Asphalt mixture performance and testing

Development of a protocol for the initial type testing of asphalt mixtures with the use of rejuvenators

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Abstract

In Europe, the approval and CE marking of asphalt mixtures is preceded by a mandatory initial type testing (ITT) study according to EN13108-20. Moreover, according to the product standards for asphalt mixtures (EN 13108 series), the application of additives such as rejuvenators are allowed, given a proof of suitability is demonstrated. However, in case of rejuvenators while using high amounts of reclaimed asphalt (RA) (> 60% for AC base courses), no further detailed information is provided in the procedures. Therefore, there is a need for a standard approach or protocol in order to carry out an ITT-study while using rejuvenators in the laboratory. This papers describes the results obtained within the framework of the research project ‘Re-RACE’ (Rejuvenation of Reclaimed Asphalt in a Circular Economy), specifically on the part of ITT testing procedure while using rejuvenators in combination with RA. The overall aim was to set up a standard procedure for the screening of the efficiency of rejuvenators by means of asphalt performance tests. Latter procedure should also be adequate in terms of representing how a rejuvenator is applied during real production in an asphalt plant and reflect the behavior of the asphalt mixture on the road. In this study, a series of parameters effecting the impact of the rejuvenator on the performance of the asphalt mixture such as the way the rejuvenator is added, the mixing and exposure time (time between mixing and compaction) and different concentrations of the rejuvenator were investigated for different rejuvenators. As current practice includes the use of soft binders, latter were also included in the research program for comparison. This paper discusses and draws conclusions from test results for compactibility, water sensitivity, resistance to rutting, stiffness and fatigue behaviour. Moreover, results are compared to field data as obtained from test sections constructed previously.

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1. INTRODUCTION

In Belgium recycling is applied successfully for over 40 years, and the country is herewith one of front-runners in Europe [2, 12] . Due to its success, RA (Reclaimed Asphalt) is likely to be used a second time; in the future we might be confronted with the 'multiple recycling' of RA [3]. The fatigue behavior and the adhesivity of this material are considered as the most critical parameters to continue of even increase the use of RA in a sustainable way in the future. Therefore, the use of rejuvenators becomes interesting. A rejuvenator is an additive that is added to the aged binder (as present in RA) and that is capable of regenerating the properties of the old binder to the properties of the original binder.

However, there are still multiple gaps in knowledge for the application of rejuvenators in the asphalt business:

- There is a lack in knowledge on the impact of rejuvenators on the performance of asphalt mixes with recycling.
- There is need for a type testing procedure/ methodology to evaluate the performance. The addition of rejuvenators to the production of asphalt is, according to the current European product standards for different types asphalt (NBN EN 13108-1 to 7), allowed. They are described and considered as additives, added in small amounts. Before additives can be used in asphalt, an "establishment of suitability" is required. This can be fixed in a European norm, guidance, or procedures, which are based on a demonstrable 'satisfactory use' of the product. This latter need to based on research and/or success in practice. Unfortunately, this is a very vague description of what is needed. Also on the way how to test and to evidence a performance, very little information is available.

In this paper, we present a part of the project Re-RACE ("Rejuvenation of Reclaimed Asphalt in a Circular Economy") run at BRRC and subsidized by Belgian Bureau for Standardization NBN. The project has different subparts, among which research on binder level, mix level and validation with test sections on the road. The paper presents the research on asphalt mix level, which had three goals:

- Contribution of a suitable and representative procedure to perform the initial type testing (ITT) in the lab when using RA in combination with rejuvenators.
- Validation of this procedure by comparison with the results of an asphalt mix produced in the asphalt plant.
- Impact of rejuvenators on asphalt performance

The first goal can further be described as the search for a procedure for the execution of an ITT in the lab according to NBN EN 13108-20 and this in combination with the use of RA and rejuvenators. It is desirable that the procedure for mixing and compaction of samples in the lab represents the mix and its behavior from production on site.
In the asphalt plant, multiple ways are possible for the addition of rejuvenators [5,6] . The two most applied procedures are:

1. The rejuvenator is equally spread on the reclaimed asphalt at ambient temperature on the conveyor belt that transports the RA to the parallel drum.
2. The rejuvenator is directly added into the plug mill.

The different times (mix- and exposure times) possibly play an important role, as time and temperature are important factors in the course of the mixing and diffusion processes that occur.
In this paper different exposure times and application procedures are therefore applied. Their impact on mix performance is compared for different variants. For one type of rejuvenator the results were also compared to results on site.

2. EXPERIMENTS

In this project, all experiments were performed on an asphalt mix for under layers AC-14 base: a Belgian type APO-B with the use of 70% RA, performance based (fundamental requirements) and satisfying the highest traffic category B1-B2 [11]. The target binder class was a 35/50. It was the same mix as used as under layer in the test sections and used for the validation of the lab experiments in the context of the Re-RACE project with one type of rejuvenator (rejuvenator 1) and reported in another paper for this conference by Vansteenkiste et all, 2020 [1] . The customer (in particular: the asphalt contractor Stadsbader NV) also provided all raw materials, as well as the bulk material during the construction.

The mix without the addition of rejuvenator and 50/70 as virgin binder was taken as reference mix for this study. Three different variants were considered: the same mix with a bitumen 50/70 in combination with rejuvenator (2 different types) and the same mix with a softer pen bitumen 70/100 (without rejuvenator). This latter simulates the current practice, where the lower pen value of the aged binder from the RA is compensated by the higher pen of the virgin binder, to obtain in the final mix the required pen value. The general composition of the mix is summarized in table 1; information on RA and rejuvenators is given in table 2.

