Effect of RAP temperature on asphalt mix performances (hot and warm)

Xavier Carbonneau[1, a], Yves Legal[1, b], Sebastien Quigniot[1, c], Myriam Desroches[2, d]

[1] *Asphalt mixes department, Campus for Science and Techniques COLAS, magny les hameaux cedex, France*
[2] *Chemistry department, Campus for Science and Technique, Magny les Hameaux cedex, France*

[a] carbonneau@campus.colas.fr
[b] legal@campus.colas.fr
[c] quigniot@campus.colas.fr
[d] desroches@campus.colas.fr

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ABSTRACT

Warm mixes are still the main issue in road construction. Environmental and economics stresses lead necessary to a combination of these technologies with recycling.
These new ways to produce asphalt mixes face several problems, resulting from their specific composition and way of production. Mix designs studies in laboratories are not well adapted to make these mixes in a way close to what is produced in plants. Questions arise about how to prepare RAP and to produce mixes in lab when foam is used. When mix design is only based on laboratory studies, this can slow down the acceptance of these technologies. To promote these techniques, Colas has implemented an important test program, and on site measurements on new plants.
A mobile laboratory has been installed and the main existing industrial processes of production, with additives and foam, using RAP warmed or not, have been fully evaluated. Workability, water resistance, but also mechanical performances used in a fundamental approach necessary for pavement design have been completely assessed. Usual mix design of the same mixes has been conducted in the laboratory with materials sampled at the plant, allowing to be sure that no bias could come from the components. Wearing and base courses with 40% RAP content has been studied. The question of the blending of the binders has been evaluated through a detailed analysis of all the binders, pure, extracted from RAP, and extracted from the mixes. Both performance tests and chemical composition of the binders have been investigated, in order to draw some relationships with the mix performances. We especially focused on the state of aging of the binders.
The main characteristic of this experimental trial was that it covers all the existing productions capabilities on the same site. The effect of the process, production of a hot or warm mix, using cold or heated RAP, was fully covered, giving us a necessary better understanding of the effect of the process, leading to more relevant criteria to obtain optimized warm mixes with RAP. These will be an important reference to increase the development of warm mixes with RAP

Keywords: Foam, Mechanical Properties, Performance testing, Reclaimed asphalt pavement (RAP) Recycling, Warm Asphalt Mixture

1 INTRODUCTION

The first work on reducing the manufacturing temperature of asphalt mixes started more than 10 years ago. Although initial progress in Europe was very good, the deployment of warm mixes there is still very limited, in contrast with the United States for example where it steadily increased between 2009 and 2012 [1]. The adoption of techniques which consume less energy nevertheless remains a strong economic and social obligation. Models that simulate the environmental impact of possible alternatives show that the optimum solution lies in the combined use of lower temperature manufacturing techniques and the recycling of asphalt pavement. This combination elicits some hesitation among infrastructure owners, who quite legitimately require a guarantee that the performance achieved will be equivalent to that of hot mixes. Taking advantage of recent investment in its industrial facilities, the Colas Group has organised a large-scale research programme in order to gain additional knowledge about these processes. This paper describes the on-site tests and complimentary laboratory studies that have been conducted on a number of the manufactured mixes.

2 CONTEXT

The deployment of warm mix technologies combined with recycling raises a number of technical issues with regard to the representativeness of laboratory mix designs studies and the possible ways that Reclaimed Asphalt Pavement (RAP) could contribute to the actual performance of mixes in situ.

With regard to the representativeness of studies with RAP, the test procedures specified in the standard that applies to the production of mixes in the laboratory [2] fail by a considerable margin to represent the possibilities of present-day industrial facilities [3]. It is possible to incorporate RAP either in a cold moist form or dried and pre-warmed prior to mixing with the aggregate and added virgin binder. This possibility is not well simulated in the laboratory where the RAP is frequently added after it has been conditioned at 110°C. Such pre-warming is consistent with the industrial conditions that apply in plants that are equipped with two tubes, one of which is dedicated to RAP for high-rate recycling.

