Two case studies with high levels of RA enabled by a rejuvenating agent

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ABSTRACT

Sustainability is a recurring theme for the paving industry due to economic and environmental benefits. Global focus is increasing on the proper reuse of valuable recyclable materials, including Reclaimed Asphalt (RA). Reusing RA in new pavement provides economic advantages by reducing natural resource requirements. However, care must be taken to maintain the same level of performance for the end product.

For the asphalt industry, there are two barriers to incorporating more RA. One involves overcoming the poor quality of the aged binder in the RA. The other relates to specifications that do not allow high percentages of RA even where the final performance is proven.

In Italy, national specifications do not currently allow more than 25% RA due to anticipated poor performance. Nevertheless, the national industry is highly interested regarding RA in new asphalt mixtures. To enable incorporation of high amounts of RA while maintaining final asphalt mix performance, a bio-based rejuvenating agent was designed to restore the properties of aged RA binder.

This innovative product was validated in the laboratory by testing RA binder and RA-containing asphalt mixes. Afterwards, asphalt mixes with 40% and 50% RA were scaled up in two trials on national highways, using mixes from two different plants. Samples were collected from these trials, allowing evaluation of the performance of the produced mixes, and enabling comparison with earlier laboratory validations. Based on these results, this product enables the use of higher amounts of RA in new asphalt mixes while maintaining performance levels. Overcoming the barrier of poor performance would allow future changes in specification limits.

Key words: Reclaimed Asphalt, RA, RAP, recycling, asphalt, bio-rejuvenator, rejuvenation, Environmental, Reusing

Keywords: Additives, Asphalt, Environment, Reclaimed asphalt pavement (RAP) Recycling, Rejuvenators

1. INTRODUCTION

Our planet is small and overcrowded. Natural resources are limited, and generated energy is also limited to some extent. Fortunately, awareness of this problem is growing, and people and industries are attempting to reuse materials before discarding them so as to not compromise the existence of future generations. Reusing or recycling helps save on new raw materials, reduce CO_2 emissions linked with raw material production, and consequently decrease the contribution to global warming.

For the pavement industry, the focus is on the overall management of natural resources used in the production of aggregates and binder. Worldwide, the asphalt industry has been recycling between 10–30% reclaimed asphalt (RA) in the final hot asphalt mix since the 1970s, with significant cost savings; however, this is only a small portion of the potential benefit, both economic and environmental, that can be derived from the high reuse of RA.

Economic and environmental constraints are increasingly leading to the evaluation of products throughout their entire life cycle, meaning that a recycled product, in order to be economically and environmentally sustainable, should perform at least similarly to a product made of virgin materials.

Nowadays, the use of RA at concentrations up to 20% in new asphalt mixes is widely accepted. Proportions greater than 20% RA typically generate discussion, and experiences vary from country to country. In most countries, it is assumed that asphalt mixes with high RA content do not perform well, and for this reason specifications allow only a relatively low RA content in new asphalt mixes. The main limiting factor is the ageing of the binder. The ageing mechanism is complex, and is accompanied by negative effects ranging from oxidation to chemical modification [1, 2,3], causing the binder to become harder and more brittle [3,4], and thus more prone to cracking, a significant disadvantage [5,6].

To enable an increase in the use of RA up to 100%, a recent technology has been developed to restore the mechanical properties of the aged binder, mobilizing it in the final mix in order to allow adequate blending with the fresh virgin binder. In a recent technological development, a bio-based additive (A) has been specifically engineered and developed to solve this problem and to allow the reuse of RA into new asphalt mixes without compromising final performance.

In Italy, as a consequence of economic crisis, the paving industry is constantly searching for solutions that on one hand maintain the expected performance, but on the other hand allows an increase in profits, while simultaneously reducing the ecological footprint.

