Assessment of the performances of foamed asphalt mix containing RA

Ciryle Somé[1, a], Alexandre Pavoine[1], De Marco Laurent[1], Vincent Gaudefroy[2], Laura Andrieux[1], Di Stasio Gérard[1], Andrade Roberto[1]

[1] *Laboratoire EcoMatériaux (LEM), CEREMA, Sourdun, France*
[2] *IFSTTAR, Nantes, France*

[a] ciryle.some@cerema.fr

Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.056

ABSTRACT

A series of laboratory tests have been performed to evaluate the rutting depths and the water sensitivities of French BBSG 3, 0/10 asphalt mixtures (EN 13108-1 (2007)) containing reclaimed asphalt pavement (RA). Two soft binders and one reference paving grade bitumen have been used to produce the mixes: a soft 50/70 grade bitumen (Nyfoam 60) a very soft 160/220 bitumen (Nyfoam 190) and a reference 35/50 bitumen. The mixes have been manufactured in warm (WMA) and hot mix asphalt (HMA) conditions thanks to a new laboratory foaming plant. The foaming parameters such as the half-life time (t1/2) and the expansion ratio (ER) have been optimized based on a parametric study. The influence of RA content has been evaluated using Wheel track (EN 12697-22) and water sensitivity (EN 12697-12) tests. It was found that the increase of the RA content decrease the rutting depth. For the high RA content, the water sensitivities comply with the EN 13108-1 (2007) requirements.

Keywords: Foam, Reclaimed asphalt pavement (RAP) Recycling, Warm Asphalt Mixture

1. Introduction

Recycled asphalt pavement has been widely used since four decades. Nowadays, the use of RA in asphalt mixture is a necessity in some regions because of the lack of the quarries and the cost of materials transport. In addition, recycling asphalt pavement creates a cycle of reusing materials that optimizes the use of natural resources. In France, the use of 30% of RA in hot mix asphalt is now a common practice. The use of more than thirty percent of RA in hot mixes and less than 30% in warm mixes remains exceptions which need more laboratory investigations. It is known from the El Beze's spectroscopy study that the entire RA binder cannot be remobilized during mixture production [1]. However, these conclusions are not consistent with the recent rheological studies of Béghin et al [2, 3]. The remobilization problem is crucial when using high RA content or when recycled asphalt is produced following warm mix procedure in which the reduction of the manufacturing temperature coupled with the RA addition do not guarantee the final performances. Recently, a comparative study between laboratory and field performances, has been conducted by Corbonneau et al. [4] varying the RA content in warm and hot mix process. They study shows that the use of RA increases the complex modulus of the extracted binders. However, the assessment of the complex modulus after the extraction and the distillation of the binders does not allows concluding about the miscibility of the virgin bitumen and RA binders in the mixes. In addition, in the case of warm mixes, the conclusions shall be moderated because of the diversity of the manufacturing processes.
This study focuses on the influence of RA incorporation in warm mix with foamed bitumen process. The experimental study conducted aims to evaluate the possibility of high RA content addition in warm process using two paving grade bitumen 50/70 and 160/220. This possibility has been analysed in terms of mechanical performances (rutting depth, water sensitivity).
This paper is organized as follows:
The first part is dedicated to the description of the materials and the experimental procedure. The theoretical background regarding constituents' heating temperatures has been reminded. The second part deals with the optimization of the production of the foamed bitumen and the last part is devoted to the mechanical performances characterization.

2. Materials

2.1 Binders

The binders comprise the virgin bitumen's and the RA binder. The virgin bitumen is either Nyfoam 60 or Nyfoam 190. They have been provided by Nynas' company. They have been selected because of their hypothetic foaming quality. The RAs have been provided the RCM' company. The RA binder has been extracted and characterized. A control mix has been manufactured with common paving grade bitumen 35/50. The properties of the binders are given in the Table 1.

