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Testing of reclaimed asphalt model systems for the evaluation of the effectiveness of rejuvenators

D. Dalmazzo[1], L. Urbano[1], P.P. Riviera[1], E. Santagata[1]*
[1] Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy
*ezio.santagata@polito.it

Abstract. This paper presents the results of a preliminary study on the use of a novel approach for the evaluation of the effectiveness of rejuvenating agents used in asphalt mixtures containing reclaimed asphalt (RA). Such an approach is based on the mechanical testing of model systems constituted by a single-sized RA material, in its original state and after pretreatment with rejuvenators, compacted to a target volumetric condition. Model systems were prepared by making use of two rejuvenators and by also considering a reference combination of virgin binder and aggregates extracted from the RA. Tests were carried out for the evaluation of stiffness modulus and indirect tensile strength as a function of curing time. Experimental results showed that the proposed approach can capture the changes occurring in the aged RA binder as a consequence of the effects induced by rejuvenators. Quantification of the rejuvenating effects was carried out by analyzing recorded stiffness and strength variations, and by referring to a ductility toughness index, introduced to better describe stress-strain response after failure.

Keywords: reclaimed asphalt, rejuvenators, model systems, stiffness modulus, indirect tensile strength

1 Introduction

Reclaimed asphalt (RA) obtained from the milling of existing asphalt pavements is widely used as a recycled component of asphalt mixtures, thereby leading to a reduction of the depletion of nonrenewable natural resources [1,2]. Although agencies limit the reuse of RA to prevent a loss of fatigue endurance and thermal cracking resistance [3], significant amounts of RA can be employed if rejuvenating agents are used to restore the original properties of the aged binder contained in it. In current recycling techniques, the effectiveness of such additives is one of the crucial aspects to consider in order to correctly tailor the composition of the asphalt mixtures and to define a realistic maximum content of RA.

The effectiveness of rejuvenators is usually evaluated by directly analyzing the performance of mixtures containing RA [4-6], or by assessing the rheological properties of the binders extracted from the mixtures by means of solvents [7,8]. In such cases, the true effects of rejuvenating agents are partially superposed either with those of mix-dependent factors (including aggregate interlock) or with those that derive from the use of solvents (homogenization during recovery and presence of unknown residues)

[5,7,9]. Hence, both procedures do not capture the peculiarities of different rejuvenators, which may diffuse to a different extent through the aged binder films, consequently affecting to different degrees their rheological and bonding characteristics [10].

This paper illustrates the preliminary results obtained by making use of a novel approach for the assessment of the effectiveness of rejuvenators, which relies on the testing of model systems made of a single-sized RA material. It is believed that such an approach, to be further validated and improved by means of additional testing, truly highlights the effects of rejuvenators on RA binders and may be functional for the ranking and selection of different products to be employed in paving applications.

2 Materials and methods

Model systems considered in the investigation were made of a single-sized 5/8 RA characterized by a binder content equal to 4.4% by weight of aggregates (EN 12697-39) and a maximum density equal to 2.592 g/cm^3 (EN 12697-5). This RA fraction was derived from a stockpile obtained from the milling of different bituminous layers of a national motorway. Particle size distribution of RA and of its extracted aggregates (EN 933-1) are shown in Tab.1, where P is the percent passing and D is the sieve opening.

Table 1 Particle size distributions of RA and extracted aggregates.

	D (mm)	8	6.3	5.6	5	4	2	1	0.5	0.063
RA	P (%)	100	56	28	2	-	-	-	-	-
Aggregates	P (%)	100	76	57	39	28	20	15	12	5.5

Two rejuvenators, named A and B, were employed in the study. The first is a mixture of paraffinic hydrocarbon oils and the second is a non-toxic additive with a vegetable oil base. According to the manufacturers' data sheets, A and B were characterized by a specific gravity at 20 °C in the range of 0.86-0.90 g/cm^3 and of 0.98 g/cm^3, respectively; by a viscosity at 20 °C in the range of 40-54 mm/s^2 and of approximately 500 Pa s, respectively; and by a flash point temperature greater than 220 °C and of about 150 °C, respectively. Both products, liquid at ambient temperature and sprayed cold on hot RA (preheated at 150 °C), were dosed at 8% by weight of RA binder, corresponding to 0.34% by weight of RA. A virgin neat bitumen (of the 50/70 penetration grade) was also employed in the investigation for the manufacture of reference samples as discussed in the following.

Model systems were prepared with the single-sized RA material, either in its original state or pretreated with a rejuvenator, which was compacted to a target value of the voids in mineral aggregates (VMA), set at 30%; subsequent tests were carried out in the indirect tensile configuration for the assessment of stiffness and strength.

