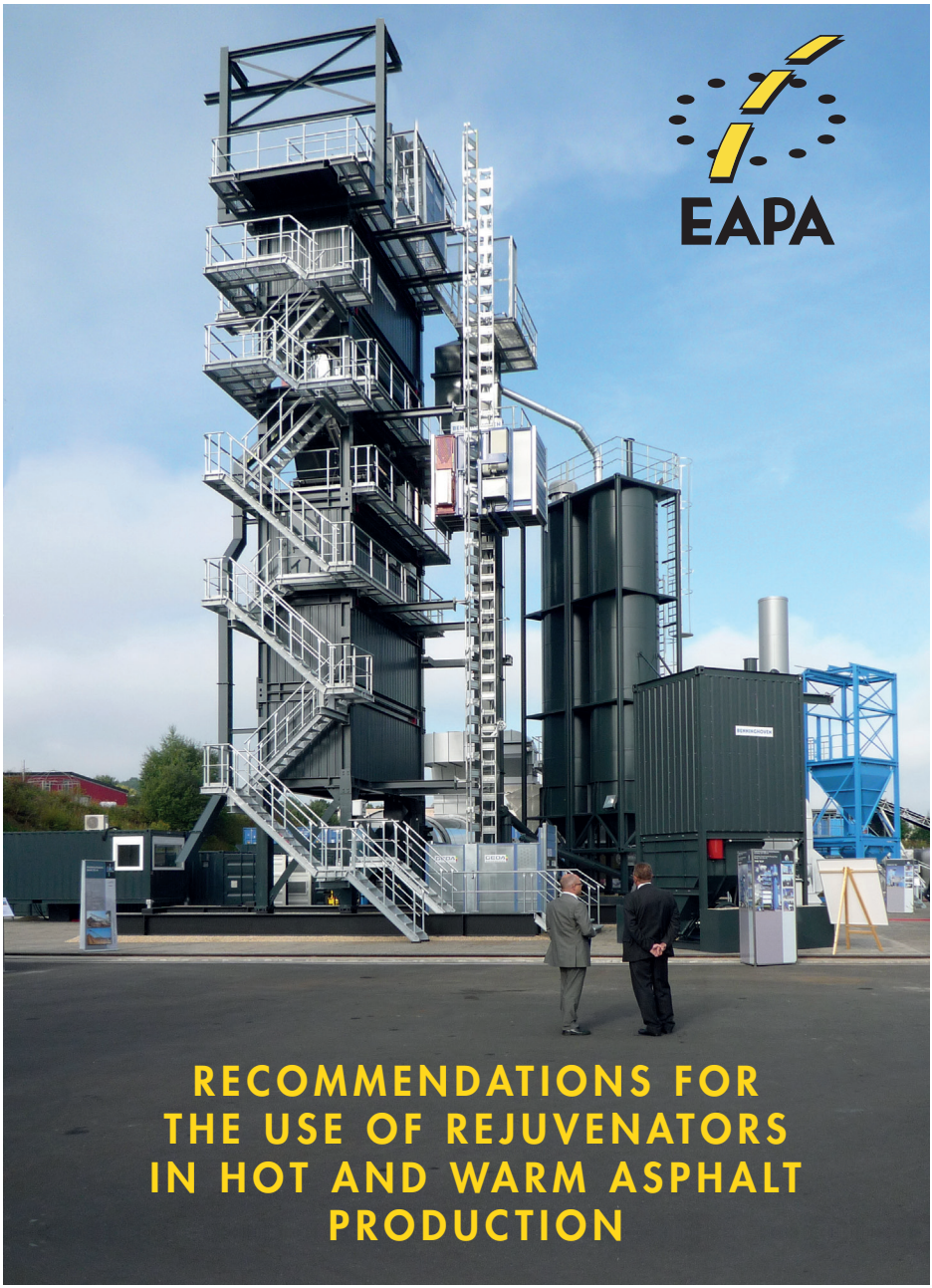

RECOMMENDATIONS FOR THE USE OF REJUVENATORS IN HOT AND WARM ASPHALT PRODUCTION

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EXECUTIVE SUMMARY / SCOPE

This document seeks to describe current understanding on the potential benefits and the underlying conditions of using rejuvenators to optimise the reuse of reclaimed asphalt in asphalt production. This document is intended for the asphalt industry to help increase their knowledge level regarding the use of rejuvenators and to provide indicative guidance to enable selection of rejuvenators that are fit for purpose and optimal for the intended application.

