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RILEM TC RECOMMENDATION

Recommendation of RILEM TC 264 RAP on the evaluation of asphalt recycling agents for hot mix asphalt

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Abstract This recommendation is based on the results of an inter-laboratory study organised by the RILEM technical committee TC 264-RAP "Asphalt Pavement Recycling"—Task Group 3 (TG3) focusing on Asphalt Binder for Recycled Asphalt Mixture. The TG3 aimed to evaluate the effect of a specific family of materials known as asphalt recycling agent (ARA) on the aged binder under different configurations. Even though ageing is an irreversible phenomenon, effective ARA must have the capability to improve the flexibility of the bituminous materials and their resistance against cracking susceptibility with no adverse effect on the rutting resistance of pavements containing reclaimed asphalt. A total of 17 participating laboratories analysed the properties of binder

This recommendation has been prepared by the task group TG3 within RILEM TC 264-RAP to gain more insight into the methods of evaluation for the rheological performance of aged asphalt binders through the use of asphalt recycling agents. The recommendation has been reviewed and approved by all members of the TC64-RAP.

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blends composed of aged binder from reclaimed asphalt in three different contents (60, 80, 100%), ARA and virgin binder. The physical properties of the blends were thoroughly evaluated through traditional and rheological binder testing. This recommendation proposes to restore the original material properties at low and intermediate temperatures (i.e. cracking resistance) while balancing the high-temperature characteristics (i.e. rutting susceptibility) with durable impact throughout the progression of ageing phenomena. Therefore, useing of the Dynamic Shear Rheometer is foreseen as a more suitable and sustainable means to evaluate binder blends containing an asphalt recycling agent. Compared with conventional testing, the proposed approach requires fewer materials while resulting in a faster experimental procedure with one single test.

Keywords Reclaimed asphalt · Asphalt Recycling Agent (ARA) · Binder · Rheology · Ageing · Dynamic shear rheometer

1 Introduction

The aim of the RILEM TC RAP—TG3 on Asphalt Binder for Recycled Asphalt Mixture was to develop a protocol for the assessment of the ageing behaviour of binder blends composed of Reclaimed Asphalt (RA) binder, virgin binder (Vb) and Asphalt Recycling Agent (ARA). Blends were selected reflecting the most common state of the practice, where RA is combined with both virgin binder and ARA and mineral aggregates. For the sake of simplification and considering the influence on the evolution of the material characteristics, this study was carried out at the binder level where these components are fully blended, as ageing shows the dominant effects on this component of the mixture. It must be remarked that the aggregate-binder skeleton and the volumetric properties greatly impact the asphalt mixture's behaviour, especially at high temperatures.

In the simulation of the mix design of a recycling asphalt mixture with RA and ARA, the RA content is set by the RA binder content in the mixture. Virgin binder is added to adjust the required binder content in the mixture and in corporated in the binder blend accordingly. Therefore, RA binder content depends on the amount of RA used in the mixture and its aged binder content. For example, to simulate a 60% recycling mixture at the binder level, 60% (by mass) of RA binder is blended with 40% virgin binder. This process assumes that the binder contents in the RA material and final asphalt mixture containing RA are

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identical. The ARA has the function to restore the lost properties of the aged binder, and its content/dosage is typically determined to meet the desired target requirements (e.g. desired penetration/viscosity value and/or PG grades).

In the RILEM TG 3 inter-laboratory testing, binder blends of RA binder, virgin binder (binder 50/70) and ARA with simulated RA contents of 60, 80 and 100% were prepared and subsequently short- and long-term aged with the Rolling Thin Film Oven Test (RTFOT) [1, 2] and Pressure Ageing Vessel (PAV) [3, 4]. The binder blends were analysed in three ageing states: unaged, short-term (STA) and long-term aged (LTA). Their physical properties were measured using conventional testing methods such as penetration [5, 6] and softening point ring and ball [7, 8]. The rheological characterisation was performed with the Dynamic Shear Rheometer (DSR) [9, 10] for complex modulus and phase angle measurement and Bending Beam Rheometer (BBR) for the relaxation properties [11, 12] (Fig. 1). In order to reduce the experimental demand, the participating laboratories were divided into three groups based on the recycling content (60, 80 and 100%). Therefore, each laboratory conducted the experimental campaign only on the preassigned binder blend. The detailed procedure is described in the State of the Art-Report (STAR) [13] and different publications [14–16].

