Materials and Structures

Recommendation of RILEM TC237-SIB on Fragmentation Test for Recycled Asphalt

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Recommendation of RILEM TC237-SIB on Fragmentation Test for Recycled Asphalt

Method for characterizing the evolution of recycled asphalt particle size distribution due to work operation (mechanical action) through fragmentation test

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Abstract This recommendation describes how to characterize the Reclaimed Asphalt (RA) through the fragmentation test. The guidelines given hereafter are based on the results of a Round Robin Test (RRT) organized by the RILEM Technical Committee 237-SIB ‘‘Testing and characterization of sustainable innovative bituminous materials and systems’’ and provide information on the testing procedure, data analysis and indications for the preparation of a test report.

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This recommendation was developed by the task group TG6 within RILEM TC 237-SIB consisting of Gabriele Tebaldi, Eshan Dave, Martin Hugener, Augusto Cannone Falchetto, Daniel Perraton, Andrea Grilli, Davide Lo Presti, Marco Pasetto, Andreas Loizos, Kim Jenkins, Alex Apeagyei, James Grenfell, Maurizio Bocci. The draft recommendation was submitted for approval to the full TC and subsequently approved by RILEM TC 237-SIB.

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1 Introduction

The use of reclaimed asphalt (RA) in asphalt mixture is common practice in the pavement construction industry, due to both economical and environmental benefits [1]. This material is obtained from old asphalt pavement at the end of their service life after a milling or a demolition process. RA mainly consists of aggregates, aged and oxidized bitumen and mastic and, in many instances, it appears as a conglomerate of multiple aggregate particles of different sizes and shapes.

The particle size distribution of RA depends on a number of factors: (1) the original asphalt material; (2) the specific milling and demolition devices, operations and conditions; (3) the extent of distress conditions and the current aging; and (4) the handling of the milled RA. In addition, during the construction process, the particle size distribution of RA evolves due to mechanical actions (mixing, handling, compaction etc.) and temperature variations (during storage and mixing). Therefore, it is necessary to know this evolution to implement a reliable mix design process since the mechanical performance of the recycled asphalt mixture is heavily dependent on the gradation curve of RA. For example, previous studies [2-6] have shown that even small changes in the grading curve can have a significant impact on the mixture performance, and as a result, it is extremely important to keep the aggregate sizes and their distribution under control. Moreover, the evolution of the particle size distribution of RA under mechanical actions is specific to each RA source, prompting the need of including this change in gradation into a "fingerprinting" protocol for characterizing RA material.

Because RA is extremely heterogeneous, this is not a simple challenge, particularly during the quality control phases. The main difficulty lies in the fact that the conventional methods used to classify RA do not involve a quick and simple test that can be used in the laboratory to produce reference values and to secure fast data that may be compared with those references values in the field operation. In addition, there is no other test procedure to characterize the evolution of RA particle size distribution at present.

2 Scope

The present recommendation gives guidance for a new experimental procedure to differentiate the RA from different sources. Specifically, it refers to the test procedure of the fragmentation test. This recommendation is based on the results of a round robin test (RRT) organized by the RILEM Technical Committee 237-SIB TG 6 “Testing and characterization of sustainable innovative bituminous materials and systems - Cold Recycling”. This document contains guidelines on material preparation, testing procedure, data analysis and presentation of results. The proposed testing method fill a gap in existing international standards; additional details on the results of the RRT can be found in Tebaldi et al. [7-9].

The application of this test procedure is intended as part of an RA characterization protocol as well as for use in mix design procedures of asphalt mixtures that incorporate RA. It is recommended that this test is used to enhance the reliability of mix design procedures so that the final product in field operation is comparable to the designs conducted in the laboratory. In addition, since the recommended procedure includes testing at different temperatures, results provide insight on the availability of bitumen from RA, which can be potentially reactivated, as a function of temperature and characterize the influence of temperature on the evolution of particle size distribution. Furthermore, the test method can provide a first guidance in decisions regarding the selection of the specific recycling technology: hot, warm or cold recycling.

