STUDY ON THE ROLE PLAYED BY RAP BINDER IN ASPHALT MIX PERFORMANCE

Xavier Carbonneau, Flavien Lubineau
COLAS

ABSTRACT

In the road industry, the pressure to shift towards more environmentally-friendly development processes has fostered a growing focus on recycling techniques. This approach is not new, but its novelty today lies in the recent trend to maximize reclaimed asphalt pavement (RAP) contents, thus requiring major investments in industrial tools. This change has led to a sharp increase in the number of RAP mix design studies, which in turn has left us with many questions: what is the representativeness of laboratory manufacturing methods compared to industrial reality in the field?; what is the impact of lab protocol on the mechanical characteristics measured in the lab?; what role does the binder contained in the RAP play in the performance of the final mix? This article will essentially focus on the last issue, with a view to quantify the impact of the binder in a given mix containing RAP on modulus measured in the final mix. To demonstrate the said, we selected a base course mix design that is studied with different RAP contents and compared to control mixes, one of which simulates a perfect mix of added bitumen and aged binder. In parallel, performance trends are compared to changes in modulus measured on the mix's binder. This first approach makes it possible to forge ahead with the idea that it is possible to use modulus to demonstrate the impact of RAP on mix performance.

Keywords: RAP, binder, Modulus

1. INTRODUCTION

The use of recycled asphalt pavement (RAP) is not new, but environmental pressures, the desire to make savings and the development of more reliable industrial equipment which is able to attain high proportions are leading to a considerable rise in its application. The variability of RAP is a limiting factor for its use except in the case of large-scale maintenance operations on homogeneous pavements which provide a "uniform" source once suitable milling techniques, possibly associated with crushing and screening operations, have been specified.

The economic interest of the technique is based on an implicit hypothesis that the binder in RAP will contribute to the performance of the mix and also reduce the amount of pure or rejuvenating virgin added binder that is required. It is assumed the binder makes a full contribution in this respect, but to date no study has been performed that irrefutably validates or invalidates this hypothesis.

With a view to clarifying this issue, we conducted a study that attempts to quantify the contribution of the binder in RAP to the performance of mixes. Before presenting the approach we have adopted and our analysis of the results, we shall rapidly describe some previously published findings.

2. THE CURRENT STATE OF KNOWLEDGE WITH REGARD TO THE MOBILIZATION OF THE BINDER OF THE RAP

The literature contains a large number of studies on this topic which set out to demonstrate the degree of blending using tracers or by measuring a mechanical characteristic that reflects the blending of the virgin added binder and that extracted from RAP. In the last case, it is almost exclusively the modulus of the mix which is evaluated.

Here we can mention the work of Laëtitia El Bèze [1] on the blending of binders from RAP with virgin binder during the coating stage. The selection of appropriate tracers which can be detected in the intergranular binder film makes it possible to demonstrate that at least partial blending of the binder from the RAP and the virgin added asphalt takes place. However, this approach, because of the dimensional limits of the characterization techniques, required the use of a model mix, manufactured with enough binder to provide a sufficiently thick intergranular asphalt film. The mix obtained contained no filler. Finally, the material which was used as RAP consisted of a laboratory-aged model mix which meant that its initial composition was known exactly and it was possible to exploit the tracers fully. This approach is limited by the constraints that are imposed by the control mix design. We can assume that the mix design had conflicting effects, as the absence of filler will tend to increase the fluidity of the binder in comparison to that in real RAP and therefore facilitate mixing, but the fact that the binder film is considerably thicker than in conventional mixes may mean more energy is required to achieve good blending.

As recycling was developed in the USA, a considerable amount of work has already been performed there, in particular in order to codify practices in the framework of the Superpave mix design method [2]. A technique has thus been proposed for taking account of the characteristics of the binder in RAP and selecting the penetration grade of the added binder on this basis.

A 2009 study, conducted at the Illinois Center for Transportation, attempted to quantify the contribution of the binder in RAP to performance [3]. To this end, different batches were prepared with RAP contents of 20 and 40 % and asphalt with a penetration grade of 64-22 and 58-28 and then subjected to modulus measurements. A protocol that simulated perfect blending of the coating binder with that in the RAP was also developed. The modulus of the binders was also measured and the results were used to estimate the modulus of the mix with the Hirsch model. But even if a significant increase in the modulus was observed as the proportion of RAP was increased, precise quantification of the contribution of the binder in the RAP was not possible.

Finally, we should mention the study conducted in Nottingham by Nguyen [4]. Working with a RAP which was controlled because it was manufactured in a laboratory and then incorporated in a mix to produce a coated material with identical composition made it possible to avoid issues related to the possible effect of the granular skeleton. The visual approach employed in this research with an oxide-tinted blend whose dispersion was observed for different mixing conditions or has a similar bias to that in the work of El Bèze [1], with a possible effect of the viscosity of the particular type of mastic used. This research has also shown the benefit of using RAP with a small particle size, in order to facilitate dispersion and its “incorporation” within the final blend. At the same time, the mechanical characteristics were evaluated by techniques that included modulus measurements and the results show that the performance increased with the degree of mixing and the fineness of the RAP.

