SIIV - 5th International Congress - Sustainability of Road Infrastructures

Study of Sustainable High Performance Bituminous Mixtures

Pietro Leandri\textsuperscript{a*}, Giacomo Cuciniello\textsuperscript{b}, Massimo Losa\textsuperscript{a}

\textsuperscript{a}Department of Civil and Industrial Engineering (DICI), University of Pisa, Largo Lazzarino 1, Pisa 56122, Italy
\textsuperscript{b}Department of Civil and Environmental Engineering, University of Wisconsin, Madison WI 53406-1691, United States

Abstract

The RAP (Reclaimed Asphalt Pavement) utilization in bituminous mixtures highlights the need to evaluate the effects RAP binder produces in terms of stiffness and brittleness increase. The research is focused on the evaluation of the mechanical properties of a bituminous mixture containing a significant percentage of RAP and produced with a controlled viscosity bitumen. Both the fresh and the RAP binder have been characterized at low temperatures by the BBR. The research has pointed out a general increase in stiffness induced by the RAP binder, but the mixture maintains a good workability even if the fatigue resistance is lightly reduced.

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Keywords: RAP; warm mix asphalt; controlled viscosity bitumen.

1. Introduction

As well as mechanical characteristics, specific surface performances are also required to the pavement wearing course. In fact, it must provide high levels of friction, it has to protect other pavement layers from climate actions and, in addition, it might reduce the wheel rolling noise providing also, a comfortable riding. The requirements listed above have become, during the recent years, much more restrictive than before. To face these requirements, the research has provided new bituminous mixtures, more advanced and able to satisfy the required performance. Among these new mixtures, the study considers the Splittmastix Asphalt.

The Splittmastix Asphalts (SMA) mixtures go towards these requirements increasing the friction, waterproofing other pavement layers and subgrade and least but not the last they can reduce rolling noise [1]. Due to their high performance levels required, their construction needs the use of high quality materials whose costs are only partially compensated by money. In fact, being the bitumen and the aggregates un-renewable resources,
their cost has also to be valued in terms of sustainability. Considering this last issue, the international scientific community points out the needs of using recycled materials in both road maintenance and new constructions. Therefore, the utilization of the RAP in high-performing mixtures represents a well-balanced solution between eco-sustainability and technology. The main purpose of this study is based on the above concepts; in fact, it aims to define a rational outline for the study and the development of mixtures containing high percentages of RAP.

Initially the study defines a theoretical base for establishing the maximum percentage of RAP that can be introduced in the mixture without changing their low temperatures behavior; subsequently, the study points out the effects produced by RAP on the mechanical characteristics of the mixtures.

2. The use of RAP in bituminous mixtures

The oxidized bitumen contained in RAP (RAP binder) represents the most noticeable difficulty to overcome for the use of RAP in Hot Mixture Asphalt (HMA). The bitumen oxidation is linked to a double aging process: “Short Term Aging” and “Long Term Aging”. The first takes place during paving while the second is caused by the oxidative components of the atmosphere. The reduction in viscosity, caused by the oxidation, leads to a worsening in workability at high temperatures. In addition, the bitumen contained in RAP is particularly stiff, therefore at low temperature it could show brittle behavior as Thermal Cracking.

In order to reduce the effects caused by the introduction of the RAP in the mixtures, a controlled viscosity bitumen has been used. This type of binder is required to gain high level of workability at lower temperatures compared to the ones used for traditional binders and moreover to reduce the stiffening effects caused by the use of the RAP binder.

3. Description of the experimental program

Some model existing in technical literature [2, 3, 4] allow to predict low temperature cracking in asphalt pavements; this work aims to determine the allowable percentage of RAP in a wearing course mixture by using an innovative experimental procedure.

The work has been developed in two steps.

First of all the binder contained in the RAP has been characterized by using a procedure that avoids the binder extraction by the use of solvents that can affect the binder rheological properties [5, 6]. This part of the study has been carried out in collaboration with the University of Wisconsin-Madison.

After that, the mix design has been carried out and the bituminous mixture has been characterized in terms of workability and mechanical properties.

3.1. Extraction and characterization of the binder contained in the RAP

The characterization of the RAP binder has been carried out following the methodology developed at the University of Wisconsin – Madison [5] which is based on the rheological analysis of a fraction of RAP, called Selected Reclaimed Asphalt Pavement (SRAP) obtained through sieving.