3 Referenced documents

The following section provides a list of international standards and documents linked to the present recommendation.

ASTM Standards

- ASTM C136/C136M-14 (2014) Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM International, West Conshohocken, PA
- ASTM C702/C702M-11 (2011) Standard Practice for Reducing Samples of Aggregate to Testing Size, ASTM International, West Conshohocken, PA, 2011
- ASTM D1557-12 (2012) Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)), ASTM International, West Conshohocken, PA

EN Standards

- EN 933-1 (2012) Tests for geometrical properties of aggregates - Part 1: Determination of particle size distribution - Sieving method. European Committee for Standardization, Brussels, Belgium
- EN 13108-8 (2016) Bituminous mixtures - Material specifications - Part 8: Reclaimed asphalt. European Committee for Standardization, Brussels, Belgium
- EN 13286-2 (2012) Unbound and hydraulically bound mixtures - Part 2: Test methods for laboratory reference density and water content - Proctor compaction. European Committee for Standardization, Brussels, Belgium

4 Definitions

Please refer to "Recommendation of RILEM TC237-SIB: Protocol for Characterization of Recycled Asphalt (RA) Materials for Pavement Applications" for definitions that are relevant to this recommendation.

5 Materials preparation

The RA to be tested can be obtained from different sources, different asphalt mixtures, prepared for different pavement layers. It can differ in asphalt binder type and content, aggregate type, particles size and distribution, milling operation pavement conditions and distresses, storage time and conditions (protected or unprotected stockpiles).

The initial sample amount has to be large enough to be representative for the RA origin and sufficient to complete the fragmentation test. For the pre-treated RA samples, no specific protocol is recommended. Nevertheless, it may be advisable to air dry the material at room temperature for 24 hours and then place it in a thermostatically controlled oven at a temperature of 40°C for 24 hours prior to testing. Homogenization of the main samples before reducing them to test samples is standard practice.

6 Test procedure

The fragmentation test provides an indication on the particle resistance to fragmentation under a series of shocks induced by dropping a steel mass, namely a rammer, on a confined sample placed in a steel cylindrical mould. In the specific case, the modified proctor test procedure [14, 15] is used to perform a series of impact tests on different sources of RA.

The fragmentation test measures the amount of RA passing through a control sieve after a fixed series of strokes carried out with a normalized falling mass. The material crushed to sizes finer than a specified control sieve is separated and expressed as a percentage of the initial weight of the material placed in the mould. The passing through the control sieve (PCS) is expressed as percentage of the initial weight of the material and recorded. Table 1 presents, as an example, the details regarding proctor device used by the five laboratories that participated to the RRT organized by the RILEM Technical Committee 237-SIB TG6.

Table 1 Summary of testing procedure used by each laboratory involved in the RRT

	LAB *A*	**LAB *B***	**LAB *C***	**LAB *D***	**LAB *E***
Inside mould diameter (mm)	101.6	150.0	100.0	151.2	152.3
Rammer weight (g)	4 535	4 535	4 500	4 535	4 800
Height of fall (cm)	45.7	45.7	45.7	45.7	45.0
Blows per layer	56	56	56	56	50
Number of layers	5	5	5	5	5
Control sieve (mm)	1.6	1.6	1.6	1.7	1.6

The test is performed on different aggregate fractions 20 / 30 mm, 14 / 20 mm, 10 / 14 mm, and 5 / 10 mm. The first number of the fraction represents the size of the sieve for which 100% of material is retained, while the second number refers to the size of the sieve where 100% of material is passing. Figure 2 shows a schematic of the fragmentation test procedure: the material is first sieved (Figure 2 a and b) and then compacted in five layers (Figure 2 c) with a fixed number of blows per layer (Table 1) using a standardized falling mass. Finally, the fine material produced by the impact of the hammer is sieved with a control sieve (PCS) (Figure 2 d). The test is repeated at three different temperatures: 5, 20 and 40°C, to evaluate the difference in material response under different conditions. An example of fragmentation test results from the RRT is presented in Table 2.