It emerges from the above than any study that attempts to show how the binder in RAP contributes to performance will inevitably be limited to the selected experimental conditions and constituents. The particle size of the available RAP, the mixing protocol applied (type of mixer and duration) and the temperature at which the constituents are conditioned prior to manufacture can also affect the result, making it difficult to quantify precisely how the binder in the RAP and the conditions of the study respectively affect measured performance.

3. ADOPTED APPROACH

The modulus would seem to be the most easily measured mechanical property for which it should be possible to show the contribution of the binder in RAP. This hypothesis results from the trend that can be seen in Figure 1, namely that the modulus of the mix increases with the modulus of the binder. This graph shows the complex bending modulus of the mix measured on trapezoidal specimens at 15 and 10Hz as a function of the modulus of the coating binder measured with a DSR also at 15°C and 10Hz. A number of mixes, which have not been shown differently on the graph, include RAP. For these, the abscissa corresponds to the characteristic measured exclusively on the virgin added binder.

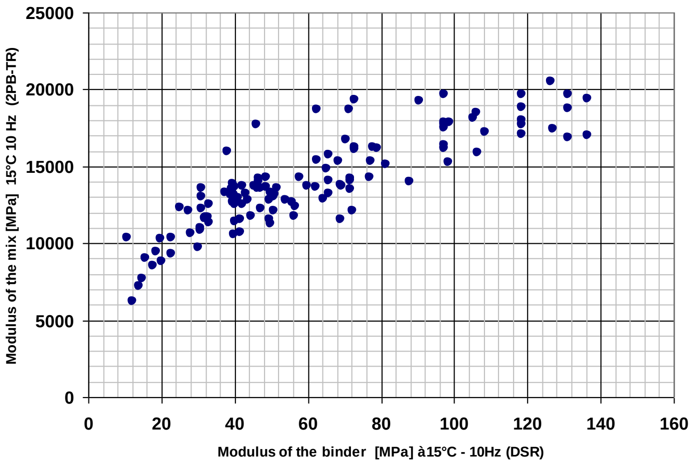

Figure 1: Modulus of the mix versus the measured modulus of the virgin coating binder

The research presented in this paper therefore includes a systematic evaluation, for all the batches, of the modulus of the mix from a diametral compression test at 15°C 124 ms, and a characterization of the virgin added binder, the binder in the RAP and, if applicable, of the perfect blend between the added binder and the binder in the RAP in their respective proportions in the mix. It should be noted that the diametral compression test is specified in the standard EN 12697-26 [5] and correlates very well with the complex modulus result from a bending test on a trapezoidal specimen [6].

Two complementary approaches were thus implemented at the same time.

The first consisted of comparing the modulus values obtained for mixes with identical binder contents and grading curves but different manufacturing processes. A comparison was made between the measured performance of the mix with RAP and an identical mix design which simulates a perfect blend of the two binders (that in the RAPs and the virgin added binder, as shown in Figure 2).

Figure 2: Adopted procedure for simulating a perfect blend of the virgin added binder and the binder in the RAP

This part of the study was brought to a close with the manufacture of warm mixes with the same composition, and other mixes in which the proportion of aggregate was varied. This work is similar to that conducted at the University of Illinois, but we used a product with a large percentage of high modulus binder, and have only made comparisons between the measurements made on binders and mixes.

The second approach consisted of comparing the modulus values obtained on a mix design (testing different types of binder) with those obtained with the same mix design (the same blended aggregate skeleton) but by adding 30% of RAP and modifying the added binder content so as to maintain the same richness modulus as the "control mix". This made it possible to cover the widest possible range of performance and maximize the possible differences between the modulus values in the mix design with or without RAP.

4. CHARACTERISTICS OF THE CONSTITUENTS USED IN THE STUDY

4.1 The composition of the RAP and the selected mix designs

In order to quantify how the binder in the RAP contributes to the performance, we arbitrarily decided to work with a known mix, a 0/14 High Modulus Asphalt made with silico-calcareous alluvial aggregate from the Rhine, with a binder content of 5.7%. The Recycled Asphalt Pavement used for the study was taken from a stockpile that was being used in a mixing plant. The binder content and the measured characteristics of the binder extracted after drying in a thin layer (approximately 5cm) in an enclosure for 12 hours at 50°C as set out in Table 1.

Table 1: Characteristics of the binder extracted from the batch of Recycled Asphalt Pavement used for the study.

Binder content	4.25 %
Penetration (1/10 mm)	12
TR&B (°C)	69
G* 15°C 10Hz (MPa)	83

Based on the three types of constituents described above (aggregate, recycled asphalt pavement and pure coating asphalt), several groups of mixes were manufactured in a laboratory. These are described in Table 2.