The SRAP is the fraction of RAP passing the 0.30 mm sieve and retained at the 0.15 mm sieve (Figure 1a). Subsequently the SRAP is burned in the ignition oven in order to evaluate the percentage of binder which it contains. The RAP binder content of the RAP used in this study is about 4.8 %, whereas the SRAP binder content is about 10.9 %. This significant difference in binder content is due to the higher specific surface that the SRAP has in comparison with the RAP. The low temperatures classification of the RAP binder was carried out according to the Superpave procedure. It classifies the binders in terms of Performance Grade (PG) which is a synthetic index that summarizes the mechanical properties of binders [7, 8]. The Bending Beam Rheometer (BBR) has been used for the binder low temperatures classification (Figure 1b).
Three kinds of materials have been characterized:

- **Fresh binder.** The Fresh binder is a bitumen that has never been used. Previous characterization, the binder is submitted to both the aging processes. The “Short Term Aging” has been carried out through the Rolling Thin Film Oven Test (RTFOT), while the “Long Term Aging” through the Pressure Aging Vessel (PAV). In the following of the paper the Fresh binder is the bitumen A.

- **SRAP Mortar.** The SRAP mortar is a bituminous mortar made of SRAP + Fresh binder aged through RTFOT. The SRAP mortar is composed by the SRAP aggregate mixed with 34.5% of binder. This binder is made of the 76.3% of Fresh binder (short term aged through RTFOT) and the 23.3% of RAP binder. Previous the characterization through the rheometer (BBR), the SRAP mortar is long term aged through the PAV.

- **RRAP Mortar.** The RRAP mortar is a bituminous mortar made of limestone material from the burned SRAP called “Burned SRAP aggregate” and the 34.5% of Fresh binder short term aged through RTFOT. Previous the characterization through rheometer (BBR), the RRAP mortar is long term aged through the PAV.

According to the time-temperature superposition principle, suitable for bituminous binders, the BBR test can be carried out at a temperature 10°C higher than the Superpave classification temperature and considering a loading time equal to 60” instead of 2 hours. Under these time-temperature conditions, the stiffness values obtained are the same to the ones obtained under longer loading time conditions (2 hours). Each material, already described, has been submitted to two testing temperatures: -6°C and -12°C. Along the test, the rheometer provides, at fixed time intervals, the value of the flexural stiffness of the specimen at the test temperature. The stiffness values are subsequently interpolated on a bi-logarithmic plane through a 2nd order parabolic curve. This curve explains the stiffness versus time variation. The rheometer provides also the angular coefficient of the straight-line tangent to the parabolic curve (m-values). This value describes the reduction in stiffness of the specimen versus time. The Superpave prescribes that for the loading time equal to 60”, the stiffness has to be less than or equal to 300 MPa, whilst the m-value has to be greater than or equal to 0.3.

The "low temperature critical value", which is used for classifying the binder, is the higher (i.e. worse) of the two temperatures determined from BBR data.

From the results plotted in the Figure 2a and the Figure 2b, the "low temperature critical value" of the Fresh binder (bitumen A) is -19.8°C (10°C is added to speed up laboratory testing). In the SHRP classification system, the low temperature range is divided into 6°C increments which correspond to the SHRP binder grades (>16, >22, >28, >34). In this case, the binder is within the first range and would be classified as PG XX-16. Looking
indeed over the stiffness data about the two mortars, they show that a binder composed by the 23.3% of RAP binder and 76.7% of Fresh binder(bitumen A), has a low temperatures PG equal to -10°C.

Whereby, the conclusion drawn states that the blending of 23.3%of RAP binder, compared to the total binder content (corresponding to a RAP percentage of 36% in the dry mixture) worsens the low temperatures mechanical characteristic more than the ones of the fresh binder.

Looking at the stiffness data (Table 1), in particular the ones related to the Fresh binder and the SRAP Mortar (76.7% bitumen A + 23.3% RAP binder), it is possible to obtain an interpolation straight line that shows the PG variation versus the percentage of RAP binder (Figure 3). From this relationship, the maximum allowable percentage of RAP binder that doesn’t affect the PG is obtained. The 15.6% is the suitable percentage of RAP binder that can be added (corresponding to 25.6% of RAP in the dry mixture) without worsening the low temperatures PG.