The rationale of such an approach relies on the fact that the use of a single-sized RA material compacted to a very high VMA value is believed to yield model systems with a structure in which the response under indirect tensile stresses is mainly dependent upon the bonding of the binder phase, ultimately affected by employed rejuvenators, with limited effects due to aggregate interlock. The absence of agglomerations and fines in the RA material also eliminates any additional phenomena which may occur during heating and compaction, thus affecting the results of volumetric and mechanical tests. It is essential to underline that model systems do not reproduce, by any means, bituminous mixtures constituted by 100% RA, which are conceived with a continuous grading and exhibit a response under loading similar to that of standard asphalt mixtures.

Model systems were prepared at 150 °C by mean of the gyratory shear compactor (EN 12697-31) with a fixed geometry (100 mm diameter, 65 mm height), suitable for mechanical tests. Target density corresponding to 30% VMA was derived from preliminary compaction tests carried out at the same temperature, with the consequent identification of the quantity of material needed for the preparation of final specimens.

The investigation considered three types of model systems. The so-called “black system” (BS), constituted by RA with no rejuvenator; the “rejuvenated systems” (RS-A and RS-B) prepared making use of RA pretreated with rejuvenator A or B; and the “white system” (WS), also referred to as reference system, obtained by combining the aggregates extracted from the RA with the previously mentioned virgin neat bitumen (with a dosage equal to that of the RA).

The structure common to all the considered model systems (with constant and controlled volumes of solid aggregate skeleton and binder) is schematically represented in Fig. 1a, while the corresponding phase distribution, variable from one type of model system to the other, is displayed in Fig. 1b.

Following their preparation, model systems were cured for 3 days at 20 °C and thereafter subjected to tests for the determination of indirect tensile stiffness modulus, ITSM (EN 12697-26C) and indirect tensile strength, ITS (EN 12697-23). In order to capture the time-dependent effect of rejuvenators, which originates from their progressive diffusion through the aged RA binder, further tests were carried out for the determination of ITSM after 7, 10, 15 and 52 days of curing, and for the determination of ITS after 52 days of curing. Experimental data recorded during ITS tests were processed in the usual fashion, for the determination of strength, and with the assessment of normalized tensile stresses (given by the actual calculated tensile stresses divided by the maximum value at failure) as a function of calculated compressive strains [11,12]. Such a representation was functional for the evaluation of the ductility toughness index (DTI), calculated as the integral of the normalized curve in the post-peak region (considered to extend up to a strain of 2E-2 mm/mm from the peak), believed to be a parameter that directly depends upon the behavior of the binder present in the model system.

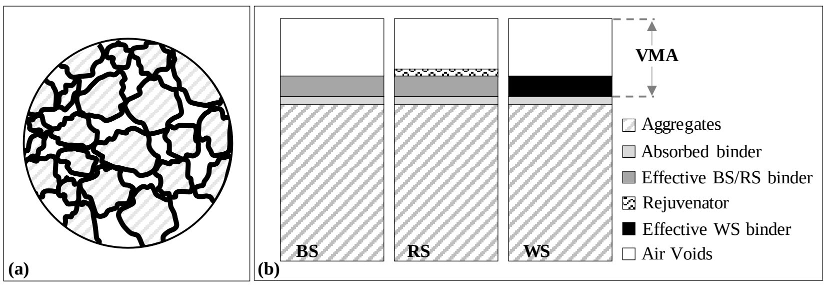

Figure 1 Structure of model systems (a) and corresponding phase distributions (b)

3 Results and discussion

Average results obtained from ITSM tests performed at different curing times on the model systems are shown in Fig. 2. As expected, the BS displayed the highest stiffness moduli as a result of the presence of the aged stiff RA binder. When the RA binder was replaced by the virgin neat bitumen (in the case of the WS), stiffness values decreased significantly, with an approximate reduction of 50%, regardless of curing time. It is interesting to observe that use of the two rejuvenators seemed to restore the stiffness properties of the RA binder with corresponding stiffness moduli of the RS-A and RS-B very close to those of the reference WS. It was also noticed that the two rejuvenated systems did not display a clear time-dependency of stiffness, with variations around the mean value which were similar to those exhibited by the other two systems (BS and WS). Such an outcome was explained by considering the very small strain levels imposed during ITSM tests, which may not be sufficient to highlight the progression of diffusion phenomena within the bitumen films covering the aggregate particles in RA.