Table 2: Manufacturing conditions applied in the study

Group of mix	Composition	Analysis performed
A	Aggregate: 0/14 Alluvial RAP: 30% Added asphalt: 50/70 pen	Manufacturing methods Hot with conditioning of RAP, warm, and simulating a perfect blend of the mixing binder and the binder extracted from a RAP
B	Aggregate: 0/14 Alluvial Added asphalt: 160/220, 70/100, 50/70, 35/50, 20/30 and 10/20	Reference value of variation of E* against G*
C	Aggregate: 0/14 Alluvial RAP: 30 % Added asphalt: 160/220, 70/100, 50/70, 35/50 20/30 and 10/20	Effect of the modulus of the added binder (G*) on the modulus of the mix
D	Aggregate: 0/14 Alluvial RAP: 20, 30 and 40% Added asphalt: 50/70	Effect of proportion of RAP

4.2 The characteristics of the different coating binders

In order to cover the largest possible range of modulus values for the coating binder, all the available classes of pure binder were used. The characteristics measured for the different batches are set out in Table 3. The modulus was measured at 15°C -10Hz.

Table 3: Characteristics of the different pure asphalts used. (1) (2) are indices that identify the two batches of 50/70 pen asphalt used in this part of the study

Class of pure coating asphalt	Penetration at 25°C (1/10 mm)	T R&B (°C)	G* 15°C 10 Hz (MPa)
10/20	12	68	98
20/30	20	62	66
35/50	35	54	37
50/70 (1)	49	49	43
50/70 (2)	58	50	20
70/100	81	46	16
160/220	175	40	8

It can be seen that with the full range of binders that we have used, the measured modulus values of the softest binder and the hardest binder differ by a factor of 10. The measured characteristics of the binder extracted from the RAP are closer to those of a hard binder, the result being quite similar to those for a 10/20 asphalt. Two batches of 50/70 asphalt with markedly different modulus values were used during the study. The batch manufactured without RAP, using all the pure asphalts, provides us with a control study that shows how the modulus of the mix varies with that of the binder, when all the other characteristics are kept constant (nature of the materials, binder content, voids content).

5. MANUFACTURING CONDITIONS

All the batches were manufactured with a Rainery mixer. The RAP was dried beforehand then conditioned at 110°C for 2h30 +/- 30 min before the mixes were manufactured. The coating binders were at their normal temperature of use. The target temperatures for the mixes were those specified in the standard NF P 98-150 [7] as a function of the class of the mixing binder. The recommended temperature was obtained by slightly overheating the added aggregate, as shown in Table 4. This manufacturing procedure was also used to manufacture the warm mixes with 50/70 pen asphalt, whose final target temperature was 120°C.

Table 4: A chart for selecting the temperature to which the new aggregate should be heated as a function of the proportion of RAP and the target temperature of the mix, in the case of dry RAP (Based on [8]).

Recommended temperature for mix	RAP content (%)		
	20	**30**	**40**
120	125	125	130
140	150	155	160
160	175	180	190
180	200	210	230

For each mix, a batch of 4 or 5 specimens was manufactured with a diameter of 100 mm and a thickness of between 40 and 50 mm using a Gyropac gyrotary shear press.

6. RESULTS

The results obtained for the mixes in group A (see Table 2) are presented in Figure 3. The modulus value of the mix made with 50/70 pen asphalt and 30% of RAP is not significantly different from the control mix. This result does not seem to indicate that the binder in the RAP makes an obvious contribution to performance. However, the measured value is also close of that obtained with a batch that simulates a perfect blend of the asphalt extracted from the RAP and the virgin added asphalt. It is therefore not easy to reach a conclusion.

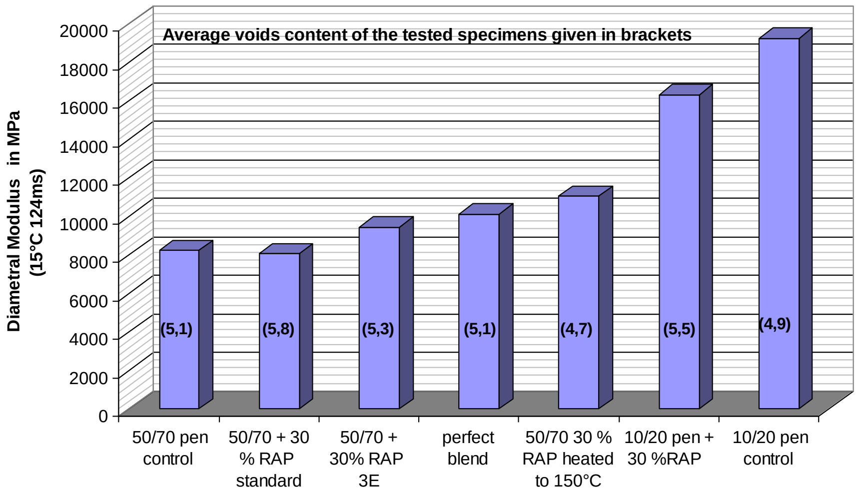

Figure 3: Modulus values measured on the different batches of group B mixes [see Table 2]