Table 1: Binders' properties

	Penetration (0.1 mm)	Softening temperature	Viscosity at 25°C
Nyfoam 60	58.1	49.65 °C	335 mm^2/s
Nyfoam 190	167	38.55 °C	135 mm^2/s
Binder in the RA	16	62.3 °C	Not measured
Reference binder 35/50	35.3	53.75 °C	

2.2 Mixes

French asphalt concretes BBSG 3, 0/10 (according to EN 13108-1 (2007)) have been manufactured according to the mixture composition described in Table 2. The mixture is obtained by mixing the aggregates, the RA and the foamed bitumen in a mixer. More or less RA contents have been used depending of the penetration of the added binder. The following RA contents have been investigated:

- For reference bitumen 35/50: the RA content have been limited to 0% and 20% to ensure good compaction of the asphalt mixture,
- For Nyfoam 60 bitumen: 0%, 20%, 40% of RA contents have been used,
- For Nyfoam 190 bitumen: 0%, 20%, 40%, 60% and 70% RA contents have been used.

In addition, the WMA produced have been compared to reference HMA.

Table 2: Target composition of the mixture

Granular fractions	Pourcentages (by mass)
0/2	26.1 %
2/6	23.7 %
6/10	42 %
Filler (limestone)	1.9 %
Bitumen	6.3 %

3. Experiments

3.1 Parametric study for optimal foamed bitumen production

The foamed bitumen is obtained by injecting water droplets into the hot bitumen. It is a transient phenomenon which is difficult to control. It depends on several parameters such as water content, injection pressure, temperature and the nature of the bitumen. Foamed bitumen is usually characterized by its expansion ratio (ER) and its half-life time. It is assumes that the expansion of the foamed bitumen allows a better coating of the aggregates, but it not clearly proved that better performances of the final mix are obtained. Moreover, the mixing of the aggregates with the foamed bitumen destroys rapidly the foam. According to Jenkins [5], the coating quality of the aggregates depends on the foamed bitumen temperature. He states that excellent coated aggregates are obtained when the temperature of the foamed bitumen is higher than 90 °C.
Thus, a preliminary study has been conducted to determine the best expansion ratio and half-life time for the bitumen according to the added water content. The experiment has been carried out keeping constant the injection pressure of the water and the air respectively to 650 kPa and 200 kPa in the plant. The results are represented on figure 1. It can be seen that the minimum expansion ratio is obtained for the lowest water content which also corresponds to the highest half-life time. Whatever the bitumen used, the maximum expansion ratios are obtained between 4% and 6% of water content. However, the expansion ratio of the Nyfoam 190 is lower than that of the Nyfoam 60. The inverse phenomenon is observed on the half-life time curves. Then, the best choice of water content is not evident. So, a mean maximum expansion coefficient of 5.5% has been considered to the next studies. However, a comparison between 1% and 5.5% water content on the stripping is realized in the next sections.

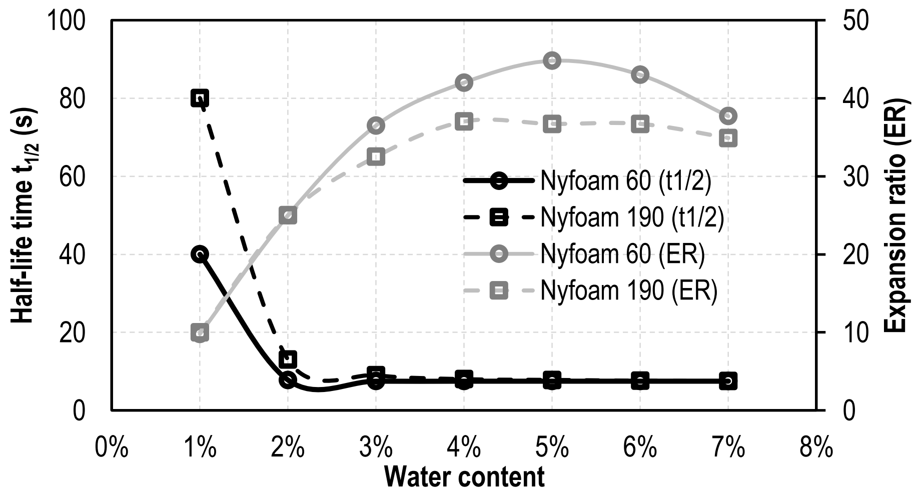

Figure 1: Evolution on the half-life time ($t_{1/2}$) and the expansion ratio (ER) according to the water content