2. OBJECTIVE AND SCOPE

The objective of this paper is to present the results obtained from a full-scale validation project to assess the performance of asphalt mixes containing RA, both via pre-assessment in the lab, and also, and most importantly, by assessing the performance of the asphalt mixes produced on the plant and applied on the road. The focus is on the direct comparison between reference mixes, current daily practice with low RA content, and equivalent asphalt mixes with increased RA content. The aged bitumen contained in increased RA asphalt mixes was treated continuously with a bio-based additive (A) during the plant production process before it came into contact with the other asphalt mix components.

The project comprised two full-scale case studies:

A) Increase from 15% to 40% RA in a batch plant (Plant N.1) with double RA line feeding (binder mix). The mixes were produced at the Pesaresi S.p.A. mix plant (Rimini, Italy) and laid down on the A14 motorway, between Montemarciano and Senigallia (Trial N.1).

B) Increase from 30% RA to 50% RA in a batch plant (Plant N.2) with single RA line feeding (base mix). The mixes were produced at the PAVI S.r.l. mix plant (Foligno, Italy) and laid down on the SS77 highway, between Colfiorito and Foligno (Trial N.2).

The effectiveness of the additive (A) was evaluated throughout all phases, from early laboratory assessment to plant production, handling, application, and post-trial evaluation. A direct comparison was made versus the reference asphalt mixes and versus national specifications [7, 8].

3. MATERIALS AND TESTING PROCEDURES

3.1. Bio-based additive (A)

Bitumen stiffens and becomes brittle as it ages, due to chemical modifications within the binder. Major modifications include the loss of maltenes, which act to soften and lower the viscosity, mainly through evaporation, and the increase in asphaltenes and polar aromatics through oxidation. Historically, aged binder rejuvenators, such as petroleum flux oils, only address the former issue. Such an approach does not serve to break the stronger intermolecular associations built by the ever-increasing polarity of the asphaltenes. For this reason, the bio-based additive used in this project serves to redistribute and stabilize the compositional elements of the aged binder.

Table 1 summarizes features of the additive that, although being very effective in restoring aged binder properties, it is also designed specifically to be safe, stable, miscible, long-lasting, bio-renewable, and sustainable. In addition, the ability of additive (A) to mobilize aged RA binder has been demonstrated in previous studies [9].

Table 1 – Bio-based additive (A) features

Property	Problem addressed	Additive property
Health	Safe for humans and the environment	Additive is classified as non-hazardous by Hazardous communications regulations [10]
Flash point	Risk of explosion at mix plant	Additive has a flash point higher than 280°C thereby minimizing risk
Volatility	Additives should not evaporate at the mix plant or on the road over time	Additive has less weight loss (lower amounts of volatile organic compounds) at usage temperatures than virgin bitumen
Consistency	As RAP binders are highly variable, additive needs to be of consistent quality to ensure mix consistency	Additive is made from refined and purified feedstock and reacted further to consistent specifications
Miscibility	Product should remain fully miscible with bitumen at use concentrations, use temperature, and road lifetime	Spot studies on marble plates have shown the additive to be miscible and will not exude from pavement
Thermal stability	Product should not decompose at plant, under compaction conditions or after long exposure on the road	Additive does not decompose at mix plant temperatures and remains stable
Oxidative stability	Product should not lose effectiveness through oxidation	Additive was designed to maintain effectiveness under RTFOT and PAV conditions
Sustainability	Product is preferred to be derived from sustainable resources	Additive is approximately 90% from bio-renewable resources
Non-food	Product should not be derived from food or feed sources	Raw materials do not compete with the food chain industry

3.2. Reclaimed asphalt (RA)

Plant 1/Trial 1**:** The RA was sampled at the mix plant N.1, where it is crushed and screened into two sizes, 16 RA 0/12 and 12 RA 0/8. The stockpiles of both sizes of RA were sampled and characterized in terms of aggregate gradation and aged bitumen properties according to EN13108-8.

Plant 2/Trial 2**:** The RA was sampled at the mix plant N.2, where it was screened and crushed into 12 RA 0/8. The stockpile of RA was sampled and characterized in terms of aggregate gradation and aged bitumen properties according to EN13108-8.

