



Rheological Binder Analysis for Determining the Maximum Reclaimed Asphalt Pavement (RAP) Content in Asphalt Mixtures

Simone Raschia¹ , Giovanni Marchegiani^{1,2}, and Stefano Tattolo¹

¹ S.T.S Mobile S.r.l, Via G. Conti 10, 60131 Ancona, Italy
s.raschia@stsmobile.it

² Department of Theoretical and Applied Sciences, Università Degli Studi eCampus, 22060 Novedrate, Italy

Abstract. This study focuses on the design of sustainable asphalt mixtures containing high dosages of Reclaimed Asphalt Pavement (RAP). Since aged RAP binder reduces fatigue and cracking resistance of the asphalt mixture, polymer-modified (PMB) and highly polymer-modified binders (HPMB) are preferred to improve the material ductility. In this research, a binder-scale rheological testing was developed to estimate the maximum RAP content in order to ensure adequate fatigue performance.

The experimental program involved a reference mixture produced with 20% RAP and a PG 70–10 bitumen and three mixtures produced with a PG 82–10 binder and 20%, 30% and 40% RAP. The bituminous blends composed of virgin binder and laboratory-aged binder were characterized in terms of Linear Amplitude Sweep (LAS) Test and Performance Grade (PG) Intermediate Temperature (PG-IT). The asphalt mixtures mechanical properties were determined in accordance to Indirect Tensile Fatigue Tests (ITFT).

The results obtained from the binder scale analysis highlighted comparable fatigue properties between the reference blend (PG 70–10 binder and 20% RAP) and the bituminous blend containing the PG 82–10 binder and 40% RAP. The characterization of the asphalt mixtures produced in laboratory and in production plant validated the 40% of RAP aggregate as the maximum allowable with the PG 82–10 binder.

Keywords: RAP · binders · mixtures · fatigue · LAS · ITFT

1 Introduction

Nowadays, the design of asphalt pavement materials must necessarily consider high dosages of Reclaimed Asphalt Pavement (RAP) aggregate. In fact, RAP aggregate represents an important source of combined aggregates and aged binder that allows the production of more sustainable asphalt pavement materials, by reducing the employment of natural aggregates and virgin bitumen [1]. However, the presence of aged binder in the mixture bituminous phase leads to poor fatigue and cracking resistance [2].

Polymer-modified (PMB) and Highly polymer-modified bitumen (HPMB) types are a valid solution to cope with high dosages of RAP aggregate, since the presence of styrene-butadiene-styrene (SBS) polymers in increasing dosage confers to the asphalt mixture enough elasticity or ductility to improve the poor cracking resistance brought by the RAP aged binder [3].

In order to meet the current environmental targets, the main request from the asphalt pavement industry is to assess the maximum RAP aggregate content for the materials production in a specific project without affecting negatively the fatigue resistance properties. In general, this aspect is approached in laboratory by performing fatigue tests at different RAP aggregate contents, leading to significantly time-consuming experimental activities [4]. On the other hand, the traditional fatigue tests are a well-known and established laboratory procedure to compare different materials in terms of resistance, without the possibility to directly predict the pavement life [5].

At the same time, the binder scale characterization in terms of fatigue is advantageous in terms of quantity of the material needed for testing and experimental timing, even though the stresses applied to the bitumen are not representative of the real field stresses that realistically occur [6].

Consequently, this study aims to validate a binder scale rheological characterization in order to determine the maximum RAP content that can be used in asphalt mixtures design while ensuring the required fatigue resistance properties, i.e. comparable to a reference mixture.

2 Materials and Methods

2.1 Bituminous Binders and Aggregates

The study was conducted employing three bituminous binders: two polymer-modified bitumen, a PG 70-10 and a PG 82-10 and one un-modified binder (PG 58-22) artificially aged to obtain a simulated RAP binder (Table 1). The aged binder was achieved with an ageing protocol composed by one Rolling Thin Film Oven Test (RTFOT) and two Pressure Ageing Vessel (PAV) ageing procedures performed at 100 °C [7].

It is observed the higher level of polymer modification of the PG 82-10 binder compared to the PG 70-10 binder, pointed out by the results in terms of Performance Grade (PG) Intermediate Temperature (PG-IT).