3.2 Experimental study

The virgin aggregates and the RA have been heated separately during 12 hours in ovens before the mixture manufacturing. The virgin bitumen has been preheated to 160 °C during 4hours. The mixer tank is pre-heated in an oven to the desired mixing temperature. During the manufacturing, the RA and the aggregates are mixed during 30 seconds for homogenization before the injection of the foamed bitumen. The foamed bitumen has been produced thanks to the Wirtgen WLB 10 laboratory foaming device (see figure 2).
5.5% water content which leads to the maximum expansion ratio has been used to produce the foamed bitumen. All the constituents are mixed during 180 seconds. The mixture is compacted thanks to a roller compactor

(according to EN 12697-33) for the wheel tracking test and by a gyratory compactor (according to EN 12697-31) for the water sensitivity tests.

Figure 2: Experimental device for foamed binder production

3.3 Manufacturing temperature determination

For laboratory HMA production, the manufacturing temperatures which depend on the grade of the bitumen are defined in EN 12697-35. When using RA in the mix formulation, the manufacturing temperature is basically determined through the penetration of the final binder of the mixture which is evaluated from the mixture law given as follows (see EN 13108-1 (2007) or [6]):

$$\begin{cases} \log\left(Pen_{B(mix)}\right) = \alpha_{B(RA)} \cdot \log\left(Pen_{B(RA)}\right) + \left(1-\alpha_{B(RA)}\right) \cdot \log\left(Pen_{VB}\right) \\ T_{R\&B,B(mix)} = \alpha_{B(RA)} \cdot T_{R\&B,B(RA)} + \left(1-\alpha_{B(RA)}\right) \cdot T_{R\&B,B(VB)} \end{cases} \qquad \text{Equation 1}$$

Where,

$Pen_{B(mix)}$ is the calculated penetration of the binder in the mixture containing RA;
$Pen_{B(RA)}$ is the penetration of the binder recovered from the RA;
Pen_{VB} is the penetration of the added (virgin) binder;
$\alpha_{B(RA)}$ is the ratio by mass of the binder from the reclaimed asphalt to the total binder of the mixture;
$T_{R\&B,B(mix)}$, is the calculated softening point of the binder in the mixture containing reclaimed asphalt;
$T_{R\&B,\ B(RA)}$, is the softening point of the binder recovered from the reclaimed asphalt;
$T_{R\&B,\ B(VB)}$, is the softening point of the added (virgin) binder.

From Equation 1, the penetration and the softening temperature of the binder in the mixture can be determined from the data given in the Table 1. Therefore the manufacturing temperature can be determined according to the standard 12697-35 from the penetration of the binder in the mixture. Let's reminded that the EN 12697-35 (2007) recommends to heat RA at 110°C. However, the temperatures at which the virgin aggregates must be heated to obtain the desire mixing temperature are not indicated in the standard. For this reason we used the Equation 2 given by Navaro [6]. This relation has been chosen because it includes thermo-physic parameters such as specific heat which allows to characterize the heat transfer between the constituents of the mixture during the mixing. This relation can be obtained by the enthalpies balances [6] by rewriting all binders and aggregates contents relatively to the total mixture.

$$T_{VA} = T_{mix} + \frac{Cp_B\left[\alpha_{VB}^{mix}\left(T_{mix}-T_{VB}\right) + \alpha_{B(RA)}^{RA}\left(T_{mix}-T_{RA}\right)\right] + Cp_A \cdot \alpha_{A(RA)}^{RA}\left(T_{mix}-T_{RA}\right)}{Cp_A \cdot \alpha_{VA}^{mix}} \qquad \text{Equation 2}$$

Where:

$\alpha_{B(RA)}^{RA}$ and $\alpha_{A(RA)}^{RA}$ are respectively the binder and the aggregates contents in the RA;

$\alpha_{B(mix)}^{mix}$ is the binder content of the RA in the mixture,

$\alpha_{A(RA)}^{A(mix)}$ is the RA aggregates content in the mixture aggregates content;

$\alpha_{B(RA)}^{B(mix)}$ is the RA binder content in the mixture binder content.

