Recycling of high percentages of reclaimed asphalt using a bio-rejuvenator – a case study

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ABSTRACT

Worldwide, hot recycling of reclaimed asphalt (RA) has actually raised interest because of the many advantages related to environmental issues. The benefit of reusing RA is associated not only to the reduction of aggregate requirements and the preservation of natural resources, but also to the reuse of aged bitumen from the RA, implying a reduction of the required amount of virgin bitumen.

However, the aged bitumen contained in the RA is typically oxidized and hardened, leading to a fragile behavior in the pavement layers, especially when high amounts of RA has to be recycled (more than 30% RA). For this reason, the use of specific additives is strongly recommended in order to restore the desired bitumen properties and consequently produce an asphalt concrete with the expected mechanical characteristics.

This paper presents the results from a trial section on the highway connecting Ancona to Perugia in the center of Italy. An asphalt mixture, for a base course, containing 50% of RA and a bio-based rejuvenator was characterized in the laboratory and then produced in a mix-plant and laid down in the field for the final validation of the hot recycling process. The results shows that, by using the rejuvenating additive, high percentages of RA can be reused in the production of new asphalt concretes, maintaining good mechanical characteristics of the final mixture and thus complying with the existing technical specifications.

Keywords: Additives, Mixing plant, Reclaimed asphalt pavement (RAP) Recycling, Rejuvenators

1. INTRODUCTION

The traditional road pavement maintenance procedure, consisting of milling of distressed asphalt layers before overlaying, determines the production of large amounts of reclaimed asphalt (RA) as a product of the milling operation [1]. However this material should not be demoted to a waste product [2,3], as the important residual properties of bitumen and mineral aggregates contained in the RA could be profitably exploited through hot and cold recycling techniques [4].

In particular, hot recycling of reclaimed asphalt (RA) has increasing interest worldwide, due to economic and environmental benefits. Indeed, the use of RA instead of virgin aggregates allows the reduction of aggregate supplying and thus the preservation of mineral resources [5,6]. The phenomena of RA aged binder mobilization and its blending with the new virgin bitumen during mix production are still under investigation worldwide. Nevertheless, a reduction of the required amount of new virgin bitumen for the production of asphalt concrete (AC) is potentially the most ambitious target.

To achieve this goal, the most critical issue is related to the ageing process, which causes a progressive change in its physicochemical properties [7]. As a consequence, RA aged binder often shows a stiff behavior and reduced coating properties. In addition, the maximum amount of RA to be reused in AC production depends not only on the ability to correct the physicochemical characteristics of the aged bitumen but also on the type of processing of the mix plant [8]. For these reasons, the amount of RA which is typically recycled in hot mixtures does not exceed 30%.

When using a higher amount of RA, the use of specific additives is strongly recommended to achieve adequate workability and final mechanical performance [9, 10, 11]. Additives should be non-hazardous and stable over a wide range of temperatures, from production to application. In addition, they must not experience any exudation or evaporation, in order to ensure a good performance over the designed lifetime of the asphalt pavement [12, 13].

The present research project focuses on the use of a specific bio-based rejuvenator to produce AC using a high amount of RA without scarifying the mix performance and complying with the Italian specifications. In particular, this paper presents the results from a trial section on a highway connecting Ancona to Perugia, in the center of Italy.

2. OBJECTIVE AND EXPERIMENTAL PROGRAMME

This paper deals with a validation programme focusing on the hot recycling of RA using a bio-rejuvenator (BR). This study reports the experiences taken from a trial section on the highway connecting Ancona to Perugia in the centre of Italy. Three ACs for base layers were compared: the reference mixture using 30% of RA and no additive (30RA), a mixture containing 50% of RA and 4% of BR (50RA4BR) and a mixture containing 50% of RA and 6% of BR (50RA6BR). The comparison involved verification of mixtures composition, volumetric and mechanical tests on cores and lab-produced specimens.

The experimental programme consists of two main steps:

- sampling of loose AC and testing in laboratory;
- extraction of cores and testing in laboratory.

About 50 kg of each AC were sampled behind the paver before compaction. For each AC, the granular composition (EN 12697-2) and bitumen content (EN 12697-1) were checked. Moreover, specimens were compacted in laboratory using a gyratory compactor (GC), following to Italian specifications [14]. Table 1 lists the specimens produced at different compaction energies.