Table 2 – Reclaimed asphalt aggregate gradations

Size (mm)	Plant 1		Plant 2
	16 RA 0/12	12 RA 0/8	12 RA 0/8
20	100	100	100
16	100	100	100
12,5	87	100	100
8	38	99	96
4	22	76	75
2	18	55	52
0,5	13	32	25
0,25	11	24	18
0,063	7,3	12,8	9,0
Bitumen content	3,2%	4,6%	5,7%
Penetration	19 × 0,1 mm	18 × 0,1 mm	12 × 0,1 mm
Softening point	74°C	76°C	77°C

3.3. Virgin binder

The virgin binder used in both trials was a 50/70 PEN grade, penetration of 53x0,1mm and softening point of 48°C, meeting EN12591.

3.4. Experimental program

The experimental program consisted of two main phases:

Phase 1 – Laboratory (Plant/trial 1):

- Laboratory design of asphalt mixes with increased RA content to meet current Italian national specifications.

Phase 2 – Full-scale road trials (Plant/trial 1 and Plant/trial 2):

- Assess the performance of multi-plant produced asphalt mixes when when applied on the road using normal and routine procedures according to standard Italian specifications.

The objective was to evaluate the effectiveness of the bio-based additive on asphalt mixtures with increased RA content in order for them to meet national specifications, "Azienda Nazionale Autonoma Strade" (ANAS, Autonomous National Road Agency), 2010 [7] and "Autostrade per Italia S.p.A." (Italian Motorway Society), 2008 [8]. The specifications values and limits are presented together with the obtained testing results in tables 3, 4 and 5 and also in the figures 1, 11 and 12..

In the laboratory, all the mixes were compacted by gyratory compaction (EN12697-31). The Italian mix design is based on the volumetric approach using gyratory compaction. The air voids are assessed for different compaction levels, being 100 gyrations the design compaction level. The ITS is determined at the design compaction level and the ITSR is determined at 50 gyrations. The optimum selected bitumen content is the bitumen content necessary to achieve 4% voids after 100 gyrations on the gyratory compactor.

After the road trial, cores were taken and tested in the laboratory. The volumetric properties were determined, and mechanical tests were performed to assess the characteristics of the asphalt mix versus existing National Italian specifications.

4. MIX DESIGN

A complete set of mix designs was made to assess the asphalt mixes in plant N.1, according to specifications. When increasing the RA content, mixes typically did not meet specifications; thus the final additive dosage was the quantity necessary to treat the aged bitumen so as to impart to the increased RA mixes a similar performance as the reference mix.

The grading curves of the mixes with increased RA content were adapted to be equivalent to the grading of the reference mixes in order to enable a valid comparison.

The mix design defined a dosage of 6% additive as necessary to treat the aged binder for the final mix to meet existing specifications, without any increase in the total virgin binder content [11].

Table 3 – Mix designs, Plant 1

Parameter	Standard	Specifications In Place	Virgin Mix	Mix with 15% RA	Mix with 40% RA (6% A*)	Mix with 50% RA (6% A*)
RA Binder Content (%)	EN12697-1	---	0	0,5	1,7	2,0
Virgin binder content (%)		---	4,8	4,2	3.,1	3,0
B - Total Binder Content (%)		4,1 to 5,5	4,8	4,7	4,8	5,0
ITSR – Water Sensitivity (%) (50 Gyrations)	EN12697-12	---	100	82	97	94
ITS – Indirect Tensile Strength (MPa) (100 Gyrations)	EN12697-23	0,75 to 1,35	1,32	1,21	1,32	1,35
ITC** – Indirect Tensile Coefficient (MPa) (100 Gyrations)	EN12697-23 (Italian Spec.)	≥70	92	76	94	98
ITSM – Indirect Tensile Stiffness Modulus (MPa) (100 Gyrations)	EN12697-26	---	6723	8160	6618	7129