Table 1: Mix composition

Fraction	Amount (m%)
Stone fraction (> 2 mm)	59.1 %
Sand fraction (2 mm – 0.063 mm)	32.9 %
Filler – Fines (< 0.063 mm)	8.0 %
	100 %
Total binder in mix (target 35/50)	4.21 %
Total Binder on aggregates (target 35/50)	4.40 %

Table 2 : Information on RA and rejuvenators

RA	Amount in APO-B mix (m%)	70 % added (66.67 % AG + 3.33 % binder)
RA binder	Amount (m%)	4.76 % in RA => 3.19 % in mix / 3.33 % on aggregates
	Penetration (10^{-1} mm)	21
	Softening point (°C)	62.8
Virgin binder 50/70	Amount (m%)	1.07 % on aggregates
	Penetration (10^{-1}mm)	60
	Softening point (°C)	50.3
Rejuvenator 1	Supplier	Kraton Chemicals
	Commercial name	Sylvaroad RP1000®
	Type of rejuvenator	Tall oil – engineered biobased oil
	Amount to add (m%)	3.4 % on old binder (info supplier)
Rejuvenator 2	Supplier	AKC
	Commercial name	Lynpave®
	Type of rejuvenator	Linseed - vegetable oil – Engineered biobased oil
	Amount to add (m%)	3.45 % on old binder (info supplier)

For all variants, samples were prepared for following performance tests, which are required for a standard ITT for this type of mix (AC 14 base = APO-B) according to the Flemish tender specifications SB250 vs 4.1 [11]:

- Determination of the density and air voids with gyratory compaction according to NBN EN 12697-31;
- Determination of the water sensitivity according to NBN EN 12697-23 + NBN EN 12697-12;
- Determination of the resistance against permanent deformation (rutting) according to NBN EN 12697-22.
- Determination of the stiffness NBN EN 12697-26 Annex A
- Determination of the resistance to fatigue cracking according to NBN EN 12697-24 Annex A

As mentioned above, tests were done with and without rejuvenator. In case of rejuvenator, two methods of addition were applied:

- The 'cold' method: the rejuvenator was spread on the cold RA before the RA is heated.
- The 'warm' method: the rejuvenator was added in the lab mixer, when the warm RA is added to the mix.

Related to the mixing in the lab, following points of attention needed to be considered:

- to spread the very small amount of rejuvenator equally onto the RA (usually of the order of a few g per kg of asphalt), several methods were evaluated as part of a preliminary study. The most efficient and accurate way appeared to be by using a dropping bottle with larger top. Depending on the type of rejuvenator, suppliers recommend to heat the additive to 60°C in order to slightly reduce the viscosity. In case of preparation of gyratory specimens (+/- 1500 g in this case), the needed amount is only a few grams, corresponding to 50 to 100 drops. However, it is necessary to weigh in order to know the exact amount.

- The mixing of the asphalt was following the European method NBN EN 12697-35. In table 1 and chapter 6 of NBN EN 12697-35, it is stated to heat the RA to the temperature that is used in the asphalt plant for 2.5 ± 0.5 h. In our project, this was 130°C. With significant amounts of RA (> 20%), which was the case in our project (70%), the temperature of the virgin aggregates needed to be adjusted according to formula (1) below to obtain the desired reference compaction temperature. The reference compaction temperature must be in accordance with the relevant product standard using the overall penetration or softening point calculated from the penetrations or softening points and proportions of both the added fresh binder and the binder recovered from the reclaimed asphalt. For our AC 14 base mix, this is in accordance with NBN EN 13108-1. The target binder penetration was a 35/50, however turned out to be around 30 pen.

$$T_{\mathrm{FA}} = \frac{(100 \ * T_{\mathrm{TLMT}} \ - \ p \ x \ T_{\mathrm{RA}})}{(100 \ - p)} \qquad (1)$$

- Due to very high amount of RA, the application of the rejuvenator and following the information and feedback from the trials at the asphalt plant, we were obliged to introduce some deviations for the temperatures of the materials.

  - The temperatures of the materials at mixing and compactions were :

RA	130°C (for 2.5 ± 0.5 h)	- same as in plant
Raw – virgin material (aggregates)	270 °C (overnight)	- calculated with (1)
Bitumen and filler	160 °C	
Mixing temperature	180 °C ± 5	
Start of the compaction temperature	170 °C ± 5	

- For the sequence of addition of all materials and the total mixing time, we could work within the frame and restrictions of NBN EN 12697-35.

  - For all variants, the mixing time was in total 4 minutes and 30 sec (maximum in EN12697-35 is 5 min).

  - The sequence of adding the different materials was different for the 'cold' or 'warm' method. In case of the 'warm method', the sequence differed slightly from the standard method. We started with the RA and the adding of the rejuvenator. Then the raw materials were added, followed by the binder and the filler. This means that the sequence of adding RA and fresh aggregates was switched compared to the reference mix and the mix with the cold addition of a rejuvenator.

The effect of two different exposure times was studied:

- 15 minutes between mixing and compaction: this corresponded with what is normally followed in the lab for ITT purposes: if compaction temperature is attaint, compaction follows mixing immediately. If not, the mix is cooled down or is shortly put back in the oven until the appropriate temperature is reached. In order to better control this for all variants, we decided to put the mix in the gyratory mould and put in an oven at compaction temperature for a fixed time of 15 minutes for every sample. Then the sample was compacted to the desired number of gyrations.
- One hour between mixing and compaction to simulate the time between mixing and delivery of the mix on the construction site and hence allow the action of the rejuvenator during this whole period. We note that this can also still comply with NBN EN12697-31 for gyratory compaction, where it is stated that one must put the mix back in the oven for 30 min to 2 hours in case reference compaction temperature is not reached. For this purpose, the mix was put in a covered tin in the oven, together with the gyratory mould. After 1 h the tin was poured into the mould so that the mix is loosened again (one hour in a gyratory mould can induce a certain structuring and stiffening of the mix, while in practice the mix is also dropped from the truck into the finisher). The specimens were then compacted at compaction temperature.

3. RESULTS & DISCUSSION

3.1. Compactibility via gyratory compaction.

The compactibility of the different AC-14 base (APO-B according to Flemish standard SB250 vs 4.1) mixes was investigated by comparing gyratory specimens compacted according to NBN EN 12697-31. This test allows following the evolution of the geometric void content in function of the number of gyrations. The specification for this type of mix according to SB 250 vs 4.1 is set at min. 5.0% and max. 10.0% after 60 gyrations for the highest traffic classes ("bouwklasse B1-B5") and 4 to 9% for lower traffic classes ('Bouwklasse B6 to B10). For all mixes, four specimens were prepared, and the average was calculated from the 3 withheld specimens according to the procedure described in the Flemish specification SB250 vs 4.1, chapter 14 par. 5.5.2.2.B.

In table 3, the results for the void content (average and standard deviation) after 60 gyrations are summarized.

