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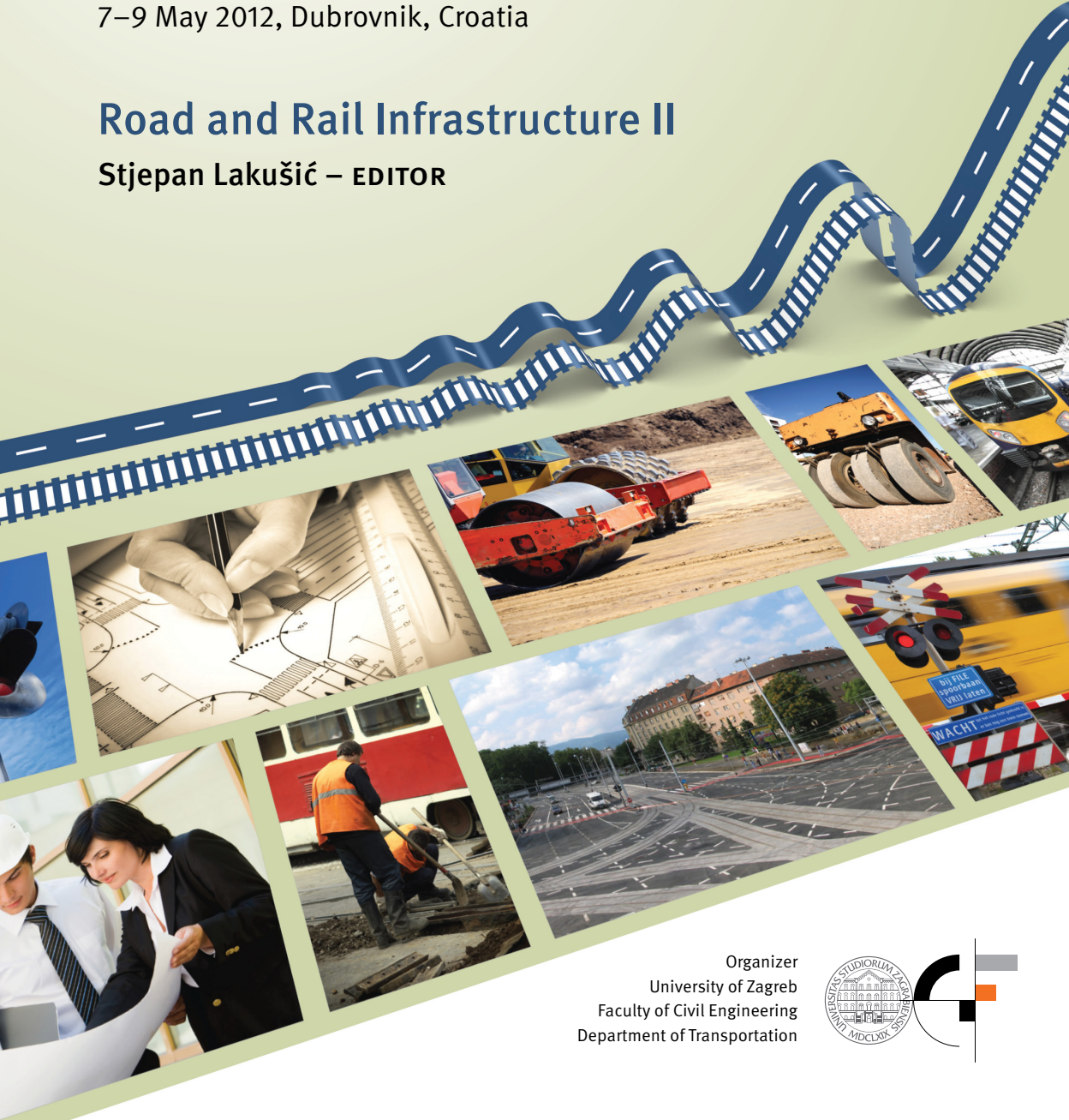**2ⁿᵈ International Conference on Road and Rail Infrastructure**
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Road and Rail Infrastructure II

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

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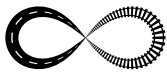
BINDER MOBILIZATION IN RAP AND ITS CONTRIBUTION TO MIX PERFORMANCE