Furthermore, we can also observe that the measured performance of the warm mix was also of the same order of magnitude. With regard to the modulus, the warm mix manufactured at a temperature over 100°C, was better able to mobilize the binder in the RAP than one using a low temperature manufacturing process. A possible explanation of this result which is disappointing with regard to demonstrating how the binder in RAP contributes to performance is that the modulus of the 50/70 pen binder used for this evaluation was already relatively high, 43 MPa at 15°C 10Hz (see Table 3). The temperature of the RAP seems to be an extremely important factor, as shown by the test results obtained with the mix whose RAP had been conditioned beforehand for 2h30 at 150°C. Its influence may also be increased by a possible change in the binder in the RAP during the conditioning phase at 150°C. Our research did not check this.

Group B exhibits a correlation between the modulus value measured on the mix and that determined on the coating binder, for the entire range of normally used asphalts, even including binders that are not used in hot mixes in France. These findings are shown in Figure 4. They show that with constant mix design and density it is possible to make a direct link between the modulus of the mix and that of the binder.

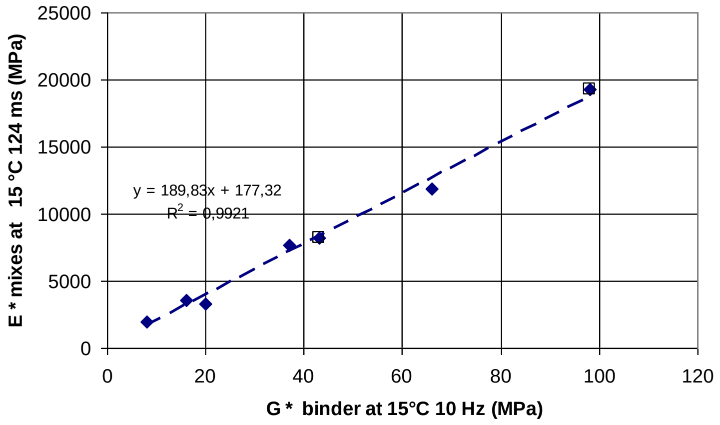

Figure 4: Measured modulus versus the G* value of the coating binder with constant grading curve and density.

On this basis, we can also better analyze the results of the measurements made on the mixes in group C. We can also compare the modulus values obtained for the mixes in groups B and C. To make this comparison we must ignore any impact on the modulus of the difference in the mineralogical nature of the aggregate in the RAP and the virgin aggregate. Table 5 sets out the measured mean values.

Table 5: Measured modulus values for the different batches in Groups B and C as described in Table 2. The mean geometric voids contents for each batch of specimens that underwent modulus tests are given in brackets.

Class of coating binder	Modulus of formulae without RAP [B]	Modulus of Formulae with 30% RAP [C]
10/20	19251 (4.9)	16303 (5.5)
20/30	11833 (5.2)	11318 (5.7)
35/50	7688 (5.2)	7876 (5.2)
50/70 (1)	8222 (5.1)	8051 (5.8)
50/70 (2)	3344 (5.3)	5255 (5.2)
70/100	3578 (5.5)	5463 (3.8)
160/220	1945 (5.7)	3536 (5.8)

In the case of the blends manufactured with the softest binders, we can observe that those which include RAP have a higher modulus than those with only alluvial aggregate, while the opposite applies to the blends made with the hardest binders.

We can also present the analysis of the data in this table by plotting the modulus of the mix against that of the binder. This raises the question of what value to adopt for the modulus of the binder. The possible extremes are known as they correspond either to the hypothesis that no blending will occur, in which case the abscissa consists of the modulus of the added binder, or a perfect blend. In the second case, the modulus is estimated on the basis of the proportions of coating binder and binder from RAP in the mixture and their respective moduli by applying the following equation:

$$\text{Log } G^*_{\text{(perfect blend of binders)}} = a \text{ Log } G^*_{\text{virgin asphalt}} + b \text{ Log } G^*_{\text{Asphalt from RAP}}$$

(a and b being respectively the proportions of binder extracted from RAP and virgin asphalt in the binder in the mixture, a+b=1. It should be noted that these percentages differ from the percentage of RAP in the mixture.

We have plotted these two extreme hypotheses on Figure 5, which also states the values obtained for the B group of mixtures.