2 Synthesis on the results of the RILEM TC RAP—TG3 interlaboratory activity

This section provides a concise summary of the results from the interlaboratory campaign conducted by TG3. The outcome of this work is used to prepare the present recommendation. In the inter-laboratory testing campaign, results from 17 laboratories from all over the world were analysed. Almost all participants provided softening point temperature, and DSR results at intermediate and high temperatures. A few laboratories performed DSR measurements below 0 °C using the 4 mm plate geometry [17–19]. Penetration value at 25 °C and BBR results were available only from a limited number of laboratories, as the amount of extracted RA binder was not sufficient for all participants to complete an entire testing program. The detailed results are discussed in the STAR [13] and elsewhere [14–16].

In summary, the rejuvenated blends' overall ageing behaviour was similar to the virgin binder, independently of the RA content. There was a slight difference among the different recycling contents, particularly for the 100% blend; however, the difference was often within the test methods' accuracy. Figure 2 and Fig. 3 show the average results of the three blends with different RA content together with the virgin binder at high and intermediate temperatures for all laboratories. As mentioned in the previous section of this document, each laboratory tested a binder blend with a single recycling content. Therefore, the results provided in the figures are divided by recycling level (60, 80 and 100%) and reported as the average for each group of laboratories working on the same recycling percentage. In addition, to avoid any confusion in the plots, the error bars were not included as they would highly overlap. In addition, not all laboratories conducted the penetration test as this requires a significant amount of binder that could not be extracted for all participants. Figure 2 demonstrates the close relationship in the high-temperature range between softening point and DSR shear modulus $|G^*|$ at 58 °C and 1.59 Hz. A temperature of 58 °C for the DSR shear

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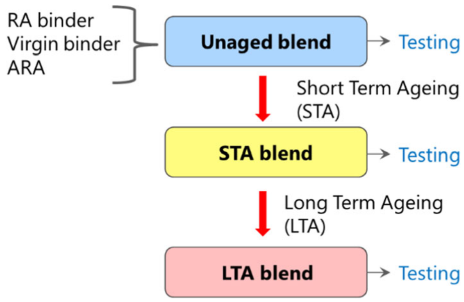

Fig. 1 Ageing and testing scheme

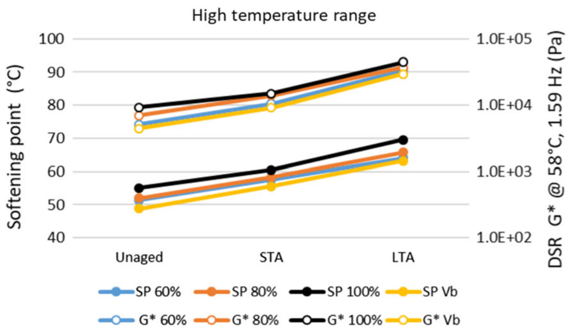

Fig. 2 High temperature domain results: Softening point (SP) and DSR |G^*| at 58 °C and 1.59 Hz (Vb: virgin binder)

modulus was selected to address the high-temperature behaviour of the binder when the pavement surface layer is exposed to warmer conditions during summer. However, other temperatures in the range of 50 °C to 70 °C can be defined, as the trend/outcome will not change significantly. Accordingly, the penetration value at 25 °C and DSR shear modulus |G^*| at 28 °C and 1.59 Hz were compared for the intermediate temperature range (Fig. 3). As in the inter-laboratory DSR measurements were performed in temperature steps of 6 °C, 28 °C instead of 25 °C was selected for obtaining |G^*|, assuming that this relatively small temperature difference will not affect the outcome. This decision is supported by the consistency of the plots in Fig. 3. In this plot, an opposite trend can be observed as penetration values decrease with increasing modulus; this tendency was graphically counterbalanced for visualisation purposes by inverting the y-axis for |G^*|. Therefore, TG3 recommends using DSR rheological measurements at 28 °C and 58 °C to replace the empirical penetration and softening point testing methods. This approach offers different advantages, such as less material for sample preparation and a broader application range, including the investigation of modified binders. For the low temperature range below 0 °C, the results obtained with the DSR with the 4 mm plate-plate geometry appear to be reliable [17–19], despite the limited data received. However, the experience is still limited, and the method's accuracy has not been widely determined.