***** *The additive dosage is per weight of aged binder*

*** ITC, Indirect Tensile Coefficient used in Italy as a mechanical parameter. ITC=(π.d.ITS)/(2.dv), being d: diameter, ITS: indirect tensile strength and dv: vertical displacement*

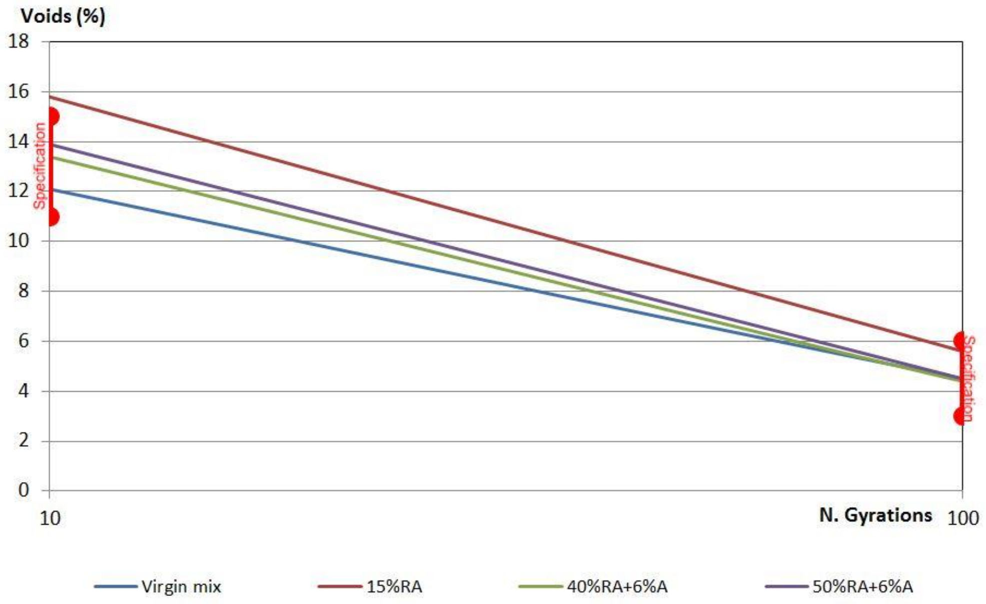

Figure 1 –Gyratory compactions of designed mixtures

The main objective of the project was to assess the performance of multi-plant-produced mixes when applied on the road using normal and routine procedures according to Italian specifications. For this reason, for the plant N.2, only a quick assessment versus asphalt mix specifications was made in order to define the additive dosage. The conclusion was that 4% additive was needed in order to achieve the desired specification performance without any increase in virgin binder content when compared with a virgin asphalt mixture.

Table 4 – Mix designs, Plant 2

Parameter	Specifications In Place	Virgin Mix	Mix with 30% RA	Mix with 50% RA (4% A*)
Binder Content from RAP (%)	---	0	1,7 0,9 (Active)	2,9
Virgin binder content (%)	---	4,8	3,6	1,4
B - Total Binder Content (%)	4,0 to 4,8	4,8	5,3 4,4 (Active)	4,3

** The additive dosage is always calculated per weight of aged binder*

The target total bitumen was 4,4%, but because the customer considers only 50% mobilization of RA binder, if performance additives are not used, the mix formula included an "excess" of 0,8% virgin binder. This extra bitumen is used as a preventive measure with the objective of compensating "inactive" bitumen in RA that acts like a "black rock", in order to prevent premature cracking in high RA asphalt mixtures. This preventive measure was not applied in the mixes with RA treated with the additive enabling some more bitumen savings, in the specific case of plant trial N.2.