There is a need for this guidance as the word "rejuvenator" does not yet have an official definition and there is an increasing demand to classify the various products being made available on the market seeking to be used as a "rejuvenator".

This document does not provide recommended specifications because there is currently no European Commission Mandate to set up a harmonised standard. Therefore it indicates properties which might be relevant depending on the recycling method used, the properties of the reclaimed asphalt, the required performance of the asphalt etc.

This document does not address the use of 'in-situ' pavement rejuvenators as e.g. used in Nordic countries or preservatives which are applied to existing materials without extracting them from the paved area.

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1. INTRODUCTION

The re-use and recycling of asphalt pavements is now well established and commonly applied within Europe. Asphalt materials are 100 % re-usable into new asphalt pavement materials without the need to degrade its original functionality.

While the reuse of reclaimed asphalt with standard bituminous binders up to 50 % addition rates is successfully achieved, new challenges are arising. Over recent years more polymer modified and harder grade bitumens have been used in asphalt production [1] and therefore reclaimed asphalt based on them may not be adequately reused with 'standard' technology. At the same time, environmental and economic drivers demand the maximisation of the reuse of reclaimed asphalt by increasing its percentage into new mixes. In this context, the industry has clearly identified a need for new technologies to face the coming needs and technical requirements. The rejuvenators are aimed to serve the industry and the end users.

The binder of reclaimed asphalt generally becomes harder during the in-use phase. In order to meet the requirements for new asphalt mixtures, those with a high reclaimed asphalt content (25% or more) often require the use of either softer binders or softening agents or rejuvenators. The use of these softer binders or rejuvenators tends to reduce the stiffness of the aged reclaimed asphalt binders and improves performance under many conditions. Furthermore, rejuvenating additives restore the rheological behaviour of the aged binder from reclaimed asphalt when blent with the (pre-heated) reclaimed asphalt. Rejuvenators also can avoid the need of using a soft paving grade bitumen to meet the requirements.

The decision, whether the use of a softer binder or a rejuvenator is technically advised, depends on e.g. the quality and stiffness of the binder of the reclaimed asphalt, the amount of reclaimed asphalt to be added, the characteristics of the mixture to be produced, etc. The asphalt producer must test the final asphalt mixture properties to meet the obligations of the intended use and the contractual conditions.
This document deals with the use of rejuvenators in hot and warm mix asphalt

production where the resulting binder should meet the specifications of a paving grade bitumen according to EN 12591. For the use of rejuvenators in asphalt production with the aim of having a resulting binder according to EN 14023 (polymer modified bitumen), a more comprehensive evaluation might be needed, but the general approach could be based on the information provided in this paper.

2. CHARACTERISATION OF REJUVENATORS

Rejuvenators are agents intended to restore the rheological properties of the aged binder of the reclaimed asphalt. They cannot bring back the chemical composition of the original binder at production stage. Especially effects of oxidization of specific parts of the bitumen cannot be reversed within the industrial production in an asphalt plant. But the purpose is to improve the rheological behaviour in order to reconstitute all relevant mechanical properties of the binder necessary to produce a sufficient asphalt mix in conformity with the applicable technical regulations and suitable for the intended use.

Rejuvenators should only be incorporated into asphalt if it can 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.

DESIRABLE REJUVENATOR PROPERTIES

The properties needed depend on the use of the product and its application and encompass mainly physical properties but will also include some chemical properties.

Compatibility with bitumen (aged and virgin) and other mixture components is vital to ensure successful use of rejuvenators.

Properties of rejuvenators should be provided by the supplier and be supported by recommendations in terms of handling, use and application. There is not a unique set of properties for rejuvenators and different types need to be assessed to determine suitability.

The characterisation of rejuvenators must cover

- HSE & Waste considerations
- Desirable rejuvenator properties such as
    - o General properties like: Origin / type, Appearance, Density and Flash point; and
    - o Application related properties such as Kinematic Viscosity (cSt) at 60 °C, Kinematic Viscosity (cSt) at 20 °C and High temperature observations
- Effects on aged bituminous binder and resultant asphalt mixtures

3. CHARACTERISATION OF THE BITUMEN OF THE RECLAIMED ASPHALT

This chapter gives recommendations for testing the bitumen of the reclaimed asphalt. The bitumen of the reclaimed asphalt needs to be characterised in order to be able to compare all necessary initial properties (of the bitumen of the reclaimed asphalt) with the properties of the bitumen of the reclaimed asphalt and the rejuvenator (after blending and conditioning) as described in chapter 4.