As a result of this inter-laboratory testing, a protocol was developed to evaluate the ARA binder blends. The protocol is intended as a guideline to determine an appropriate binder blend, essentially composed of RA binder, virgin binder and ARA for a hot mix asphalt containing RA. The procedure should be fast and reliable, using a small quantity of material for sample preparation to avoid the tedious and time-consuming extraction of large amounts of RA binder. The proposed approach represents an alternative to the comprehensive analysis commonly performed when relying on the Performance Grade (PG) system [20] based on DSR and BBR testing at various temperatures.

3 Limitations of the protocol

This recommendation is valid for non-modified binders in hot mixes. Modified binders containing polymers, waxes, rubber, etc., were not investigated in the present RILEM TC RAP inter-laboratory testing. However, this proposed approach can be possibly applied to this set of materials as a starting point for further investigation. The protocol is intended to provide a first indication of the suitability of a binder blend for hot and potentially warm mixes with high content of RA. However, further evaluation at the asphalt mixture level is recommended.

4 Protocol for the evaluation of ARA-binder blends

The proposed protocol is intended to serve as a simple and user-friendly tool to evaluate binder blends for new asphalt mixtures containing large amounts of RA. Emphasis is put on fast test execution (single-point measurements at a single frequency and three temperatures in place of the more demanding combinations of tests methods used in the PG system), small sample while including the critical impact of ageing in the analysis. Figure 4 shows the seven steps of the proposed protocol.

5 Step 1: Define preliminary proportions for the intended recycling hot mix asphalt

The binder blend must accurately represent the binder in the specific Hot Mix Asphalt (HMA) containing the selected amounts of RA. In this protocol full blending is assumed between aged RA binder and added virgin binder in the recycling HMA regardless of the degree of ageing of the RA binder. Depending on the pavement and mixture type, binder content and binder type are restricted and have to be considered in the choice of the virgin binder and ARA. Information on recycling and binder content in recycling HMA is needed to define the binder blend composition.

6 Step 2: Define the target properties of the binder blend

There are different possibilities to define the target properties of the binder blend, either from experience or by comparison with a reference binder successfully used for a similar HMA without RA. In general, the behaviour of mixes without RA is well known. Therefore, using the characteristics of such reference for comparison purposes with the properties of the binder blend is a good option, as described below.

First, the reference binder must be evaluated and aged in parallel to the binder blend, as performed in the TG3 inter-laboratory testing [13]. However, with growing experience, target properties can be defined, and additional testing of a reference binder is not needed anymore.

Binder properties at high, intermediate and low temperatures are established depending on the climatic conditions in different regions. Historically, the penetration value at 25 °C and the softening point temperature have been used as target properties for binders in recycling asphalt mixtures. However, the inter-laboratory testing has shown that the complex modulus |*G**| is equivalent for non-modified binders and needs less testing material. This facilitates the testing as fewer samples need to be prepared after ageing. Therefore, the DSR is recommended as a testing method for high and intermediate

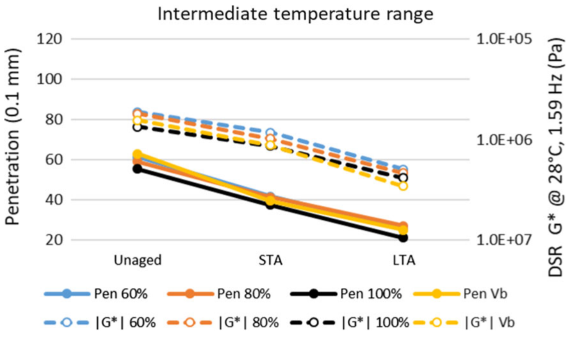

Fig. 3 Intermediate temperature domain results: Penetration value at 25 °C (Pen) and DSR |*G**| at 28 °C and 1.59 Hz (Vb: virgin binder)