X. Carbonneau, F. Lubineau, B. Yvinec, Jean Paul Michaut
COLAS DGE, France

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 lies in the recent trend to maximize the use of reclaimed asphalt pavement (RAP). Furthermore and for a long time mixing plants have been improved to introduce more and more high percentage of RAP. The pressure with sustainable development and the possibility to increase the RAP use have increased the RAP mix design study requirements. With this latter, many questions have been raised such as: what is the right laboratory method? How does the RAP binder influence the performance of the final mix?
This article mainly deals with the last query and gives some answers regarding to the final mix properties. Base course mix design has been chosen and tested with different RAP contents and then has been compared to the traditional base course asphalt concrete. Then asphalt concrete performances have been compared to the binder stiffness modulus, itself taking into account the RAP and the new binder. One of the first finding is that RAP binder mobilization has an influence on the final property of the asphalt concrete performance.

Keywords: RAP, binder, stiffness modulus

1 Introduction

The use of recycled asphalt pavement (RAP) is not new, but due to environmental pressures and for making savings, it is leading to a considerable rise in its application. The variability of RAP could be a limiting factor when we use it at high percentage in the mix but it's not a problem when the RAP percentage is lower than 20%. Nevertheless, for using at high percentage, a 'uniform' source coming from homogeneous pavements (obtained after milling or crushing or screening) is necessary.
One of the economic interests of this latter is based on an implicit hypothesis that the RAP binder contributes to the performance of the final mix and also reduces the amount of the added pure binder. For clarifying this issue, a study has been conducted to quantify the contribution of the RAP binder to the final mix performances. Before presenting the adopted approach and the results, some of the previously published findings are described.

2   The present knowledge

Numerous studies have been lead to demonstrate the blending degree using tracers or by measuring mechanical characteristic as the mix stiffness modulus.

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. 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. European standards give the following formulation (for penetration formula 1 or for softening points formula 2) when reclaimed asphalt is used in new formulation for the determination of the final binder in the mix.

$$a \log \text{pen}\,1 + b \log \text{pen}\,2 = (a+b) \log \text{pen}\,\text{mix} \qquad (1)$$

with pen 1 for added pure binder and pen 2 for RAP binder:

$$\text{Trb mix} = a\,\text{Trb1} + b\,\text{Trb2} \qquad (2)$$

with Trb1 softening point for added pure binder and Trb2 softening point for RAP binder. (a) and (b) are the percentages of each binder and a + b = 1.

More recently in some European countries, requirements have been made for avoiding the use of RAP in the EME formulation at a high RAP level due to the fact the used RAP binder had the characteristics of soft binder.

3   The adopted approach

The mix stiffness moduli seem to be the most easily measured mechanical property in which the contribution of the binder in RAP could be showed. This hypothesis results from the trend that can be observed from Figure 1. The modulus of the mix increases with the modulus of the binder. This graph shows the complex modulus of the mix measured on trapezoidal specimens at 15°C and 10Hz as a function of the binder stiffness measured with a DSR also at 15°C and 10Hz. The abscissa corresponds to the characteristic measured exclusively on the virgin added binder. A number of mixes including RAP, which have not been shown differently, are shown in Figure 1.

The research presented here includes a systematic evaluation, for all the batches, of the mix stiffness from a diametrical compression test (EN 12697-26 with test conditions of 15°C and 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. Two complementary approaches were also 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 RAP and the virgin added binder, as shown in Figure 2).

The second approach consisted of comparing the modulus obtained on a mix design (with different types of binder) and those obtained with the same mix design (same blended aggregate skeleton) but by adding 30% of RAP. The added binder content was modified in order to maintain the same richness modulus as the reference mix.
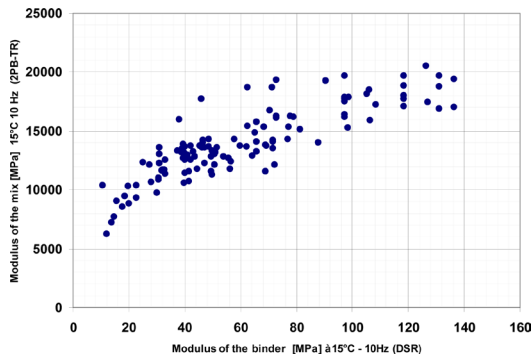
Figure 1   Modulus of the mix versus the measured modulus of the virgin coating binder

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

3.1 Characteristics of the used study constituents

In order to quantify how the binder in the RAP contributes to the performance, a known mix, 0/14 High Modulus Asphalt Concrete (EME) made with silica-calcareous alluvial aggregate from the Rhine River has been adopted.