The reclaimed asphalt itself shall be characterised by using EN 13108-8.
The binder properties shall be declared as described in EN 13108-8.

For high reclaimed asphalt additions additional testing of the reclaimed asphalt feedstock might be useful for the rejuvenator selection. This additional testing can be seen as product Type Testing. The minimum relevant bitumen properties to be determined for rejuvenator selection are:

- Penetration value (determined according to EN 1426)
- Softening point temperature Ring & Ball (determined according to EN 1427)

Other properties of potential interest may include:

- Dynamic Viscosity at 135 °C (determined according to EN 13302)
- Stiffness and m-value after long term ageing obtained with the Bending Beam Rheometer BBR (determined according to EN 14771)
- or alternatively Fraass breaking point temperature (determined according to EN 12593)

For a deeper understanding of the properties of recovered binder, it may be of further interest to investigate the rheological properties using DSR measurements in an appropriate temperature range.

4. CHARACTERISATION OF THE BITUMEN EXTRACTED FROM THE RECLAIMED ASPHALT BLENDED WITH REJUVENATOR

Characterisation of the bitumen of the reclaimed asphalt processed with the help of a rejuvenator is relevant to be able to select an appropriate product and to obtain some guidance to determine the method and the amount (percentage) of rejuvenator to be added.

The final choice of the rejuvenator and amount has to be determined as per standard determination of product type for addition of reclaimed asphalt and additives as per EN 13108-20.

4.1. EFFICIENCY OF REJUVENATORS

To be able to adjust the rejuvenator dosage, the specific efficiency of an additive has to be determined. In general, several criteria could be used for this purpose, which should be selected to likely fulfil the contractual conditions as well as the suitability for the intended use.

The indication of the efficiency of the rejuvenator could be based on bitumen testing only or on bitumen and asphalt testing. In any case the asphalt producer shall confirm the results of the bitumen testing by doing asphalt testing, using the general principles of Type Testing.

For determining the amount of rejuvenator needed several approaches are possible. The producer needs to relate the rejuvenator type and dosage to the binder properties of the desired specification, for which the supplier of the additive should provide data on how the product interacts with bitumen.

In case of being based on "Bitumen Testing only" the efficiency of rejuvenators could be based on the results of:

- Consistency changes
    - based on penetration value at 25 °C
    - based on softening point temperature
    - if applicable based on viscosity (for soft asphalt)

Other properties of potential interest may include:

- Resistance to hardening after short term ageing (RTFOT)
- Low temperature behaviour after long term ageing (RTFOT and PAV) can be evaluated with a Bending Beam Rheometer BBR[1]
- Flash point on blended bitumen
- Penetration index

In addition, further testing can be performed for information including amongst other rheological properties received by the use of a Dynamic Shear Rheometer (DSR).

As mentioned in the EN 13108 standard for Bituminous mixtures where reclaimed asphalt can be used the penetration value or the softening point temperature of the binder in the resulting mixture shall meet the penetration value or softening point temperature requirements of the targeted grade.

That means that the rejuvenator's dosage selection shall at least be based on meeting the penetration value or softening point temperature requirements of the targeted grade, unless performance testing of the final mixture would prevail.

4.2. AMOUNT OF REJUVENATOR NEEDED BASED ON PENETRATION VALUE AND/OR SOFTENING POINT TEMPERATURE

For each application it should be considered whether penetration and softening point temperature have to reach certain values to meet standard binder categories or performance-based testing of the final asphalt mixture would prevail.

In Europe penetration value and softening point temperature are used to characterise bituminous binders. This approach can be used to determine the amount of rejuvenator needed.
If needed this 'simple' approach can be followed by a more comprehensive one by using DSR results (see paragraph 4.3.).

[1] *BBR is preferred to the more empirical Fraass breaking point test*

For determining the effect of rejuvenators, the main focus is on obtaining flexibility (again) and after that the consistency at high temperature (rutting resistance) has to be checked. So, the dosage needed for recovering the penetration value has to be determined first and after that the minimal softening point has to be checked.