Cores were extracted the day after the construction. Bulk density (EN 12697-6), Indirect Tensile Stiffness Modulus ITSM (EN 12697-26), Indirect Tensile Strength ITS (EN 12697-23), Indirect Tensile Coefficient ITC and Indirect Tensile Fatigue ITF resistance (EN 12697-24) were measured on cores coming from the trial section according to Table 2. ITC is a parameter which, according to Italian specifications, cannot be lower than a minimum specified value (65 MPa) and that can be calculated according to Eq. 1.

$$ITC = \frac{\pi \cdot D \cdot ITS}{2 \cdot \delta_{v,max}} \tag{1}$$

where D is the specimen diameter and $\delta_{v,max}$ is the vertical deformation corresponding to the load peak during ITS test.

Table 1: Tests on loose mixtures

Testing	Extraction to determine grading and bitumen content (EN 12697-1/2)	Compaction by means of GC (EN 12697-31)	
Compaction level	Loose mixture	100 gyrations	200 gyrations
Mixture	**Repetitions**	**Repetitions**	
30RA	1	5	3
50RA4BR	1	5	3
50RA6BR	1	5	3

Table 2: Tests on cores

Testing	Bulk density	ITSM	ITS	ITF
Mixture	**Repetitions**			
30RA	4	3	3	4
50RA4BR	4	3	3	4
50RA6BR	4	3	3	4

3. MATERIALS

3.1 Aggregate

Virgin and RA aggregate were sampled at the mix plant and characterized in terms of gradation (Figure 1). The materials were designated complying with EN 13043. For the fine aggregate and filler washed sieving method was used to achieve a more accurate indication. In addition, the bitumen content in the RA and its penetration value were determined according to EN 12697-1 and EN 1426, respectively. The RA bitumen content resulted 6.0% by virgin aggregate weight (5.7% by RA weight) and its penetration was 12 dmm.

Virgin and RA aggregate fractions were adequately proportioned in order to fit the grading envelope for a base course [14].

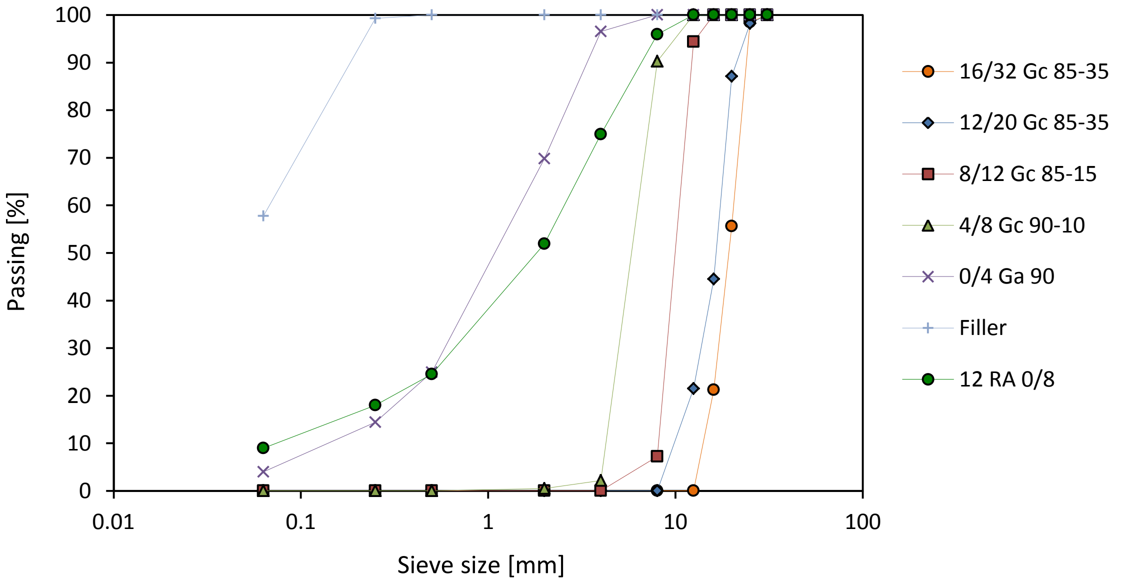


Figure 1: Grading of aggregates and RA (after bitumen extraction)

3.2 Bio-rejuvenator (BR)

The rejuvenating additive used in the present study is a miscible, long-lasting and sustainable bio-based material which, in a previous study [12], has proved to effectively mobilize oxidised RA binder and restore aged bitumen physical properties.