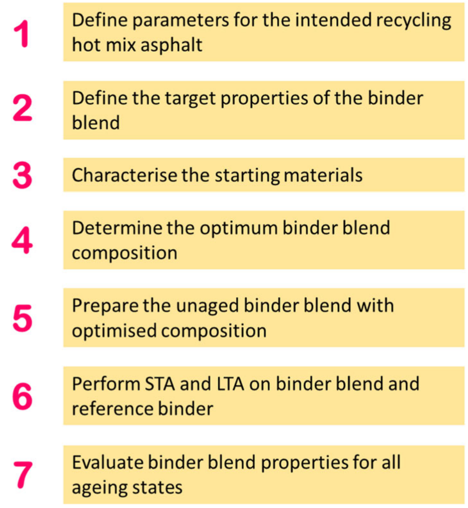

Fig. 4 Flow diagram of the 7 step evaluation protocol

temperatures. A temperature of 28 °C for the intermediate and 58 °C for the higher range is proposed, as this is comparable with temperatures of penetration value at 25 °C and softening point temperature, respectively. In addition, for both measurements, the same 25 mm plate could be used in general. Figure 5 shows an example for 80% RA content from a single laborotoray.

For assessing the properties at low temperature, DSR equipped with 4 mm plates represent a valid testing option [17–19]; however, this is not yet commonly used. Therefore, at the present stage, DSR with 8 mm plates at + 6 °C with a small strain level is recommended as an alternative. Table 1 summarises the proposed testing and corresponding

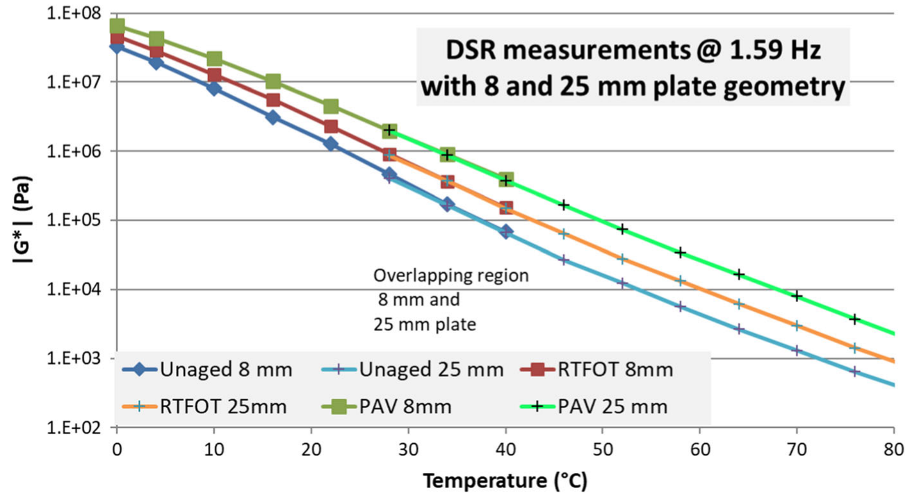

Fig. 5 $|G^*|$ @ 1.59 Hz measured with 8 and 25 mm DSR plate geometry for RA content of 80%

Table 1 Recommended target properties

Temperature range	TG 3 recommendation	Ageing state
High	DSR $|G'^*|$ @ 58 °C, 1.59 Hz	STA
Intermediate	DSR $|G'^*|$ @ 28 °C, 1.59 Hz	Unaged, STA, LTA
Low	G'' @ + 6 °C, 1.59 Hz (with 8 mm plate) or DSR G'' @ −20 °C, 1.59 Hz (with 4 mm plate)	LTA

ageing level for determining the material properties at intermediate, high and low temperatures.

7 Step 3: Characterise initial materials

Characterisation of the core material, essentially RA binder and virgin binder, is needed for step 4, where trial blends are prepared. If different RA fractions are used, the binder content of all RA fractions has to be determined. This step is necessary because binder content is significantly higher than in coarser material in the case of fine RA fractions.

8 Step 4: Determine the optimum binder blend composition

In this step, the binder blends that were designed with RA binder, virgin binder, and three different ARA dosages, by RA binder weight, are prepared to evaluate the effect of the ARA. The percentage of the RA binder is defined by the RA content in the final HMA. The amount of virgin binder is given by the difference between the total binder content and the RA binder content. As the amount of ARA is strongly dependent on the consistency of the RA binder, and the amount and type of virgin binder, there is no general rule for initial ARA dosages for the three binder blends. This mainly depends on the amount of RA binder; therefore, the ARA dosage is best determined in relation to the RA binder amount. Based on the work performed by RILEM TC 264-RAP TG3, a tentative range of ARA/RA binder dosages of 5, 10, 15% by weight of RA binder is proposed to start defining the ARA content. However, this represents a possible first trial and might differ depending on the type of ARA and virgin binder, recycling rate, and RA binder content. By interpolation or extrapolation (depending on ARA type) of the $|G^*|$ at 28 °C, as a function of the tentative ARA dosages, the optimum ARA dosage is determined. One should keep in mind that the interpolation/extrapolation of $|G^*|$ is an exponential function of the ARA concentration.

