Laboratory evaluation of half warm recycling with bio-based additive

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ABSTRACT

It is now widely recognized that Reclaimed Asphalt (RA) is a valuable source of material for asphalt mixes. RA provides a sustainable solution with both economic and environmental benefits. This value can currently be realized in cold recycling as with using emulsions, or in hot in plant reuse. In addition to these methods, an alternative may be to use a half-warm process, typically at a temperature below 120 °C. Because RA contains aged binder that is harder than standard bituminous binder, it requires an elevated temperature in order to "mobilise" the binder. At lower mixing temperatures, such as ambient temperature or that used in half-warm mix, the RA is usually considered to be "black-rock" aggregate-like in character, providing no cohesion/strength in the asphalt mixture. Although processing at these lower temperatures produces lower performance mixes that do not attain specification levels equal to HMA, there are certain economic advantages that can be realized.

A laboratory study has been conducted to evaluate the effect of a highly effective bio-based additive in combination with 100 % RA. The main challenge was determining how the binder from the RA can be mobilized at ambient temperature and above, and whether some cohesion and strength can be imparted. The study utilized simple asphalt testing such as a gyratory compaction and Indirect Tensile Strength measurements, and the results indicate that 100 % RA treated with a limited amount of additive can attain characteristics similar at least to those produced by cold mixing asphalt or half-warm mix asphalt (HWMA). Furthermore, in this case, no curing time was required.

This new technology could find applications in hot in-place recycling, where the temperature of the milled road can vary from 80 °C to 180 °C, cold in-plant recycling with a temperature above 60 °C, or even with pretreatment of RA on the stockpile.

Keywords: Additives, Asphalt, Cold Asphalt, Low-Temperature, Reclaimed asphalt pavement (RAP) Recycling

1 INTRODUCTION

There are four different ways to recycle/reuse Reclaimed Asphalt (RA), combining cold vs. hot and in-plant vs. in situ recycling [1, 2, 3]. The most common way to recycle RA is cold recycling, where the old pavement is milled, mixed with bituminous binder, and eventually combined with cement [4]. However, with cold recycling, the final performances of the asphalt material are not similar to virgin Hot Mix Asphalt (HMA), and thus do not extract the full value of the RA. Therefore, in order to maximise the value from RA, hot in-plant reuse is the preferred option. In this process, RA is processed in a hot mix plant and mixed again with virgin aggregates and virgin bitumen [5]. The current range of RA content is almost 100 % for cold in situ recycling and up to 50 % for hot in-plant reuse.
The aim of this paper was to identify an alternative route to process RA at 100 % into a new asphalt mixture using a specifically designed rejuvenating agent at half-warm temperatures. Current cold recycling technologies require additional binder to provide cohesiveness and strength to the mix. Different techniques are used for this, including the use of bitumen emulsion or foamed bitumen. For cold recycling or hot mix, as the bituminous binder from the RA is not fully mobilized, this leads to extra binder content in the final mix that can be detrimental to the end characteristics of the mix. In addition, these techniques require curing times in the range of hours to days to build strength for the mix.
Processing RA at lower temperatures provides additional economic advantages, even if the characteristics of the end product do not meet the specifications required for HMA. Furthermore, it requires limited machinery for its processing. This application is better suited to remote areas or secondary roads, where asphalt mix plants are not easily accessible, or where the expected service level for the road is low.
This study focused on evaluating mixtures manufactured at ambient temperatures and above, but not those as high as for hot or warm mix asphalt. This evaluation was conducted on a laboratory scale, through an initial screening study using the mixing process at ambient temperature, prior to a more comprehensive evaluation of mixing conditions with different temperatures and maturation times.