The aggregates used for the bituminous mixtures production were sampled from the asphalt production plant. Two coarse aggregates fraction (6/14 and 12/24), one fine aggregate fraction (0/4), one limestone filler and one RAP aggregate source with nominal maximum aggregate size of 20 mm were considered in this study. The RAP aggregate residual bitumen content is 4.91% by aggregates mass.

2.2 Methodology

The experimental program was carried out in two subsequent steps: a first bituminous binders scale analysis and a second asphalt mixtures scale investigation.

Table 1. Bituminous binders properties

Properties	Standard	Value			
		PG 70–10	PG 82–10	PG 58–22	
				Un-aged	Aged
Needle penetration @ 25 °C (dmm)	UNI EN 1426	43	68	83	12
Softening Point (°C)	UNI EN 1427	67.2	81.0	45.9	96.8
Elastic Recovery (%)	UNI EN 13398	82	98	N/A	N/A
Viscosity @ 160 °C (Pa·s)	UNI EN 13302	0.270	0.508	0.090	1.058
PG-IT (°C)	ASTM D6373	24	21	N/A	N/A

Binder Scale. The objective of this step is to determine the maximum aged binder content (20%, 30% or 40%) allowable with the PG 82-10 binder in order to have comparable fatigue life resistance with a reference bituminous blend (PG 70-10 bitumen and 20% of aged binder).

The four blends were characterized in terms of PG Intermediate Temperature (PG-IT) and by means of the Linear Amplitude Sweep (LAS) Test (AASHTO TP 101) at both 20 °C and PG-IT, after a long-term ageing protocol (RTFOT + PAV).

Mixture Scale. Three bituminous mixtures were produced and tested in this phase: (1) Mixture produced in laboratory with the PG 70-10 bitumen and 20% of RAP aggregate; (2) Mixture produced in laboratory with the PG 82-10 bitumen and the maximum RAP aggregate content; (3) Mixture produced and sampled from the asphalt plant with the PG 82-10 bitumen and the maximum RAP aggregate content.

The laboratory asphalt mixtures were mixed at 180 °C and compacted at 160 °C. The compaction was carried out with a Shear Gyratory Compactor (SGC), specimens' diameter of 150 mm and compaction energy of 120 gyrations.

The asphalt plant mixture was sampled during the realization of a field test section and compacted in-situ with no additional heating at 160 °C. The compaction protocol was the same as above.

The total bitumen content (considering the RAP binder) was set equal for the three mixtures to 4.8% by aggregates mass. The mixtures characterization included air voids content determination, Indirect Tensile Strength at 25 °C (UNI EN 12697-23), Indirect Tensile Stiffness Modulus at 5 °C, 20 °C and 40 °C (UNI EN 12697-26 – Annex C) and Indirect Tensile Fatigue Test at 20 °C (UNI EN 12697-24 – Annex E). However, only the fatigue resistance results will be reported and analyzed.

3 Results

3.1 Binder Scale

Results obtained from the binder scale analysis on the bituminous blends are shown in Fig. 1. The results are reported as an average of three tested sample for each binder in terms of PG-IT (Fig. 1a) and LAS Test (Fig. 1b, Fig. 1c, Fig. 1d, Fig. 1e and Fig. 1f). The values related to the reference blend (PG 70-10 with 20% of aged binder) are shown as a red line, and the trend lines related to the PG 82-10 bituminous blends are also reported.