An example illustrating the influence of the amount of rejuvenator on empirical parameters in relation to the rejuvenator amount (for a certain rejuvenator) is shown in figure 1. The dosing of rejuvenator depends on the type of rejuvenator used.

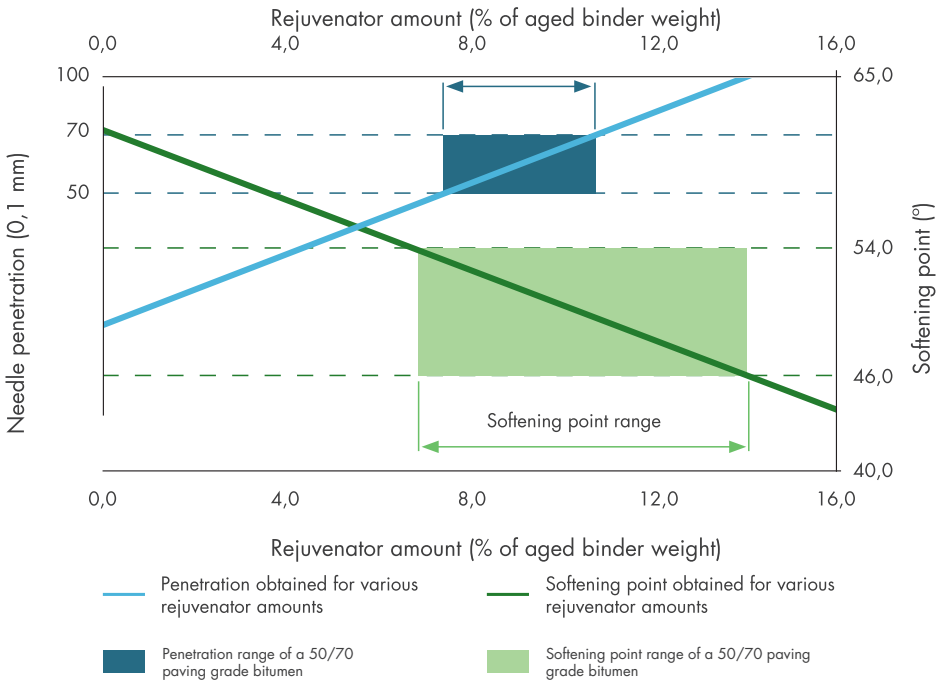

*Figure 1: **Example** of blending chart for a certain rejuvenator and a certain reclaimed asphalt [2]*

Figure 1 shows the range of dosages where the rejuvenated binder meets the criteria of a 50/70 paving grade bitumen for a given rejuvenator. The optimal dosage differs depending on the selected property. Therefore, it is important to choose an appropriate parameter in order to meet the requirements put on asphalt binders set in EN 12591 after rejuvenation. So even in the case of only empirical properties one has to look for the interpretation of the parameters. So the choice of parameters which are going to be used to for the evaluation of the rejuvenator's optimal dosage is very important.

4.3. AMOUNT OF REJUVENATOR NEEDED BASED ON COMPREHENSIVE APPROACH

After having completed the 'simple' approach there might be a need for a more comprehensive follow-up by using DSR results.

For this comprehensive approach master curves can be created for G* and phase angle δ for fresh rejuvenated blends, rejuvenated blends after short term ageing (STA) and rejuvenated blends after STA and long term Ageing (LTA). These master curves show the effect of rejuvenators on the fresh blend and on the STA and STA + LTA blends. With this technique it can be determined whether the rejuvenator really rejuvenates and remains over time and it provides information about the behaviour of the STA and STA + LTA blend.
For the comprehensive approach also a Black diagram could be used. Both methods (master curve and Black diagram) have advantages and disadvantages. The advantage of the curve in Black diagram is that it does not need any transformation of measured values as for creation of master curve.