Another question that is raised is the representativeness of laboratory studies for characterising the performance of warm mixes and guaranteeing their behaviour in situ, and the subject is more important for warm foam mixes for which foam pilots are used.

Data on the fundamental characteristics of asphalt samples from plants according to EN 13108-1[4] are also limited. In view of this, the Colas Group has decided to take advantage of large-scale industrial investment which included the commissioning of a new mixing plant in order to launch a major test programme.

The industrial site

The programme was conducted in the Rhône-Alpes Region, at the Group’s Bonneville site (in the Département of Haute-Savoie) where an AMMANN Contimix 300 mixing plant was installed in early 2013, as shown in Figure 1. This continuous mixing plant has a capacity of 300 tons/hour and possesses a dedicated tube for heating RAP for applications with high RAP contents. This makes it possible to avoid overheating the virgin materials that may otherwise be necessary to obtain the target temperature for the mix in the case of high RAP content as such overheating may impair the quality of the added virgin binder. The result is a more homogeneous mix with a better mobilisation of the binder in the RAP. The plant in question also possesses an asphalt foam production facility.

Figure 1: The mixing plant and an aerial view of the Bonneville site

3 THE CHARACTERIZED FORMULAS

Results presented hereafter focused on a 40% RAP content base course. This enabled us to cover all the industrial variants in RAP conditioning and the manufacture of mixes with fixed constituents. We produced a control hot mix, with cold or temperature-conditioned RAP and a warm foam mix. This meant that, quite exceptionally, we were able to study the effect of this aspect of industrial production independently, as a single clearly identified source of RAP was used. The aggregate consisted of silicaceous limestone (Bnc II chippings).RAP has been also characterized.

Table 1 gives details of the 6 base course mixes and the manufacturing temperatures. The temperature of the RAP given in the table corresponds to an average determined over the entire duration of production.

Table 1: Formulas of the mixes manufactured and laid

Reference	Formula	Production temp (°C)
B1	AC 14 base course 50/70	150
B2	AC 14 BC 50/70 R40 (cold RAP)	160
B3	AC 14 BC 50/0 R40 (RAP at 101°C)	160
B4	AC 14 BC 50/70 R40 (RAP at 134°C)	160
B5	AC 14 BC 50/70 R70 (RAP at 130°C)	165
B6	AC 14 BC 50/70 foamed R40 (RAP at 120°C)	132

The size of the area to be surfaced meant that considerable amounts of mix were required, approximately 1500 tonnes. These volumes enabled the plant to operate under a fully stabilised regime for each formula, as in all cases the minimum required weight of mix was over 100 tonnes. The real manufacturing temperatures attained were, of course, monitored at the plant. It order to avoid any bias resulting from stabilisation of the operating regime of the mixing plant, the best possible use was made of the hot mix storage capabilities in order to insulate the different batches as far as possible. The material was removed after a minimum of 1 hour 30 of storage in a silo, halfway through the manufacturing process.

4 TEST PROGRAMME

The scale of this programme makes it unique .The short lifetime of foamed asphalt means any attempt to characterise an industrially manufactured sample of mix that contains it is biased as it must be reheated in order to manufacture laboratory specimens. It was therefore decided to set up a field laboratory. This consisted of the combination of a mobile laboratory and the temporary transformation of a plant room into a genuine mix design laboratory. The mobile laboratory comprised PCG 3 Gyratory Shear Press (GSP), a press for moulding Duriez specimens and a gyropac press.

In addition, a room at the site was provided with all the equipment necessary for storing, temperature conditioning, weighing, measuring and degassing specimens prior to determining their moisture content, shown in Figure 2

Figure 2: The CST mobile laboratory and its equipment

The deployment of these resources at the site made it possible to conduct gyratory shear and Duriez tests on site as well as manufacture the specimens required for modulus measurements. All the material required for each specimen was taken at the same time from a loader bucket that was filled under the plant's mix storage hopper.

Core sampling on all the constructed test strips was conducted, allowing to measure void content and modulus on all products. Samples of the constituents were also taken, making it possible to conduct conventional mix design studies subsequently.