2 EXPERIMENTAL PLAN

2.1 Rejuvenating agent

In hot in-plant processing, virgin bituminous binders are used. When RA is reused in hot mix, softer bituminous binder or sometimes fluxes, and more recently, specific rejuvenating additives are used. In cold asphalt mixtures, bitumen emulsion or foamed bitumen, sometimes with derivate petroleum flux oils or vegetable oil, are used [3]. This technique is also applied to cold recycling.
In this study, SYLVAROAD™ RP 1000 Performance Additive, a pine-based rejuvenating agent was considered. This additive was specifically designed to be highly effective on aged bituminous binder [6, 7]. A dosage of 5 % restores the aged binder properties by 2 grades, causing it to behave like virgin bituminous binder. The typical dosage is 3–7 % of the aged binder content, depending on its properties. In the case of 100 % RA recycling, this allows the final binder content to remain within a suitable range, avoiding excess of binder that can lead to inappropriate permanent deformation.

2.2 Screening evaluation

An initial experiment was conducted in the laboratory by mixing RA and the additive at ambient temperature. This phase used hard RA that required 10 % additive per weight of RA binder content. For reference, untreated RA was also considered. The mix was made by hand at ambient temperature in 2 kg batches.
The mixes were then poured into tubes without any compaction. The different batches, including treated and untreated materials, were left in the tubes for 5 hours, 1, 3, and 7 days. Subsequently, for each set of samples, the tubes were removed and the samples observed, to determine how the sample remains in the cylindrical shape and the material appearance.
The purpose was to identify any potential advantage of having the rejuvenating agent already at ambient temperature, in the mixing process, with respect to how RA granulates are mobilised, and, in the cohesion of the material over time, to check whether it behaves similar to untreated RA or yields some additional tangible benefit.

2.3 Evaluation of mixing conditions

Following the screening phase, a mix evaluation was conducted, to compare different mixing conditions and basic characteristics including compaction and strength measurements.

2.3.1 Reclaimed Asphalt

The RA used in the study was normally aged asphalt material from an existing road. The binder content was high at 5,2 %, and didn't require additional binder. Figure 1 shows the grading curve, a standard RA gradation with filler content of about 10 %. Although the RA displayed coarse gradation, the actual mineral gradation following extraction was different, with high filler content and sand.

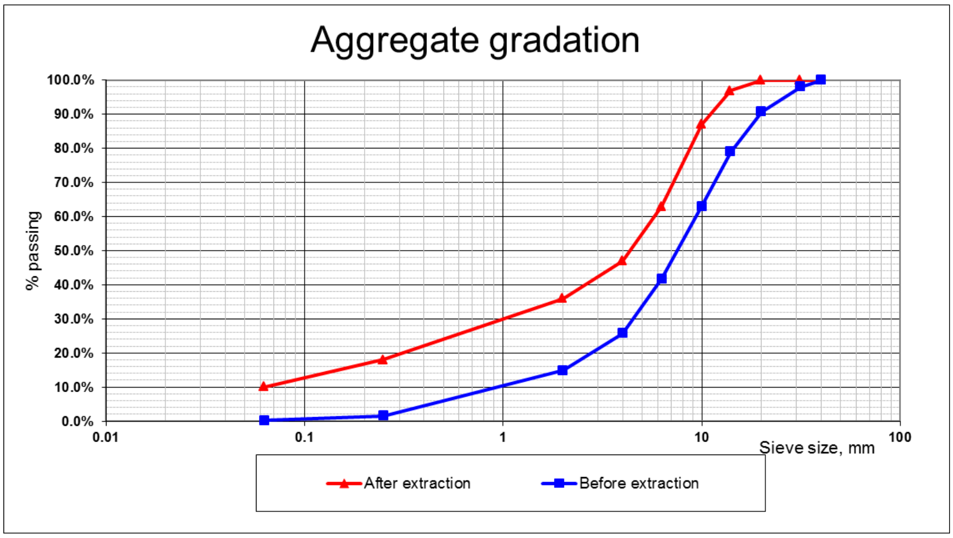

Figure 1. RA gradation curve

The binder from the RA was extracted and recovered in order to determine its basic properties. The penetration value (EN 1426) at 25 °C was 17 0,1 mm and the softening point (EN 1427) was 68 °C. These values are reasonable for RA. Based on these properties, a dosage of 5 % of the additive was used, enough to recover the binder properties similarly to those of the standard reference 35/50 pen grade bitumen.