Cp_A (800 J.kg^{-1}.K^{-1}) and Cp_B (1992 J.kg^{-1}.K^{-1}) are respectively the specific heat of the aggregates and the binders.

T_{RA} and T_{VB} are respectively the RA and the virgin binder temperatures before the mixing operation.

The estimation of the virgin aggregates heating temperature (T_{VA}) requires the definition of the virgin binder content, virgin aggregates content, RA aggregates content and the RAs' binder content according to the total mixture mass. These mass fractions are determined by the following set of relations:

$$\begin{cases} \alpha_{VB}^{mix} = \dfrac{1}{\beta}\left[\dfrac{1-\alpha_{B(RA)}^{RA}}{\alpha_{A(RA)}^{A(mix)}}\cdot\dfrac{\alpha_{B(mix)}^{mix}}{1-\alpha_{B(mix)}^{mix}} - \alpha_{B(RA)}^{RA}\right] \\ \alpha_{VA}^{mix} = \dfrac{1}{\beta}\left[\left(1-\alpha_{A(RA)}^{A(mix)}\right)\cdot\dfrac{1-\alpha_{B(RA)}^{RA}}{\alpha_{A(RA)}^{A(mix)}}\right] \\ \alpha_{A(RA)}^{A(mix)} = \dfrac{1}{\beta}\left[1-\alpha_{B(RA)}^{RA}\right] \\ \alpha_{B(RA)}^{mix} = \dfrac{1}{\beta}\left[\alpha_{B(RA)}^{RA}\right] \\ \beta = \alpha_{B(RA)}^{RA} + \left(1-\alpha_{B(RA)}^{RA}\right) + \left(1-\alpha_{A(RA)}^{A(mix)}\right)\cdot\dfrac{1-\alpha_{B(RA)}^{RA}}{\alpha_{A(RA)}^{A(mix)}} + \left(\dfrac{1-\alpha_{B(RA)}^{RA}}{\alpha_{A(RA)}^{A(mix)}}\cdot\dfrac{\alpha_{B(mix)}^{mix}}{1-\alpha_{B(mix)}^{mix}} - \alpha_{B(RA)}^{RA}\right) \end{cases} \qquad \text{Equation 3}$$

In this study:

- the RA has been heated 110°C (T_{RA}=110°C),
- the WMA mixture temperature are imposed to 140°C (Tmix=140°C)
- the HMA mixture temperature are imposed to 160°C (Tmix=160°C)
- for each RA content, the virgin aggregates have been heated to the temperature T_{VA} according to Equation 2. Then, T_{VA}=140°C for RA 0%, T_{VA}=148°C for RA 20%, T_{VA}=160°C for RA 40%, T_{VA}=185°C for RA 60% and T_{VA}=210°C for RA 70%.

4. Results

4.1 French Wheel tracking test

The susceptibility of a bituminous materials to permanent deformation is grasped by measuring the rut depth induced by the repeated passage of a wheel on a mix plate at a reference temperature of 60 °C according to the standard 12697-22 (large size device). It allows simulating in the laboratory the effect of traffic on a roadway. The plates used have been manufactured and compacted thanks to a roller compactor. For each asphalt concrete, the test has been carried out on two plates. The percentage of rut has been measured with a depth gauge as a function of passes. The first 1000 passes are carried out at room temperature, and the others at 60 °C. The influence of the RA content on the rutting depth is represented on figure 3 and on figure 4 respectively for the Nyfoam 190 and the bitumen Nyfoam 60. For lower the RA contents, the test is performed over a limited range of number of passes due to the outbreak of the security system when the rutting depth is important.

