Properties at Low Temperatures of Warm Mix Containing High Content of Multi-recycled RAP

A. Pedraza, Hervé Di Benedetto, Cédric Sauzéat, and Simon Pouget

Abstract Within the framework of the French national project "Innovation for Materials and Processes for Improving the Multi-Recycling of Mixtures" (IMPROVMURE), founded by the French National Research Agency (ANR), a research work including an experimental campaign on the thermomechanical behaviour of bituminous materials at low temperatures was performed. Three types of bituminous mixtures were produced following a warm process with foamed bitumen. The first mixture contained 0% Reclaimed Asphalt Pavement (RAP). The second mixture contained 70% RAP coming from milling. A third mixture was prepared, containing 70% of the second mixture aged artificially in the lab. Therefore, the fourth mixture was made of 70% of the third mixture subjected to the same aging process. Thermal Stress Restrained Specimen Test (TSRST) on the three bituminous mixtures were performed on cylindrical samples at the University of Lyon/ENTPE. The failure temperature (T_F) and failure stress (σ_F) were used to compare the behaviour of mixtures at low temperature. Influence of RAP content and air void content was studied. The air void content showed an effect inversely proportional to the failure stress.

Keywords Reclaimed asphalt pavement · Multi-recycling · TSRST · Warm mixture

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1 Introduction

The French project called IMPROVMURE aims to studying the behaviour of bituminous mixtures containing Reclaimed Asphalt Pavement (RAP), with several recycling cycles (multi-recycling). It was founded by the French National Research Agency (ANR) [1] and was part of the French National Projet MURE.

One of the objectives of this project was to determine the thermomechanical properties at low temperatures of bituminous mixtures with high RAP content (40, 70 and even close to 100%) produced after several recycling operations (up to 3 cycles). Three different techniques were also studied for mixtures manufacturing (hot, warm with additives and warm using foamed bitumen) [2].

This paper presents the results of three kinds of bituminous mixtures produced with warm mixing, under laboratory conditions and using a foamed bitumen treatment. This work was performed within the collaboration between the EIFFAGE company and the Tribology and System Dynamics Laboratory (LTDS) of the University of Lyon/ENTPE.

The Thermal Strain Restrained Specimen Test (TSRST) allows a characterization of behaviour by coupling the thermal and mechanical effects at low temperatures. Cylindrical samples were tested at the LTDS, University of Lyon/ENTPE.

2 Materials and Samples

Three warm bituminous mixtures were considered for the experimental campaign. According to European standards the bituminous mixtures are classified as BBSG 0/10 (semi-coarse asphalt concrete with NMAS (Nominal Maximum Aggregate Size) up to 10 mm aggregates, designed for wearing course). The same grading curve was fixed for the three bituminous mixtures. Likewise, total bitumen content was fixed at 5.4% (total weight) for all mixtures. The bituminous mixtures were produced under laboratory conditions using a foamed bitumen (called LWF) [3].

The first bituminous mixture without RAP was named LWF0-0 and it was considered as reference material. A 35/50 penetration grade binder was used.

The bituminous mixtures with 70% RAP content were named LWF70-1 and LWF70-3. A 160/220 penetration grade binder was added. The RAP introduced in the mixture LWF70-1 came from a milling process. It contained 4.16% of a 10 mm penetration grade aged bitumen. The RAP introduced in the mixture LWF70-3 was obtained from LH70-1 mixture, according to the following procedure:

(a) One part of LWF70-1 non compacted was taken
(b) This sample was subjected to an aging process developed by RILEM (International Union of Laboratories and experts in construction materials, systems and structures) [4]. The procedure consists in warming the sample at 135 °C for 4h and at 85 °C for 9 days. The resulting material was considered as RAP with two recycling cycles.

(c) A new non compacted mixture was produced with this RAP (with same grading curve, 70% RAP content, 5.4% total binder content and the same 160/220 penetration grade virgin binder added)
(d) Step (b) was repeated using the mixture obtained at step (c).

Finally, the mixture obtained at step (d) was considered as RAP subjected to 3 ageing cycles. It contained 5.4% of a 18 mm penetration grade aged bitumen. It was used to produce LWF70-3 bituminous mixture (identically in step c).

To evaluate the influence of aged bitumen in RAP material on final penetration blend bitumen, the empirical law so-called "log-log" rule Eq. (1) was applied.

$$\log(pen_{blend}) = a\ \log(pen_a) + b\ \log(pen_b) \tag{1}$$

where a and b are mass fractions of fresh added bitumen and RAP binder respectively [4–6]. Calculated binder blend penetration of all bituminous mixture is shown in Fig. 1. The penetrations calculated are close to 35/50 penetration grade binder, added to reference bituminous mixture.

