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Abstract	Cold recycling of reclaimed asphalt (RA) is a promising technique to build or to maintain roads, combining performance and environmental advantages. Although this technique has been extensively used worldwide,

there is no unique and internationally-shared method to characterize cold recycled mixtures. The previous work of the RILEM TC 237-SIB TG6 successfully attempted to characterize different RA sources with both traditional parameters (gradation, bitumen content and geometrical properties) and non-conventional properties (fragmentation and strength testing). The current RILEM TC 264-RAP TG1 mainly focuses on the influence of different RA sources on physical and mechanical characteristics of cement-bitumen treated materials (CBTM) using foam or emulsified bitumen, taking into consideration compaction and curing methods. This paper presents results from the first step of the inter-laboratory project in which foamed bitumen and cement were used as binders. The influence of two RA sources, one from Alabama (USA) and one from San Marino, were investigated through the collaboration of several laboratories. Specimens were manufactured with the same diameter by means of both Marshall and gyratory compactors and then cured following two procedures: free surface drying (FSD) and partially-surface drying (PSD). A preliminary study allowed obtaining specimens with similar volumetric properties. Along with compactability and water loss, the indirect tensile stiffness modulus was measured and analyzed. The results have shown that the RA source and curing procedure influence the CBTM mechanical properties.

Keywords (separated by '-')	Cold recycling - Foamed bitumen - Reclaimed asphalt - Strength - Water loss

Experimental Investigation on Water Loss and Stiffness of CBTM Using Different RA Sources

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Abstract Cold recycling of reclaimed asphalt (RA) is a promising technique to build or to maintain roads, combining performance and environmental advantages. Although this technique has been extensively used worldwide, there is no unique and internationally-shared method to characterize cold recycled mixtures. The previous work of the RILEM TC 237-SIB TG6 successfully attempted to characterize different RA sources with both traditional parameters (gradation, bitumen content and geometrical properties) and non-conventional properties (fragmentation and strength testing). The current RILEM TC 264-RAP TG1 mainly focuses on the influence of different RA sources on physical and mechanical characteristics of cement-bitumen treated materials (CBTM) using foam or emulsified bitumen, taking into consideration compaction and curing methods. This paper presents results from the first step of the inter-laboratory project in which foamed bitumen and cement were

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used as binders. The influence of two RA sources, one from Alabama (USA) and one from San Marino, were investigated through the collaboration of several laboratories. Specimens were manufactured with the same diameter by means of both Marshall and gyratory compactors and then cured following two procedures: free surface drying (FSD) and partially-surface drying (PSD). A preliminary study allowed obtaining specimens with similar volumetric properties. Along with compactability and water loss, the indirect tensile stiffness modulus was measured and analyzed. The results have shown that the RA source and curing procedure influence the CBTM mechanical properties.

Keywords Cold recycling · Foamed bitumen · Reclaimed asphalt · Strength · Water loss

1 Introduction

Cement-bitumen treated materials (CBTM) are produced with a significant amount of reclaimed asphalt (RA), bitumen emulsion or foamed bitumen, cement and water. CBTM is a hybrid material which inherits properties from both asphalt concrete (AC), since the bituminous component plays a significant role, and cement-treated materials (CTM), since the cement influences stiffness and curing of the mixture [1, 2].

The RILEM TC 237-SIB TG6 on cold recycling worked in 2012–2018 on the characterization of reclaimed asphalt to be used for cold recycling [3]. This characterization differs from the commonly used RA characterization when used in hot recycling where the aged bitumen softens, and the aggregate gradation combines with the virgin materials that usually are the dominant component. In cold recycling, the RA behaves as it is and for instance black gradation, fragmentation resistance and geometric properties of particles have a significant influence on the performance of the final product. At the end of the TG6 mandate, the RILEM TC 264-RAP launched a new TG, so-called TG1, on cold recycling with the purposes of sharing mix design and curing procedures that can better support the selection of the optimum mixture in relationship with RA characteristics and product performance. A new inter-laboratory testing program has been proposed to the TG1 members to evaluate the influence of different RA sources, appropriately selected and characterized, on strength and stiffness of cold recycled mixtures. The objectives of this paper were to assess both the influence of the RA source and curing conditions on properties of CBTM, such as water loss and stiffness.

2 Materials

Two RA sources, one from the Republic of San Marino so-called RA1 and another one from NCAT-USA so-called RA2, were preliminary characterized by means of the fragmentation test which measures the amount of produced fines (passing material to 1.7 mm sieve size) after modified Proctor compaction [4].

The RA1 and RA2 properties are reported in Table 1. The two RA sources mainly differ each other by fragmentation resistance, gradation and maximum size.