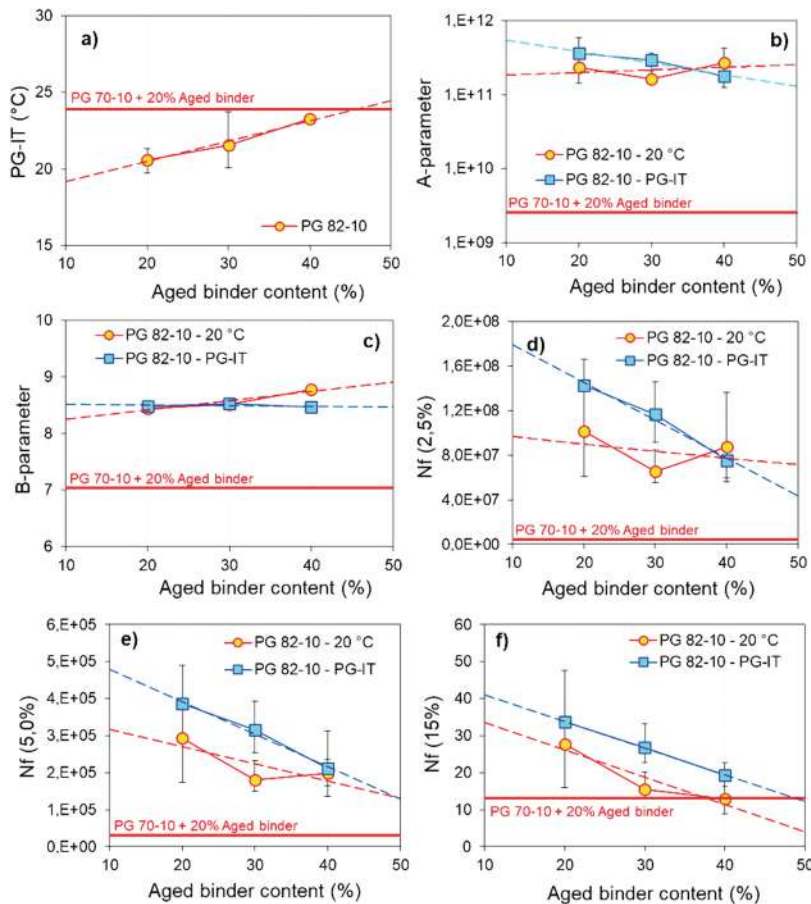


Fig. 1. Fatigue tests results of bituminous blends: a) Average PG-IT values, b) Average A-parameter values, c) Average B-parameter values, d) Average cycles to failure at a strain level of 2.5%, e) Average cycles to failure at a strain level of 5%, f) Average cycles to failure at a strain level of 15%.

The reference average PG-IT recorded is 23.9 °C, while the PG-IT values obtained by the bituminous blends containing the PG 82-10 binder are 20.6 °C, 21.5 °C and

23.3 °C with 20%, 30% and 40% of aged binder, respectively (Fig. 1a). According to these findings, the PG-IT determination suggests a maximum RAP content of around 45% combined with the PG 82-10 binder.

LAS Test results show that both parameters A and B of the PG 82-10 bituminous blends are higher than the value related to the reference binder, regardless the testing temperature (Fig. 1b and 1c). Furthermore, both parameters are not significantly influenced by the increasing dosage of aged binder.

Figure 1d, Fig. 1e and Fig. 1f show LAS Test results in terms of cycles to failure at strain levels of 2.5%, 5% and 15%, respectively. It is globally highlighted the detrimental effect brought by the increasing aged binder content on the fatigue resistance. It is observed that for small strain levels (2.5% and 5%), the values obtained at a testing temperature of 20 °C on the PG 82-10 bituminous blends are less sensitive to the increasing dosage of aged binder compared to those obtained at a testing temperature equal to PG-IT. In both cases, the results indicate a maximum aged binder content higher than 50% in order to reach the same properties of the reference bituminous blend. Both trend lines related to the bituminous blends at higher strain levels (15%) remark the same sensitivity (slope) to the increasing aged binder content. However, the maximum aged binder contents related to the testing temperatures of 20 °C and PG-IT are close to 40% and 50%, respectively.

From the binder-scale analysis, an aged binder content of 40% was conservatively adopted as the maximum, as it corresponded to the lowest value obtained among the several parameters investigated. Accordingly, the asphalt mixtures produced with the PG 82-10 binder were formulated with 40% of RAP aggregate.

3.2 Mixture Scale

The three mixtures tested for the mixture scale analysis were characterized by the same aggregate gradation (Fig. 2a). The two mixtures produced in laboratory refer to the design grading curve, while the gradation of the mixture plant-produced was controlled after binder extraction (UNI EN 12697-1 and UNI EN 12697-2). The fatigue tests results in terms of A and B parameters and fatigue life parameter ϵ_6 are shown in Fig. 2b.