5 TESTS METHODS

For the general requirements defined in EN 13108-1, compactibility and water sensitivity were determined according to EN 12697-10 [5] and EN 12697-12[6], and rutting resistance was measured only on laboratory produced mixes, under large rutting device as defined in EN 12697-22 [7] (see figure 3)

Figure 3: test conducted for general requirements: (a) gyratory shear compaction, (b) water resistance with Duriez, (c) rutting resistance on large device

Fundamental characteristics were determined on plants samples, and also for some products on laboratory produced specimens. Modulus was determined according to EN 12697-26 [8], with indirect tensile test on cores or moulded specimens (annex C) or with two point bending tests, both methods been well correlated [9]. The EN 12697-24 [10] standard was used for fatigue resistance and EN 12697-46 [11] for low temperature behaviour. Test methods are illustrated figure 4.

Figure 4: Modulus measurements, (b) Modulus and fatigue on trapezoidal samples, (c) TSRST

6 RESULTS

6.1 Monitoring production and laying.

All test sections were laid on the mixing plant access roads and a parking area. Laying was monitored by measurements of Troxler nuclear density gauge measurements. The mixes were laid in 4 metre strips using a VÖGELE 1800-2 asphalt paver. The road base asphalt mixes were laid in 9 cm thick and were compacted with a type P1 tyred compactor and a type BW 170 Asphalt manager vibratory roller. The production of each formula was monitored as laid down in the standard NF EN 12697-1 and 2. No significant disparity was observed between the theoretical values and the samples taken during production, apart from a very small (2 to 3%) shortage of 2 mm particles. In all cases the binder content was correct to within at least 0.2%.

6.2 Results of on-site tests

6.2.1 Compactibility

No significant difference was noticeable on the different mixes produced. All the recipes with RAP present in this experiment a lower void content compared to the reference mix. But the production process did not change the compactibility behavior determined with the gyratory shear test.

6.2.2 Water resistance

The results are presented in Table 2.

Table 2: Duriez test results

Reference	Formula	Duriez Test		
		%voids	**Cd (MPa)**	**I/C (%)**
B1	AC 14 base course 50/70	8.9	7717	89
B2	AC 14 BC 50/70 R40 (cold RAP)	7.3	9983	90
B3	AC 14 BC 50/0 R40 (RAP at 101°C)	7	11437	97
B4	AC 14 BC 50/70 R40 (RAP at 134°C)	7	11013	96
B5	AC 14 BC 50/70 R70 (RAP at 130°C)	4.8	15787	94
B6	AC 14 BC 50/70 foamed R40 (RAP at 120°C)	6.4	11453	90

The water resistance of the B6 warm mix formula manufactured with foamed asphalt and RAP heated to 120°C was similar to that of the hot mix formula with cold RAP. It should be highlighted that these high i/C values are made even more remarkable by the fact that the compressive strengths after conservation in air were 10% greater for all the road base asphalt formulas with heated RAP (B3, B4, B5, B6) than for those manufactured with cold RAP (B2).

6.2.3 Modulus

The modulus values were determined on specimens that were moulded at the site and on core samples taken from the various test strips. As the voids content sometimes differs between the two kinds of specimens, the modulus values measured on the core samples can be corrected by a density effect to permit direct comparisons. The extrapolation has been performed over a relatively small range of density which will necessarily lead to a good approximation.

The results are set out in Table 3.

Table 3: Modulus values (in MPa) determined at 15°C and 124ms for specimens that were moulded at the site and core samples taken from the various test strips.

Reference	Formula AC 14 BC	Moulded specimens		Core samples		
		% voids	**modulus**	**% voids**	**Modulus**	**Estimated after correction**
B1	50/70	6.4	7876	8.8	6134	7334
B2	50/70 R40 (cold RAP)	6.5	10635	8.8	8778	9928
B3	50/0 R40 (RAP at 101°C)	6.4	11620	7.8	9414	10114
B4	50/70 R40 (RAP at 134°C)	6.5	10342	9.1	8527	9827
B5	50/70 R70 (RAP at 130°C)	6.1	12789	5.2	11046	10596
B6	50/70 foamed R40 (RAP at 120°C)	6.4	10320	7.7	8720	9370

All the mixes give a higher modulus than the reference one. It is very possible that this is the outcome of the contribution of the binder in the RAP, as at this recycling rate the RAP provides a significant proportion of the binder in the mix, as has been shown elsewhere [12].

