A rheological study on rejuvenated binder containing very high content of aged bitumen

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Abstract Hot recycling of reclaimed asphalt pavement (RAP) coming from flexible pavement rehabilitation is a technique able to ensure real economic and environmental benefits related to the reduction of virgin bitumen and aggregate supply and to the reuse of a recycled aggregate. Otherwise, adequate performance of recycled materials with high amount of RAP must be guaranteed since the recycling involves the presence of old and stiffened aged binders within the mixture. In this perspective, the present experimental study was aimed at verifying in the laboratory the performance at mid and high-service temperatures of bituminous blends composed by 40% of virgin binder and 60% of old rejuvenated bitumen (simulating aged bitumen coming from RAP). Rheological properties of materials were studied through the dynamic shear rheometer, testing unaged, short-term aged and long-term aged samples. Viscosity, stiffness and permanent deformation resistance of recycled blends seemed to guarantee comparable behavior with those of original bitumens, regardless the aging condition of the materials. These findings seemed to demonstrate the effectiveness of the hot recycling procedure using rejuvenators to obtain suitable bituminous binder containing high amount of aged bitumen.

Keywords Hot recycling, Reclaimed asphalt, Rejuvenator, DSR.

1 Introduction and problem statement

Hot recycling of reclaimed asphalt pavement (RAP) in renewed bituminous mixtures is a technique dated back 30 years so that, nowadays, is a standard procedure adopted in many countries (Hugener and Kawakami 2017). The most significant reasons are connected to the well-documented economic and environmental savings due to the reduction of virgin bitumen and aggregate supply and the prevention of waste transportation and disposal (Newcomb et al. 2007). Actually, huge research efforts are spent worldwide for the increasing of RAP amount within mixes, as well

as paving industry and agencies are strongly applying political pressure towards this direction (McDaniel et al. 2012). Regardless recycling rate, appropriate bitumen grades for adequate performance of pavements must be guaranteed to meet technical prescriptions (Izaks et al. 2015). This fact must be considered in view of the re-use of RAP, which involves the inclusion in mixes of relevant quantity of aged bitumen at the end of its life characterized by significantly different mechanical and chemical properties (Chen et al. 2007). For these reasons, rejuvenators are recommended to face lacks in chemical composition and rheology of oxidized bitumen coming from RAP and restore their initial properties (Pradyumna and Jain 2016).
Given this introduction, the present paper illustrates an experimental study aimed at verifying the feasibility of recycling high amount of RAP (up to 60%), focusing on rheological properties of binders. To accomplish this objective, a comparative analysis of virgin bitumens with respect to blends constituted by virgin bitumen, aged bitumen (simulating bitumen coming from RAP) and rejuvenator was carried out.

2 Materials and methods

2.1 Materials

In order to replicate all processes involved in hot recycling, a virgin bitumen (V) was short-term aged (V_S) and long-term aged (V_L) in the laboratory simulating the RAP bitumen. A commercial rejuvenator (R) was blended with the long-term aged binder V_L to restore the original properties of virgin bitumen. The selected rejuvenator is a chemical additive at liquid state formed by a package of specific compounds. Base on the producer's specifications, three dosages (3, 6 and 9% by bitumen weight) were used in this study to identify the optimum R content. Then, a blend (B) composed by the virgin bitumen V, the long term-aged bitumen V_L and the rejuvenator R (optimally dosed) was prepared to replicate the final binder obtained during hot recycling of RAP. Short and long-term aging were finally executed also on blend B to assess the behavior of the recycled binder in different service life conditions. Tables 1 reports the basic properties of the tested binders: preliminary results indicated an optimum R content close to 6% (with respect to the bitumen weight), since consistencies of rejuvenated binder V_LR_6 and original (unaged) one (V) were very close. In this regard, B blend was manufactured introducing the rejuvenator at 6% by weight with respect to the V_L binder.