4.4. THE SELECTION OF AN APPROPRIATE REJUVENATOR

The tests mentioned in this paragraph are meant to determine the effect of addition of rejuvenator to the 'old and aged' binder of the reclaimed asphalt. In this regard, there are different stages to be taken into account:

Rejuvenators are said to fulfil several tasks:

a. It 'restores' some bitumen properties of reclaimed asphalt incorporated into new hot mix. Beside other properties, mainly penetration value (for flexibility) should be increased and the softening point temperature should be decreased (for consistency at elevated temperature) to the desired consistency level.
b. After STA and STA+LTA the hardening of the rejuvenated bitumen should be limited to no more than standard paving grade bitumen.

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c. In situations where the low temperature behaviour is important it might be necassairy to check whether the low temperature behaviour of the rejuvenated bitumen after STA+LTA is fit for purpose by Bending Beam Rheometer (BBR) testing.

NOTE: In some cases it is recommended to check the mutual compatibility of all 3 components too.

Penetration value and softening point temperature can be used as a simple procedure to see which amount of rejuvenator is needed to obtain the "Target penetration" or "Target softening point". These tests show the effect of the rejuvenator on penetration value or the softening point temperature, respectively, when compared with the test results of chapter 3.

Empirical tests such as penetration and softening point often do not provide further information regarding selection of the appropriate rejuvenator and the long-term behaviour of rejuvenated binders, because they do not give a deeper insight into the underlying rheological phenomena. In order to obtain more information for selecting an appropriate rejuvenator and to estimate the long-term binder behaviour the Dynamic Shear Rheometer (DSR) can be used to determine binder properties such as complex shear modulus IG*I and phase angle δ. The measurement is often carried out for different temperatures and frequencies on original and aged binders.

Properties of binders can be presented as master curves for G* and δ or by the presentation of |G*| and δ in a Black diagram, or G' and G" in a Cole-Cole plot, as described in the literature on rheological behaviour of binders. Impact of aging or the comparison between different binders and/or rejuvenators can be demonstrated in this way.
The low temperature domain can be addressed by using Bending Beam Rheometer measurements to determine critical temperatures for the creep stiffness and the m-value, or the difference of them (ΔTc).

It cannot always be guaranteed that all original properties of an aged binder of the reclaimed asphalt can be recovered by using rejuvenators. A best compromise has to be achieved. While with ageing the binder becomes stiffer which

is a positive effect against rutting resistance, it also turns more brittle at intermediate temperatures, which marks a negative effect in terms of cracking susceptibility. Thus rejuvenators primarily have to reconstitute the low and intermediate temperature behaviour without degrading the high temperature domain.

4.5. RECOMMENDATION FOR TEST METHODS TO DETERMINE BINDER CHARACTERISTICS

Test method	Fresh rejuvenated blends	Rejuvenated blends after STA	Rejuvenated blends after STA + LTA
Pen	x	x	x
R&B	x	x	x
Dynamic Viscosity at 60 °C	x	x	
Dynamic Viscosity at 135 °C *)	x		
G* (as master curve) (DSR)	x	x	x
δ (as master curve)	x	x	x
BBR Creep stiffness			x
BBR m-value**)			x
BBR ΔTc**)			x

*) The effectiveness of the rejuvenators in regenerating aged binders could be evaluated by measuring viscosity with different rejuvenator contents at construction temperature.

**) The temperature where S = 300 MPa and the respective m-value are requested in the draft of the new European specification norm for Polymer Modified Binders (EN 14023), which is currently under revision. The evaluation of Tm=0,3 is not demanded there. Thus the laboratory should be asked for Tm=0,3, if the use of ΔTc is planned

Table 1: Overview of test methods recommended

The Annex of this document shows an example of a flow chart of a possible procedure for rejuvenator evaluation on binders. It can be split in 4 levels depending on the degree of complexity of the project:

- Level 0 is based on prediction of dosage using default effect of the rejuvenator
- Level 1 is based on standard empirical specification according to EN 12591
- Level 2 include the resistance to hardening
- Level 3 is for information, a step further through long-term aging through PAV
- Level 4 is for information with rheological analysis.

5. CHARACTERISATION OF COMPACTED ASPHALT SPECIMEN CONTAINING RECLAIMED ASPHALT + REJUVENATOR

The test methods used to determine the mechanical characteristics of a mixture are well established, with regards to the specification of those properties by end users depending on e.g. traffic, climate, etc. and are typically outlined in National Application Documents or equivalent technical regulations defined by a specific contract. Mechanical characteristics which should be assessed when using rejuvenators may include: stiffness, resistance to permanent deformation, fatigue resistance, low temperature properties, water sensitivity, as well as other mixture mechanical characteristics e.g. compactability.