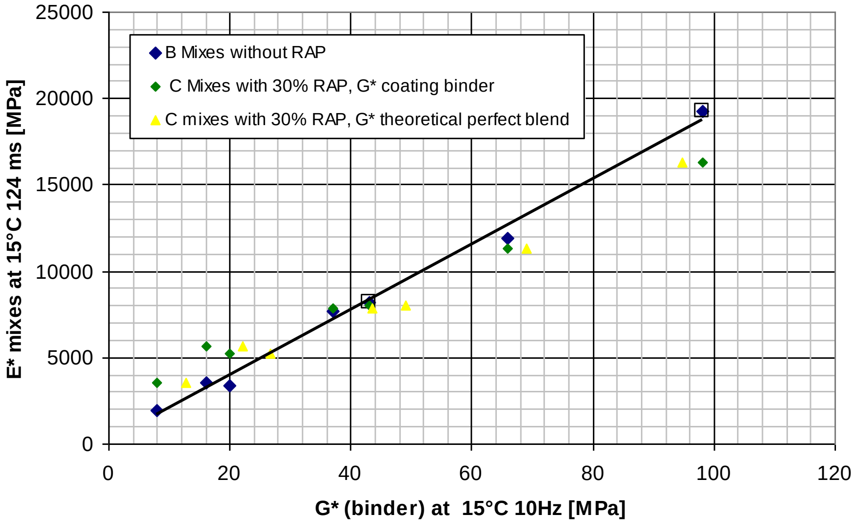

Figure 5: Modulus values measured on the formulae with 30% of RAP versus the modulus of the binder, with the value for the coating binder or that calculated for a perfect blend.

When the modulus G* of the coating binder is placed on the abscissa, the points are quite significantly distant from the line given by the formula with 100% alluvial aggregate. When the G* value of the binder calculated in the case of a perfect blend is placed on the abscissa, there is an increase in the value on the abscissa for the formulae with the softest binder and a reduction in the case of the formula with 10/20 pen asphalt, which is the only binder with a higher modulus than that determined for the binder extracted from the RAP (see Tables 1 and 3). In the case of the binders with the lowest modulus values, the points which correspond to a perfect blend are close to the control line for the case without RAP.

7. ADDITIONAL ANALYSIS

The mixes with 30% of RAP described above are mixtures in which the binder in the RAP accounts for only 20% of the binder in the mixture. It is therefore possible to calculate the maximum modulus value that can be attained in the case of a perfect blend between the binders from RAP and the virgin added asphalt. This has been plotted on

Figure 6, for two arbitrary values of G* at 15°C-10Hz for the virgin coating asphalt, respectively 20 and 98 MPa. These values correspond to those measured on the 50/70(2) and 10/20 pen asphalts mentioned above (see Table 3). In the case of the binder extracted from RAP, a value of 83 MPa has been applied.

If we look at the plot that shows the change in the calculated modulus in the case of the perfect blend between our 50/70 pen binder(2) and the binder from the RAP, it can be seen that the increase in the modulus is fairly marked. Nevertheless, to reach a similar level to that achieved with a 35/50 pen asphalt, using the experimental value stated in Table 3, the binders from RAP must account for slightly less than 45% of the blend's total binder content. In contrast with the hypotheses chosen here, the effect of the binders in the RAP on hard asphalt is much less pronounced.

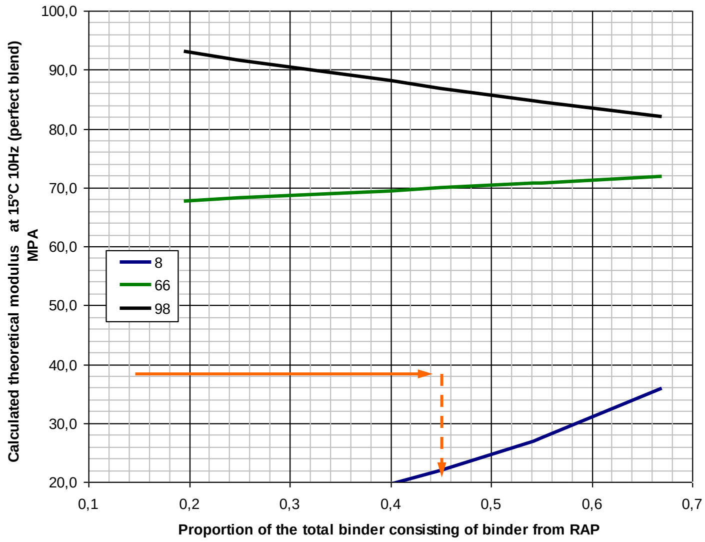

Figure 6: Theoretical modulus value of the perfect blend between added binders and binders from the RAP versus the proportion of binders from RAP in the mixture.

This last point also helps to explain results obtained for Group D, manufactured with a 50/70(1) pen asphalt with a G* value of 43 MPa, for the 3 percentages of RAP (20, 30 and 40%), which are presented in Table 4 below.

Table 4: Measured modulus values for the group D batches with different proportions of RAP.