Table 1 Summary of material codifications and basic properties

Code	Material description	Penetration at 25°C	Softening point
V	virgin bitumen	53 mm·0.1	49.0 °C
V_S	short-term aged virgin bitumen	32 mm·0.1	53.7 °C
V_L	long-term aged virgin bitumen	15 mm·0.1	68.3 °C
R	rejuvenator	–	–
V_LR_3	V_L + 3% rejuvenator by bitumen weight	33 mm·0.1	53.7 °C
V_LR_6	V_L + 6% rejuvenator by bitumen weight	56 mm·0.1	47.8 °C
V_LR_9	V_L + 9% rejuvenator by bitumen weight	84 mm·0.1	40.2 °C
B	blend V + V_L + R (at 6% to V_L weight)	49 mm·0.1	46.8 °C
B_S	short-term aged B blend	30 mm·0.1	54.6 °C
B_L	long-term aged B blend	18 mm·0.1	65.3 °C

2.2 Methods

Blending of the different components were performed though a mechanical stirring instrument, heating the bitumens V and/or V_L at 160 °C and adding the cool liquid rejuvenator. Bitumens proportions were fixed at 40%-60% for binders V and V_L respectively (simulating a recycling rate of about 60%).

Short-term aging simulation was achieved in the laboratory through the well-known Rolling Thin Film Oven (RTFO) procedure (EN 12607-1). Then, long-term aging was obtained lengthening the RTFO procedure to 325 minutes according to Muller and Jenkins (2011) who indicated similar effects for the abovementioned extended RTFO (ExRTFO) and the standardized Pressure Ageing Vessel procedure.

According to Figure 1, the assessment of the rheological properties of materials was achieved using a Dynamic Shear Rheometer (DSR).

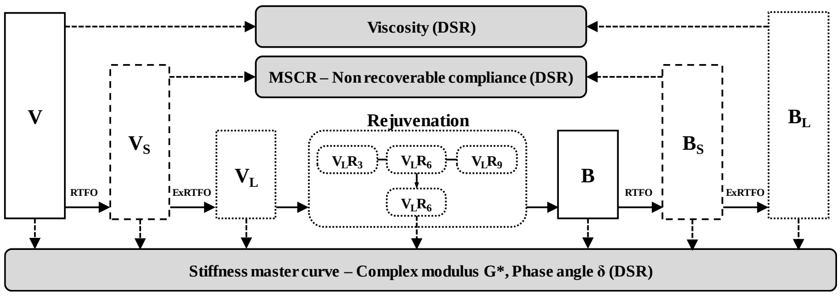

Fig. 1 Summary of experimental program

Viscosity tests were performed on unaged binders (V, B) according to EN 13702 with a 50 mm cone-plate geometry. Tests were carried out at 60 °C (shear rate: 0.05 s^{-1}), 100 °C (shear rate: 50 s^{-1}) and 150 °C (shear rate: 500 s^{-1}). Short-term aged binders (V_s, B_s) were subjected to Multiple Stress Creep Recovery (MSCR) tests (EN 16659) at high temperatures (50 to 80 °C) determining the non-recoverable creep compliances J_{nr} at shear stress of 0.1 and 3.2 kPa. Percent $J_{nr-diff}$ (i.e. the difference of J_{nr} at 3.2 and 0.1 kPa, normalized with respect J_{nr} at 0.1 kPa) was also calculated. Frequency sweep tests (EN 14770) were finally performed on V, V_S, V_L, V_LR_6, B, B_S and B_L to construct the complex modulus (G*) master curves at 20 °C based on the time-temperature superposition principle using the well-known Williams-Landel-Ferry (WLF) theory (Williams et al. 1955). Tests were executed in a wide range of temperatures (from 10 to 80 °C) and frequencies (from 0.1 to 10 Hz) in strain-controlled mode (0.05% shear deformation).

3 Results and analysis

3.1 *Shear viscosity*

Figure 2a shows that unaged V and B bitumens did not exhibit significant variations of shear viscosities thanks to the rejuvenation process suggesting almost the same mixing and compactions temperatures according to AASHTO T 312 (Figure 2b). Thus, R seems able to restore viscosity of original binder despite the significant presence (60%) of aged hard bitumen coming from RAP.