Table 2 Recommended target properties

Target property	Acceptance criteria in relation to the reference binder
DSR |G^*| @ 58 °C, 1.59 Hz	$\geq$ (100%—f) |G^*|$_{ref}$
DSR |G^*| @ 28, 1.59 Hz	$\geq$ (100%—f) |G^*|$_{ref}$ and $\leq$ (100% + f) |G^*|$_{ref}$
G'' @ + 6 °C (with 8 mm plate) or DSR G'' @ −20 °C (with 4 mm plate)	$\leq$ (100% + f) G''_{ref}

Ref: reference binder; f: acceptance criteria for recommended target properties

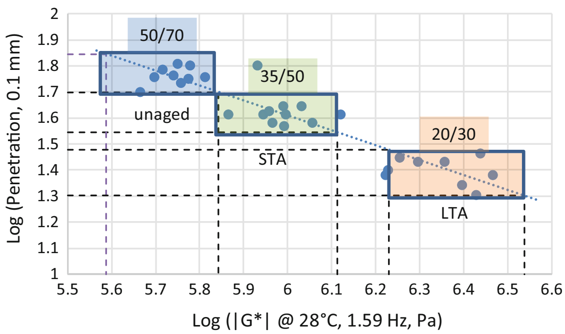

Fig. 6 Penetration versus |G^*| for all binder blends in logarithmic scale with the corresponding acceptable tolerance of approximately 25% of the binder penetration grades

If only a target property at one temperature, generally in the intermediate range (|G^*| at 28 °C), is defined, the calculation of the optimum ARA dosage is straightforward. If the target properties for low and/or high temperatures need to be considered (Table), a compromise is often necessary, or components/content of the binder blend has to be changed and re-evaluated. As the high-temperature performance improves with ageing, an excellent strategy to determine the optimum dosage is to target the intermediate temperature properties and check the high temperature (after STA) not to fall below the minimum value.

9 Step 5: Prepare the unaged binder blend with optimised composition

A sufficient amount of binder blend for ageing and testing is prepared with the optimum ARA dosage determined in the previous step. Using only DSR measurements, where the largest sample for the 25 mm plate and 1 mm height weighs only around 1 g, the whole procedure can be carried out with two RTFOT containers. In this case, the PAV plate with 50 g of binder is the limiting factor. Theoretically, with smaller PAV plates holding 20 g even one RTFOT container would be sufficient. This requires 50 g of binder in total (15 g for testing the unaged blend, 35 g for RTFOT ageing, of which 10 g is used for testing and 20 g for PAV ageing). Depending on the recycling rate, the required 50 g of binder blend can be prepared by performing the binder extraction and recovery on 0.7 – 1.2 kg of RA.

10 Step 6: Perform STA and LTA on binder blend and reference binder

Both the binder blend and the reference binder are first subjected to STA and afterwards to LTA. For the STA, standard RTFO(T) ageing is recommended [1, 2]. Next, the defined properties after STA are measured, which give information on the expected ageing after the production and construction of the hot mix. These values are compared with the defined target properties.

For long-term ageing, standard (after STA) PAV ageing for 20 h at 100 °C is recommended [3, 4]. However, the ageing time and temperature can be changed depending on climate and environment, pavement type, and expected lifetime. For specific climatic conditions and materials (i.e., PmB), extended ageing such as LTA with a duration was found to be more realistic [21].

11 Step 7: Evaluate binder blend properties for all ageing stages

The binder blend and the reference binder are tested according to the predefined testing scheme for all ageing levels, including the unaged state. The results are compared against the target properties and the defined acceptance range. The acceptance criteria are defined as the tolerance relative to the reference binder, for which the result of the blend is acceptable (Table 2). In Fig. 6, the binder blends in all ageing states are shown with the corresponding range of log |G*| for different binder grades. On this basis, an average acceptance tolerance f of 25% for |G*| can be deducted (Fig. 6).

In case the results do not meet (all) the expected target properties, the initial parameters have to be adjusted, for which the following options are available:

- change of the ARA type or dosage
- select a different virgin binder
- reduction of the RA content

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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