A mineral filler characterized by 91% of passing material at 0.008 mm sieve size, 50.1% voids of dry compacted filler measured by means of a Rigden apparatus (EN 1097–4) and a stiffening power $\Delta_{R\&B}$ of 11.5 °C (EN 13179–1) was selected to adjust both RA gradations following the respective maximum density curves. A GU type cement (CSA A3000) with compressive strength at 28 days of 43.9 MPa (ASTM C109) and Blaine surface area of 410 cm^2/g was chosen to improve the bituminous mastic consistency and short-term resistance. The bitumen has a penetration value of 64 $mm \cdot 10^{-1}$ (EN 1426) and a softening point of 52 °C (EN 1427). A preliminary study established 1.9% of water by bitumen weight to achieve at 170 °C an expansion ratio of 10 and half-life of 6 s considered suitable for foam applications.

The two CBTM mixtures consisted of 4.0% of added water, 3.0% of bitumen, 1.5% of cement, 5.5% and 10.0% of filler and 93.0% and 88.5% of RA, for RA1 and RA2 respectively. Dosages refer to the total solid weight (RA, filler and cement). The dosages of water and bitumen were chosen according to common values typically used for cold recycled material [5, 6]. Mixtures were coded as CBTM16RA1 and CBTM10RA2 using RA1 and RA2 respectively. CBTM16RA1 and CBTM10RA2 gradation follow the Fuller distribution with D_{max} = 16 mm and D_{max} = 10 mm, respectively.

Table 1 Properties of RA1 and RA2

Property	Standard	Unit	RA1	RA2
Bitumen content	ASTM D6307	%	5.51	5.49
Nominal maximum particle size	ASTM D448-03	mm	16	10
Maximum specific gravity	ASTM C127-128	–	2.482	2.498
Water absorption	ASTM C127-128	%	1.10	1.08
Fragmentation @5 °C	ASTM D1557	%	7.6	–
Fragmentation @20 °C	ASTM D1557	%	6.7	13.9
Flakiness index	EN 933-3	%	5	–
Shape index	EN 933-4	%	3	–

3 Testing Methods and Procedures

According to a preliminary study, the two mixtures were compacted to get a representative air void content of 14.3% ± 1% using both Marshall and Shear Gyratory Compactor (SGC).

The compaction with Marshall was performed employing around 1100 g of mixture placed in the mould and compacted with 50 blows on each side. The same amount of material was used for specimens compacted with the SGC. In this case, the compaction was carried out at fixed specimen height, 67.7 mm, which was reached with an average of 40 gyrations for mixtures. Compacted specimens were demoulded and divided into two subseries following two protocols: free surface drying (FSD) and partially sealed drying (PSD). FSD required specimens to be cured in the air so they can dry from all sides, whereas PSD required to seal the cylinder sides of the specimen by a plastic film to allow drying only from the specimen top surface.

Specimens were cured in a climatic chamber for 14 days at 40 ± 2 °C and 55 ± 5% of relative humidity and weighted every day to monitor the water loss over time. Both mixtures were characterized in terms of the indirect tensile stiffness modulus (ITSM) test at 2, 10 and 20 °C (EN 12697-26). ITSM was measured after 3 h conditioning at the testing temperature. At least 3 test repetitions for each series were performed.

4 Results

4.1 Water Loss

Figure 1 shows the average values of water loss as a function of curing days at 40 °C for both CBTM16RA1 and CBTM10RA2. The results shown are related only to Lab.1 and each curve is an average of 10 specimens. Water loss evolution appears to follow a bilinear trend changing rate significantly after 3-day curing period. As can

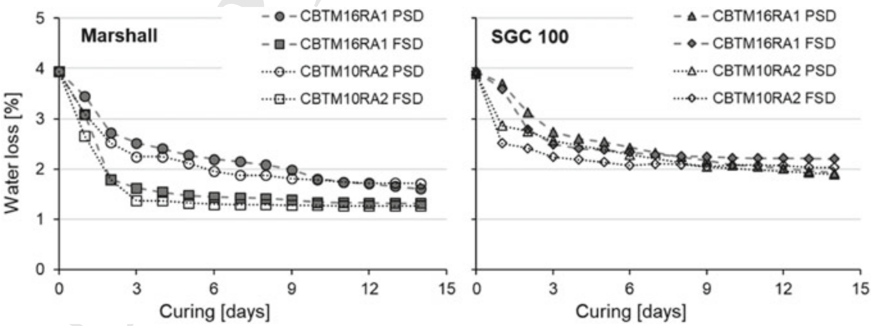

Fig. 1 Experimental data of water loss for the studied mixtures

Table 2 Parameters obtained by a bilinear regression on water loss results

Series	Regression factors 0-3d (phase 1)			Regression factors 3-14d (phase 2)			Phase1 versus phase2	PSD versus FSD
	s_1	k_1	R^2	s_2	k_2	R^2	s_2/s_1 (%)	Δ days
CBTM16RA1 Marshall FSD	−0.823	3.845	0.934	−0.025	1.629	0.858	3.094	–
CBTM10RA2 Marshall FSD	−0.856	3.724	0.952	−0.010	1.381	0.779	1.116	–
CBTM16RA1 Marshall PSD	−0.499	3.909	0.962	−0.085	2.731	0.977	16.988	16
CBTM10RA2 Marshall PSD	−0.563	3.798	0.951	−0.051	2.341	0.871	9.027	21
CBTM16RA1 SGC 100 FSD	−0.516	3.977	0.956	−0.024	2.494	0.854	4.695	–
CBTM10RA2 SGC 100 FSD	−0.507	3.525	0.739	−0.016	2.222	0.692	3.119	–
CBTM16RA1 SGC 100 PSD	−0.417	4.001	0.973	−0.074	2.885	0.967	17.720	9
CBTM10RA2 SGC 100 PSD	−0.406	3.635	0.786	−0.058	2.684	0.944	14.264	11