The two dosages of BR, i.e. 4% and 6% by aged binder weight, were an outcome of the mix design as well as on experience based on aged binder properties.

3.3 Virgin bitumen

The virgin binder used in the present study was a 50/70 bitumen (EN 12591).

It has to be highlighted that the virgin bitumen content was different between mixtures with 30% and 50% RA. As the bitumen included in the RA was 5.7%, for 30RA mix RA brought about 1.7% bitumen in the mix. When no additive was used, 0.85% bitumen by mix weight was considered as “active”. Thus, 3.1% of virgin bitumen was added in order to have, on one hand, about 4% of active bitumen and, on the other hand, to respect the maximum limit of total bitumen provided by Italian specification (4.8% by mix weight).

For 50RA4BR and 50RA6BR mixtures, RA brought about 2.9% bitumen by mix weight. Differently from 30RA mix, the presence of the bio-rejuvenator allows to consider all this bitumen as mobilized. Therefore, about 1.4% of virgin bitumen, i.e. less than a half compared to 30RA mixture, was added.

4. PRODUCTION DETAILS AND GENERAL INFORMATION ON THE TRIAL SECTION

The mixtures were produced in a batch plant (Figure 2), where RA is usually used in a unique fraction which has the designation 12 RA 0/8 according to EN 13108-8. In the present study, a feeding belt allowed the RA to join the virgin aggregate before the entrance of the drier. Typically, no more than 25% of RA is normally heated in a drum drier but in this case a special patented drum allowed the introduction up to 50% RA, avoiding its direct contact with the dryer flame.

Figure 2: Overview of the mix-plant, with the belts that convey the RA before and after the drier

A pump connected to a series of 3 nozzles (Figure 3) was set in order to spray a fixed amount of BR directly on the RA particles, before RA getting in contact with virgin aggregates. Care was taken to ensure a uniform transverse distribution of the additive over RA. The speed of the RA feeding belt was calibrated before the production of hot recycled AC to assure the target percentage of BR to be sprayed on the RA.

Figure 3: Spraying system installed over the RA belt

Figure 4a shows the heated aggregates (virgin + RA) for the 50RA4BR mix, collected at the exit of the drier. The effect of the additive can be already observed since the bitumen in the RA was mobilized and partially covered the virgin coarse aggregate. Even if a limited amount of virgin bitumen (1.4 % by mix weight) was added in the pugmill, the perfect covering of all aggregates was reached at the end of the production process (Figure 4b).

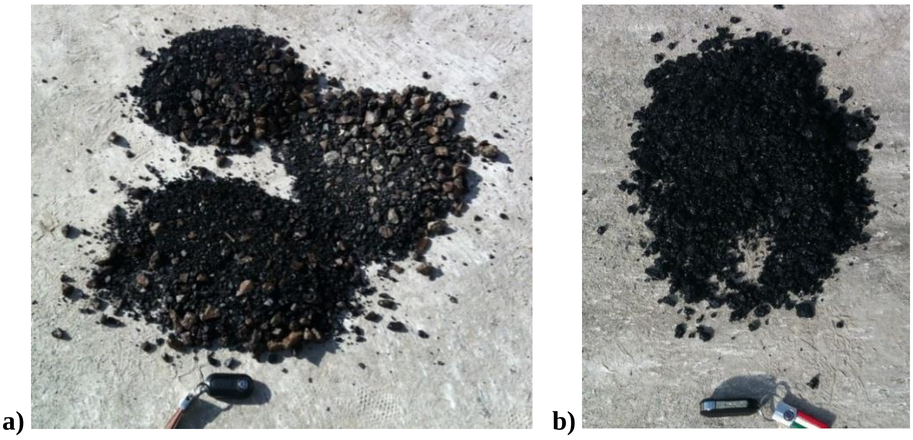


Figure 4: a) 50RA4BR mix at the exit of the drier (without virgin binder); b) Final mix (with virgin binder)

The trial section was built on 16th September 2014, with an air temperature of about 16 °C. The temperature of the mixtures (Table 3) was measured directly on the selected trucks after AC discharge at the mix plant, by using a laser thermometer. It can be observed that the mixture 50RA4BR resulted noticeably colder, probably due to inaccuracies at the plant when shifting from a mixture to another. The ACs were laid down by means of a paver and compacted through a 7 tons double-drum vibratory roller and 15 tons rubber wheeled static roller.