The results have been compared to those of the reference mix produced with a classical 35/50 paving grade bitumen. The results reveal that all WMA produced with the soft binder rut easily than the HMA. Moreover, the results clearly show the influence of RA contents on the resistance to the permanent deformation. Since the Nyfoam 190 bitumen is very softer, the corresponding asphalt concrete ruts easily, specifically for lower RA contents. This can be explained by the penetration of the binder of the mixture ($Pen_{B(mix)}$). Indeed, when using 0%, 20%, 40%, 60% and 70% RA contents in the Nyfoam 190 bitumen, the penetrations of the binder of the mixture are respectively 167, 105, 66, 41 and 33. Then, the increase of RA content decreases the penetration of the binder which leads to reduce the rutting depths. When RA content achieves 70% the rutting depth is below 5% which is the threshold value to comply with the standard EN 13108-1 (2007) requirements. Therefore, this bitumen is suitable to be used for higher recycling content. Similar conclusions can be drawn for the bitumen Nyfoam 60, even if the rutting depths are smaller than these obtained with the Nyfoam 190. However, when a total remobilization of the RA bitumen is assumed, the amount of virgin bitumen added in the mixture become smaller when RA content is higher, this induces more compaction difficulties.

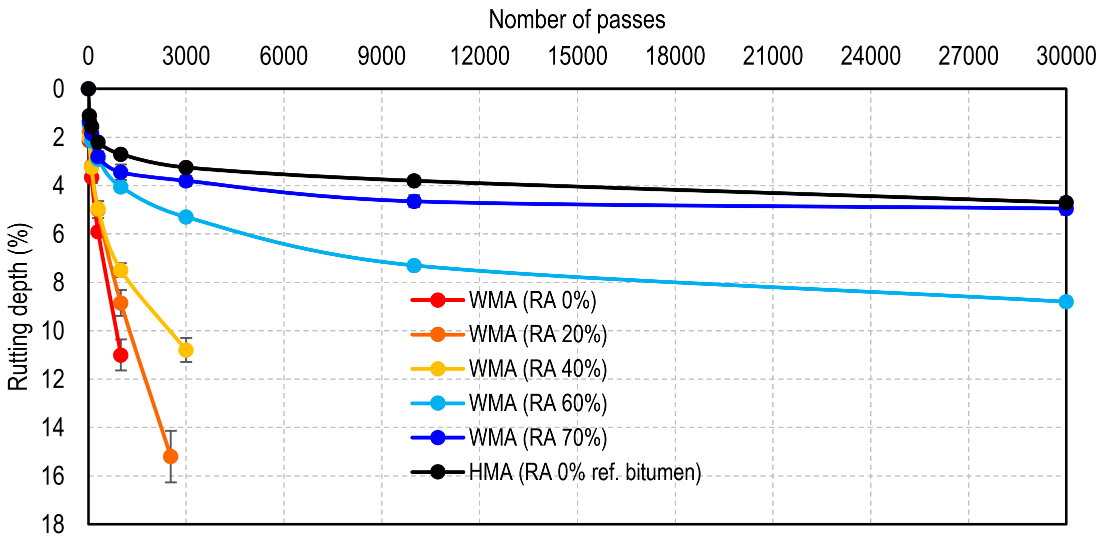

Figure 3: Influence of the RA content on the rutting depth for the very soft bitumen Nyfoam 190