Table 3: Gyratory results after 60 gyrations (BRRC-results)

	AC 14 base 70 % RA reference with 50/70	**AC 14 base 70 % RA + 3.4 % Rejuvenator 1 on old binder**	**AC 14 base 70 % RA + 3.4 % Rejuvenator 1 on old binder**	**AC 14 base 70 % RA reference with 70/100**	**AC 14 base 70 % RA + 3.4 % Rejuvenator 2 on old binder**	**AC 14 base 70 % RA + 3.4 % Rejuvenator 2 on old binder**
		method 1 cold	**method 2 warm in mixer**		**method 1 cold**	**method 2 warm in mixer**
	15 min waiting before compaction					
Voids (%)	5.1%	4.9%	5.0%	5.6%	4.5%	4.4%
St.dev.	0.7%	0.3%	0.2%	0.2%	0.4%	0.6%
	1 hour in tin before compaction					
Voids (%)	5.9%	*5.8%*	6.1%	5.8%	5.7%	4.9%
St.dev.	0.4%	*0.3%*	0.1%	0.4%	0.1%	0.1%

In table 4 results for bulk material from the test sections for some of the mixtures are summarized as provided by the asphalt plant. This table also contains data on the verification and comparison between the 2 labs, to make sure data could be compared.

Table 4: Gyratory results after 60 gyrations on bulk material

	BRRC	Asphalt plant	Results test sections	
	Verification mix lab	Verification mix lab	on **bulk material** by asphalt plant	
	AC 14 base 70% RA reference	AC 14 base 70% RA reference	AC 14 base 70% RA reference	AC 14 base 70% RA + 3.4% Rejuvenator 1
Voids (%)	4.9 %	5.0 %	5.0 %	5.1 %
Stdev	0.4 %	0.4 %	0.4 %	0.5 %

From these results in tables 3 and 4, we can analyze the different items and parameters that are studied. In order to evaluate and discuss the different variants, results and complete curves to 60 gyrations are plotted with one parameter at the time. In figures 1 to 5, the complete curves to 60 Gyrations are plotted. The figures represent mostly one parameter at the time for visibility and understanding.

<u>Method of addition: Cold vs warm addition of rejuvenator</u>

For both rejuvenators, the suppliers recommended the warm addition in case of lab studies.

In figure 1, mixes with rejuvenator are compared for cold and warm addition (only the variant of 15 minutes is represented) and compared to the gyratory curve of the bulk compacted material from the jobsite.

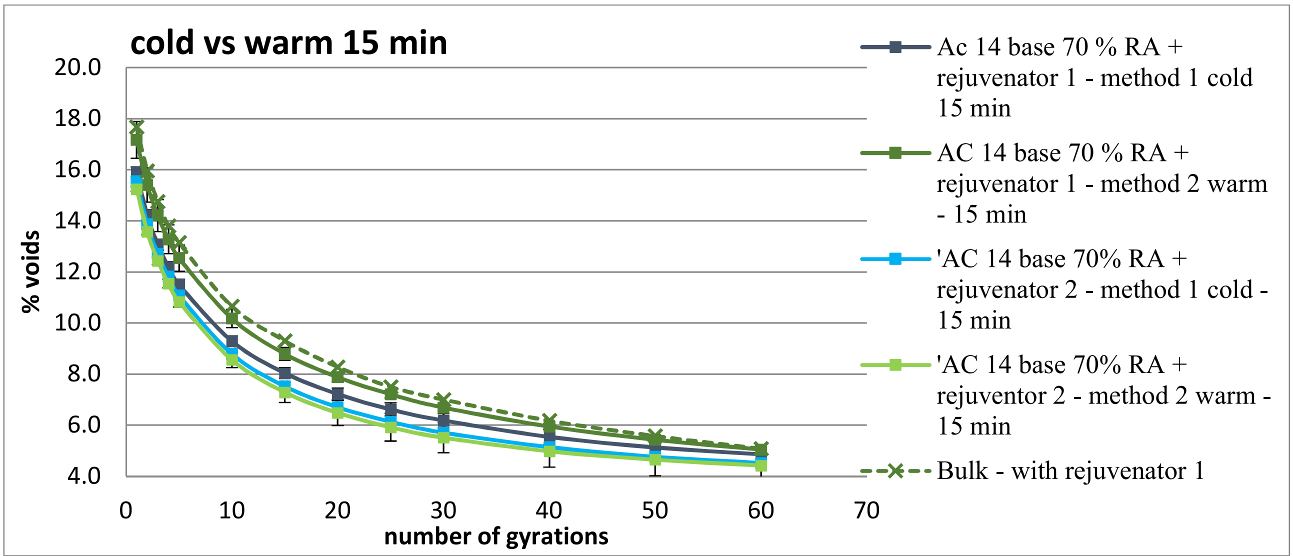

Figure 1: Gyratory curves – 15 min waiting time – cold vs warm addition

Comparing the cold and warm addition, it seems that when compacted shortly after the mixing (figure 1), there is only a slight difference observed for rejuvenator 1, but not for rejuvenator 2. For the latter, we do not observe any difference. When compared to the bulk compacted specimens, the warm method seems the closest to the reality for rejuvenator 1.

Checking the cold versus warm addition when waiting 1 hour before compaction (figure 2), there is no difference for rejuvenator 1, while rejuvenator 2 shows better compactibility with warm addition. This type of rejuvenator is continuing reacting through polymerization, being a siccative (drying) oil.

Based on these results and taking in account the repeatability of this test, we cannot claim that one method is better than the other is. There is no real difference. Therefore, we come to the recommendation for further ITT testing, to use the warm addition as it was used and recommended by the suppliers [10]. If there is some time before the mix can be compacted, it seems also somewhat less sensitive.

