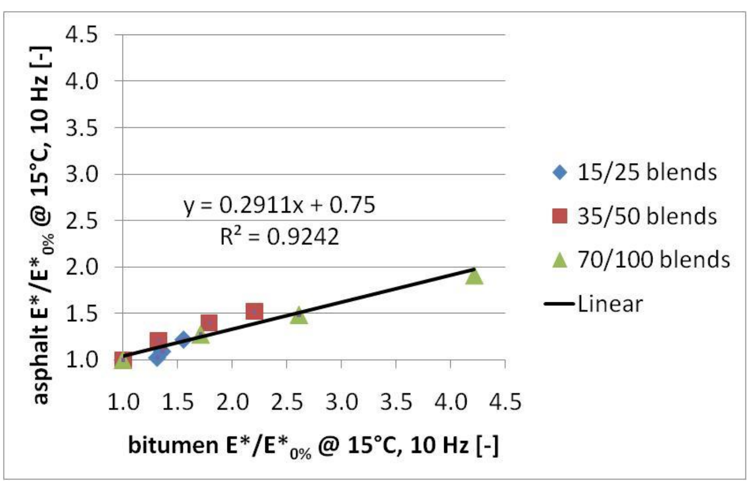

Figure 8: Asphalt vs. bitumen normalized complex modulus values at 15°C, 10 Hz

Fatigue test results are reported in Table 3 for all materials. Figures 9 and 10 show parameters ε_6 and b for the three base bitumens, while Figures 11 and 12 show them for all asphalt mixtures. Figure 13 reports measured void contents of all asphalt samples used for fatigue tests. Fatigue parameters for asphalts have been evaluated according to the European norm NF EN 12697-24 [8]. In absence of a specific norm, parameters for bitumens have been evaluated in a similar way. However, a significant scatter was found in bitumen data: R^2 values for bitumens 15/25, 35/50 and 70/100 are, respectively, equal to 0.77, 0.81 and 0.49.

Table 3: Fatigue test results on all materials

material	fatigue @ 10 °C, 25 Hz					
	ε_6 [µstrain]		b [-]		$\Delta\varepsilon_6$ asphalt* [µstrain]	asphalt % void [-]
	bitumen	asphalt*	bitumen	asphalt*		
RAP	-	-	-	-	-	-
15/25	4090	135	-0.331	-0.136	6	4.0%
15/25 + 20% RAP	-	147	-	-0.130	7	4.0%
15/25 + 40% RAP	-	121	-	-0.230	14	3.4%
15/25 + 60% RAP	-	142	-	-0.142	4	3.2%
35/50	7228	117	-0.175	-0.182	4	3.5%
35/50 + 20% RAP	-	130	-	-0.169	5	3.9%
35/50 + 40% RAP	-	131	-	-0.179	5	2.9%
35/50 + 60% RAP	-	121	-	-0.152	5	3.5%
70/100	6437	118	-0.422	-0.222	5	4.4%
70/100 + 20% RAP	-	129	-	-0.180	5	3.5%
70/100 + 40% RAP	-	128	-	-0.173	6	3.2%
70/100 + 60% RAP	-	135	-	-0.144	6	2.7%