5. PLANT PRODUCTION & APPLICATION

The plant 1 trial was held on October 1, 2014. This mixing plant is of the batch type and has a double RA feeding line. The first line allows the introduction of up to 25% RA into a recycling ring fitted in the heating drum, in the last 1/3 of the length after the flame. The second line allows the introduction of up to 15% of cold RA directly into the pug mill.
The RA-aged bitumen was treated directly, on the transportation belt, with the additive being added before processing through the plant. The adding system was previously calibrated in order to assure that the correct additive dosage was applied.

Figure 2 – Plant 1, batch plant with double line RA feeding

Figure 3 – Plant 1, RA being treated with additive

The Plant 2 trial was held on September 16, 2014. This mixing plant is batch type and has a RA feeding line directly into the beginning of the heating drum. The plant can produce asphalt mixes with RA content up to 50%. The heating drum has a special patented design that protects virgin aggregates and RA from being in direct contact with the flame, which, besides being dangerous, would also result in accelerated ageing of the RA binder.
The RA-aged bitumen was treated directly on the transportation belt with the additive, before being processed through the plant. The adding system was calibrated previously in order to ensure that the correct additive dosage was applied.

Figure 4 – Plant 2, batch plant with RA feeding

Figure 5 – Plant 2, RA being treated with additive

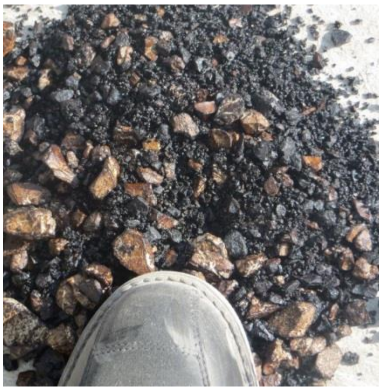

Figure 6 – Plant 2, 50% RA+50% virgin aggregates (without virgin binder) collected after the drying drum before going into the elevator

The produced mixes for both trials were transported and applied on the road on the dates mentioned above. The feedback was extremely positive; no differences were stated in handling and applying asphalt mixes with increased RA content.
For trial N.1, the job site was a motorway located about 1 hour distant from the plant. The asphalt mixes were used in the binder layer. The layer has a nominal thickness of 6 cm. The mixes were put in place around 90 minutes after plant production. The average temperature recorded in the paver hopper was about 160°C.
For trial N.2, the job site was a highway located at about 20 min distance from the plant. The asphalt mixes were used in the base layer. The layer has a nominal thickness of 10 cm. The asphalt mixes were put in place around 30 minutes after plant production. The average temperature recorded in the paver hopper was about 145°C.

Figure 7 – Trial 1, laying compaction, and density control

Figure 8 – Trial 2. compaction

6. IN-FIELD VALIDATION

6.1. Core analysis

In order to assess the performance of the designed asphalt mixes, multiple cores were taken from the pavements in trial N.1 and trial N.2. This procedure, based on quality control methods, allows the suppression of artefacts and well-controlled specific conditions that limit the final comparison and conclusions. More specifically, if the binder and additive blending in the laboratory mimics the occurring blending on the asphalt plant or if the type of laboratory compaction influences the final mix performance assessment.
Some cores were disaggregated to perform tests to assess the bitumen content and aggregate grading curve.
The remaining cores were tested for void content and then used for testing according to Italian national specifications.