Table 3: Temperature of the mixtures on the truck

Mixture	Temperature [°C]
30RA	160
50RA4BR	138
50RA6BR	163

5. RESULT ANALYSIS

5.1 Composition of mixtures

Each bituminous mixture was tested to determine the total bitumen content (virgin and coming from RA) and the aggregate gradation. These tests were carried out on loose mixtures.

Table 4 reports the bitumen content of each mixture in comparison with the acceptable range established by Italian specifications. All mixtures respected the limits, though the bitumen content of the 30RA mixture was lower than expected. Indeed, it was supposed to have 3.1% of virgin bitumen which, summed with the bitumen from the RA, should have given a value about 4.8% by mixture weight. In addition, it has to be noted that the 50RA6BR mixture showed a lower bitumen content than 50RA4BR mixtures.

Table 4: Bitumen content in the produced mixtures for base course

Bitumen content [% by mixture]		Bitumen content [% by aggregates]		Target binder content [% by mixture]
Mixture	**Loose mixture**	**Mixture**	**Loose mixture**	
30RA	4.10	30RA	4.28	4.80
50RA4BR	4.30	50RA4BR	4.49	4.30
50RA6BR	4.03	50RA6BR	4.19	4.30
Bitumen content acceptable [% by aggregates]				4.0 ÷ 5.0

Table 5 and Figure 5 show the gradation of each mixture in comparison with Italian specifications [14]. All mixtures showed some discrepancies from the reference envelope. However, the curves were similar to the design gradation. From Table 5, it can be noticed that the mixture with 6% BR had a higher content of coarse fractions in comparison with the design gradation. Certainly, this influenced the compactability and the mechanical performance of mixture.

Table 5: Grading of the produced mixtures

Sieve size [mm]	Total passing [%]		
	30RA	**50RA4BR**	**50RA6BR**
31	100.0	100.0	100.0
20	93.9	98.7	86.3
16	87.1	88.8	74.8
12	74.9	79.4	61.0
10	62.2	64.5	48.9
8	55.9	56.5	42.1
4	39.0	35.3	27.8
2	27.3	25.1	19.7
1	17.5	18.3	14.8
0.5	11.6	14.0	11.4
0.25	8.2	10.9	9.4
0.125	6.1	8.4	7.9
0.063	4.8	6.0	6.7