* evaluated according to NF EN 12697-24

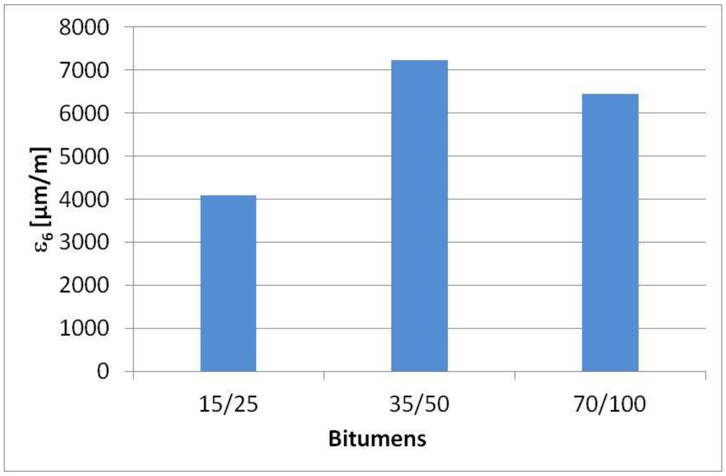

Figure 9: ε_6 parameter for base bitumens at 10°C, 25 Hz

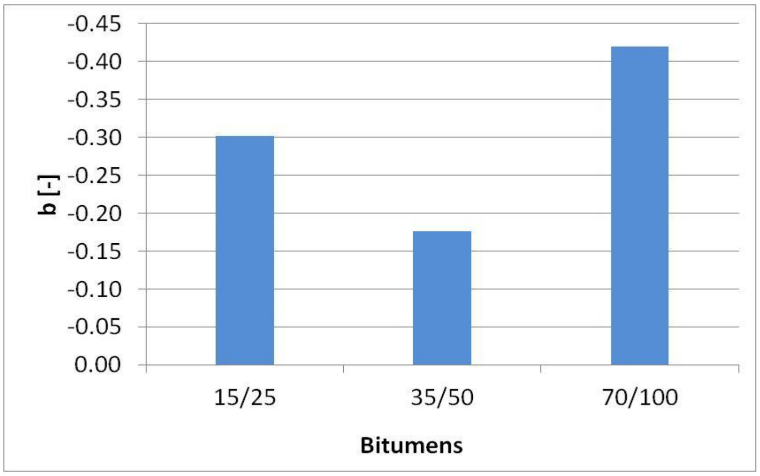

Figure 10: b parameter for base bitumens at 10°C, 25 Hz

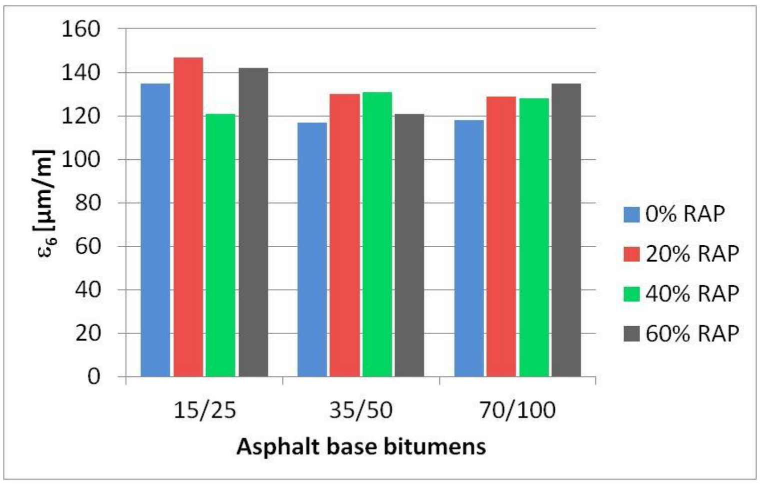

Figure 11: ε_6 parameter for asphalt mixtures produced from base bitumens, at 10°C, 25 Hz; French fatigue specification for High Modulus Asphalt Mixes (NF P 98-140) is indicated

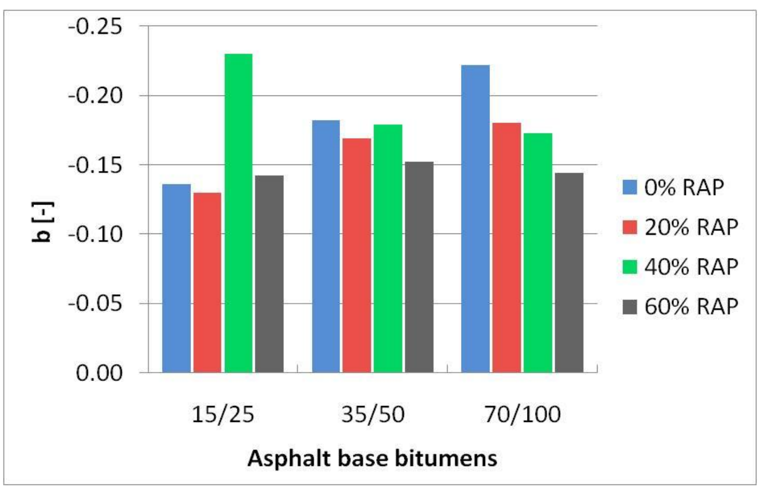

Figure 12: b parameter for asphalt mixtures produced from base bitumens, at 10°C, 25 Hz