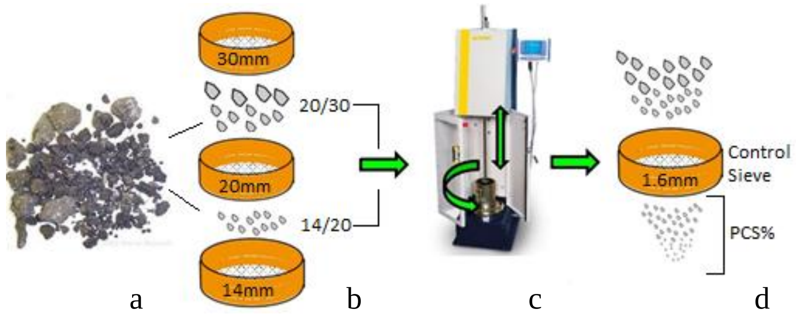


Fig. 2 Procedure and apparatus used in the fragmentation tests (ASTM D 1557, 2012)

Table 2 Example of fragmentation test results

Source of RAP		A			
Temperature test: 5°C					
Size	100% passing	30 mm	20 mm	14 mm	10 mm
Classes	100% retained	20 mm	14 mm	10 mm	5 mm
Weight before hammering (g)		192	235	213	242
Material passing the control sieve after hammering (g)		24	19	17	21
Coefficient of fragmentation (Percent passing control sieve, PCS)		12.5	8.1	8.0	8.7
Temperature test: 20°C					
Size	100% passing	30 mm	20 mm	14 mm	10 mm
Classes	100% retained	20 mm	14 mm	10 mm	5 mm
Weight before hammering (g)		304	215	169	146
Material passing the control sieve after hammering (g)		14	15	12	13
Coefficient of fragmentation (Percent passing control sieve, PCS)		4.6	7.0	7.1	8.9
Temperature test: 40°C					
Size	100% passing	30 mm	20 mm	14 mm	10 mm
Classes	100% retained	20 mm	14 mm	10 mm	5 mm
Weight before hammering (g)		287	276	242	220
Material passing the control sieve after hammering (g)		8	8	9	9
Coefficient of fragmentation (Percent passing control sieve, PCS)		2.8	2.9	3.7	4.1

7 Data analysis

Since the grading curve influences the mixture performance, it is extremely important to keep under control the aggregate sizes and their distribution. The aim of the fragmentation test is to predict the reliability of the gradation of a granular mix taking in consideration the accidental changes caused by the breaking of RA conglomerates. As mentioned before, four fraction classes are considered: 20/30 mm, 14/20 mm, 10/14 mm and 5/10 mm. For each fraction, RA particles are completely retained on the smaller size sieve and pass through the larger size one, while the mean particle size between two consecutive sieves is defined as:

$$mean\ \ particle\ size = \sqrt{size\ of\ \ the\ sieve\ 'i'\ \text{x size of the sieve}\ 'i+1'} \qquad (1)$$

The analysis of the data should include the evolution of the material passing through the control sieve (PCS) produced under fragmentation as a function of temperature. Figure 3 provides an example of the PCS trend of the different RA material used in the RRT of the RILEM Technical Committee 237-SIB TG6 for the different testing temperatures.