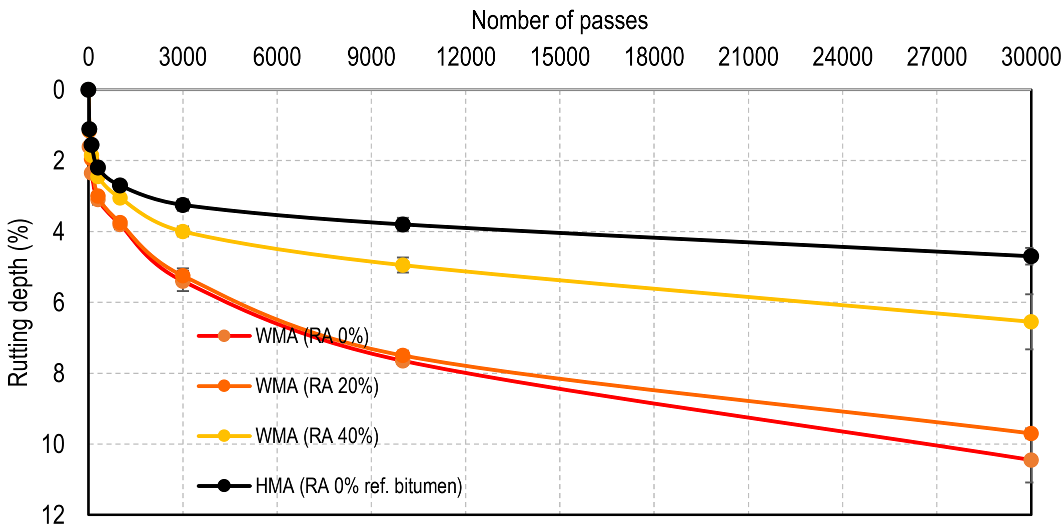

Figure 4: Influence of the RA content on the rutting depth for the soft bitumen Nyfoam 60

To highlight the influence of the added bitumen on the reclaimed asphalt resistance to the permanent deformation, the rutting depths have been evaluated using three bitumen (reference 35/50 bitumen, and the two Nyfoam bitumen) and 20% RA content. The results are represented on figure 5 and compared to reference HMA The harder the added bitumen, the smaller the rutting depth. This shows the importance of the choice of the added bitumen to minimize the asphalt concrete rutting depths. Only the results with the reference bitumen complies with the standard EN 13108-1 (2007) requirements for the 20% RA content.

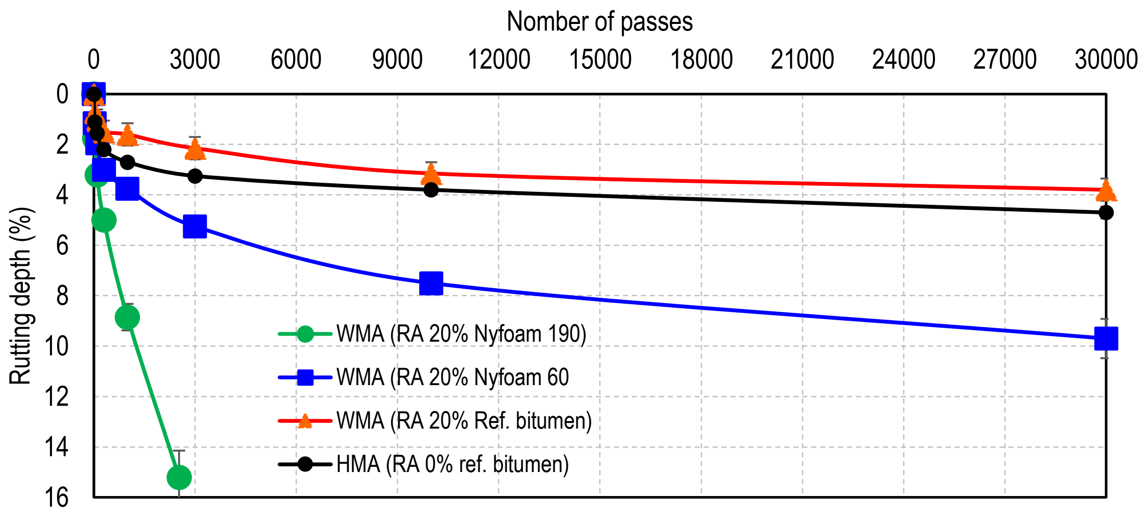

Figure 5: Comparison of the rutting depths of three bitumen using 20% RA content

4.2 Water sensitivity

For each mixture, ten cylindrical specimen, which have 120 mm diameter, have been compacted with a gyratory compactor. Half of them were cured in thermoregulated chamber at 18°C and the other ones have been immersed in water at 18°C. After seven days conservation, compression tests were carried out in accordance with the standard EN 12697-12, to measure the failure strength. The maximum resistances of the samples cured in air (C) and the samples cured in water (i) have been recorded, this allows to deduce the ratios i/C of the compression strengths.