	Formula with 20% RAP		Formula with 30% RAP		Formula with 40% RAP	
Test temperature (°C)	10	15	10	15	10	15
% of voids	5,9		5,8		5,4	
Modulus at 15°C 124ms [MPa]	14322	10332	13682	8051	16655	10560

There is not a large increase in the modulus value as the proportion of RAP increases − the formula with 30% of RAP even has a slightly lower modulus than the blends with 20% of RAP. However, in the case of these three mixes, RAP provides respectively 13.3, 19.7 and 26.3% of all the binder. From these data, we can calculate the theoretical value of the modulus in the case of a perfect blend for these three mixtures. The result is respectively 46.9 48.9 and 51.1 MPa. If we return to the initial hypothesis which ignores the effect of the minor variation in the granular skeleton on the modulus for the mix and that we estimate the variation to which this increase in the theoretical G* value should correspond, we reach an estimation of the order of 380 MPa between 20 and 30% of RAP and below 800 MPa between 20 and 40%. These effects are almost lower than the reproduceability of the test. They may therefore explain the difficulty in measuring a difference between two mixes which only differ in terms of the proportion of RAP.

A final study was conducted as part of the research on another high modulus mix design, with dioritic virgin aggregate. The total binder content of the mixture was fixed at 5.3%. The batch of RAP used was also different and had a binder content of 5.8%. In a similar way to what had been done earlier, a control modulus was established on the basis of the modulus of the coating binder, but this estimate was only made for 3 mix designs using 160/220, 20/30 and 10/20 pen asphalts. The characteristics of the virgin binders and of the residual binder from the other batch of RAP are set out in the table below.

Table 5: Characteristics of the virgin binders and the binders extracted from the RAP

Class of the pure coating asphalt	Penetration at 25°C (1/10 mm)	TBA (°C)	G* 15°C 10 Hz (MPa)
10/20	10	72	144
20/30	20	62	66
160/220	175	40	8
AE	11	69	96

In passing, we can note here too the high variability of the modulus in the case of 10/20 pen asphalts when we compare the result in Table 5 with that given in Table 3. Once again, there are very great disparities according to the batch and the origin of the binder as was the case for the 50/70 pen asphalts.

In addition, the batches with 4 proportions of RAP (15, 30, 45 and 60%), were manufactured with two asphalts (160/220 and 10/20 pen) as the added binder, in order to determine the modulus. The above percentages of RAP, corresponded respectively to 16, 32, 48 and 64 % of binder from RAP in the total binder content of the mixture. The blends were adjusted in order to achieve the most constant grading curve possible for the mixture, as shown in Figure 7, likewise the proportion of the added binder was corrected in order to keep the total binder content constant.

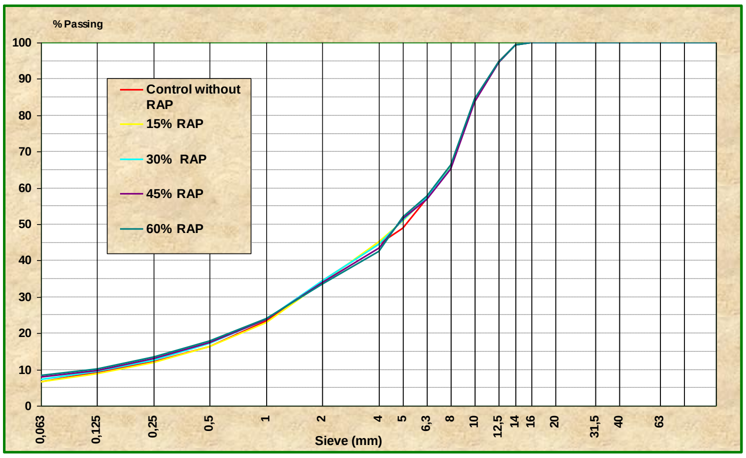

Figure 7: Comparison between the different grading curves for blends including 0, 15, 30, 45 and 60 % of RAP

The 160/220 pen binder was used in order to create the only experimental conditions which are likely to clearly demonstrate how the binder extracted from RAP contributes to the performance with reference to the conclusions drawn above. Here too, it is important to ignore the effect of the nature of the granular constituents of the mix on the modulus, and this decision is open to debate in the case of the highest contents, particularly if the final workability and density of the mix vary considerably from one batch to another.

We decided to examine the change in the modulus of the mix as a function of the modulus of the binder. As above in the case of the binder, we arbitrarily chos two extremes corresponding respectively to the modulus of the added binder or the theoretical modulus calculated with the hypothesis of a perfect blend. This approach is shown in Figure 8.