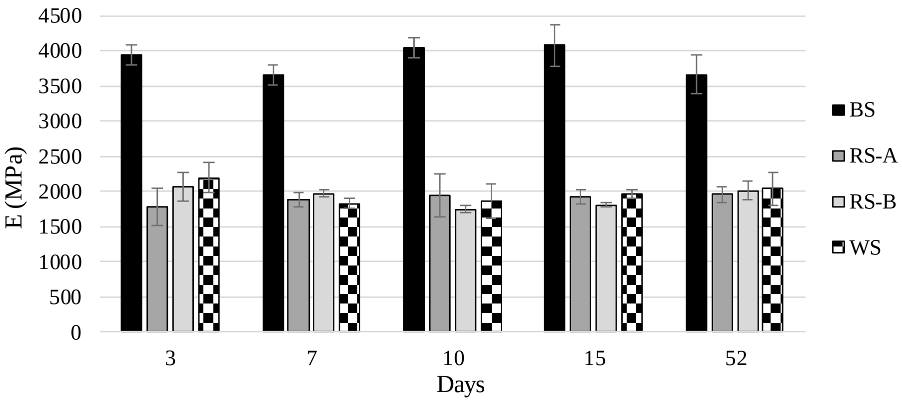

Figure 2 Stiffness moduli of model systems as a function of curing time

As shown in Fig. 3a, average indirect tensile strength values obtained from ITS tests were consistent with those of ITSM tests in terms of the relative ranking of the model systems. In fact, the BS exhibited the highest ITS, while the WS, RS-A and RS-B displayed significantly lower values, quite close to each other. However, it was also observed that the presence of rejuvenators clearly increased the compressive strain at failure (Fig. 3b). As in the case of ITSM results, the time-dependency of the rejuvenated systems could not be appreciated. Once again, this was interpreted by considering the limited strain values reached at failure.

Fig. 3c displays the DTI values of the considered model systems. As expected, the stiff and more brittle binder contained in the BS led to the lowest DTI values, while the highest values were recorded for the system containing virgin binder (WS). Values associated to the rejuvenated systems (RS-A and RS-B) were intermediate between those of the two other types of model systems.

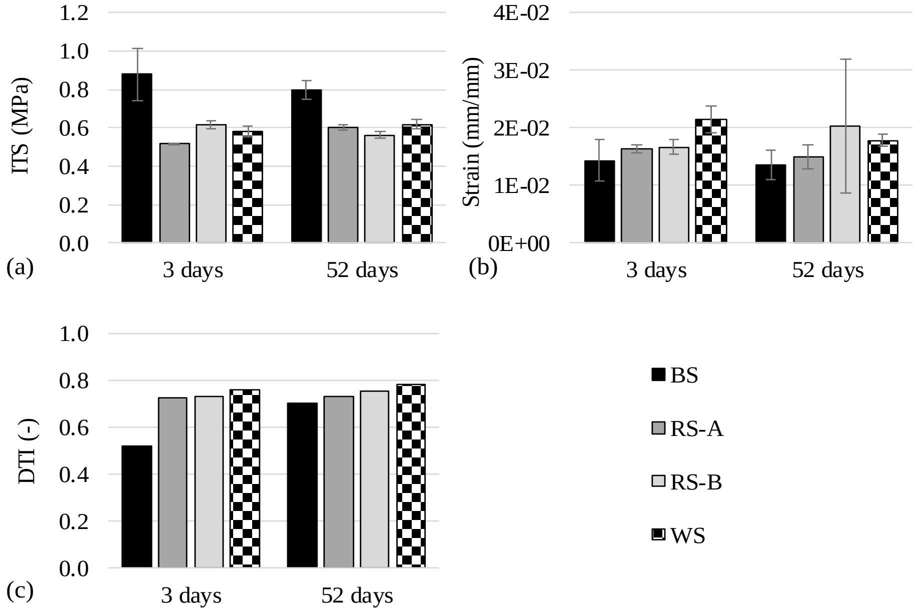

Figure 3 ITS (a), compressive strain at peak (b), and DTI values (c) of model systems as a function of curing time

Analysis of the DTI seems to provide interesting information on the true rejuvenating capability of the employed products, thereby allowing a comparison among them. In particular, obtained results suggest that both rejuvenators had an almost immediate diffusion through the aged binder films, leading to a very high values of DTI after 3 days of curing, which were only slightly improved in the long term (after 52 days).

The outcomes synthesized above, to be considered with caution as a result of the limited data set, can be explained by referring to the high strain level imposed in post-peak conditions and with the corresponding loss of residual interlocking. In such conditions, the response of the binder contained in a model system is bound to be mainly affected by its cohesion, which should also reflect ongoing rejuvenating phenomena.

4 Conclusions

Based on the results presented in this paper, it can be concluded that the proposed approach for the evaluation of the effectiveness of RA rejuvenating agents, which relies on the preparation and testing of model systems, is extremely promising. In particular, it presents the advantage of avoiding the use of solvents for the extraction of aged binders, thereby allowing the assessment of their response under loading with no alteration of their structure and composition. In such a context, it was shown that valuable information can be obtained by focusing on the post-failure response of the model systems when loaded in the indirect tensile mode.

Further studies are certainly needed in order to improve and validate the proposed approach. As a first step, tests should be carried out by exploring, in a systematic fashion, the effects associated to the use of RA of different age and origin, and to the adoption of variable percentages of employed rejuvenators.

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