be noticed in Fig. 1, the general trend does not seem influenced by the compaction method and mix type, whereas the curing method influenced the water loss evolution, considerably. PSD method showed a lower water loss than FDS method. At the same time, Marshall compacted specimens showed higher water loss than SGC compacted specimens, probably caused by the different intergranular voids dispersion and size.

The experimental data were analyzed by a bilinear regression considering the intersection point at a 3-day curing time and Table 2 shows the regression factors (s = slope; k = intercept value and R^2 = regression coefficient) for all series. FSD implied a fast decrease of water content until 3 days (phase 1) then a rather flat evolution (phase 2). This evolution was less remarkable for PSD series. FSD showed a higher rate difference between phase 1 and phase 2 than PSD. By extending the regression equation, PSD required more than 10 additional days to reach the FSD final water content.

4.2 ITSM

Figure 2 depicts the ITSM values at 2, 10 and 20 °C for all series. It can be affirmed that PSD allows higher ITSM values than FSD. Moreover, CBTM10RA2 seems stiffer than CBTM16RA1 as well as SGC specimens seems to have higher stiffness

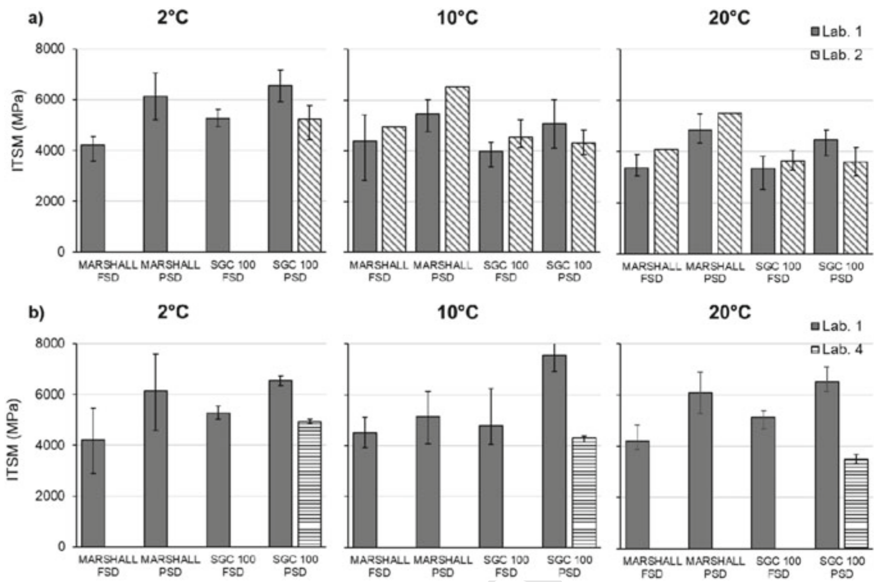

Fig. 2 ITSM results for: **a** CBTM16RA1, **b** CBTM10RA2

than Marshall specimens. Slow water evaporation and a higher water content allows more effective cement hydration to be achieved with direct effect on stiffness values. However, the results from different laboratories showed a notable scattering of values. Probably 3 repetitions for each series are not enough and the reproducibility of the testing method has to be improved.

5 Conclusions

This paper shows the results from the first phase of the RILEM 264-RAP TG1 inter-laboratory project focused on cold recycling. Particularly, the influence of two RA sources in two mixtures using foamed bitumen and cement as binders were investigated. The results showed that even if RA2 has fragmentation value poorer than RA1, the correction of the gradation curve through mineral filler following the respective maximum density gradation (Fuller distribution) allows CBTM10RA2 to behave similarly to CBTM16RA1. Water loss evolution followed a bilinear trend changing rate after a 3-day curing period, significantly. FSD induced a fast decrease of water content until 3 days (phase 1) then a rather flat evolution (phase 2) with the highest rate difference between phase 1 and phase 2. PSD prevented water evaporation and potentially required more than 10 additional days to reach the FSD final water content. The higher water content probably allows a more effective cement hydration in PSD entailing higher ITSM values than FSD. Moreover, SGC specimens seems to show higher stiffness values than Marshall specimens. However, the results from different laboratories showed a remarkable scattering of values and reproducibility of the testing method has to be improved.

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Chapter 2

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