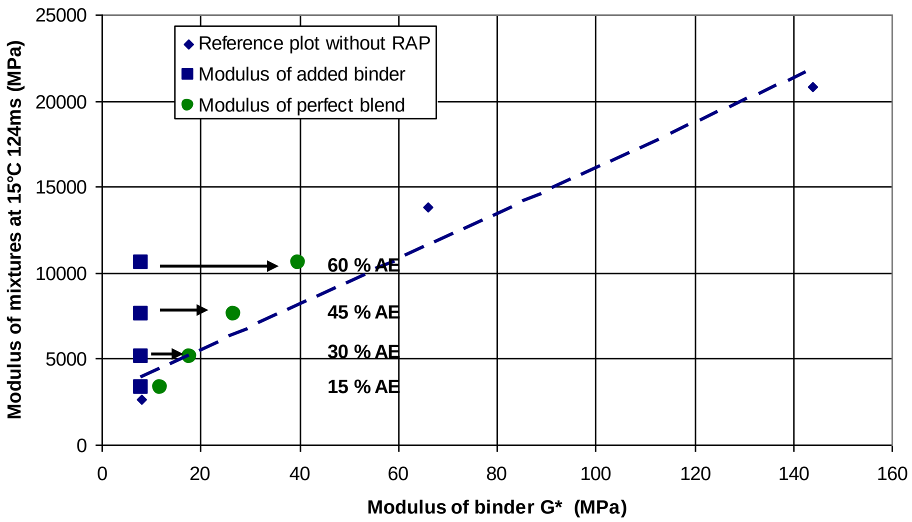

Figure 8: Graph showing the measured modulus value for mixtures with 160/220 pen asphalt and different proportions of RAP, depending on whether the abscissa shows the modulus of the added binder or a perfect blend between the binder extracted from the RAP and the added binder.

In this case, we can see that there is a very considerable increase in the modulus as the proportion of RAP rises. The values measured on the mixtures are much nearer those that can be estimated from the control consisting with the 3 compositions without RAP.

This last approach clearly shows their significant contribution to the modulus. It also confirms that in order for the contribution to be apparent from the measurement of a mechanical property of the mixtures, the constituents must be carefully selected and the binder in the RAP must account for a major proportion of the total asphalt in the mixture. But as this contribution has been demonstrated in the case of a soft binder, it also occurs in the case of a harder added asphalt. The virgin coating binder will necessarily have the correct viscosity as it is used at the recommended temperature for its class. In addition, the fact that the final temperature of a mixture is higher will also assist the homogenization of the product.

8. OUTLOOK

It is the last results which demonstrate the contribution made by the binder extracted from the RAP to performance. It should be borne in mind that this contribution also depends on the test procedures used in the laboratory, the particle size distribution of the RAP and the mixing techniques.

However, a considerable amount of work still needs to be done in order to promote recycling by demonstrating that the technique has been fully mastered and that performance is guaranteed. This involves issues connected with fatigue strength, the adaptation of mix designs and the selection of a class of coating binder, the specific case of warm mixes (whose increased use can only be beneficial), and the representativity of this work with respect to our industrial equipment.

This study did not consider fatigue strength. This is fundamental for the materials used in sub-base and road base layers in which it is possible to maximize the proportions of RAP and use the aged hard binder they contain efficiently. However, at the present time, we do not have an indicator that is based solely on the intrinsic characteristics of the binder extracted from RAP that gives a reliable idea of how it will affect the fatigue strength of the mix. We did not perform the necessary research in the framework of this study. In spite of the large number of findings that are available within the Colas Group, on, for example, High Modulus Asphalt containing RAP, shown in Figure 9, no specific risk is apparent. It is reasonable to think that, as with the modulus, below a high level of recycling it is the characteristics of the virgin added binder which dominate. Moreover, some mixtures containing recycled materials have exceptional performance. It is also possible that, with binders which are known for their good fatigue performance and which generally have a lower modulus, recycling may provide a way of optimizing mix designs to an even more [9].

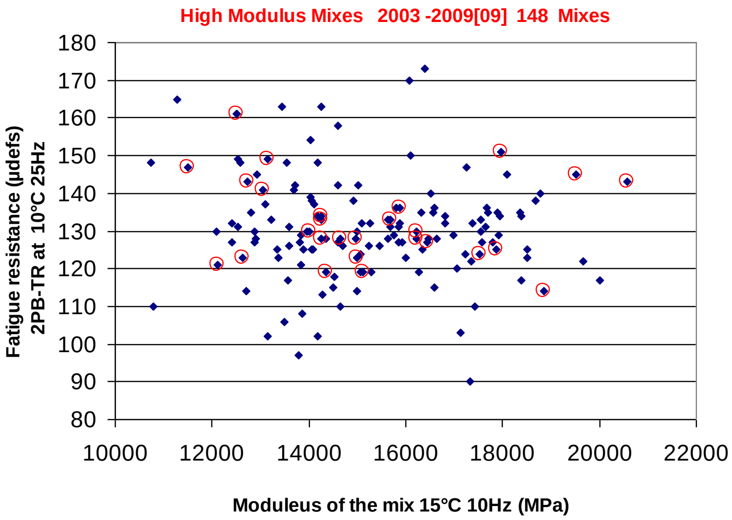

Figure 9: Modulus and fatigue performance of the formulae of High Modulus Asphalt with and without RAP (formulae with RAP shown in red).