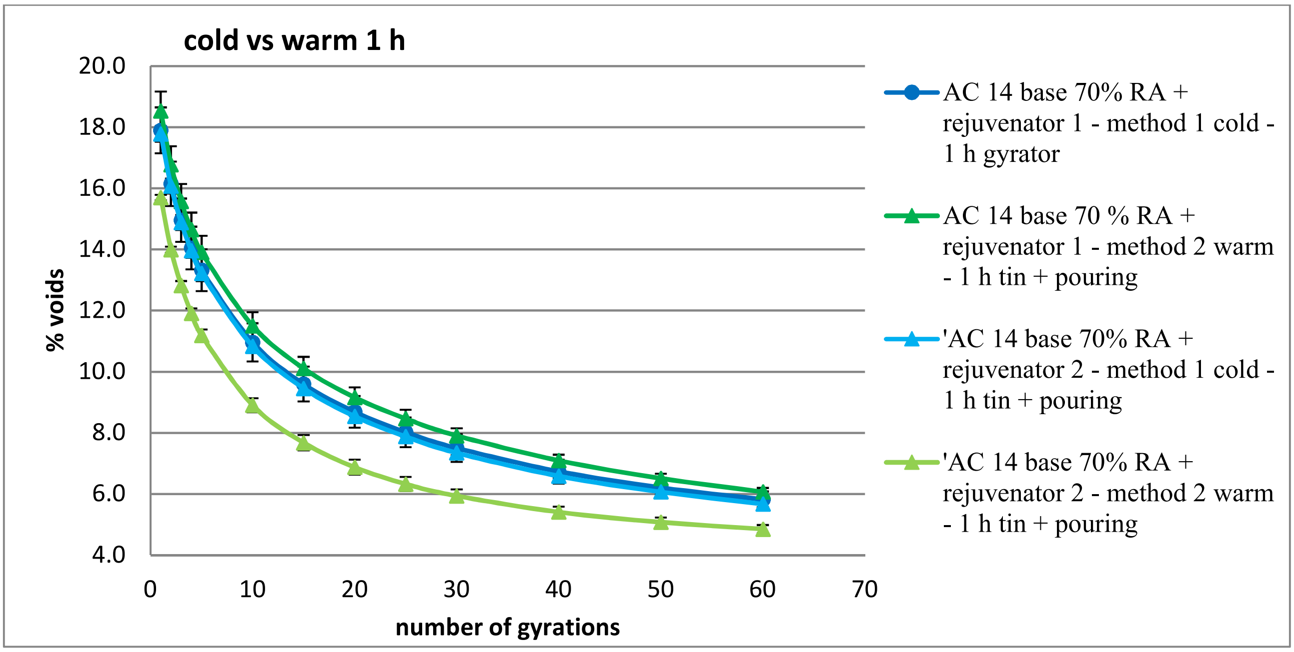

Figure 2: Gyratory curves – 1 h waiting time – cold vs warm addition

<u>Exposure time: waiting time between mixing and compaction: 15 min vs 1 h in tin and pouring</u>

As mentioned before the NBN EN 12697-31 allows waiting time up to 2 hours between mixing and compacting, if compaction temperature is not reached. Especially in case of use of rejuvenators, one might assume that this can have an influence on the result. Does the rejuvenator continue to work (react), or is it only oxidation of the mix that occurs if one waits?

In figure 3, gyratory curves are plotted for reference mixes with 50/70 and 70/100 and for the mixes with rejuvenators 1 and 2 for both exposure times: 15 min vs 1 h. For visibility, only the mixes with warm addition are given for the latter.

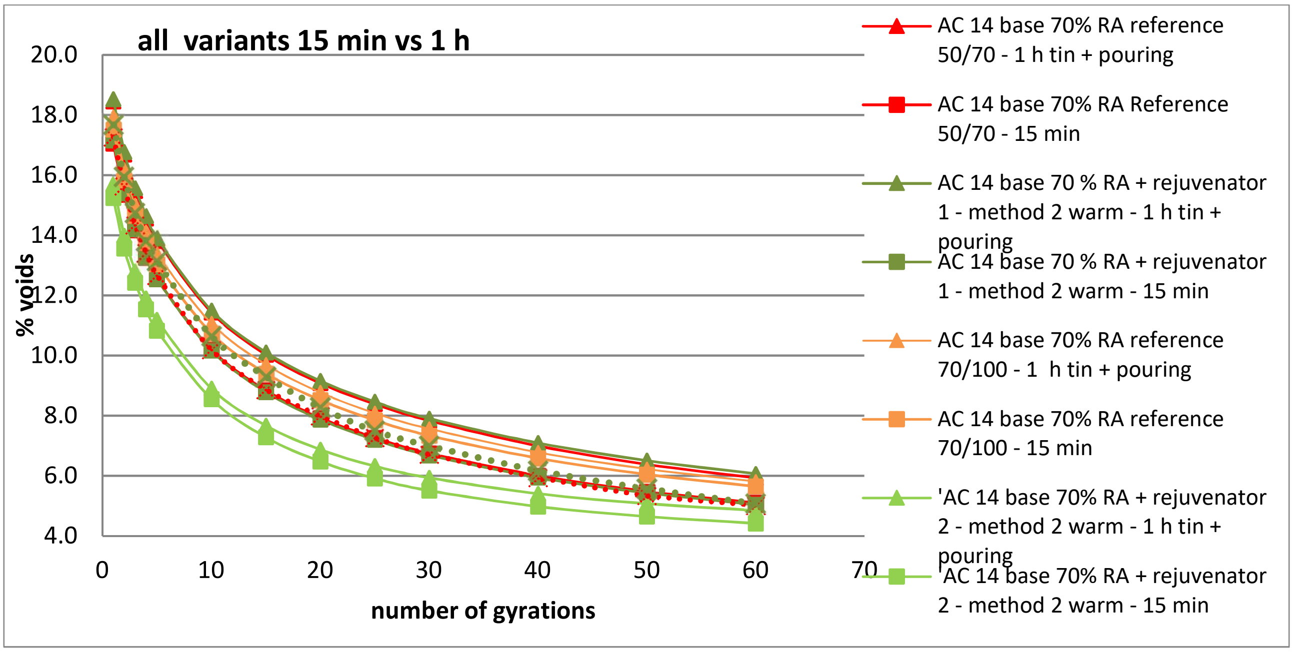

Figure 3: gyratory curves for different variants: 15 min and 1 h exposure time.

From these results, one observes that:

- In all cases, the waiting time of 1 h has rather a negative effect than a positive. There is a decrease in compactibility compared to the 15 min waiting: all lines of 1 h (Δ symbol) are lying higher than the lines for 15 minutes (□ symbol), for the same mix variant.
- The reference with 50/70 and the variant with rejuvenator 1 show about the same 'aging' or stiffening when exposing them to longer times. The reference with 70/100 remained rather the same after 1 h. Also the mix with rejuvenator 2, demonstrates less influence of exposure time.
- The 15 minutes exposure time corresponds very well with the results obtained on site (see tables 3 and 4 and fig. 3 for the reference mix and the mix with rejuvenator 1 for which this could be evaluated)

Hence, from this study we can conclude that there is no need to wait for 1 hour between mixing and compaction to give the necessary time for the rejuvenator to act. It rather has a negative effect on the result or does not add extra information to the evaluation of the efficiency or benefit of the rejuvenator. Therefore, for further ITT purposes, we recommended rather to compact immediately after mixing, and even limit the waiting time. The allowed time mentioned in the European norm, appears to be rather long and influences clearly the results.