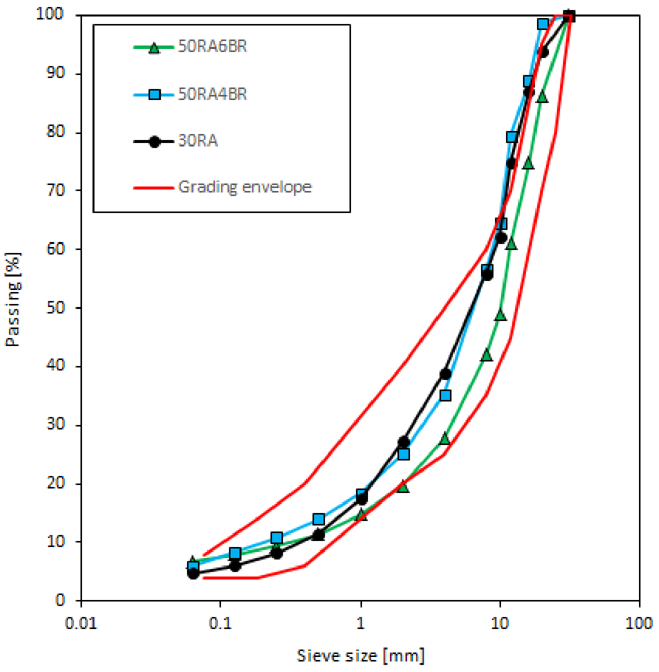


Figure 5: Grading curve of mixtures in comparison with the Italian specification

5.2 Compaction behaviour of lab-produced specimens

According to the experimental programme, the loose mixtures sampled in field during the construction of the trial section were compacted in laboratory by means of a GC at different compaction energies. Figure 6 shows the air voids contents of each mixture at 10, 100 and 180 gyrations and compare them with the limits imposed by Italian specification. It has to be noted that the reported air void contents refer to the specimen bulk density measured by dimensions.
Results showed that specimens produced using the reference 30RA mixture had higher air voids content than 50RA mixtures. 50RA4BR and 50RA6BR mixtures complied with Italian specifications in terms of V_m at 10 and 100 gyrations, evidencing the good effect of the additive in increasing mix workability.

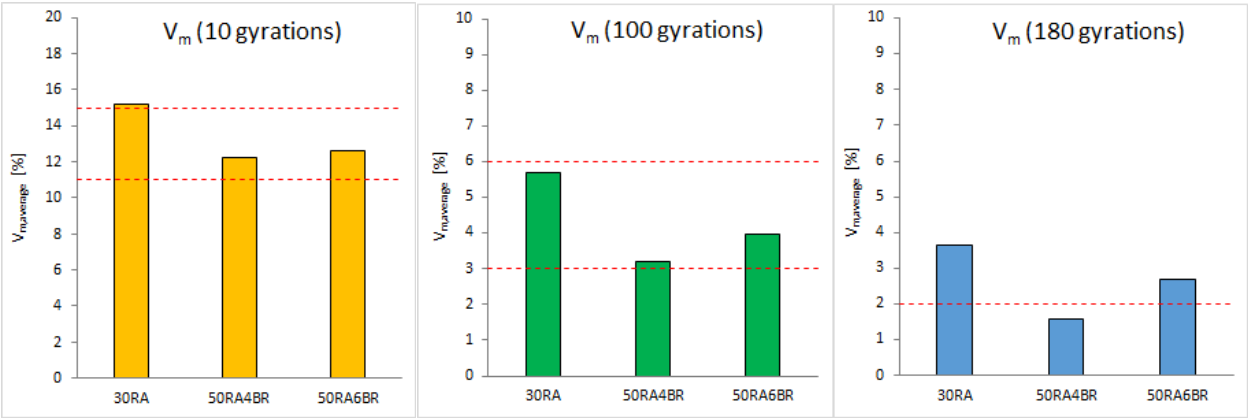


Figure 6. Air voids content at 10, 100 and 180 gyrations

5.3 Density and volumetric properties of the cores

Two cores for each mixture were adjusted, by cutting the bottom off and then separating vertically in 2 halves, in order to obtain 4 test specimens. The core density was measured using the EN 12697-6, Procedure C (sealed specimen). In Figure 7 the average density value for each mixture are presented.

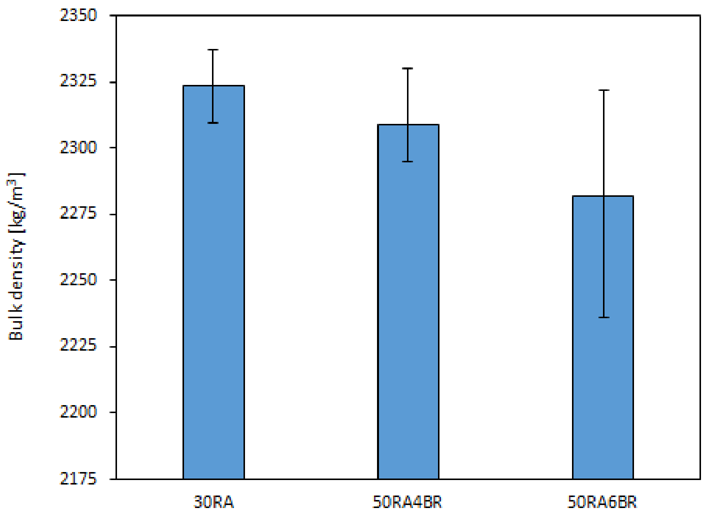


Figure 7. Average bulk density of the cores

Based on the composition of each mixture, the maximum density was calculated in order to evaluate the volumetric properties of cores (Figure 8).