It is not possible to conduct more detailed analysis of the possible effects of heating the RAP. For example, formula B4 exhibits a modulus value which is slightly lower than that of formula B3, but the only difference between the two is the temperature at which the RAP was conditioned prior to mixing. Likewise, formula B6, produced at a lower temperature than B3, has a modulus value which is similar to that of formula B4. We are therefore not able to conclude that a reduction in manufacturing temperature leads to a reduction in the modulus.

7 COMPLIMENTARY LABORATORY MIX DESIGN STUDIES

To help clarify the issue of the equivalence of performance between hot and warm mixes, laboratory

The foamed asphalt has a short life and its production requires a dedicated facility. Studies were conducted using a Wirtgen WLB 10 laboratory pilot connected to a pug-mill mixer. It was thus possible to produce mixes coated with foamed asphalt under safe conditions, as shown in Figure 5.

Figure 5: Pilote WLB 10 and pug mill for manufacturing foamed asphalt mixes in the laboratory

7.1 Methodology for studying foamed asphalt mixes

The constituents are temperature conditioned, with the temperature depending on the penetration grade of the added virgin asphalt and the goal of reducing the temperature by 25°C compared with the reference value established for a conventional hot mix, as set out in the standard NF P 98-150 [13]. In the case of foamed asphalt mixes, the asphalt is temperature conditioned then placed in a tank in the pilot and made to circulate prior to use. Prior adjustments ensure that the correct quantities of binder and water are added to the mixer in the form of foam.

The standard manufacturing process comprises the following steps:

1 Temperature conditioning of the aggregate (depending on the asphalt grade and target temperature)
2 Temperature conditioning of the asphalt in the pilot (agitation in a closed circuit)
3 Placing of aggregate to the mixer and dry mixing (60s)
4 Injection of foamed asphalt (2 x 5s to manufacture 20 kg of mix with a 5% binder content for example)
5 Wet mixing for 3mn (5 mn with the maximum amount of RAP)
6 Emptying the mixer

Applying the above conditions means that perfect coating can be systematically obtained. The usual temperature reconditioning stages were therefore applied for each type of test.

7.2 Road base asphalt formulas

The results are set out in Table 4. The table also gives the repeatability and reproducibility limits for the tests as stated in the LPC mix design handbook [14].

In the case of formulas B4 and B6, the RAP was dried beforehand at 50°C then conditioned for two hours 30 minutes at either 130°C or 120°C in order to simulate industrial conditions as accurately as possible. In the case of formula B2, the RAP was added in a cold and moist state during laboratory coating. The temperature did not stabilise during mixing because of the evaporation of the water contained in the RAP. The batches were temperature reconditioned for the tests.

Table 4: results of the laboratory mix designs studies

	B1	B2	B4	B6	Categories EN 13108-1	*Repeatability* Reproducibility
Manufacturing temp (°C)	150	160	160	135		
GSP (EN 12697-31) % voids 100 gyrations	8.2	5.9	5.7	5.7	V_{max} 10	
Water resistance EN 12697-12 method B I/C (%)	92	93	96	92	70	*7.8* 13.4
Rutting % voids % rut depth 10000 cycles	9.5 4.4	7 5	7.8 4.6	8.7 5.5	V_i 7- V_s 10 P_{10}	*1.11 (30 kc)* 1.16 (30 kc)
Modulus (EN 12697-26) % voids Modulus 15°C 124 ms (MPa)	9.2 7807	9.3 10675	9.5 10536	7.7 11715	V_i 7- V_s 10	

We can see that in the case of the 4 road base asphalts the differences in the results were very low, and below the limit of reproducibility for the tests. In spite of the precision of the test protocol put in place we were unable to demonstrate any differences which could be put down to the process. It is also noteworthy that in the case of the warm foamed asphalt mix with a RAP content of 40% (B6), all the results were considerably better than those required by the standard, even as regards water resistance.