Efficiency of rejuvenators compared to reference mixes without

Related to the demonstration of the efficiency of the use of rejuvenators, compared to mixes without, gyratory curves for the lab ITT samples are summarized in figure 4 (samples prepared by BRRC). For visibility, only the mixes compacted after 15 minutes and with the warm addition of rejuvenator are plotted. In figure 5, gyratory curves are plotted for the bulk samples (info provided by asphalt plant).

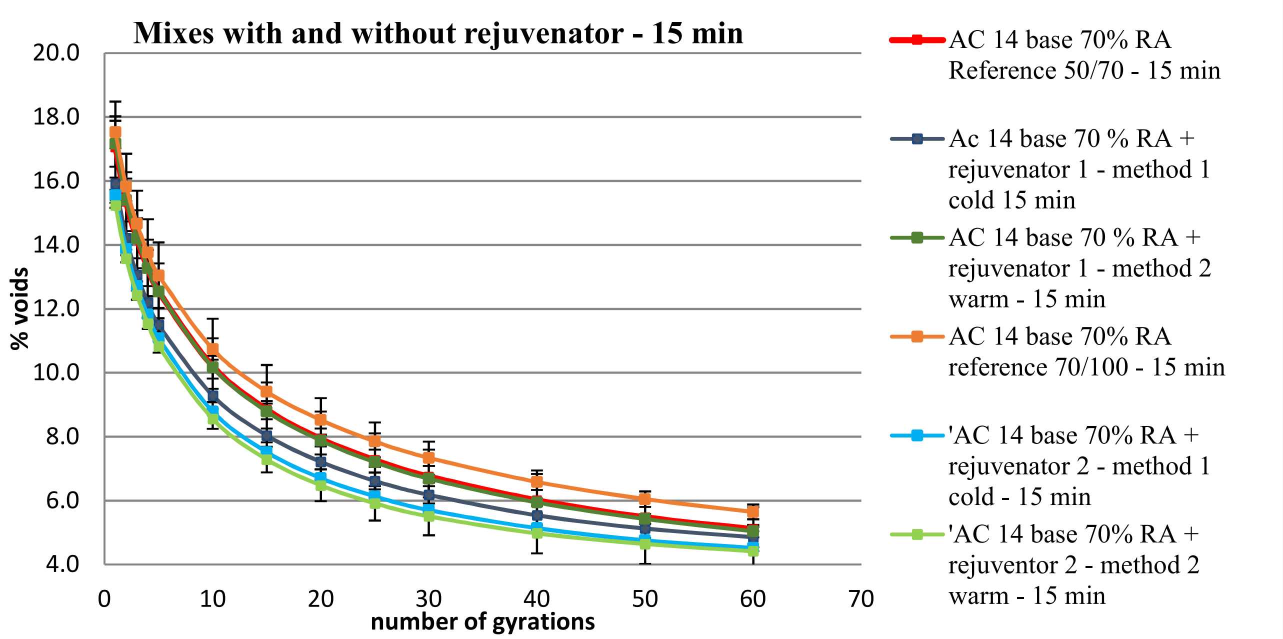

Figure 4: gyratory curves for different variants with and without rejuvenator – lab material

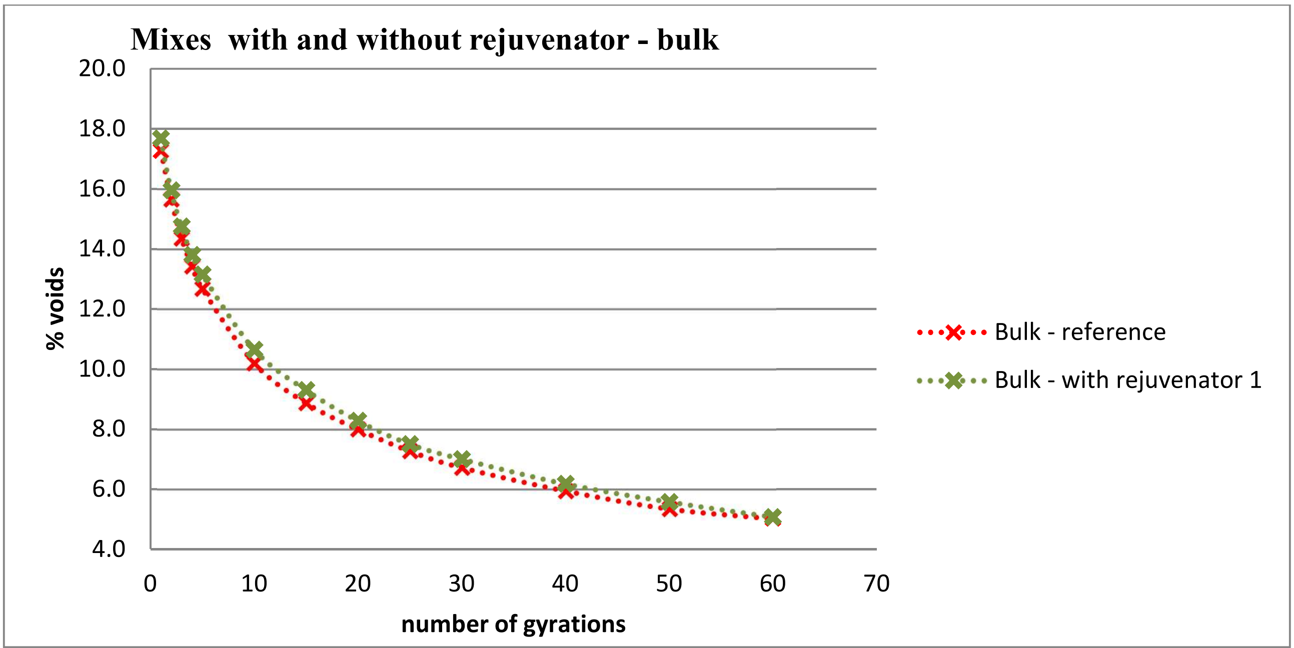

Figure 5: gyratory curves for different mixes with and without rejuvenator – bulk

From the lab ITT tests, it is difficult to evidence the improvement in workability and compactibility of the rejuvenator (also more or less depending on the type of rejuvenator), compared to mixes without. Both reference mixes show the highest lines, but at the end (after 60 gyrations), the difference is small.
In case of rejuvenator 1, we can only observe some difference in compactibility for one variant; in all other cases, we observe the same behavior as the reference mix with 50/70. In addition, the curves on the bulk material (figure 5) indicate the same: no real difference between the two mixes with and without rejuvenator.
For rejuvenator 2 the improvement is more evidenced. This latter clearly shows a better compactilibity in the early stage of the compaction and shows also the lowest end value in voids.
In contradiction to what is expected, the mix with the softer base binder 70/100 shows the worst performance and the highest voids at the end. It seems that the soft binder did not blend well with the old hard binder.
In general, we can say that we see a tendency that rejuvenators can improve workability at the early stage of compaction and/or will reach end density sooner than mixes without rejuvenator. However, in all cases about the same end compaction could be reached, whether rejuvenator is added or not.