<table>
<thead>
<tr>
<th></th>
<th>Fresh binder</th>
<th>SRAP Mortar</th>
<th>RRAP Mortar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness [MPa] - 6 °C</td>
<td>107.5</td>
<td>834.5</td>
<td>537.5</td>
</tr>
<tr>
<td>m-Value - 6 °C</td>
<td>0.332</td>
<td>0.262</td>
<td>0.303</td>
</tr>
<tr>
<td>Stiffness [MPa] - 12 °C</td>
<td>234.5</td>
<td>1625</td>
<td>1080</td>
</tr>
<tr>
<td>m-Value - 12 °C</td>
<td>0.281</td>
<td>0.215</td>
<td>0.251</td>
</tr>
</tbody>
</table>

3.2. The mixtures

According to the results of the low temperature binder characterization, a type SMA mixture has been designed. The dry mixture contains 25.6% of RAP. In order to avoid the reduction in workability, a SBS polymer modified bitumen at controlled viscosity (binder A) has been used.

In addition, other two SMA reference mixtures have been designed by using only virgin materials. In one mixtures a SBS polymer modified bitumen has been used (labeled binder B); the second was mixed with bitumen A. The three mixtures had the same particle size gradation and bitumen content (Table 2, Table 3, Figure 4).
Fig. 3. PG versus RAP binder percentage

Table 2. Volumetric composition of reference mixtures

<table>
<thead>
<tr>
<th></th>
<th>Basalt [%]</th>
<th>Sand [%]</th>
<th>Filler [%]</th>
<th>Fresh binder [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMA 0/6 Binder A</td>
<td>67</td>
<td>23</td>
<td>10</td>
<td>7.2</td>
</tr>
<tr>
<td>SMA 0/6 Binder B</td>
<td>67</td>
<td>23</td>
<td>10</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Table 3. Volumetric composition of mixture containing RAP

<table>
<thead>
<tr>
<th></th>
<th>Basalt [%]</th>
<th>Sand [%]</th>
<th>Filler [%]</th>
<th>RAP aggregate [%]</th>
<th>RAP binder [%]</th>
<th>Fresh binder [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMA 0/6</td>
<td>54.8</td>
<td>12.6</td>
<td>7.9</td>
<td>24.7</td>
<td>1.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Binder A + RAP</td>
<td>54.8</td>
<td>12.6</td>
<td>7.9</td>
<td>24.7</td>
<td>1.2</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Fig. 4. Mixtures aggregate size gradation
3.3. Mixtures characterization

All the specimens have been compacted by the Gyratory Compactor; subsequently their characteristics at both high and working temperatures have been tested. The tests carried out are:

- Workability in terms of mixture compaction in the Gyratory Compactor
- Indirect Tensile Strength (UNI EN 12697-23)
- Water sensitivity (UNI EN 12697-12)
- Resilient Modulus - Test IT-CY (UNI EN 12697-26:2004, Annex C)
- Fatigue Resistance (UNI EN 12697-24, Annex E)

4. Results

4.1. Workability

The workability has been evaluated by using the compaction curves reported in Figure 5.

![Compaction curves](image)

The compaction curves of the reference mixtures show the mixture containing bitumen A (red curve) provides a better workability than the mixture with bitumen B (blue curve). In fact, the curves show that at an equal number of gyrations, the mixture containing bitumen A achieves a higher compaction grade than the mixture containing bitumen B. The green curve, referring to the SMA mixture containing 25.6% of RAP, points out the use of a viscosity controlled binder provides a good workability, compared to the reference mixture containing bitumen B, despite of the high content of RAP. This curve shows indeed that, even if the mixture with RAP achieves a compaction grade quite lower than the bitumen A mixture, it reaches a higher compaction grade than the bitumen B mixture.
4.2. Indirect tension strength and water sensitivity

The indirect tension strength has been determined according to the UNI EN 12697-23 standard, at 25°C. The obtained results, expressed in term of Indirect Tensile Strength (ITS) and in terms of the Indirect Tensile Coefficient (CTI), are plotted in Figure 6.

The results clearly highlight the increase in both tensile strength and stiffness provided by the RAP in the mixture.