The only major differences relate to the GSC and modulus tests and were between the control formula and the three other mixes. These can be explained by the presence of RAP. In particular, the increasing modulus measured for formulas B2, B4 and B6 can be explained by the penetration grade of the binder in the RAP.

These comparisons show that hot mixes and warm mixes have equivalent performance, except perhaps for resistance to water, which may be slightly lower for warm mixes, but the difference is always below the limit of reproducibility of the test, and the I/C values met the requirements in the standard in all cases.

6.3 Comparison between the laboratory studies and in-situ performance.

As we sampled all the components, we were able to conduct later water resistance test on mixes produced in the lab. Results are presented in table 5.

The resistance to water values measured on the specimens that were manufactured on site were only slightly lower than those measured in the laboratory, but on samples with higher voids content. This is an important point, as it shows that our methodology is conservative, judging products as compliant on the basis of characteristics which may prove to be less good than those measured on the industrial product. In this case, the variability of the constituents cannot be to blame as the laboratory studies were deliberately conducted later with samples of the constituents that were taken on the day manufacturing took place.

Table 5: Comparison between the results of the DURIEZ tests conducted on site and those conducted during the laboratory study

Reference	Formula AC 14 BC	Laboratory studies			On site measurements		
		% voids	**Cd (MPa)**	**I/C (%)**	**% voids**	**Cd (MPa)**	**I/C (%)**
B1	50/70	6.5	9489	92	8.9	7717	89
B2	50/70 R40 (cold RAP)	4.6	12611	93	7.3	9983	90
B4	50/70 R40 (RAP at 134°C)	4.7	15040	96	7	11013	96
B6	50/70 foamed R40 (RAP at 120°C)	4.3	14259	92	6.4	11453	90

Gyratory shear test were also realised, and lead to the same previous conclusion, that is to say that it does not differ the production process used, and the main effect comes from the RAP.

7 FUNDAMENTAL CHARACTERISTICS

In addition to the on site characterisation procedures, large slabs of material were cut from the pavement for modulus and fatigue strength tests. Some cores were also sawed in the slabs for TSRST test. The results are presented in Table 6, which also include values measured on laboratory produced specimens for B6 mix. Figure 6 supplements this with the modulus master curves for the four mixes, sampled in the pavement.

Table 6: Results of the modulus and fatigue strength tests conducted on the slabs taken on site. The voids contents are given in brackets. (*) laboratory produced mix

	B1	B2	B4	B6	
Modulus 15°C 10hz (MPa) EN 12697-26 annex A	9244 (7.7)	11697 (7.5)	12691 (5.4)	11887 (7.5)	11581(*) (6.7)
Fatigue Strength 10°C-25 Hz µdefs EN 12697-24 Annex A	102 (7.9)	117 (7.5)	115 (5.3)	107 (7.7)	116(*) (6.2)
Failure temperature (°C) EN 12697-43	-20.7 (8.6)	-18.3 (7.3)	-20.1 (5.3)	-20 (8.1)	

