Sustainability & Environment

Types of asphalt rejuvenators and the different scenarios for the use of RAP in HMA production

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Abstract

The use of Reclaimed Asphalt Pavement (RAP) in HMA is rising worldwide. An effective rejuvenator additive has a major role in successful recycling. Several proposals for asphalt rejuvenators are available in the market, depending on their chemistry (petroleum-base, vegetal-base, amine-base, others…) that offer, combined or alone, different characteristics (bitumen thinner, asphalt workability enhancer, adhesion promoter…). This paper presents the use of multiple asphalt rejuvenators in different scenarios (high RAP content in parallel or double drum, low/medium RAP content in standard asphalt plant process, soft virgin bitumen blends…). The study focuses on establishing best practices to choose the most convenient rejuvenator additive by increasing the use of RAP in asphalt pavement mixtures while maintaining high-quality pavement infrastructures and resulting in cost, cycle life and energy savings. The use of selective vegetal-base “green” rejuvenators that regenerate the chemical and physical characteristics of the bitumen, but also improve the properties of asphalt mixes, have turned out to be the best technical and environmental option.

This paper was first published in 2020 in version 1.0 of the proceedings of the 7th E&E Congress. This second edition (version 1.1.) of the proceedings is published in June 2021. The content of this paper has not changed, but the author(s) may have provided additional information in the form of an annex.

1. INTRODUCTION

While several factors influence the use of RAP in asphalt pavement, the two primary factors are economic savings and environmental benefits [1]. RAP is an useful alternative to virgin materials because it reduces the use of virgin aggregate and the amount of virgin bitumen required in the production of Hot Mix Asphalt (HMA). The use of RAP also conserves energy, lower transportation costs required to obtain quality virgin aggregate, and preserves resources. Additionally, using RAP decreases the amount of construction debris placed into landfills and does not deplete non-renewable natural resources such as virgin aggregates and bitumen. Ultimately, recycling asphalt creates a cycle that optimizes the use of natural resources and sustains the asphalt pavement industry.

Asphalt is 100% re-usable / recyclable and should be re-used / recycled [2]. RAP can be re-used to produce new asphalt mixes (hot or warm, in the asphalt plant or in-situ) and it can be also recycled by foamed bitumen and cold methods using bitumen emulsions.

The asphalt ageing process, which affects physical and chemical characteristics of RAP bitumen, entailing a general hardening of the final bituminous blend. As well known, bitumen undergoes two different ageing phases: short- and long-term ageing [3]. The former represents the ageing during plant mix process, transportation and paving, that is related to oxidation and lighter components evaporation. Whereas the later occurs during pavement service life and is mainly linked to oxidation and physical hardening. Presence of water, local gap temperatures, thickness of the binder film and, mostly, mix porosity represent the main factors that influence the degree of long-term ageing.

Generally, ageing process causes a progressive change in bitumen rheological and chemical properties, leading to a fraction rebalance by aromatic content reduction and a consequent increase in the amount of resins (which in turn generates more asphaltenes), whereas saturates remain essentially unchanged due to their poor reactivity. Since asphaltenes play a major role in determining bitumen viscosity, it is evident that oxidation causes a stiff behaviour (bitumen hardening) in addition to poor adhesion and reduction of coating properties.

Most of the studies carried out to evaluate rejuvenator additives are based in physical characteristics. Through rheological tests or penetration and softening point tests, it is pretending to regenerate the initial bitumen physical performance [3, 4]. Nevertheless, there are not too many studies related to chemistry performance as adhesiveness.

This paper is focused to describe several kind of rejuvenator additives and their use in the different HMA production process, in order to disclose the recommended dosage and the main additive advantages (physically and chemically) depending on the rejuvenator type. Therefore, this paper is not providing a complete study based in a punctual experience. In addition, the present study focuses on analyzing the impact that different rejuvenators have on asphalt mixtures due to their chemical properties, not delving into the physical changes produced in bitumen (which has already been extensively studied in other papers).

2. TYPES OF REJUVENATORS

According to EAPA recommendations [5] the rejuvenators should only be incorporated into the asphalt when it may be shown that:

- There are no environmental impacts and/or liability problems during storage, processing, use and application of the rejuvenator, now or in the future.
- There are no disadvantages with respect to health and safety of workers and the general public, during processing, use and application, of the produced asphalt, now or in the future.
- The future reuse and recyclability of the asphalt is not endangered.
- That the health and environment classification of the asphalt is not affected by the addition of the rejuvenator (e.g. if derived from waste).
- There is no negative impact on the technical product performance of asphalt now or in the future.