4.2.1 Influence of the added water amount on the stripping resistance

The influence of the quantity of water used to produce the foamed bitumen has been studied considering 1% and 5.5% water content. Let's reminded that these water contents correspond respectively to the maximum half-life time and the maximum expansion coefficient obtained previously. The aim of this part of the study is to check if any increase of the water content in the foamed bitumen could increase damage regarding the stripping resistance of the final mixture. Two asphalt concretes have been produced with the Nyfoam 60 bitumen for this issue. Two reference HMA and WMA have been produced with classical 35/50 bitumen without added water to be compared with the Nyfoam 60 asphalt concretes. The obtained results are represented on figure 6. A slight decrease of the water sensitivity (i/C) is observed in the WMA processes. In addition, the use of 5.5% water content in the foamed bitumen does not decrease significantly the stripping resistance compared to the use of 1% added water. However, since the ratios i/C exceeds 0.7, these results comply with the standard EN 13108-1 (2007) requirements.

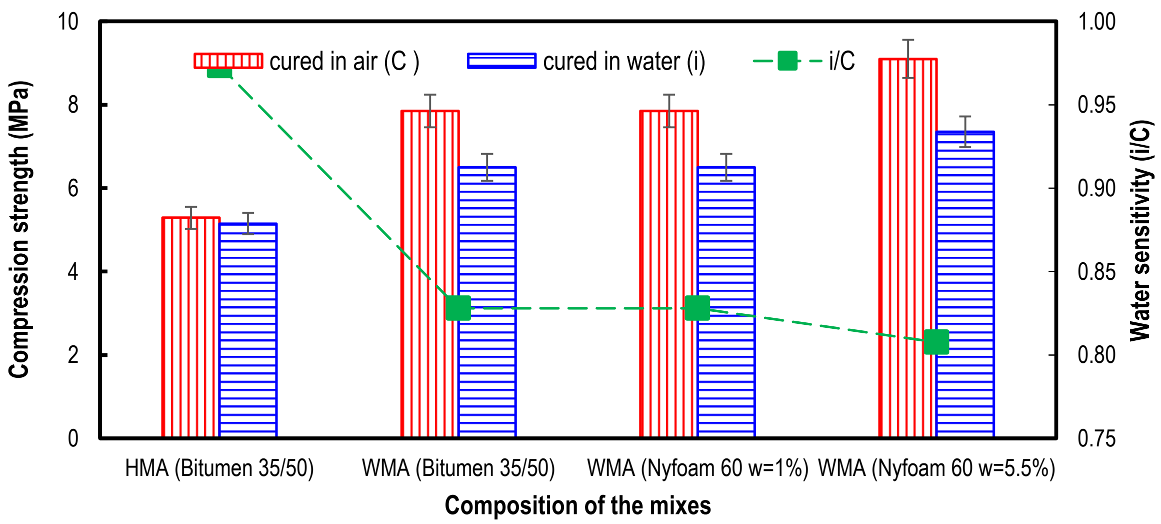

Figure 6: Compression resistances and water sensitivity (i/C)

4.2.2 Influence of high RA content on the stripping resistance

The water sensitivity has been also investigated for high RA content (60 and 70%) using the Nyfoam 190 bitumen. These RA contents have been selected because of theirs smallest rutting depths obtained previously. The compression strengths and water sensitivity ratios are represented on figure 7. The results are represented in conjunction with these obtained with reference 35/50 paving grade bitumen. Except, the WMA produced with reference bitumen, the others results are similar. This difference may be due to high air void content observed for this mixture (2% more than these of the other mixes). However, the use of high percentages of RA do not alter the water sensitivity of the mixes produced with the Nyfoam bitumen. The results comply with the requirements given in the standard 13108-1 (2007) (i/C≥0.7).