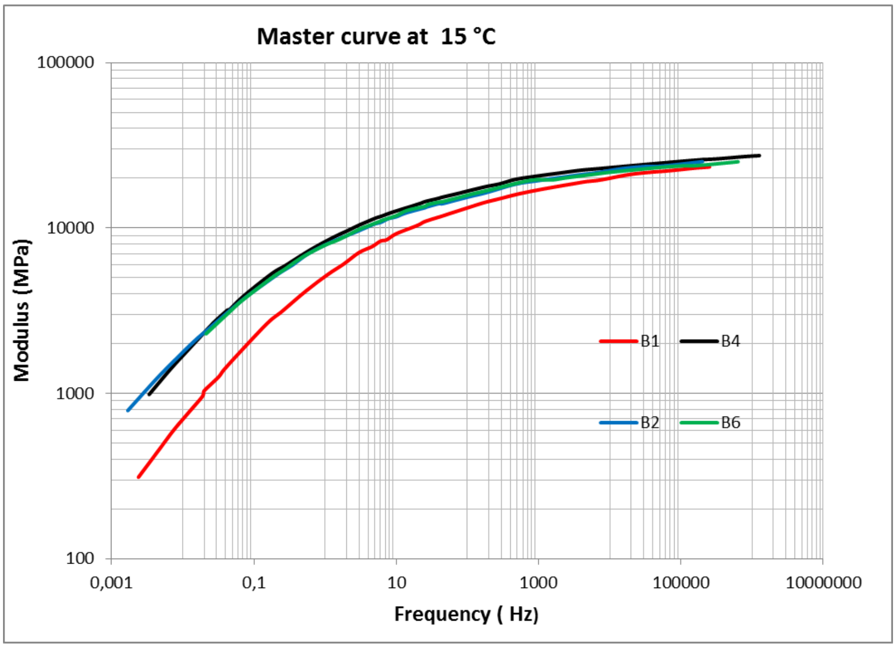

figure 6: Master curves for the road base asphalt

The differences between these four formulas were relatively minor. The three that contained 40% of RAP all had a modulus that was between 2000 and 3000 MPa higher than the control formula. This can easily be explained by the contribution of the binder in the RAP [4]. With regard to fatigue, all the mixes with RAP outperformed the control mix. Formula B4, which was produced at normal temperature with heated RAP, had the lowest voids content, a phenomenon which had not been observed on the core samples tested under diametral compression. The characteristics of the warm foamed asphalt mix were also very much better than the requirements for a Class 3 road base asphalt. For the low temperature behaviour, the only mix which seems to show a reduction of the performances is B2, with a failure temperature 2°C higher than the values determined on the three other base course tested. But the difference is low compare to the reproducibility of this test. It's also very interesting to note that mixes B4 and B6, with 40% RAP, have almost the same low failure temperature than the reference mix without RAP. The warm foam mix has the same mechanical performances than hot mixes, with an increase in modulus coming from the RAP, and low temperature characteristic as good as the reference.

Results obtained on the laboratory produced mix are really closed to the values measured on specimens from the slabs taken on site, allowing again to be quite confident in the mix design method based on mechanical tests on laboratory mixes, even for the fundamental characteristics defined in EN 13018-1.

8 ADDITIONNAL ANALYSES ON BINDERS

Finally, how does the quality of the binder in the RAP contribute to the characteristics of the fresh mix, and what changes may it undergo during the recycling process? With regard to the latter, the operation at Bonneville gave us a unique opportunity to make the first complete comparative analysis taking advantage of the fact that road base asphalt formulas with a high recycling rate (40%) had been manufactured in a way which was identical in every way apart from the method of production. The RAP was used either cold or heated. For these formulas, the binder in the RAP accounted for very slightly less than 40% of the total mix binder content. In this campaign we were not able to take samples of RAP from the end of the RAP heating tube on the Contimix 300 continuous mixing plant. It was therefore not possible to characterise the precise effect of heating the RAP to 110°C or 135°C. Our analysis therefore focused on the binder extracted from the mix that was manufactured and laid. This new formula has therefore been slightly affected by dilution of the binder in the RAP. In spite of this, this analysis provides us with an idea, for these products and this batch of RAP, of the change that has taken place in the binder in the coated material. A detailed analysis of the composition of the binder in formulas B1 B2 B4 and B6 was therefore conducted. The results are shown in figure 7.

The binder was extracted from the slab taken from the site. The results also include the characteristics of the virgin added binder and the binder extracted from the RAP that had been measured after straightforward laboratory drying.