After of bituminous mixture fabrication, the bitumen was extracted from each mixture and penetration grade of binder was measured. The experimental results varied between 22 and 27 mm (Fig. 2). An important difference was observed when the calculated and measured penetration grade binders were compared. This difference could be due to the warm up of binders during manufacturing process [3].

Using the French wheel compactor (standard NF EN 12697-33+ A1), of the French company EIFFAGE Infrastructures, one slab of 600 × 400 × 60 mm was made for each bituminous mixture.

From each slab, five cylindrical specimens were cored and sawn. These cylindrical specimens were used for the TSRST. The diameter of tested specimens was 60 ± 0.5 mm and the length 225 ± 3 mm. Three specimens from each mixture type were tested.

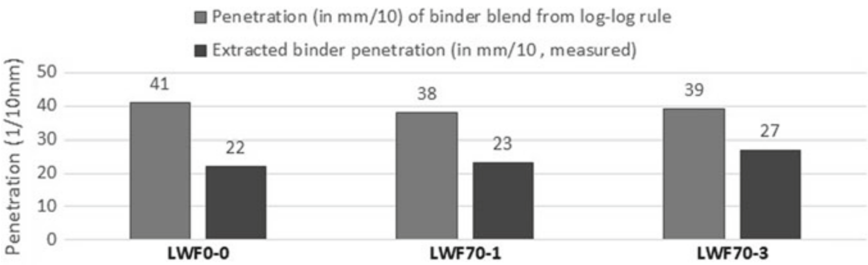

Fig. 1 Penetration of binder blends from log-log rule and measured from extracted binders

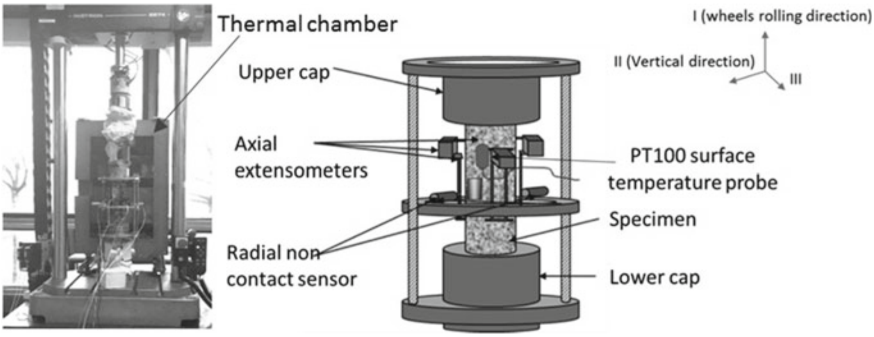

Fig. 2 Instrument for TSRTS samples

3 Thermal Stress Restrained Specimen Test (TSRST)

3.1 Testing Device

A hydraulic press equipped with a thermal chamber was used to carry out TSRST. The hydraulic press had a maximum capacity of ±25kN and a ±52.5mm axial stroke.

The thermal chamber was used for the thermal conditioning of the sample during the test. A thermal PT100 gauge was fixed to the tested samples to obtain their surface temperature.

Axial strain was measured with 3 extensometers (135 mm length) located at 120° around the specimen. The average of the 3 measurements was considered. Two non-contact displacement transducers (range 500 μm) were used to measure the radial strain of the sample, which is not presented in this paper. Figure 2 shows a general view of the specimen and strain measurement devices.

3.2 Testing Procedure and Properties at Low Temperature

Initially, the samples are subjected to a temperature conditioning at $T_i = 5$ °C, during 4 h. After that, the thermal device begins to decrease the temperature at a constant rate of 10 °C/h. The principle of the TSRST is to keep the axial strain null while decreasing the temperature inside the thermal chamber. Cooling caused a contraction of the specimen; however, the hydraulic press prevents this, therefore a thermal stress is induced inside the specimen and increases until the specimen breaks [5–7].

The measurement device is affected by the cooling induced during the test, consequently a calibration of the complete device must be carried out. The Zerodur®, a material for which the thermal dilation coefficient is perfectly known, was used for calibration. The effects of cooling on the mechanical response of the device are then evaluated and can be corrected during TSRST [8].

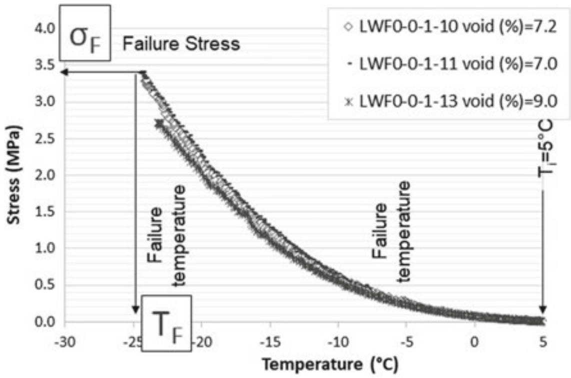

Fig. 3 Traction stress as a function of temperature curves (bituminous mixture LWF0-0)

When the cooling is induced during the test, the slope of the stress-temperature curve $d\sigma/dT$ increases progressively until the failure. When the failure stress reaches its highest value, it is referred to as the failure stress (σ_F) and the temperature at this moment is the failure temperature (T_F) [8]. The induced traction stress as a function of temperature, T_F and σ_F are the main outputs of the TSRST (Fig. 3).