Comparing 2 rejuvenators

From figure 4, we can also compare the two rejuvenators. Both rejuvenators have a similar origin (trees / plants), and have undergone, however different, chemical processes. In the FT-IR analyses, we could not observe big differences between both curves. However, a somewhat different behavior is observed in the compactibility. Rejuvenator 2 seems to have more impact than rejuvenator 1 on this property and seems less influenced by exposure time (no sign of oxidation or decrease in compactibility after one hour).

3.2. Water sensitivity by ITS-R test

The European standard NBN EN 12697-12 “Bituminous mixtures - Test methods - Part 12: Determination of the water sensitivity of bituminous specimens” in combination with NBN EN 12697-23 « Bituminous mixtures - Test methods for hot mix asphalt – Part 23: Determination of the indirect tensile strength of bituminous specimens», is at present used in Belgium to determine the performance of resistance to water (water sensitivity) of a bituminous mix. The indirect tensile strength (ITS) was performed on samples compacted in the gyrator to 25 gyrations. One series (3 specimens) was conditioned dry at room temperature; the second series (3 specimens) was conditioned in water for 72h at 40°C. The test was done at 15°C; the Indirect Tensile Strength Ratio (ITSR) was determined as the ratio of the ITS of the wet series over the ITS of the dry series (expressed in %) and is a measure for the water sensitivity of a mix. In Belgium, the specification for a type AC-14 base is 70%.

Based on the results on the compactibility discussed in the chapter before, variants were focused on waiting time (15 min and 1 h in tin before compaction). For the mixes with rejuvenator, only the warm addition was implemented.

In table 5 the results are summarized for the ITS-test. All samples had a void content (determined by NBN EN 12697-6 (method B)) between 4.3 ± 0.5% and are considered neglectable different for the purpose of having an effect on water sensitivity). Results are visualized in figure 6.

Table 5: ITS-R results

	OCW			OCW			ASPHALT PLANT		
	LAB ITT - 15 minutes			LAB ITT - 1 hour tin			BULK plant		
	ITS-d (MPa)	ITS-w (MPa)	ITS-R (%)	ITS-d (MPa)	ITS-w (MPa)	ITS-R (%)	ITS-d (MPa)	ITS-w (MPa)	ITS-R (%)
AC 14 base 70% RA reference with 50/70	3.4 ± 0.1	2.9 ± 0.1	87 ± 2	3.9 ± 0.2	3.2 ± 0.4	83 ± 7	3.5	3.5	100
AC 14 base 70 % RA + 3.4 % Rejuvenator 1	2.8 ± 0.1	2.4 ± 0.3	87 ± 7	2.8 ± 0.4	2.5 ± 0.3	88 ± 9	2.5	2.3	93
AC 14 base 70% RA reference with 70/100	3.2 ± 0.1	2.7 ± 0.1	83 ± 2	3.6 ± 0.3	3.0 ± 0.6	84 ± 10			
AC 14 base 70 % RA + 3.45 % Rejuvenator 2	3.1 ± 0.4	2.9 ± 0.2	91 ± 8	3.2 ± 0.3	2.9 ± 0.3	90 ± 7			

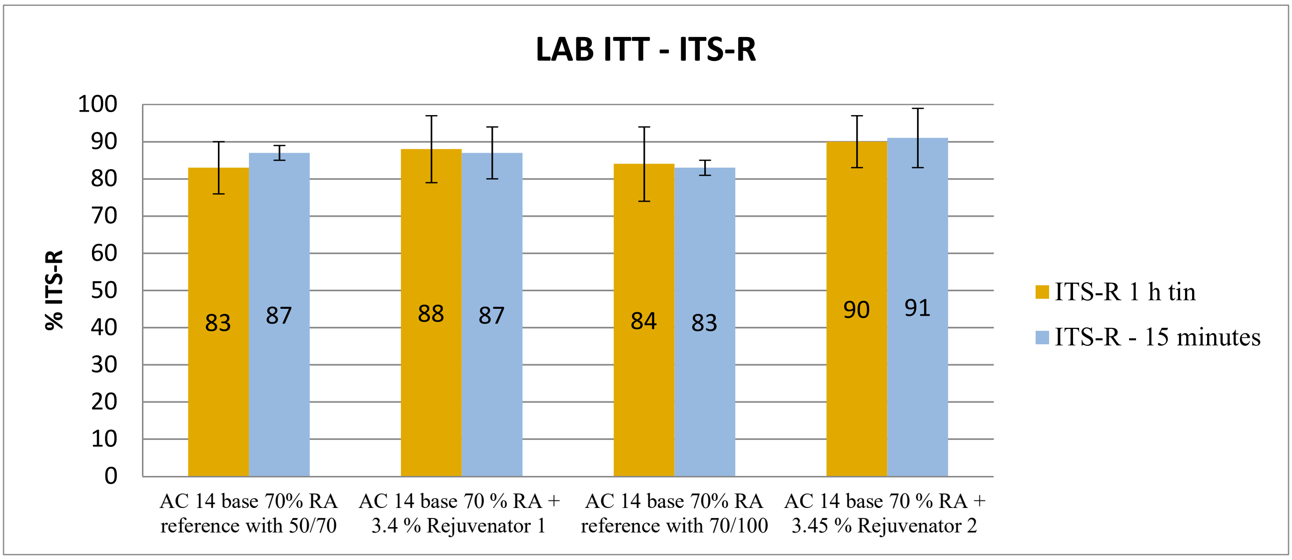

Figure 6: ITS-R for different variants

From this study it can be concluded that:

- The water sensitivity complies in all tests to the Flemish specifications (SB250 vs 4.1) for this type of mix (> 70%). As well for the reference with 50/70 as for the mixes with rejuvenator, high ratios are obtained.
- There is no significant difference in the water sensitivity for the different waiting times: ratio values remain equal if either 15 minutes or 1 hour is waited between mixing and compaction.
- There is no significant difference in the water sensitivity between the different variants (taking into account the repeatability of the test in NBN EN 12697-12: r = 15%);.
- Looking at the strength values for the dry samples, somewhat lower values are measured for the mixes with rejuvenator and soft binder (e.g. 2.8 MPa vs 3.4 MPa) compared to the reference binder. This can be explained by the fact that these mixtures are less stiff (effect of rejuvenator or softer binder). This effect is even more pronounced when waiting 1 h before compaction (e.g. 2.8 MPa vs 3.9 MPa). The mixes with rejuvenators seem less sensitive to stiffening when waiting than the reference mixture.
- When comparing the LAB-ITT values to the values of the samples made with bulk material from the test sections, values of the 15 minutes variant are closest (especially for the reference). This confirms the finding of the former tests on compactibility that ITT tests are best performed on samples compacted shortly after mixing. Waiting times should be avoided or restricted.