2.3.2 Mixing conditions

For the mixing protocol, the RA was warmed at the target temperature prior to mixing with the rejuvenating agent. Each batch contained about 3 kg, and 7,8 grams of additive only. The additive was added via a pipette and mixing by hand in a bowl was enough to spread throughout the additive, obtaining a homogenous mixture. During this process it was observed already a breaking down of RA lumps into sand and filler. The mix was stored in an oven at the same mixing temperature for the relevant period of time to "mature". Finally the material was subject to sample compaction and testing.
Four different mixing-temperatures and three different curing-times prior to compaction were considered:

- Mixing temperature
  - 20 °C, representing ambient temperature,
  - 40 °C, representing the temperature of the RA stockpile during summer,
  - 60°C, representing the temperature at the surface of the stockpile during sunny days
  - 120 °C, representing the temperature of processing RA alone for HMA.
- Curing time
  - Immediately after mixing,
  - 5 hours, to represented treatment within a day,
  - 5 days, to represent treatment within a week before reusing RA.

2.3.3 Testing

The first step consisted of evaluating the different mixing conditions based on the compactability of the product using gyratory compaction (EN 12697-31). The test was conducted at the four temperatures and the three curing times, and up to 300 gyrations. Based on these preliminary gyratory compaction results, Indirect Tensile Strength (ITS; EN 12697-23) was also measured, but only for the most relevant conditions. The Table 1 summarises the different conditions evaluated.

Table 1. Asphalt mix testing program vs. mixing conditions

		Mixing Temperature			
		20 °C	40 °C	60 °C	120 °C
Maturation time	Normal,	Gyratory	Gyratory	Gyratory, ITS	Gyratory, ITS
	5 hours	Gyratory	Gyratory	Gyratory	Not relevant
	5 days	Gyratory, ITS	Gyratory	Gyratory	Not relevant
Untreated RA	Normal	Not relevant	Not relevant	Not relevant	Gyratory

3 RESULTS

3.1 Results from the screening phase

The initial screening phase aimed to check whether there is any mobilisation and cohesion build-up in RA alone when using the bio-based rejuvenating additive. It consisted of a very simple experiment involving mixing RA and the rejuvenating additive at ambient temperature, and then pouring into a mould without compaction. After the specified time, the mould was removed and the sample was observed to determine how fast the cylindrical shape would collapse.
The results showed that all samples of untreated RA were unable to retain the cylinder shape, and the “core” collapsed after few minutes. On the contrary, in the case of treated RA, the cylinder shape remained after removing the tube. Figure 2 shows pictures of the samples kept in the mould for 5 hours, 1 day, 3 days, and 1 week. In each panel, the sample on the left is untreated RA, and that on the right is treated RA.

Figure 2. Asphalt materials after unmoulding

In addition, the shape was retained for a recordable time. Figure 3 shows the evolution of the shape just after un-moulding and after 2 hours, for the sample kept in the mould for 7 days. The longer the mix stayed in the tube, the longer the integrity of the core was retained.