In addition, taking a step further for the rejuvenators, it is also desirable that:

- Ensure workers safety, using non-hazardous products as vegetal base (green additives). Asking for health and environment classification of the asphalt when the additive is included, but also asking for health and environment classification of the rejuvenator.
- Favours asphalt workability that will guarantee a higher asphalt density and therefore better asphalt mechanical behaviour. Even reduce the asphalt production and laying temperature achieving extra environment advantages.
- Improves binder-aggregate chemical affinity. Many times the use of high RAP content penalize the Water sensitivity test values.

- Enlarge the virgin/oxidized bitumen interaction.

2.1. Chemical source

Depending on the chemistry, there are different sources of rejuvenators as petroleum-base, vegetal-base, amine-base... The chemical source has a big impact in the rejuvenator safe handling, but also in the softening capability, location in the bitumen matrix, compatibility interaction, heat-stability and odours.

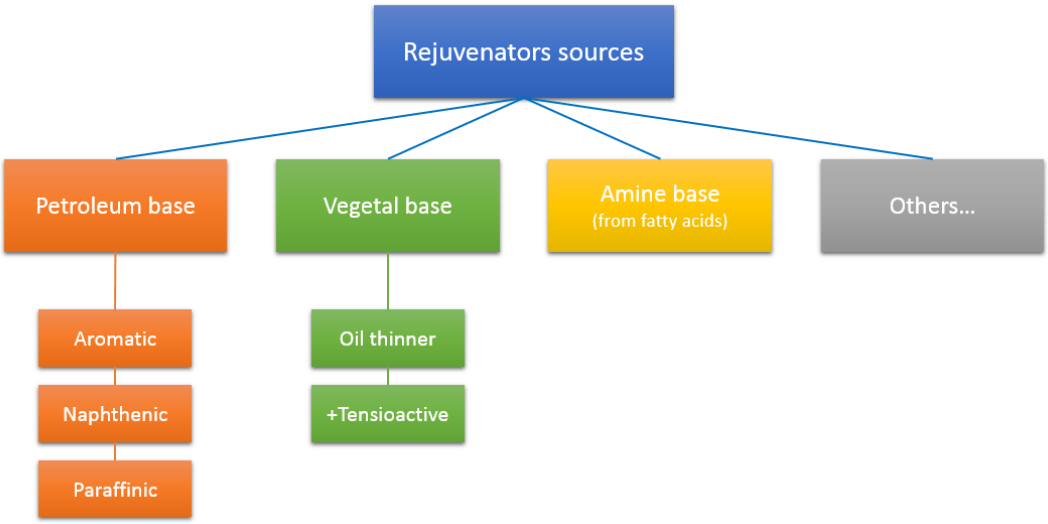

Figure 1: Rejuvenators sources according to their chemistry

The additives used as rejuvenators in this paper are described in table 1:

Table 1. Rejuvenator chemical description

Additives	Chemical description
RAP-5V	Vegetal base with tensioactive properties
RAP-EF	Vegetal base
RAP-2E	Petroleum base, paraffinic
RAP-17E	Petroleum base, aromatic

Amine base products have not been included in this study due their limited effective, imply risk for health and the environment and provide poor heat-stability.

In addition, the chemical source has a relevant impact in the additive required dosage. Some rejuvenators can demand a significant higher dosage than others. The optimal dosage of these additives in the bitumen and the corresponding asphalt mixtures must be checked by analysing the physical properties but chemical properties as well.

2.2. Physical and rheological modification

One of the aspects, deeply analysed when a rejuvenator is used, is the physical impact in the aged bitumen. It could be evaluated by rheological tests or through physical tests (penetration, viscosity, softening point, Fraass…).

Diverse rejuvenator additives provide different softening effects in the bitumen. The penetration test is commonly used as a quick way to focus a dosage range.

Figure 2 represent the softening effect (penetration values) for different chemical sources of rejuvenators.