The tests carried out on water-conditioned specimens allows to determine the mixtures water sensitivity. This characteristic is expressed in terms of the Indirect Tensile Strength Ratio (ITSR), determined according to the UNI EN 12697-13 standards (Table 4).

![Fig. 6. (a) Indirect Tensile Strength; (b) Indirect Tensile Coefficient](image)

<table>
<thead>
<tr>
<th>Table 4. Mixtures ITSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixtures</td>
</tr>
<tr>
<td>SMA 0/6 Binder B</td>
</tr>
<tr>
<td>SMA 0/6 Binder A</td>
</tr>
<tr>
<td>SMA 0/6 Binder A + RAP</td>
</tr>
</tbody>
</table>

Both the virgin mixtures are close to have the same water sensitivity. The mixture that contains RAP has lower water sensitivity than the other two mixtures; the film of bitumen that covers the RAP aggregates is thicker than the one covering virgin aggregates and contributes to reduce the mixture water sensitivity.

4.3. Resilient modulus tests

The resilient modulus has been determined at 20°C, according to the Annex C of UNI EN 12697-26:2004 standard.

The comparison of the two mixtures composed by virgin materials points out that, at the same temperature and the same load frequency, the mixture containing bitumen A (red bar) is stiffer than the mixture containing bitumen B (blue bar). Looking indeed at the mixture containing RAP (green bar), its resilient modulus is twice the modulus of the virgin mixture containing bitumen A (Figure 7a). Therefore, the contribution of the 15.7% of RAP binder provides a significant increase in stiffness.
The straight lines in Figure 7b fit the residuals strains measured at the end of each loading cycle during the resilient modulus test. The slope of the straight lines expresses their attitude to accumulate viscous strains at the same temperature and the same loading frequency. The mixture containing bitumen B (blue curve) has the highest value of the slope, therefore it is more prone to accumulate viscous strains; on the other side, the mixture containing RAP (green curve), since it has the curve with the lowest slope, is characterized by a lower tendency to accumulate viscous strains.

According to the test results, the RAP binder produces an increase in stiffness of the mixture and, moreover, it reduces its viscous strains accumulation sensitivity.

4.4. Fatigue resistance

Even if fatigue resistance of mixtures for wearing layers is not so important as for binder and base layers, with the exception of top-down cracking pavements, in order to evaluate the mixtures durability the fatigue resistance has been determined at 20°C according to the Annex E of UNI EN 12697-24 standard (Figure 8).

Fig. 7. (a) Resilient modulus of the mixtures; (b) Residuals strain recorded at the end of each loading cycle of resilient modulus tests

Fig. 9. Fatigue resistance of SMA mixtures
The fatigue curves highlight that at the same initial tensile strain, while the two reference mixtures are close to have the same durability (blue and red curves), the mixture containing RAP (green curve) has a lower resistance to fatigue (about five times lower). As it is to be expected, if on one side the RAP binder provides an increase in stiffness and elasticity, on the other side it reduces the mixture ductility.

5. Conclusions

This study proposes a rational outline focused on the study of bituminous mixtures for wearing courses containing a significant percentage of RAP. Based on theoretical and experimental considerations, the allowable percentage of RAP in the mixture has been determined in order to don’t worsen the mixture low temperatures behavior. Subsequently, the effects produced by the RAP on the mixture have been evaluated.

In particular, according to the results obtained through the rheological study of bituminous mortars, a type SMA mixture has been designed. This mixture contains a percentage of RAP equal to the 25.6% that allows to don’t worsen the mixture behavior in terms of the “Thermal Cracking”.

The comparison of the mechanical characterization results, between the mixture containing RAP and the two reference mixtures highlight that the use of a controlled viscosity binder in a mixture containing RAP allows to keep suitable the mixture workability. In addition, the RAP improves the mechanical characteristics of the mixture as well as the resilient modulus and the indirect tensile strength. The use of RAP reduces also the viscous strains accumulation and, moreover, the water sensitivity.

On the other side, despite of an increase in stiffness, the use of RAP causes a reduction in ductility, worsening the fatigue resistance of the mixture.

Future developments will have to look into the bituminous mortars at the mixture working temperatures. These new kind of prospection will aim to define the suitable ratio of RAP and virgin binder to introduce into the mixture in order to assuage the reduction in fatigue resistance.

References