The 50RA4BR mix approximately showed the same V_m than that of the reference mixture. However, it should be considered that this mixture was laid and compacted at a significantly lower temperature (more than 20 °C less) with respect to the others.

The 50RA6BR mix showed a high V_m, not complying with Italian specifications. Surely, this result was related to the incorrect gradation of the mixture, with an excess of coarse particles affecting compactability (Table 5).

These assumptions were confirmed by the VMA and VFB results.

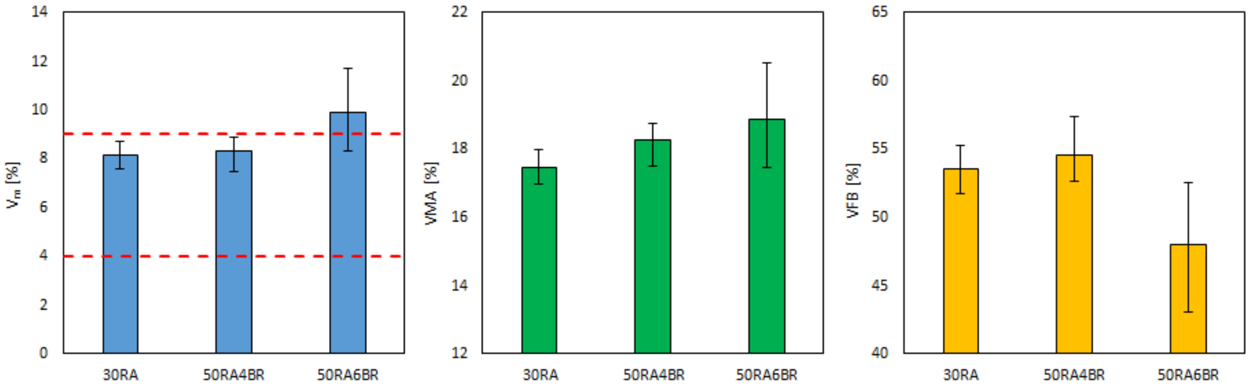


Figure 8: Volumetric properties of the cores

5.4 Mechanical characteristics of the cores

Three cores of each mixture were firstly tested to determine the stiffness modulus at 20 °C (Figure 9).

The results showed that the reference mixture with 30RA has lower stiffness than expected. Indeed, asphalt concretes for base layers typically have an ITSM between 5000 and 12000 MPa. In contrast, 50RA4BR and 50RA6BR mixtures showed adequate stiffness, high enough to assure the adequate bearing capacity of the base layer but not excessive, avoiding the risk of a fragile behaviour. In particular, 50RA6BR mixture has a lower ITSM than the 50RA4BR mixture (about 3%) due to the higher amount of additive and the higher air voids content.

Probably, this significant difference between 30RA and both 50RA mixes is due to the amount of "active" bitumen content. The aged bitumen in the 30RA mixture (not treated with BR) was not fully mobilized which led to a final mix with a lower "active" bitumen content when compared to the value determined from extraction. Further investigation will be done in the future on this matter.