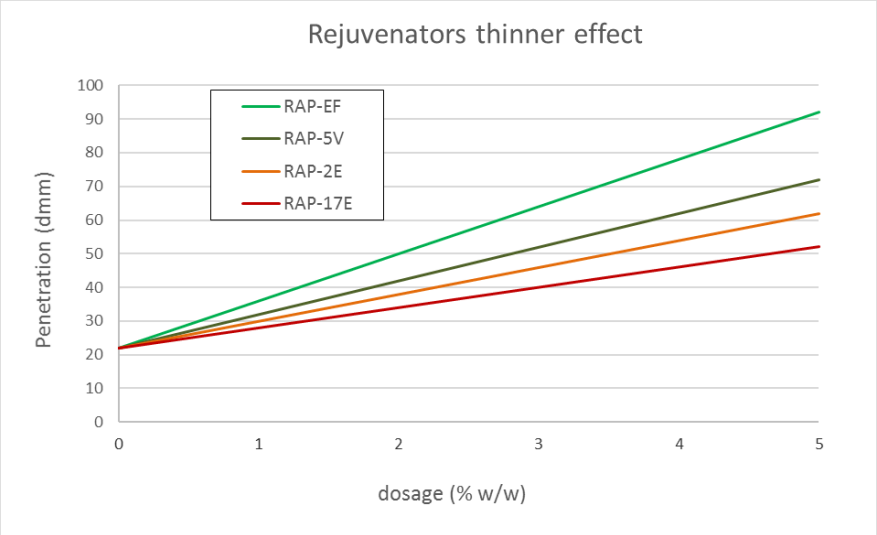

Figure 2: Rejuvenators softening effect

It is also possible to carry out the same study and analyse the softening point (SP) effect and calculate the penetration index (PI). Table 2 shows rejuvenators impact in SP and PI for a stablished dosage.

Table 2. SP and PI impact at 4% by weight of aged bitumen

Additive	Penetration (dmm)	SP (ºC)	PI
Aged bitumen	22	63,0	-0,15
RAP-5V	62	52,8	+0,03
RAP-EF	78	50,6	+0,11
RAP-2E	54	52,8	-0,32
RAP-17E	46	55,0	-0,20

It is a very common requirement for rejuvenators to recover closer bitumen physical parameters, shown before the ageing process. For that reason, it is usually assumed that the chosen rejuvenator modifies the penetration and SP by achieving the closest values to the original bitumen. According to this criteria, when a rejuvenator match the penetration and leads to a higher SP, even further than the target value, the rejuvenator is usually rejected, what might not be an appropriate criterion.

Example in table 3:

Table 3. Rejuvenator selection (by physical performance)

Additive	Penetration (dmm)	SP (ºC)	PI
Original bitumen (target)	55	50,2	-0,91
Aged bitumen	22	63,0	-0,15
+ 3,2 % RAP-5V	54	54,4	+0,05
+ 4,0 % RAP-2E	54	52,8	-0,32

In table 3 both rejuvenators have achieved the same target penetration value, at different dosages, and the softening point value of RAP-2E is lower than RAP-5V but closer to the original bitumen value. According to the usual criteria described above, RAP-2E would be selected instead of RAP-5V, but analyzing the values individually, seem always preferable a bitumen with a higher softening point (more rutting resistance) and higher PI (lower thermal susceptibility), at the same penetration value. In conclusion, RAP-5V looks like the most convenient additive in this case.

Furthermore, can be emphasized that most of rejuvenators have a positive effect on viscosity and Fraass point values (decreasing both parameters).

2.3. Chemical modification

Another important aspect is the chemical effect of the rejuvenator in the bitumen, that will affect the asphalt mixture physical performance.

Some rejuvenator additives, due to their tensioactive properties, rather than modify bitumen physical characteristics also modify its chemical behaviour. It means that these additives have ability to improve some asphalt mix properties as workability and adhesion.

An aged bitumen, due to the rebalanced asphaltenes fraction, would show lack of adhesion to the aggregates. This real factor would penalize Water Sensitivity test (ITSR) and asphalt mix density (voids content).

Table 4 shows results in the asphalt mix performance by adding 30% of reclaimed asphalt at rejuvenator dosage between 0,7% and 1,5% by weight of virgin bitumen:

Table 4. Asphalt mix performance – Additives effect at different dosages

Additive	Voids content (%)	ITSR (%)
Blank (no additives)	6,1	72
+0,7% RAP-5V	4,3	90
+1,0% RAP-EF	4,9	81
+1,2% RAP-2E	5,5	72
+1,5% RAP-17E	5,8	75

All additives are improving the voids content value (density) due to their softening effect, but only the rejuvenator with tensioactive properties (RAP-5V) is providing higher workability to the asphalt mix and achieving extra lower voids content in the same conditions.

Regarding Water Sensitivity values, better results are also obtained in the case of the additive with tensioactive properties as expected. This higher ITSR value is due to the lower void content obtained (because of the higher workability that the rejuvenators are providing) and also due to the better bitumen-aggregate adhesion (because of surfactant additive properties).