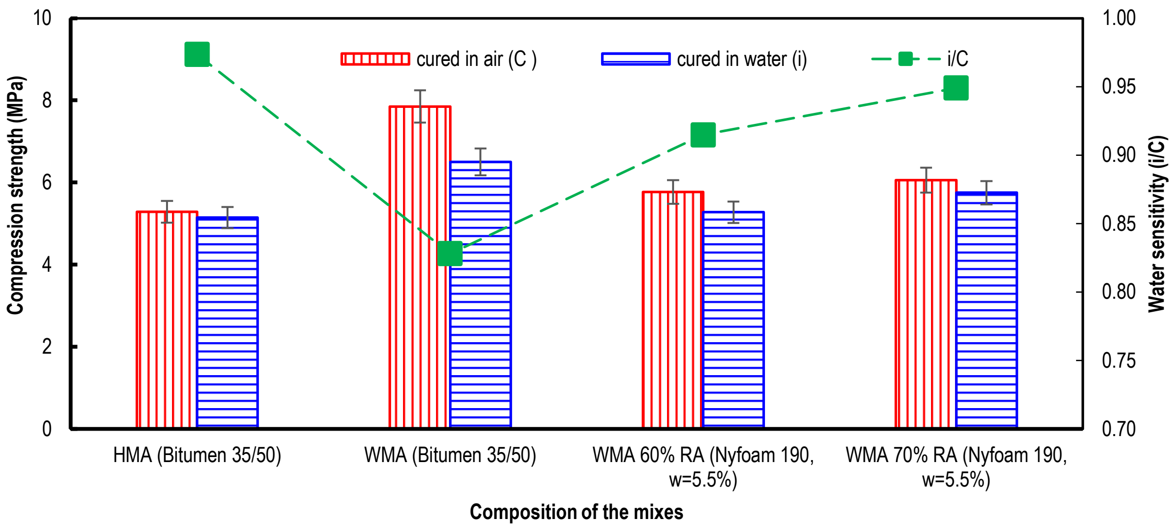

Figure 7: Compression resistances and water sensitivity (i/C)

5. Conclusion

This study is a contribution to the characterization of foamed WMA using RA. Two bitumen Nyfoam 60 and 190 and reference 35/50 paving grade bitumen have been selected for this study. The foaming parameters such as water content and temperature have been optimized first. The maximum expansion ratios (ER) of the foamed bitumen have been obtained for water content between 4 and 6% while the maximum half-life times are obtained for 1% of water content. The influence of these water contents on the stripping resistance has been analyzed. No significant difference has been observed regarding the water sensitivity (i/C ratio) and on the compression resistances for 1% and 5.5% water addition. The influence of the RA content on the resistance to permanent deformation has been assessed through the French Wheel Tracking test. The results show a decrease of the rutting depth when RA content increases. For the RA content of 70% the rutting depth and water sensitivity obtained comply with the standard EN 13108-1 (2007) requirements for the very soft bitumen Nyfoam 190. The influence of the RA content for the soft binder Nyfoam 60 is still in investigation.
The investigations of RA content in warm process started will be continue to evaluate the evolution of the stiffness modulus of the mixes, fatigue, skid resistance and fracture toughness.

References

[1] Recyclage à chaud des agrégats d'enrobés bitumineux, L. El Beze PhD Université Paul Cézanne, Aix Marseille, 2008 (In French).
[2] Régénération du bitume issu du recyclage, partie 1 Evaluation de la remobilisation du bitume par des essais de laboratoire, Béghin, A. Nicolaï, M. Jurkowski, RGRA N°926 Mars-Avril 2015 (In French).
[3] Régénération du bitume issu du recyclage, partie 2 Evaluation du vieillissement par une approche rhéologique, A. Béghin, A. Nicolaï, M. Jurkowski, RGRA N°927 Mai 2015 (In French).

[4] Enrobés tièdes et recyclage, partie 2: campagnes expérimentales, X. Corbonneau S. Quigniot, Y. Legal, M. Desroches, P. Andraud, RGRA N°925 February 2015. K. (In French).
[5] Mix design considerations for cold and half warm bituminous mixes with emphasis on foamed bitumen, Jenkins, PhD, University of Stellenbosch, 2000.
[6] Cinétique de mélange des enrobés recyclés et influence sur les performances mécaniques, J. Navaro, , PhD ANSAM, 2011 (In French).