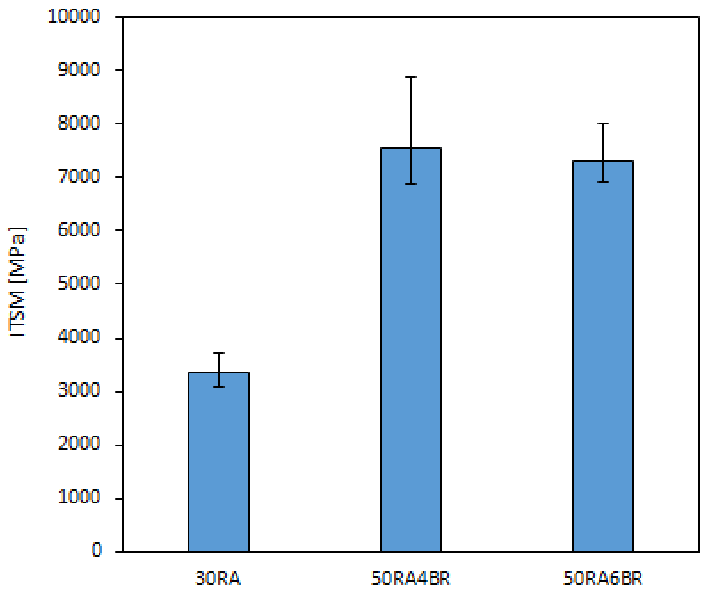


Figure 9. ITSM of the cores

The same cores used to measure ITSM were tested to determine ITS at 25°C (Figure 10).
The results confirmed the findings drawn from ITSM tests. In particular, the 30RA mixture showed low ITS and ITC values, not complying with the Italian specification. This is probably related to the low virgin binder content (Table 4), as it has to be taken into account that the bitumen coming from the RA was not rejuvenated by the additive and thus cannot be considered completely reactivated.
Differently, 50RA4BR and 50RA6BR mixtures proved to have a good strength and satisfied the ITS and ITC requirements. In detail, 50RA6BR mix showed lower ITS and ITC than 50RA4BR mix, related to the higher amount of additive and higher air voids content.