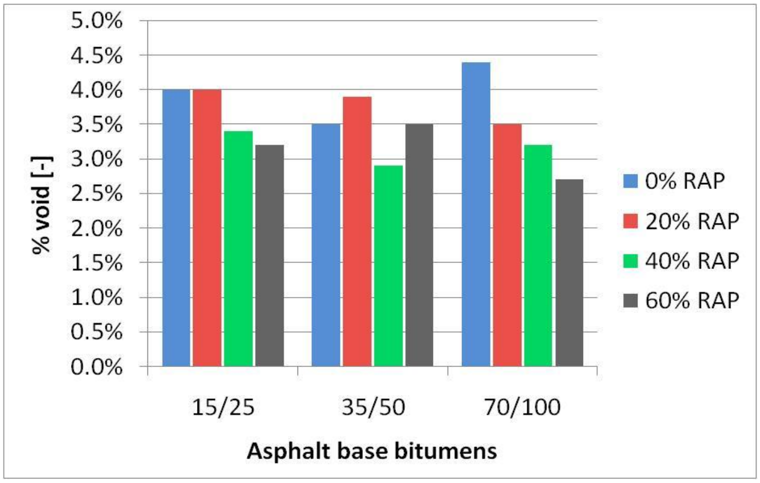

Figure 13: Void contents of all asphalt samples used for fatigue tests

Taking into account the variability due to sample void content oscillations, fatigue parameters of asphalts appear to reach an optimum for RAP content ranging from 20% to 40%. However, some outliers can be noticed, especially for the asphalt produced with bitumen 15/25 and 40% of RAP. Tests on this material will be repeated in order to verify data accuracy. In general, a 60% RAP content does not seem to cause a drastic decline of asphalt fatigue response.
Although fatigue resistance of asphalts is strongly related to bitumen properties, for this limited set of data there is no reliable correlation found between ε_6 and b values of asphalts and corresponding bitumens (Figures 14 and 15).

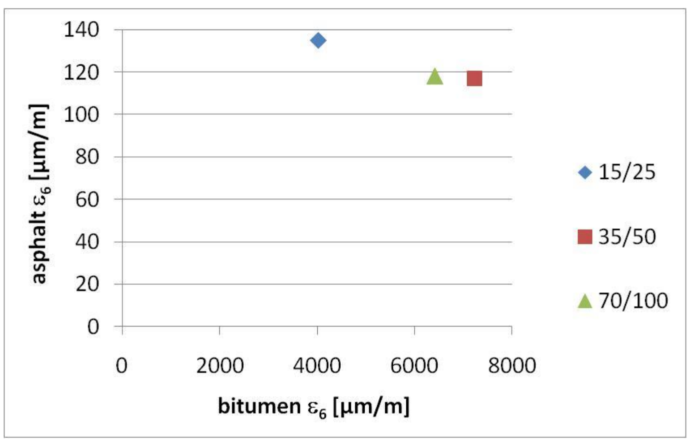

Figure 14: Asphalt vs. bitumen ε_6 values at 10°C, 25 Hz

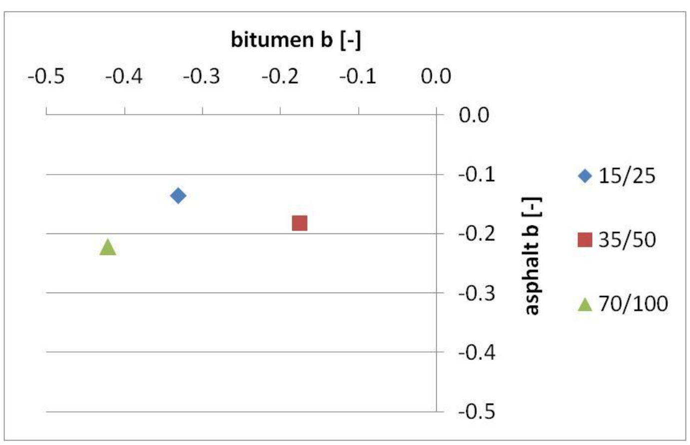

Figure 15: Asphalt vs. bitumen b values at 10°C, 25 Hz

Several possible explanations can be advanced. Fatigue characterization for asphalts and bitumens based on classical tests (such as tests performed in the study) can be erroneous, due to biasing effects existing during such tests [9, 10, 11]. In addition, reliability of DSR time sweep as a fatigue test is a non-secondary issue. Finally, a limited number of materials were included in the fatigue test experimental campaign.

4. CONCLUSIONS

As expected, RAP material content appears to have an important influence on complex modulus of asphalt mixtures and their corresponding bitumen blends. Normalization of E* with respect to values measured for mixtures and blends produced without RAP material indicates that the complex modulus increases with percentage of RAP material more importantly in bitumen blends than asphalt mixes. However, normalized E* values of all asphalts and corresponding bitumens show a linear trend.

ε_6 and b have been determined for all asphalt and bitumen materials. In general, fatigue parameters of asphalts appear to reach an optimum for RAP content ranging from 20% to 40%, although fatigue resistance of asphalts containing 60% of RAP material maintains satisfactory levels. Nonetheless, fatigue parameters ε_6 and b evaluated from experimental results do not allow for a coherent classification of materials according to their fatigue resistance. No correlation is found for mentioned parameters between asphalts and corresponding bitumens. Reliability of DSR time sweep as a fatigue test is a non-secondary issue.

Future objectives are the completion of the experimental campaign, the execution of a complete analysis of viscoelastic behavior of all materials and the development of a prediction model of complex modulus and fatigue performances of bitumens and asphalts.

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