The RAP used for this study was taken from a stockpile mixing plant. The binder content and the measured characteristics of this binder extracted after drying in a thin layer (approximately 5cm) in an enclosure for 12 hours at 50°C are in Table 1. 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 as described in Table 2. All the available pure binder classes were used to cover the largest possible range of binder stiffness modulus values. The measured binder characteristics are in Table 3.

The measured characteristics of the binder extracted from the RAP are closer to those of a hard binder, quite similar to those for 10/20 asphalt.

Table 1   Characteristics of the extracted RAP binder

Binder characteristics	
Binder content	4.2 %
Penetration (1/10 mm)	12
TR&B (°C)	69
G* 15°C 10Hz (MPa)	83

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

Table 3   Characteristics of the used grade bitumen (1) and (2) identify the two batches of 50/70 pen asphalt used in this part of the study

Grade of pure binder	Pene at 25ºC (1/10 mm)	T R&B (ºC)	G* 15ºC 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

3.2 Manufacturing conditions

The RAP was beforehand dried and then conditioned at 110ºC for 2h30 +/- 30 min before the mixes were manufactured. The coating binders were at their normal temperature of use. The temperatures are shown in Table 4.

Table 4   Chart for selecting the temperature to which the new aggregate should be heated according to dry RAP percentage

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

3.3 Results

The results obtained for the mixes in group A (see Table 2) are presented in Figure 3. The mix stiffness 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 to what is obtained with a batch that simulates a perfect blend.

The figure 4 shows the Group B values. The asphalt concrete manufactured without RAP, using all the pure bitumen shows there is a direct link between the measured asphalt concrete stiffness modulus and the one determined on the coating bitumen. The asphalt concrete stiffness variation when all the other characteristics are kept constant (nature of the materials, binder content, voids content) is directly linked to the binder stiffness modulus variation. The modulus values obtained for the mixes in groups B and C are indicated in Table 5.

Table 5   Measured stiffness for Group B and C (The geometric void content averages 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 by plotting the mix modulus versus binder modulus. 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:

$$\mathrm{Log}G*_{\text{(perfect blend of binders)}} = a\,\mathrm{Log}G*_{\text{virgin asphalt}} + b\,\mathrm{Log}G*_{\text{Asphalt from RAP}} \tag{3}$$

a and b being respectively the proportions of binder extracted from RAP and virgin asphalt in the binder in the mixture, a + b=1.
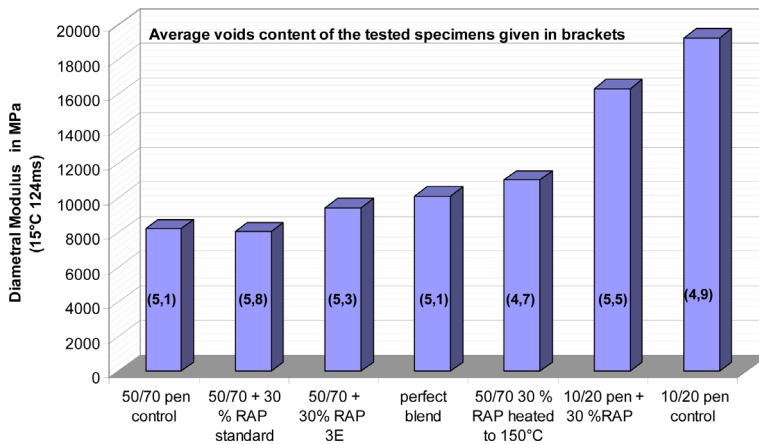
Figure 3   Modulus values measured on the different batches of group A
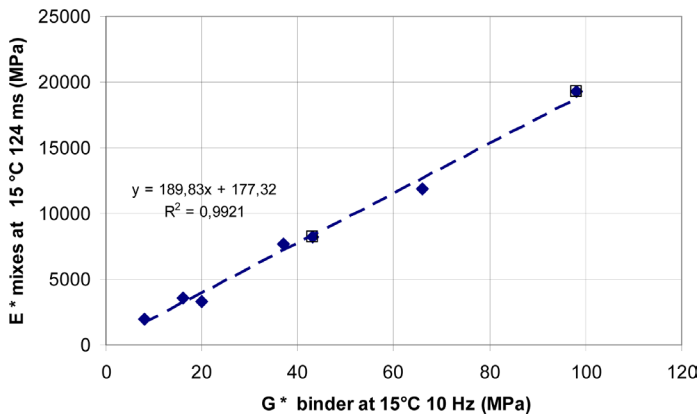