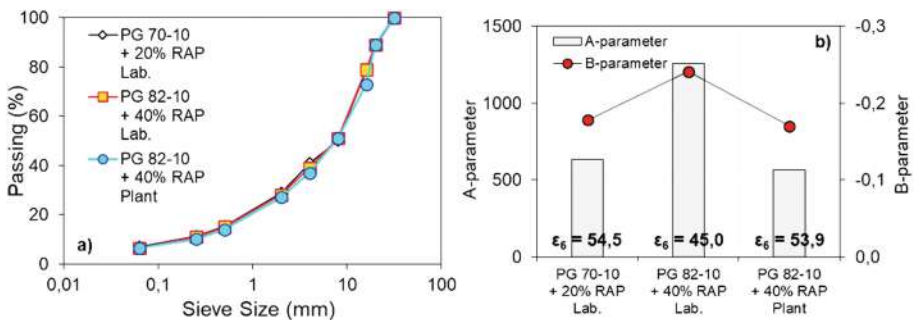


Fig. 2. a) Asphalt mixtures aggregate gradation; b) Fatigue tests results

The results in terms of aggregate gradation highlight the good correspondence among the three aggregate blends. The fatigue tests results point out comparable parameters (A , B and ε_6) between the mixtures PG 70-10 + 20% RAP produced in laboratory and PG 82-10 + 40% RAP produced in plant. On the other hand, the mixture produced with the PG 82-10 binder and 40% RAP in laboratory is characterized by a lower ε_6 value, hence a lower resistance to fatigue, than the same mixture produced in plant. However, this difference may be linked to slight differences in the properties of the bitumen used, which results are not reported here.

4 Conclusions

This study focused on an experimental approach aimed at determining the maximum RAP content in asphalt mixtures produced with two different polymer-modified bitumen. The following findings can be listed:

- Several binder fatigue parameters were considered to determine the maximum aged binder content. The 40% aged binder content was assumed as the maximum to produce recycled asphalt mixtures in accordance to PG-IT and N_f (15%) results;
- The fatigue tests results obtained from the asphalt mixtures confirmed with good approximation what was observed on the binder scale. This finding was also positively confirmed by the results obtained on an asphalt mixture produced in plant;
- This approach led to comparable fatigue performance using a polymer-modified binder containing a higher dosage of RAP aggregate with respect to the reference mixture. The two-step experimental program allowed these outcomes to be achieved within a relatively short period of time.

Additional studies should focus on the replication of this approach by considering different PMB types of bitumen, different types of rejuvenating additives and different fatigue tests configuration on asphalt mixtures.

References

1. Elnaml, I., Mohammad, L.N., Baumgardner, G., Cooper, S., III., Cooper, S., Jr.: Sustainability of asphalt mixtures containing 50% RAP and recycling agents. *Recycling* **9**(5), 85 (2024)
2. Shi, B., Dong, Q., Chen, X., Gu, X., Wang, X., Yan, S.: A comprehensive review on the fatigue resistance of recycled asphalt materials: influential factors, correlations and improvements. *Constr. Build. Mater.* **384**, 131435 (2023)
3. Zheng, K., Xu, J., Wang, J.: Viscoelasticity of recycled asphalt mixtures with high content reclaimed SBS modified asphalt pavement. *Sustainability* **15**(3), 2515 (2023)
4. National Academies of Sciences, Engineering, and Medicine. Performance Specifications for Asphalt Mixtures (2016)
5. Sudarsanan, N., Kim, Y.R.: A critical review of the fatigue life prediction of asphalt mixtures and pavements. *J. Traffic Transp. Eng. (English Edition)* **9**(5), 808–835 (2022)
6. Li, W., Lin, J., Lin, W., Yu, H.: Fatigue damage evolution mechanism of asphalt binder under variable stress repeated loading. *Polymers* **17**(4), 507 (2025)
7. Gholami, M., Khodaii, A., Hajikarimi, P.: Long-term aging simulation of asphalt mixture: a comparative experimental study. *Constr. Build. Mater.* **435**, 136856 (2024)