4 RAP, Recycling Cycle and Air Void Content Influence

A total of 9 tests were carried out for 3 different materials. Three specimens of each material were tested. The repeatability of TSRST was evaluated with the general variation of the stress as a function of temperature. Figure 3 shows that the three curves obtained from three different tests on the mixture LWF0-0 are well superimposed. The others mixtures presented a similar superimposition. This shows an excellent repeatability between the samples of a same mixture type.

Consequently, to compare the influence of RAP and recycling cycle, T_F and σ_F values were averaged for each mixture type.

Figure 4a, b present the T_F and σ_F average of types mixture obtained. The histograms the quantities of RAP do not show a significant impact on the T_F and σ_F average of the materials ($\Delta T_F = 4.20$ °C and $\Delta\sigma_F = 0.80$ MP). However, in a first analysis, this slight change of σ_F appeared to be due to the introduction of high contents of RAP.

In the second analysis, the air void content was evaluated. On Fig. 5 graph, σ_F is plotted as a function of air void content for each sample tested. We can see that σ_F shows a linear tendency according to air void content, with a negative slope. As the samples of mixtures containing RAP presents lower air void contents than samples of the bituminous mixture without RAP, it can be assumed that the increase of σ_F was due to the air void content of the samples and not RAP content, as it was initially thought.

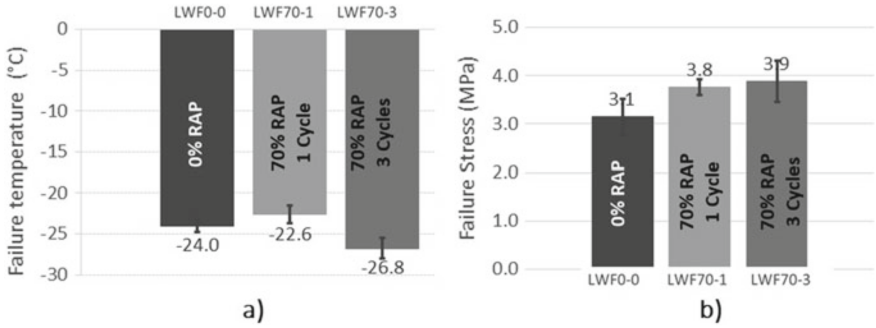

Fig. 4 Average: **a** T_F of materials types; **b** σ_F of materials

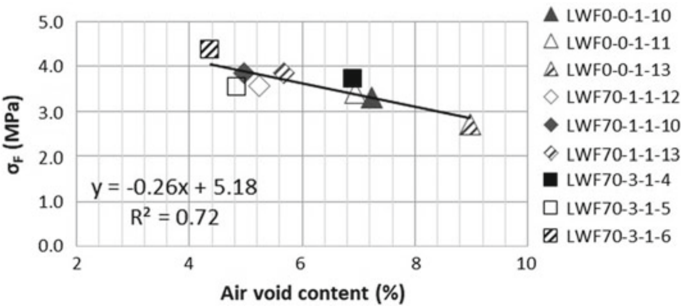

Fig. 5 σ_F as a function of air void content

The air void content did not show an effect on T_F and the recycling cycle did not show an impact on T_F or σ_F.

5 Conclusion

In this paper, three foamed bituminous mixtures were tested to study the mechanical behaviour at low temperatures by coupling thermal and mechanical effects. The three samples correspond to three content of RAP: 0, 70% of regular RAP and 70% of RAP stemming from a process simulating three recycling cycles. Three cylindrical samples of each material type were subjected to TSRST.

The repeatability of TSRST was evaluated through the variation of stress as a function of temperature, and classical outputs T_F and σ_F.

The influence of RAP content, number of recycling cycles and air void content on mechanical behaviour of bituminous mixture at low temperatures was evaluated.

The three bituminous mixtures with RAP showed similar values of T_F (−24.5 °C on average), then addition of RAP did not have a significant influence on T_F.

The first analysis showed a slight difference of σ_F, regarding the bituminous mixtures containing RAP. However, when σ_F was plotted as a function of the air void content of the samples, the values displayed a linear decreasing tendency. As the samples of bituminous mixtures with RAP show the lowest air void contents, the increase of σ_F can be explained by mixture compaction conditions.

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