Although the contribution of the binder extracted from RAP has been established, its impact on performance can only be demonstrated in special cases, when there is a high proportion of binder extracted from RAP in the mixture and a large disparity between the modulus of the added binder and that of the binders extracted from RAP. It is therefore only possible to establish that a modification of a virgin added binder is appropriate on the basis of a mix design study, supplemented by a comprehensive appraisal of the characteristics of the binders present in the mixture. It is not possible to specify a recycling rate that permits the use of a new binder of a “lower” class than that normally used for the mixture without RAP. This is because the proportion of the binder extracted from RAP will dominate at a lower recycling rate for road base asphalt than for products such as High Modulus Asphaltic concrete and High Modulus Asphalt.

In addition to the modulus and fatigue, other performance characteristics, such as low temperature performance may also be considered.

This research did not focus on warm mixes either. Environmental issues and the need to save energy mean that we must develop these techniques. What impact can a lower manufacturing temperature have on the effective contribution of the binder extracted from RAP? We do not yet have enough experience to answer this question. The Colas Group has already used these procedures at some worksites, with satisfactory results. The performance measured in the laboratory was identical with that of hot control mixes [10].

We used RAP that had been dried in advance and conditioned for 2½ hours +/- 30 mins at 110°C. This conditioning temperature is that specified in the European standard. This procedure was adopted as the mixtures with very high RAP contents (>35%) are almost all produced by mixing plants with systems that are able to heat the RAP to a temperature near 110°C. Obviously, the procedure used here does not cover all the possibilities provided by production plants, for example with some mixing plants it is possible to add cold RAP using a recycling ring at rates of up to 50%. In addition, the Colas Group has already conducted a considerable amount of work on specimens and core samples taken from worksites in order to compare the laboratory performance and the characteristics of the mix after laying. This involves different types of mixing plants (continuous and batch mixing plants), some of which were equipped with a tube for heating RAP permitting recycling rates of 50% or even more. These field data will make it possible to confirm the accuracy of the observations made in the research described in this paper and the quality of the mixes that have been laid.

9. CONCLUSION

Overall, the results presented here show the contribution of the binder extracted from RAP to the performance of the mix under our selected laboratory conditions. It substantiates the common hypotheses and practices which consider the binder extracted from RAP as an integral part of the bituminous binder in the mixture. However, it also confirms the experimental difficulties inherent in this type of demonstration. Looking beyond this theoretical study, the optimization of mixtures with high recycling rates is still a topic for research, which is made more difficult by the need to take account of new parameters such as the modulus values of the added binder and the binder extracted from RAP. Preliminary studies therefore remain a useful way of making progress in this area, if the procedures chosen take account of the current industrial potential for recycling, in particular for heating of RAP. The Colas Group is already engaged in the necessary work of supplementing this theoretical approach by monitoring a large number of worksites. This will provide an opportunity to obtain new concrete technical information in order to foster the development of recycling.

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References

[1] «Recyclage à chaud des agrégats d'enrobés bitumineux »,El Bèze, thèse Université Paul Cézanne, Aix Marseille, Décembre 2008
[2] "Recommended Use of Reclaimed Asphalt pavement in the superpave Mix design Method: Technician's manual". NCHRP Report 452, R Mc Daniel, R.M. Anderson, 2001
[3] " Determination of Usable residual asphalt binder in RAP", I. Al Qadi, S.H. Carpenter, G. Roberts, H. Oser, Q Aurangzeb, M. Elseifi, J. Trepanier, Research report ICT-09-031, Illinois center for Trnasportation, January 2009
[4] « Effects of laboratory mixing methods and RAP Materials on performance of hot recycled asphalt Mixtures" V.H. Nguyen, Thesis, Nottingham, July 2009
[5] EN 12697-26 Décembre 2004 « Méthode d'essai pour mélange hydrocarboné à chaud. Partie 26 Module de rigidité ».
[6] « Modulus measurement European standardisation possibilities », X Carbonneau, S Quigniot, Y Legal, Rilem, Rhodes, 2009
[7] NF P 98-150 janvier 2008. Exécution des assises de chaussées, couche de liaison et couche de roulement. Partie 1: Enrobés hydrocarbonés à chaud – constituants, formulation fabrication, transport, mise en œuvre et contrôle sur chantier.
[8] « Recyclage des enrobés bitumineux en centrale d'enrobage » R.Barroux BLLPC N° 105, janvier février 1980.
[9] « Analyse des performances mesurées sur Enrobés à module élevé et Graves-Bitume, proposition d'un principe de compensation » M. Chappat, X. Carbonneau, Y Lefeuvre, RGRA N° 875, avril 2009
[10] « Warm mixes with RAP: case studies » X. Carbonneau, Ph Pellevoisin, L. Brissaud, V Galera, 16th World road meeting, IRF 2010, Lisboa