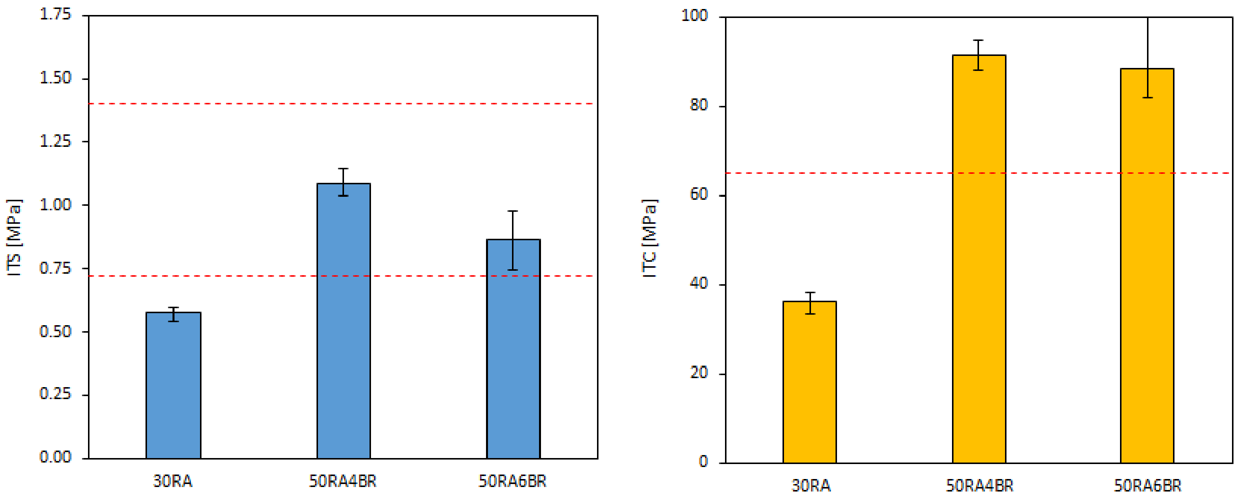


Figure 10. ITS and ITC of the cores

5.5 Indirect Tensile Fatigue Tests (ITFT) on cores

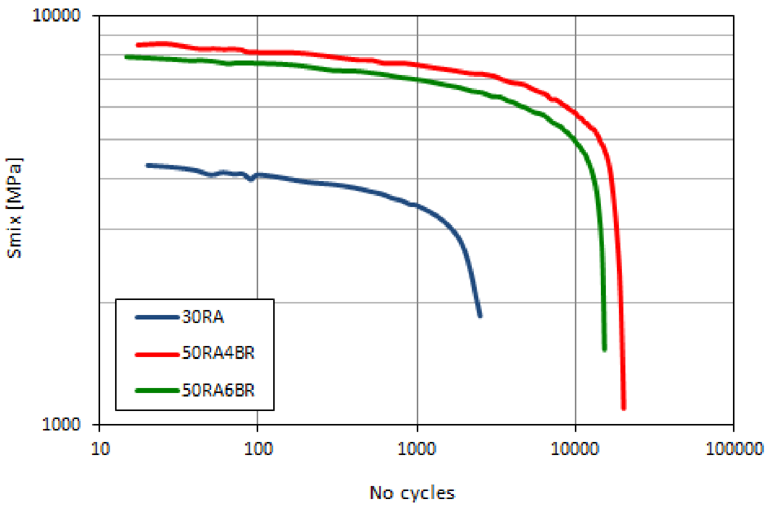
Table 6 shows the results of ITF tests carried out at 25 °C. The resistance of the mixtures to repeated haversine load cycles was determined in control stress configuration, with loading amplitude of 400 kPa. The fracture life $N_{f,tot}$ corresponds to the total number of load applications that causes a complete fracture of the specimen.
Table 6 reports the initial stiffness of the specimens and $N_{f,tot}$ values.
From Table 6, it can be noted that some data are missing in the table due to limited amount of available cores. Actually, $S_{mix,0}$ and $N_{f,tot}$ results for 30RA series are significantly lower than the values obtained for 50RA4BR and 50RA6BR mixtures.

Table 6: Results of ITF tests

Mixture	Initial Stiffness $S_{mix,0}$ [MPa]	$N_{f,tot}$
30RA	4317	2806
	3594	2224
	-	1814
50RA4BR	10161	25846
	9852	16486
	9535	15366
	7467	23246
50RA6BR	7529	25486
	9486	5226
	8900	20816

Figure 11 shows the evolution of the stiffness with the number of cycles during ITFT. From the graph, it can be observed that all the cores reached the complete fracture when the stiffness $S_{mix,f}$ was below about 2000 MPa. Even though results are available only for one specimen from the 30RA mixture, it can be observed that the mixtures with high RA and BR seem to have a longer fracture life than the currently used reference mix, for this stress level, being more resistant to repeated stress applications after reaching 50% of the initial stiffness. This is a very interesting outcome that needs to be further investigated in the future.

Figure 11: Evolution of S_{mix} with the number of load cycles with indication of the stiffness values at fracture



Mixture	$S_{mix,f}$ [MPa]	$S_{mix,f}$ / $S_{mix,0}$ [%]
30RA	1848	43
50RA4BR	1722	17
	2072	21
	1304	14
	1010	14
50RA6BR	1642	22
	1410	15
	1622	18

6. CONCLUSIONS

The present research project focuses on the use of a specific bio-based rejuvenator to produce AC using a high amount of RA without scarifying the mix performance and complying with the Italian specifications. In particular, this paper presents results from a trial section on a highway connecting Ancona to Perugia, in the center of Italy.

Three ACs for base layers were compared: the reference mixture using 30% of RA and no additive (30RA), a mixture containing 50% of RA and 4% of BR (50RA4BR) and a mixture containing 50% of RA and 6% of BR (50RA6BR). The comparison involved verification of mixtures composition, volumetric and mechanical tests on cores and lab-produced specimens.

Based on the experiences taken from the trial section, it was observed that setting a pump system to spread BR on the RA before mixing was easy, low-priced and precise enough to apply the target dosage of additive, calculated on the aged bitumen weight.

The 50RA mixtures treated with BR showed a good aggregate coating even if a low amount of virgin bitumen was used, (1.4 % by mix weight). All recycled mixtures with BR appeared easy to be laid down and compacted. Even though the 50RA mixtures with BR did not respected the design recipe due to in-plant production variability, the mixtures still presented appreciable results in terms of compactability. In particular, the 50RA4BR mixture reached density and air voids values similar to those of the 30RA mixture, even though the laying temperature was significantly lower.

Finally, all recycled mixtures with BR satisfied the Italian specification in terms of ITS and ITSM. In detail, the ITS and ITSM results for 50RA mixes with BR can be considered better than those of the reference mixtures with 30% RA and no additive. Moreover, experimental results indicated that the fracture life of the mixtures containing 50% RA and BR was longer than the 30RA mixture.

In conclusion, the full-scale validation project confirmed that a high amount of RA can be hot-recycled using low percentages of BR. Besides, it was observed that hot recycling with BR requires a low amount of new (virgin) bitumen, highlighting the capability of BR to mobilize the bitumen contained in the RA; finally, the ACs with high amount of RA treated with BR showed appropriate physical and mechanical properties.

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