If a producer chooses to include rejuvenators in his mixtures on the basis of indicative changes to binder properties, it seems logical that he assesses the resultant effect on the mixture properties which could be delivered by the change in binder properties. The effects of a new "binder system" should be carefully assessed. This is particularly relevant to the feedstock of reclaimed asphalt (and its binder) which may vary in its nature and properties over time.

6. BLENDING THE RECLAIMED ASPHALT WITH THE REJUVENATOR

It is important for the asphalt producer to determine and assess where, how and when to dose the rejuvenator at a plant.

The blending equipment and procedures depends on a range of variables including the type and properties of rejuvenator and compatibility with existing plant and equipment, such as mixing and blending phasing and timings.

As part of the Assessment and Verification of the Constancy of Performance (AVCP) for Factory Production Control to EN 13108-21, asphalt producers are required to identify the flow of ingredients and materials through the mixing process in order to identify and manage critical points of control. Consideration needs to be given to the mixing process in order to ensure effective dosing and optimised blending of rejuvenator with reclaimed asphalt, virgin binder and other mixture components.

Depending on the asphalt plant configuration various dosing points might be available:

- The rejuvenator could be added to the reclaimed asphalt at the reclaimed asphalt crusher (if available)
- At the reclaimed asphalt storage
- At the reclaimed asphalt conveyor belt
- At the reclaimed asphalt drum inlet (if such equipment or process is available).
- After the reclaimed asphalt has left the reclaimed asphalt dryer and before it enters the mixing unit (pug mill)
- In the mixing unit / pug mill

Each dosing point could have advantages and disadvantages.
A good and homogeneous distribution of the rejuvenators is important to obtain reclaimed asphalt that has received the same amount of rejuvenator. Next to that the rejuvenator should have time to react with the aged binder of the reclaimed asphalt, to be able to rejuvenate the old / aged binder.

When the rejuvenator is added at the discharging chute of the parallel drum the reclaimed asphalt is already preheated and the rejuvenator added and premixed has time to diffuse into aged binder as this material is stored for some time at reclaimed asphalt silo prior to mixing. This is more likely to maximise the diffusion time of rejuvenator into the reclaimed asphalt prior to mixing with the remaining components. This is only possible when rejuvenators have suitable flash point temperature and thermal stability.

The mixing processes itself may be the point for addition of rejuvenator, but the stage and time in the mixing process needs to be considered. Mixing is a relatively short process (25-45 seconds) and therefore the phasing of addition of rejuvenator to reclaimed asphalt (or the whole mixture) again needs to be carefully considered to achieve good result.

More information about the advantages and disadvantages of the various individual dosing points as well as a “checklist” of evaluation criteria and the evaluation of the dosing points based can be found in [3].

In all cases, plant processing characteristics as e.g. material and mixing temperatures need to be assessed to ensure that a rejuvenator is not “boiled or flashed” off from the mixture, both for quality and H&S considerations.

7. CONCLUSIONS

For the asphalt producing industry the reuse of reclaimed asphalt in the best technical way is very important for sustainability reasons. To be able to use higher rates of reclaimed asphalt in the asphalt mixture production rejuvenators can play an important role.

The decision, whether the use of a softer binder or a rejuvenator is technically advised, depends on e.g. the quality and stiffness of the binder of the reclaimed asphalt, the amount of reclaimed asphalt to be added, the characteristics of the mixture to be produced, etc. The asphalt producer must test the final asphalt mixture properties to meet the obligations of the intended use and the contractual conditions.

This document provides the asphalt industry position regarding potential benefits and underlying conditions for using rejuvenators in an effective way to optimise the reuse of reclaimed asphalt in asphalt production.
It provides a list of potentially relevant properties of rejuvenators indicative guidance to enable selection of rejuvenators that are fit for purpose and optimal for the intended application based on previous experience. This document was created since there was an increasing demand to classify the various products being made available on the market seeking to be used as “rejuvenators”.

Asphalt producers are responsible for their product and they declare the performance of their product in accordance with the requirements of the Construction Products Regulation in conjunction with European Standards (often referred to as “CE marking”). For this reason, it is very important to evaluate the efficiency of rejuvenators in the end by testing the relevant properties of the final asphalt mixture for the intended use.