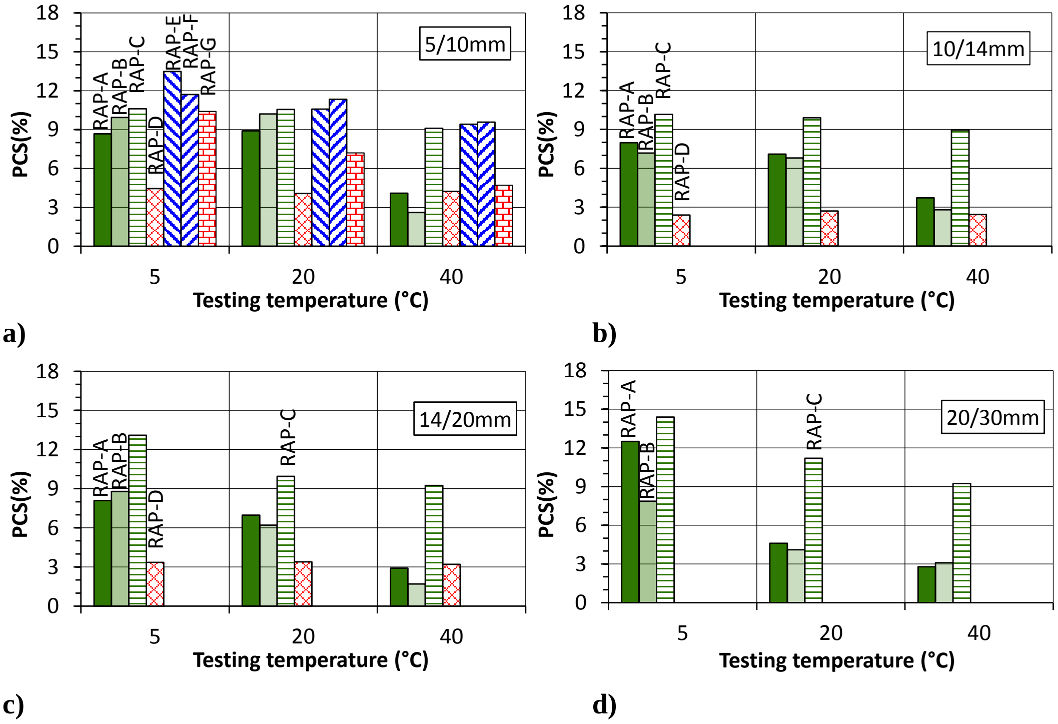


Fig. 3 Relationship between PCS and the fragmentation testing temperature on different RAP sources: **a)** class 5/10mm; **b)** class 10/14mm; **c)** class 14/20mm and; **d)** class 20/30mm

The figure shows decreasing PCS values for higher testing temperatures for the entire set of RA sources. With respect to the tested fraction classes, the PCS changes with the testing temperature according to the mean size of particles. In addition, for coarser fractions, the variation of the PCS with the temperature is more pronounced.

The coefficient of variation: CV = (standard deviation/mean value)×100, can be used to calculate the dispersion of the results in terms of mean particle size for the different testing temperatures as show in the RRT example of Figure 4. In this specific case, the dispersion of the results is much lower for low temperature (5°C) measurements compared to those obtained for high temperature (40°C) measurements.

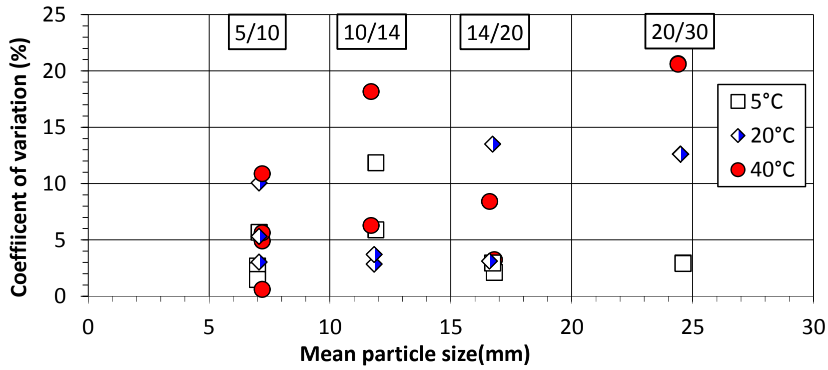


Fig. 4 Relationship between the coefficient of variation values (CV (%)) and the mean particle size of fraction group tested at different temperatures

7.1 Categorization of RA based on fragmentation potential

To classify RA with respect to its susceptibility to undergo size changes while in use, the fragmentation results obtained at 5°C can be compared to those derived from fragmentation tests performed on virgin aggregate, according to the categories defined in the EN 12620 [16] standard and presented in Table 3.