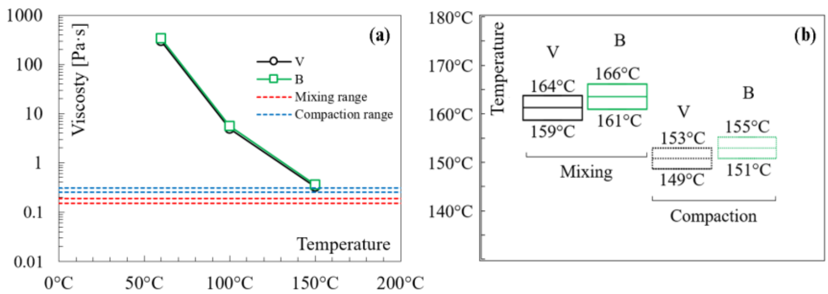

Fig. 2 V and B viscosity test results (a) and related mixing and compaction temperatures (b)

3.2 *Non-recoverable creep compliance*

Results of MSCR tests are reported in Table 2 (for the sake of brevity, only the results at the lowest and the highest test temperatures are listed). J_{nr} indicated very similar behavior between short-term aged binders V_S and B_S. According to AASHTO MP 19, J_{nr} and $J_{nr-diff}$ parameters revealed that blend B_S is characterized by the same upper limit of the Performance Grade (equal to 50 or 60 °C depending on the traffic class considered) of that demonstrated by V_S. Thus, similar permanent deformation resistance can be hypothesized between recycled blend B and the reference virgin binder V.

Table 2 MSCR test results for RTFO-aged original bitumen and blend

Material	V_S	V_S	V_S	V_S	B_S	B_S	B_S	B_S
T [°C]	50	50	80	80	50	50	80	80
τ [kPa]	0.1	3.2	0.1	3.2	0.1	3.2	0.1	3.2
J_{nr} [kPa^{-1}]	0.34	0.36	20.99	23.13	0.31	0.32	21.27	22.62
$J_{nr\text{-}diff}$ [%]	4.3		10.2		3.1		6.4	

3.3 Complex modulus

Representative G* master curves were obtained through the recognition of specific frequency shift factors according to the WLF formulation (Figure 3).

As known, aging processes were responsible of G* increases because of the material hardening after RTFO and ExRTFO procedures. Rejuvenator dosed at 6% by V_L bitumen weight allowed a downward translation of master curve towards that of virgin binder V (V and V_L data were approximately overlapped) confirming an efficient recovery of mechanical performance. Moreover, results of aged blends (B_S, B_L) and corresponding original bitumens (V_S, V_L) were very similar proving once again the effectiveness of the hot recycling. Indeed, it is worth remembering that severe stiffening caused by long-term aging might lead to brittleness and fatigue failure of material. Otherwise, considering the PG classification on the basis on frequency sweep responses, B_L displayed the same fatigue temperature limits that those of traditional long-term aged binder V_L (25 °C regardless the traffic grade).

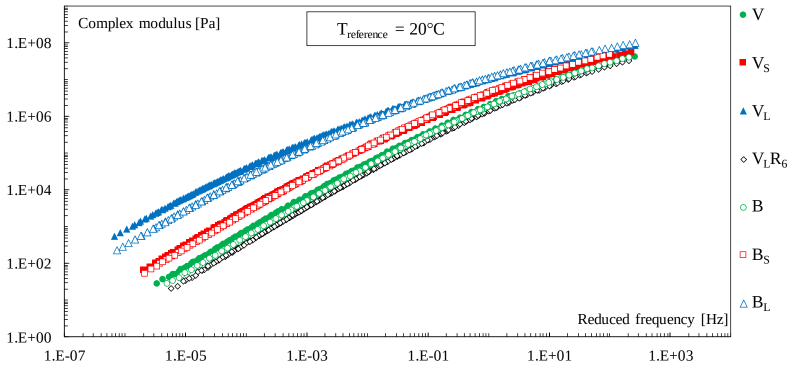

Fig. 3 Stiffness master curves: comparison between original bitumens and blends

4 Conclusions

Rheological properties of a recycled bituminous blend containing long-term aged bitumen were studied to assess the feasibility of hot recycling high amount (about 60%) of reclaimed asphalt pavement. Rejuvenation of aged binders resulted able to restore main rheological properties of tested bitumens. In fact, the comparison between virgin binders and corresponding recycled blends indicated very similar performance in terms of viscosity, stiffness and permanent deformation resistance. Thus, the feasibility of hot recycling high amounts of reclaimed asphalt pavement was demonstrated in terms of main performance of the recycled binder at mid and high-service temperatures.

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