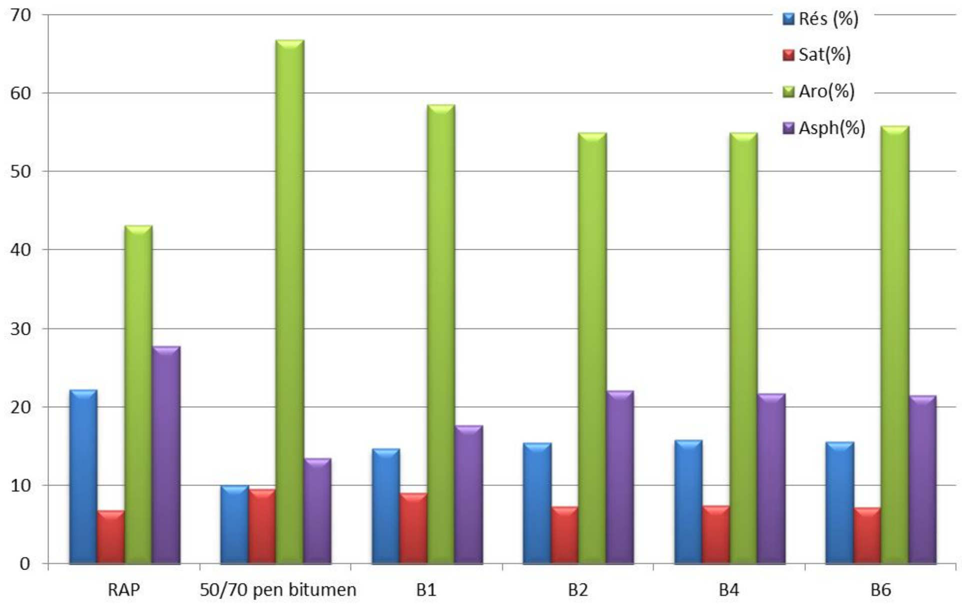

Figure 7: Composition of the binders in the different formulas compared to the virgin added binder and the binder in the RAP.

The way the composition of the virgin added asphalt changed after it had been used for coating closely matches what one would expect. The RAP used had a high asphaltene content. Finally, the chemical composition of the binders in formulas B2, B4 and B6 were very similar. In the case of formulas B4 and B6, heating the RAP did not lead to a significant increase in the asphaltene fraction in comparison to B2 to which the RAP was added cold. This also shows that we were not able to show the existence of any variation in the composition of the binder as a result of the manufacturing process for the high percentage of RAP used here.

The characteristics of the extracted binders are also set out in Table 7. Only formula B4 which contained no RAP differs from the other formulas. For all three mixes with 40% of RAP these values are similar to those of a 20/30 pen asphalt.

Table 7: Characteristics of the binder extracted from the different road base asphalt formulas

Mix reference	Penetration (1/10 mm)	$T_{R\&B}$ (°C)	G* (MPa) (15°C-10Hz)
B1	36	54	38
B2	23	60.2	49
B4	25	59.6	50
B6	26	58	48

One notes that the binders extracted from mixes B2, B4 and B6 have similar modulus values. As the binders in question were extracted from mixes with identical compositions, this seems quite reasonable, as the dissolution stage leads to perfect mixing of the components provided by the added binder and the binder in the RAP. It is also consistent with the modulus results that were measured for the laid mixes described in Table 6, which clearly shows the contribution of the RAP to the final performance of the mix.

CONCLUSIONS

This paper has shown Colas's commitment to assisting the deployment of new production methods for mixes and thereby satisfy environmental expectations. This work has provided us with valuable insights in connection with the development of production techniques for warm foamed mixes with high recycling rates. We have demonstrated, on a road base asphalt with 40% RAP content, that a hot mix or a warm foamed asphalt mix exhibit similar moduli and fatigue performance. Comparative laboratory studies of different formulas have shown that the performance of hot mixes and warm foamed asphalt mixes was similar. In all cases the differences between the two were below the reproducibility limits of the tests. Furthermore, measurements conducted on mixes produced in a mixing plant have shown that the resistance to water measured in the laboratory is equivalent to, or even lower than, that measured on the industrial mix. This confirms that no specific durability issues are associated with the use of foamed asphalt mixes.

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