Due to the softening effect, the rejuvenators are enhancing dynamic properties, then minimize cracking pathologies. This fact together with ITSR improvement brings a significant impact in the asphalt mix wearing courses and provides longer life cycles, then lower maintenance.

Other relevant aspects related to the chemical modification are the heat-stability and additive associated odours. Several rejuvenators are not heat-stable in hot bitumen (it might not be dosed into the binder tank) and could emit unpleasant smell (annoying for operators).

2.4. Safety and environmental aspects

Another important consideration to select a proper rejuvenator is related to the safety and environmental issues.

No doubt that RAP applications are very environmentally positive, when this aspect is the main reason to promote and carry out this technique. There is not sense to dose hazardous additives into the bitumen or asphalt when they penalize with a negative charge to the environment or to the operators health.

It seems logical that vegetal-based “green” rejuvenators are the most favorable type of additives in this regard. Anyway, it is always highly recommended to check in advance the product MSDS to consider any potential hazardous risk, as mandatory and official legal document.

3. REJUVENATOR SELECTION AND DOSAGE DEPENDING ON ASPHALT PLANT INSTALATION

We can find different ways to introduce the RA (Recycled Asphalt) in the asphalt mixture, depending on the asphalt plant installation.

RA is understood as a high quality raw material, milled, classified and ready to use, which meets standard requirements.

3.1. Standard Asphalt Plant

It refers to Standard Asphalt Plant process when special drum system to heat the reclaimed asphalt is not provided, then RA is directly dosed into the mixer at room temperature.

In this case, the RA is around 10% to 20% in the asphalt mix, because the main limitation for higher RA content in the recipe is the temperature, which requires an overheating of the virgin aggregates.

When a selective rejuvenator is used, RA content can be easily increased till 25% - 30%, because the selective additive will improve the asphalt workability (by tensioactive effect) in order to compensate the reduced asphalt mix temperatures. It is not possible when just a softener rejuvenator is used.

Another option is suitable when RA content is maintained and virgin aggregate temperature is reduced, using this kind of selective additives (not only softener properties).

In these scenarios, the use of a selective rejuvenator is not focused to modify the bitumen physical characteristics but it is focused to improve the asphalt workability and adhesion.

3.2. Special Asphalt Plant

It refers to Special Asphalt Plant process when Double drum or Parallel drum is provided. These equipments favour the temperature of reclaimed asphalt. In this case, there might not be RA (Recycled Asphalt) content limitation due final asphalt mix temperature and RA could be higher than 50% in the asphalt mix.

The use of higher RA content in the asphalt mix requires a greater compensation of physical properties, but also of chemical ones. High RA contents penalize workability and bitumen-aggregates adhesion, that leads to worse results in void content and water sensitivity tests, so the use of selective rejuvenators additives have been shown to compensate for all these aspects.

When a soft virgin bitumen is used, the physical low penetration property (harder) of the aged bitumen is almost compensated and it is not necessary to use any rejuvenator with a softener main profile. In opposite, the use of a selective additive at lower dosages will regenerate the bitumen improving chemical properties.

The use of a rejuvenator that provides chemical advantages in the bitumen will lead a better mechanical performance for the asphalt mixture.

4. CONCLUSIONS

- A selective rejuvenator additive has a major role in successful asphalt recycling.
- The asphalt ageing process, which affects physical and chemical characteristics of RAP bitumen entailing a general hardening of the final bituminous blend and a lack of adhesion.
- Depending on chemistry, there are different sources of rejuvenators as petroleum-base, vegetal-base, amine-base or others.
- Few rejuvenators are poly-functional and provide a softening effect and also tensioactive behaviour that will benefit the asphalt performance.
- It is important to select the proper rejuvenator additive considering physical, chemical, environmental and safety aspects.
- Physical additive performance can be analysed in the bitumen by rheological tests or standard tests as penetration, softening point, penetration index, Fraass or viscosity.
- Chemical additive parameters can be analysed by asphalt mix test as Water Sensitivity and Voids Content. It has been demonstrated in this study that a rejuvenator able to modify the bitumen properties, leads to a better asphalt mixture mechanical performance (Water Sensitivity and Voids Content).
- Environmental and health aspects are linked to the additive base source.
- Installations with double or parallel drum allow the use of higher RA content.
- The use of a selective rejuvenator favours higher RA content in the asphalt mix recipe and improves the asphalt performance.

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