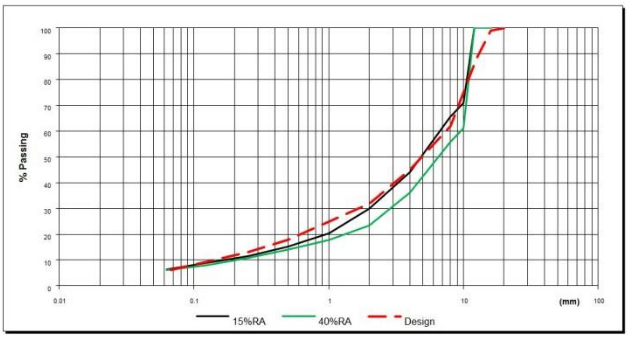

Figure 9 – Trial 1 grading curves

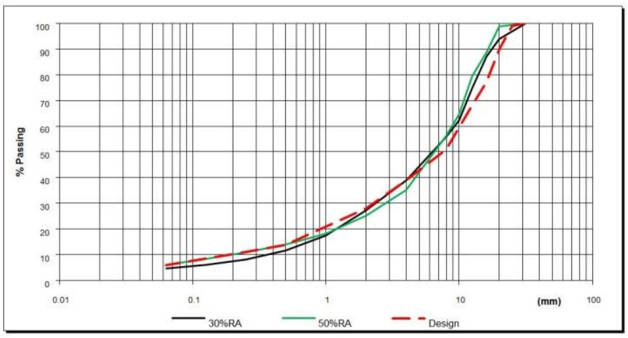

Figure 10 – Trial 2 grading curves

There were some production variations that are normal in these types of trials due to the fact that asphalt plants are not normally used to produce asphalt mixes with such high RA content. These variations in grading and bitumen content were easily adjusted in the next step of normal daily production. The reference mix of Trial N.1 had a bitumen content that was higher than defined on the mix design, and the increased RA mix had bitumen content lower than defined, still these variations were within the limits of Italian specifications. Additionally, the increased RA mix had a grading with less intermediate fines, when compared with the design, meaning that it is more difficult to achieve a low void content

due to the interlocking property of the aggregate particles and the lower binder content. Even with these variations, all the applied asphalt mixes met *in situ* compaction/void content specifications.
The remaining cores were tested for void content and then used for testing according to Italian national specifications.

Table 5 – Core results from the road trials

Parameter	Standard	Road Trial 1		Road Trial 2	
		15% RA	40% RA (6% additive)	30% RA	50% RA (4% additive)
Average batch temperature (°C)	---	160	170	---	---
Average initial compaction temperature (°C)	---	145	140	160	140
Binder Content (%)	EN12697-1	5,2	4,3	4,1	4,4
Voids content (%)	EN12697-8	4,4	7,1	8,1	8,3
ITS – Indirect Tensile Strength (MPa)	EN12697-23	1,14	1,23	0,58	1,09
ITC – Indirect Tensile Coefficient (MPa)	EN12697-23 (Italian Spec.)	72	90	36	92
ITSM – Indirect Tensile Stiffness Modulus (MPa)	EN12697-26	5031	5853	3341	7538