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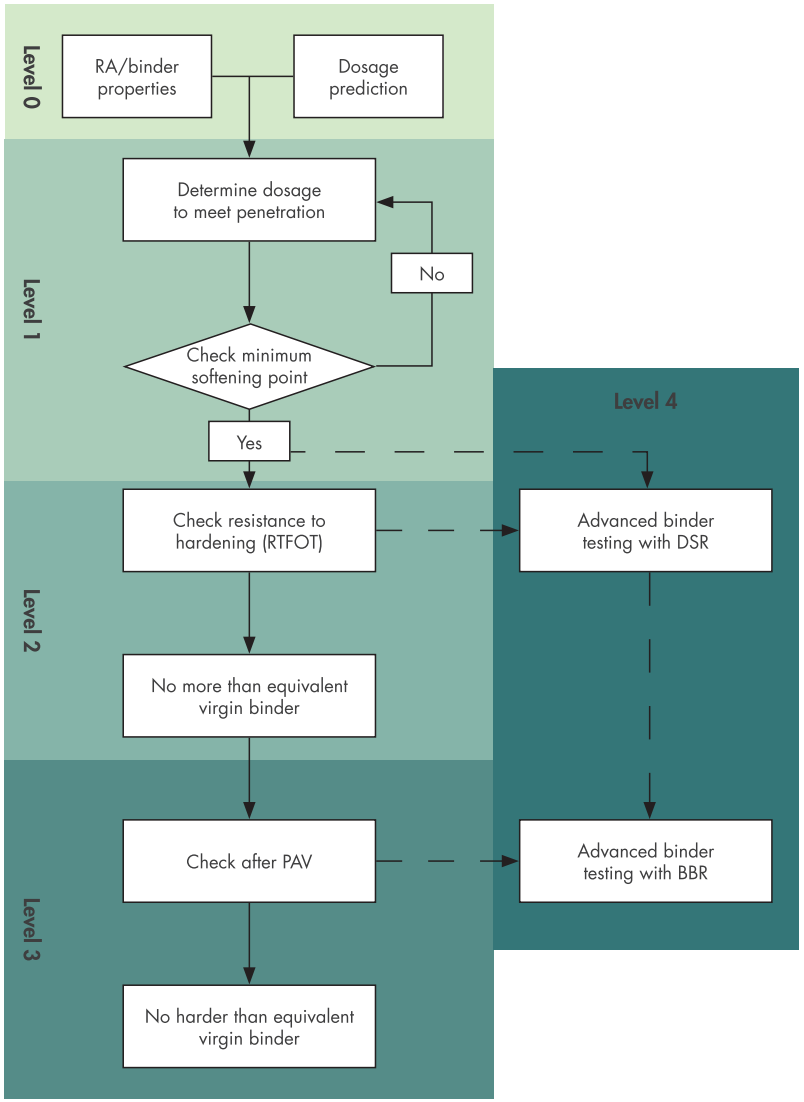
8. REFERENCES / LITERATURE

[1] Radenberg, M., Boetcher, S., Sedaghat, N. (2016). Effect and efficiency of rejuvenators on aged asphalt binder – German experiences. Proceedings of the E&E Congress 2016, 1 - 3 June 2016, Prague, Czech Republic.

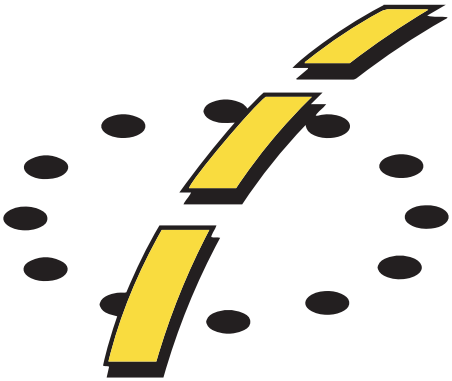
[2] Koudelka, T., Porot, L., Coufalik, P. & Varaus M. (2018). The use of rejuvenators as an effective way to restore aged binder properties. Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria.

[3] Paper regarding the research project ‘FOEN 100% recycling’. It is expected that this paper will be published in Springer’s ‘Materials and Structures’ (MAAS).

ANNEX



Example of flow chart of possible procedure for rejuvenator evaluation



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