3.3. Rutting

The determination of the resistance against rutting was determined according the European test method NBN EN 12697-22: Bituminous mixtures - Test methods for hot mix asphalt – Part 22: Wheel tracking with "large size device". Tests were done in duple at a test temperature of 50°C; specimens were 50*18*5 cm. The rut depth was measured at 15 points after different amount of cycles (usually after 1000, 3000, 10000, 20000 and 30000 cycles). The average rut depth was expressed as a percentage of the nominal thickness of the test specimen (proportional rut depth Pi(%)). The Flemish tender specification for an AC 14 base mix is for the highest traffic class max. 5% at 30000 cycles.

The wheel tracking tests are performed on the mixes with one hour waiting time at compaction temperature between mixing and compaction, but regularly blended in between (to avoid stiffening and structuring of the loose mix). The reference with 50/70 was also tested with 15 minutes waiting time between mixing and compaction. The rejuvenators, were added according to the warm method. The results are summarized in table 6 and figure 7.

Table 6: Rutting results

	AC 14 base 70% RA reference with 50/70		AC 14 base 70% RA reference with 50/70		AC 14 base 70 % RA + 3.4 % Rejuvenator 1		AC 14 base 70% RA reference with 70/100		AC 14 base 70 % RA + 3.45 % Rejuvenator 2	
	15 min		1 h		1 h		1 h		1 h	
	average	**st.dev**	**average**	**st.dev**	**average**	**st.dev**	**average**	**st.dev**	**average**	**st.dev**
Cycles	**PLD (%)**		PLD (%)		PLD (%)		**PLD (%)**		PLD (%)	
0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
1000	**2.4**	0.0	**0.9**	0.1	**1.4**	0.1	**1.6**	0.0	**1.1**	0.4
3000	**3.1**	0.1	**1.4**	0.1	**1.9**	0.1	**1.9**	0.1	**1.8**	0.5
10000	**3.9**	0.2	**1.8**	0.2	**2.2**	0.1	**2.4**	0.0	**2.3**	0.5
20000	**4.2**	0.0	**2.0**	0.2	**2.4**	0.1	**2.6**	0.0	**2.4**	0.6
30000	**4.5**	0.1	**2.2**	0.2	**2.8**	0.2	**2.9**	0.1	**2.8**	0.8
50000	**4.9**	0.1	**2.4**	0.2	**2.8**	0.2	**2.9**	0.1	**2.8**	0.7

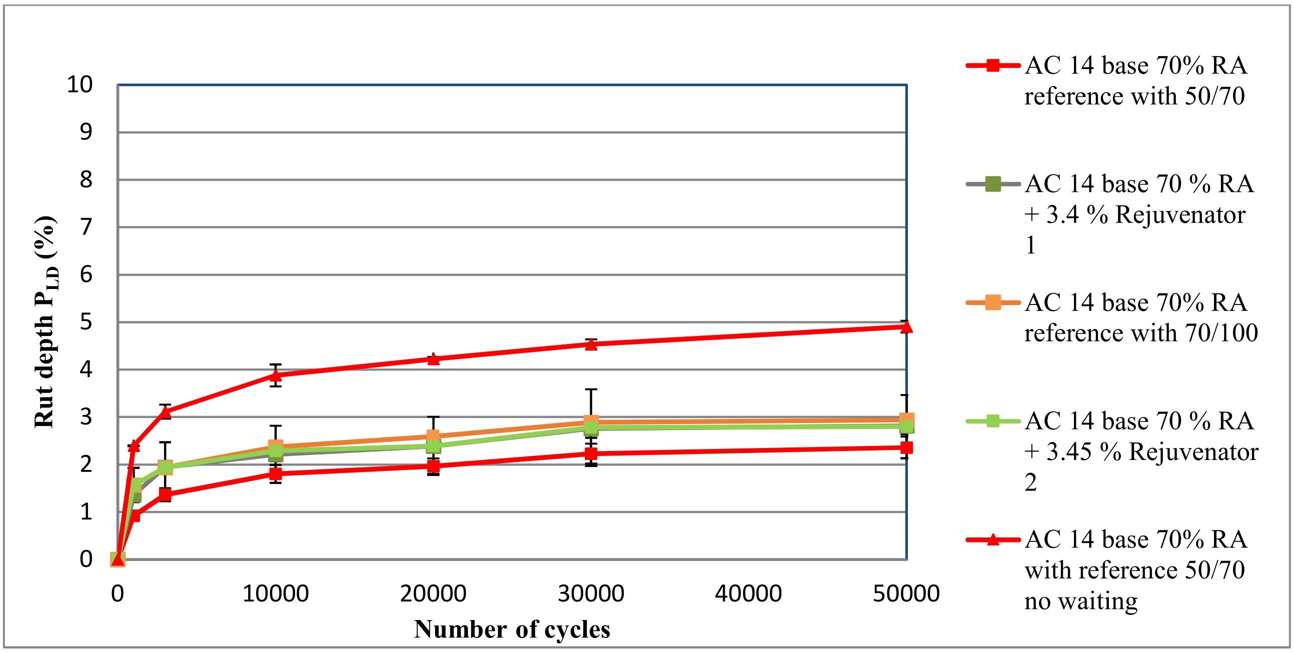

Figure 7: Wheel tracking results for different variants

From this study, it can be concluded that:

All variants have a high resistance to rutting. They comply with the specifications of the highest traffic class of the Flemish specification SB250 vs 4.0.: maximum rut depth 5%.