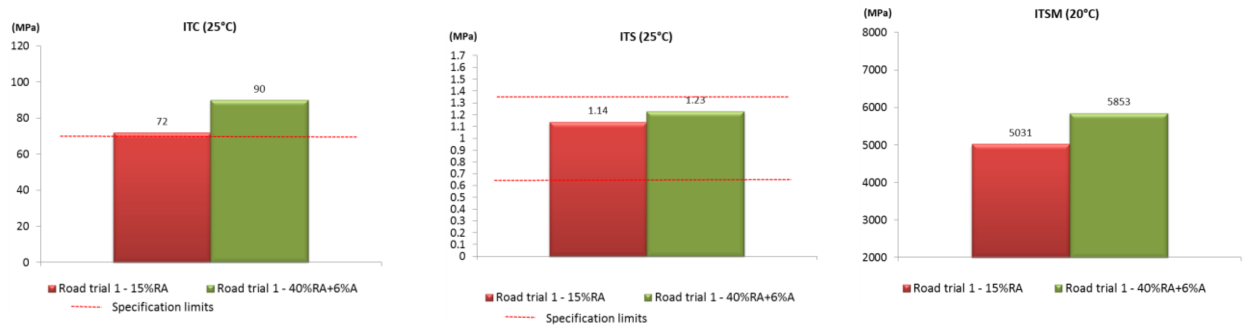

Figure 11 – Trial N.1, core testing results, ITS, ITC, ITSM

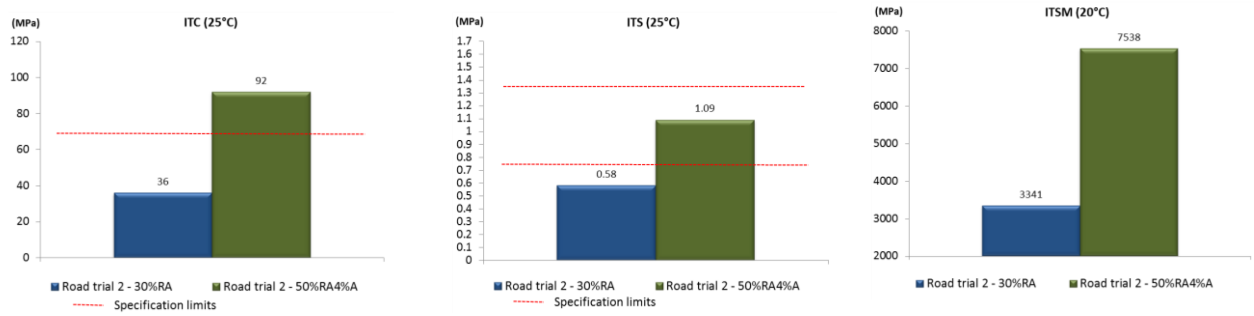

Figure 12 – Trial N.2, core testing results, ITS, ITC, ITSM

The extracted cores of all bituminous mixes with high RA content treated with additive (A) met the specifications in place, fulfilling phase 2 objective of the experimental program. The reference 30%RA asphalt mix from Trial 2 failed, by far, to meet the existing specifications highlighting the need for the RA aged binder treatment. Even though there were production/application variations, due to short production, between all mixtures (% bitumen, grading, compaction) there were still considered normal, especially when moving to plant scale newly designed mixes with increased RA content, and still within specification limits. The quality control done clearly indicates that the additive allows the increase of RA content still meeting the specifications in place.

6.2. Indirect Tensile fatigue Test (ITT) on cores from Trial 1

After performing the mandatory tests in order to check if the produced mixes met specification there were still 4 cores left, from trial 1, that were used to perform ITT (EN12697-24, Annex E). This test is normally performed at several stress levels but due to limitations on the number of specimens available only one stress level was applied. The tested cores had a diameter of 94mm and height of about 60mm. The tests were performed at 25°C targeting horizontal tensile stress of 350kPa. A haversine load with 0,1s loading time and 0,4s rest time was applied according to test standard.

Table 6 – ITT Core results from Trial 1

Mix Ref.	Core Ref.	% Bit.	Voids (%)	Stress (kPa)	Initial stiffness (MPa)	Number of cycles to fracture	Permanent Horizontal deformation at Fracture (mm)	Permanent Vertical deformation at Fracture (mm)	Stiffness before fracture (MPa)
15% RA	1	5,2	4,5	350	4470	13876	3,63	5,76	1333
	2		5,4		4180	18186	3,63	5,65	1389
	3		5,4		4043	19366	3,63	5,85	1319
	4		5,8		4114	19616	3,61	5,85	1328
40%RA + 6%A	5	4,3	5,4		5263	40566	3,59	5,74	1010
	6		6,0		6450	42806	3,65	6,00	1117
	7		6,1		5153	36576	3,59	5,87	1695
	8		7,1		5051	38066	3,64	5,54	1154