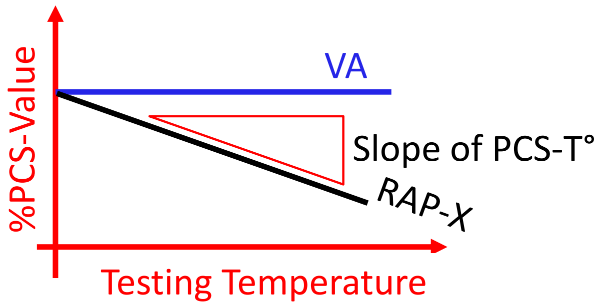
Table 3 RA categories and limits with respect to the vulnerability of RAP particles to change size while in use and the corresponding classification of RAPs tested

Categories	**B**	**C**	**D**	**E**
Limits on $PCS_{5°C\_5/10mm}$ *(%)*	⩽ 7	⩽ 9	⩽ 11	⩽ 14

7.2 Categorization of RA based on agglomerate potential

In the context of RA recycling in cold mix applications, the interaction between RA particles under processing could be affected by the bitumen phase of the RA. Particles containing softer bitumen may agglomerate more easily under processing, and may significantly change the workability and the dynamic of the laying of the cold recycled material. This aspect could be more critical for recycling at elevated temperatures with foam bitumen. Moreover, agglomerate processes could also affect the coating quality of the binder system in cold recycling. The fragmentation test results obtained at different temperatures provide the possibility of verifying the agglomerate potential of a RA material.

As previously shown, PCS values of RA change with the testing temperature, suggesting that this may depend on bitumen characteristics. This is supported by the actual independence on temperature of the PCS of virgin aggregate (VA). Therefore, the impact of RA-source on the agglomeration potential of a RA can be linked to the slope of the PCS-T° relationship as exhibited in Figure 5.



$$\text{Slope} = \frac{PCS_{T=5°C} - PCS_{T=x°C}}{\Delta T}$$

Fig. 5 Schematic representation of the relationship between the percent passing through the control sieve (PSC (%)) and the testing temperature

To compare the slopes of the PSC-T relationship from all data, RA source results for each specific fraction group, need to be first normalized with respect to the PCS result obtained at 5°C (PCS_{STD} at 5°C) as defined in equation (equation 2). It should be noted that the PCS 5°C value is typically the highest one in the testing temperature range. A standardized value of 1 means that the temperature does not affect the fragmentation results.

$$PCS_{STD\ at\ 5°C} = \frac{PCS_{T°C}(\%)}{PCS_{T=5°C}(\%)} \qquad (2)$$

A reduction of the standardized PCS values is associated to an increase in temperature suggesting a high thermal susceptibility of the material. By assuming a linear relationship, the thermal susceptibility can be linked to the slope value of the $PCS_{STD\ at\ 5°C}$ - vs T° relationship and this can be used as criterion for define categories and limits to classify the RA as shown in Table 4.

Table 4 RA categories and limits with respect to the vulnerability of RAP particles to change size in its use and the corresponding classification of RAP tested

Categories	1	2	3	4
Absolute value of the rate of change of $PCS_{STD\ at\ 5°C}$ with temperature ($\times 10^3$) ($°C^{-1}$)	⩽ 5	⩽ 10	⩽ 18	⩽ 25

8 Closing remark and test report

The fragmentation test can be used to characterize RA and possibly to classify it according to the source. Based on the present document the test report should contain:

- Relevant information on the tested RA material, such as origin, storing, and potential conditioning;
- The description of the test setup, including: mould size, rammer weight, height of fall, blows per layer, number of layers, control sieve;

- The values measured for each size class, and temperature, the weight of each class before and after hammering and the coefficient of fragmentation (PCS%);
- The value of the mean particle size and coefficient of variation;
- The category of RA in terms of fragmentation potential and agglomerate potential.

Compliance with ethical standards

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

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