Figure 4   Measured mix stiffness and binder stiffness for constant grading curve and density

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

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 binders with lowest modulus values, the points which correspond to a perfect blend are close to the control line for the case without RAP.

In the case of Group D, manufactured with a 50/70[(1)] pen asphalt (G* value of 43 MPa), for the 3 percentages of RAP (20, 30 and 40%), stiffness are presented in Table 6.
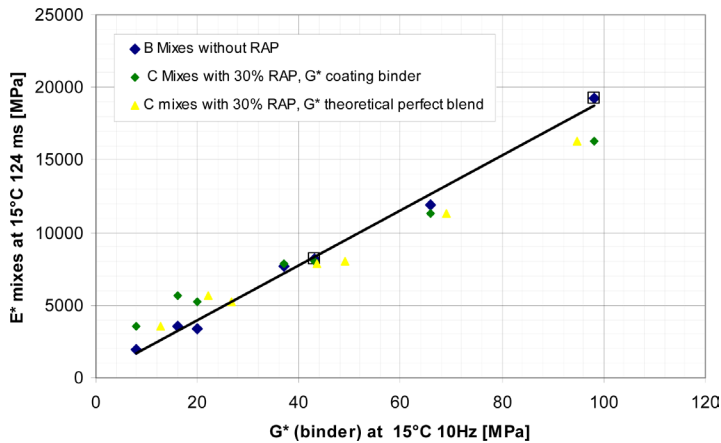
Figure 5   Mix modulus measured on the formulae with 30% of RAP versus the binder stiffness, with the value for the coating binder or that calculated for a perfect blend

Table 6   Measured modulus values for the group D

Formulation	with 20% RAP		with 30% RAP		with 40% RAP	
Test temperature (ºC)	10	15	10	15	10	15
% of voids	5,9		5,8		5,4	
Modulus 15ºC 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 blend 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 this data, the theoretical value of the modulus in the case of a perfect blend for these three mixtures can be calculated and are respectively the followings: 46.9, 48.9 and 51.1 MPa. If the effect of the minor variation in the granular skeleton is not taken into account for the mix modulus, the variation of the theoretical G* increase should correspond of around 380 MPa between 20 and 30% of RAP and below 800 MPa between 20 and 40%. These effects are almost lower than the reproducibility 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.

4 Conclusions

However, considerable amount of work must be done in order to promote and develop recycling by demonstrating that the technique has been fully mastered and that performances are guaranteed. This study did not consider fatigue strength. This is fundamental for the materials used in sub-base and road base layers in which the RAP proportions could be maximized. However, we do not have now an indicator based solely on the intrinsic characteristics of the RAP binder which gives us a reliable idea of how it will affect the fatigue strength of the mix. The necessary research in the framework had not be performed in this study, in spite of the large number of findings that are available within the Colas Group. For example, EME containing RAP are shown in Figure 6 and present no apparent specific risk.
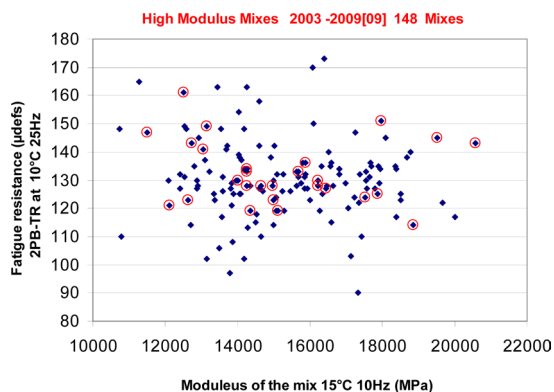

Figure 6   Modulus and fatigue performances of EME with (in red) and without RAP

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 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 EME. 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? To answer to this question more results are necessary.

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. 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. 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 develop the recycling.