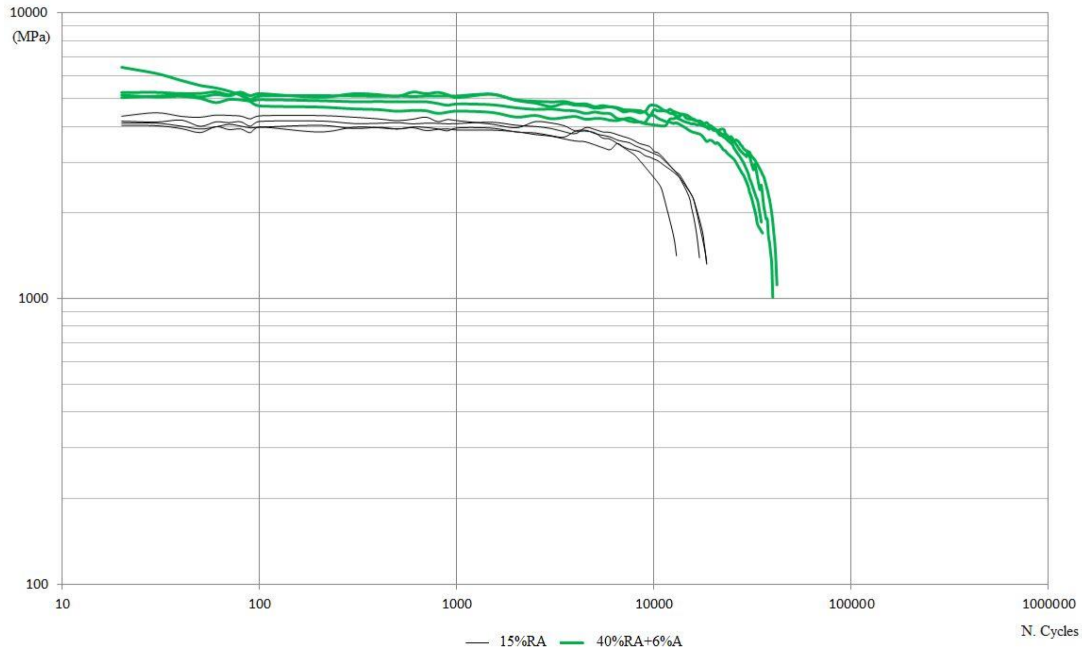

Figure 13 – Trial N.1 ITT core testing results, stiffness vs n. cycles

Typically, an increase in the content of hot recycled RA induces increased stiffness but also a more fragile behavior in the final asphalt mixture. In this case the material cannot withstand high deformations and usually premature failure occurs. However, in this specific case and even though limited ITT data is available, it seems that RA pre-treatment with additive (A) seems to correct this behavior. All the measured vertical and horizontal deformations measured just before fracture indicates similarity with the reference mix, even though the 25% increase in the RA content and also the reduced effective binder content of the 40%RA mixture.

7. Future work

Even though is not specified in Italy, and in order to link binder properties with final asphalt mixture performance, the tested cores will be used for binder extraction and testing. This work will be a subject of a future publication.

8. CONCLUSIONS

The objective of the study was to compare similar mixes, to ascertain whether mixes with increased RA content could at least maintain the same technical performance, while allowing better profitability, in order to make this technology usable in everyday asphalt mix production and paving. This solution allowed significant savings in virgin binder in Plant N.2 due to the mobilization effect (Figure 6) induced by the additive (A), which allows us to disregard the calculation of only 50% of the binder contained on the RA as active and accountable for the final mix.
These two case studies described were based on the routine and normal practice of asphalt mix production, and it was demonstrated that the use of additive (A) to treat aged binder contained in reclaimed asphalt allows it to be used in high RA content asphalt mixes, in compliance with Italian specifications, both volumetric and mechanic.
It is important to highlight that the work done with the increased RA asphalt mixes was at the maximum limit of RA introduction on both plants, and the results were very positive. This potentially opens the door to the use of higher RA contents in the plant, increasing its capacity limit.
In conclusion, full-scale validation confirmed the statements made in the lab validation phase:

1. High amounts of RA can be hot-recycled using additive (A), even in low additive dosages;
2. Hot recycling with additive (A) requires a low amount of new (virgin) bitumen, highlighting the ability of additive (A) to mobilize the bitumen contained in the RA;
3. The hot-recycling procedure with additive (A) (asphalt mix production and laying) is practical and effective;
4. Asphalt mixes with a high amount of RA treated with additive (A) showed appropriate physical properties and mechanical characteristics.

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