- There are no significant changes between the different variants, taking into account the repeatability of this test (NBN EN 12697-22: r=1,11% for a 'test result level' PiLD=7%;). Therefore, we can say that the addition of rejuvenator does not have a negative effect on the resistance against rutting or permanent deformation for this mix. Nevertheless, there is a logic trend in the results observed: the 'softer' the mix or rejuvenator added, the 'bigger' the rut depth. The hardest mix, namely the AC 14 base 70% RA reference with 50/70 (without rejuvenator), shows the best result. The AC 14 base 70% RA reference with 70/100 shows the same results as the mixes with rejuvenator. Both mixes with rejuvenator show exactly the same result.
- The AC 14 base 70 % RA reference mix with 50/70 that was compacted immediately after mixing (15 min. waiting time), shows the biggest deformation. It still fulfills the highest class of the specification (< 5%), but again there is clear evidence of an influence of the waiting time. For future testing, the waiting time should also here be limited to a minimum in order to avoid impact on the result.

3.4. Stiffness

Stiffness was determined by the two point bending test on trapezoidal specimens at 15°C and a frequency of 10 Hz according to NBN EN 12697-26, annex A. The specification in the Flemish specification SB250 vs 4.1 for an AC 14 base mix is set to min. 9000 MPa (at 15°C and 10Hz).

The stiffness was determined on 4 specimens per variant. Specimens were sawn from asphalt slabs compacted in the lab by a wheel plate compactor according to NBN EN 12697-33. The compaction was done shortly after mixing (15min); for 2 variants also specimens were made with 1 hour waiting time between mixing and compaction. The rejuvenators were added according to the warm method. The results are summarized in table 7.

Table 7: Stiffness results

[E*] 15°C-10Hz (MPa)	AC 14 base 70% RA reference with 50/70	AC 14 base 70 % RA + 3.4 % Rejuvenator 1	AC 14 base 70% RA reference with 70/100	AC 14 base 70 % RA + 3.45 % Rejuvenator 2	AC 14 base 70% RA reference with 50/70	AC 14 base 70 % RA + 3.4 % Rejuvenator 1
	15 min	15 min	15 min	15 min	1 h	1 h
[E*] avg (MPa)	16760	13470	15240	13640	16950	16480
[E*] - stdev (MPa)	810	310	200	380	410	70
[E*] stdev (%)	4.9%	2.3%	1.3%	2.8%	2.4%	0.4%

φ (°) - avg	10.5	14	11.2	13	9.1	10.7
φ (°) - stdev	1.1	0.9	0.3	0.5	0.8	0.1
φ - stdev (%)	10.5%	6.5%	2.7%	4.1%	8.8%	0.9%

All mixes comply with the Flemish standard SB250 vs 4.1 (> 9000 MPa) and have a higher stiffness value. There is a slight difference observed between the different variants: the mixes with rejuvenator show a lower value than the reference mixes with respectively 50/70 and 70/100 when the mix was compacted immediately. However, when compacted after 1 hour, the two tested mixes with and without rejuvenator are on the same level again. Latter effect can probably be attributed to the further ageing of the test specimens during that conditioning hour.

3.5 Resistance to fatigue

The resistance to cracking by fatigue is determined at 15°C and 30 Hz, according to NBN EN 12697-24 Annex A (same trapezoidal specimens as for stiffness). Based on the number of cycles to failure of the specimen as a function of the deformation or strain level ε, the so-called fatigue line is determined. The typical parameter to calculate is ε6 or the strain applied on the specimen for a failure after 1 million cycles. The specification in the Flemish specification SB250 vs 4.1 is for this type of mix AC 14 base 80 µS.

The fatigue was determined on 18 specimens per variant. Specimens were sawn from asphalt slabs compacted in the lab by a wheel plate compactor according to NBN EN 12697-33. The compaction was done for two variants with 1 hour waiting time between mixing and compaction. The rejuvenators were added according to the warm method. Due to the observed negative effect of 1 hour waiting time, we started testing the different variants with compaction done shortly after mixing (15min). The results are summarized in table 8. At this moment 3 more variants (reference with 70/100 and mixes with the 2 rejuvenators) are planned and testing is ongoing at present. All results are expected by end of 2019 and will then be evaluated.

Table 8: Fatigue results

	AC 14 base 70% RA reference with 50/70	AC 14 base 70% RA reference with 50/70	AC 14 base 70 % RA + 3.4 % Rejuvenator 1
	15 min	1 h	1 h
e6 (µstrain)	106.6	132.3	142.6
Δ e6 (µstrain)	7.7	9.5	14.7
1/b	-6.944	-6.005	-6.303
r	0.805	0.812	-0.690
[E*] 15°C-30Hz (MPa)	16265	18124	17959
n / 18	18	18	18

4. CONCLUSIONS

Based on all performance tests for an ITT study and comparison with the field data on an AC 14 base mix with and without rejuvenator, the following conclusions are drawn and recommendations formulated:

- With respect to the method of addition of rejuvenator in the laboratory: while trying to simulate the different ways to use the rejuvenator on site, a cold and warm addition method in the lab was explored. However, laboratory results did not demonstrate a clear difference between the two methods. Together with the recommendation of the suppliers and some observed tendencies, we would recommend during future ITT testing to apply the rejuvenator via the warm addition method.
- With respect to the exposure or waiting time between mixing and compaction: waiting to compact a mix in order to evidence more clearly the efficiency and working of the rejuvenator is not required. On the contrary, it has rather a negative effect. The best evaluation of results is observed when compaction follows as soon as possible the mixing, still respecting the required reference compaction temperature. We might even recommend to restrict this waiting time in the current standard EN12697-35. For the moment, one may wait between 30 min to 2 hours before compacting the mix, to reach the correct reference compaction temperature. Looking at the obtained results, we see especially for the reference mixes without rejuvenator (but also with rejuvenator), an effect of ageing. In most cases, a significant shift in results is observed.
- The benefit of adding rejuvenators to an asphalt mix containing high amounts of RA, is difficult to evidence on asphalt level, especially in case pen values of the aged binder present in the RA are not extremely low (± 20 10^{-1} mm). For most executed tests, the differences are small and within the repeatability of the test. Only some tendency

for the improvement with rejuvenator is detected for the compactibility and fatigue (preliminary). Also on stiffness some effect was observed.
- Comparing ITT results from the laboratory with results on the bulk material from the asphalt plant, the tests with the rejuvenator added via the warm addition and compacted shortly after mixing show the best correspondence.

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