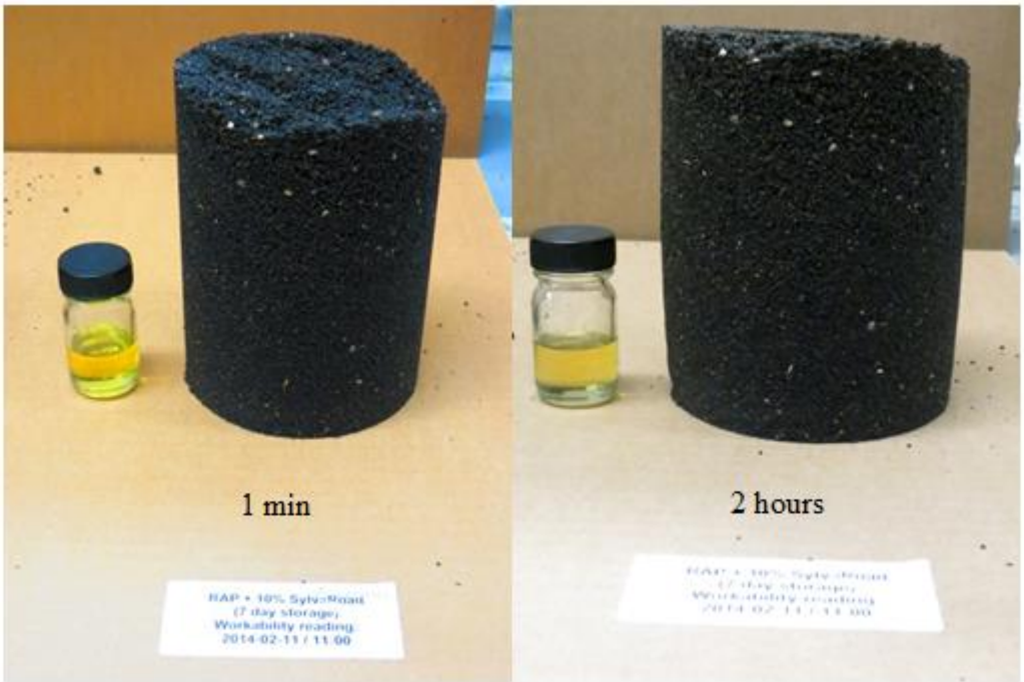

Figure 3. Sample after unmoulding

Figure 4 shows a close-up look at the mix. The treated RA appeared more shiny and with loose sandy gradation, whereas the untreated RA was grey with agglomerated mortar lumps. This observation was tangible already just after mixing with short curing time, only minutes into the mixing process. This is an interesting observation, in that treatment with the additive changes the aspect of RA gradation, bringing it closer to the true mineral gradation of the RA. It demonstrates that the bio-based rejuvenating additive changes the RA aspect and imparts some cohesion, even at ambient temperature and without any compaction energy.

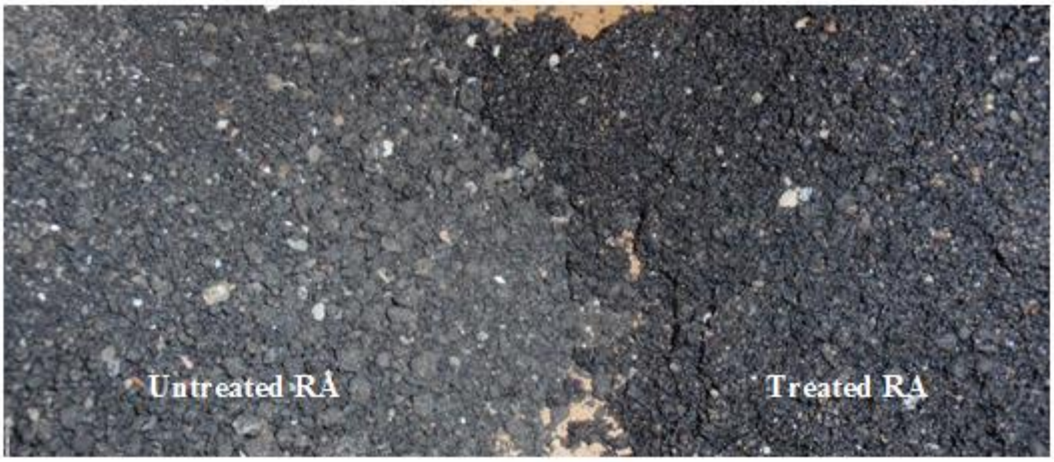

Figure 4. Close look at untreated/treated RA

3.2 Effect of mixing conditions on gyratory compaction

Based on this promising initial screening, a second evaluation phase was conducted in order to assess the influence of the mixing conditions, combining temperatures and maturation times. This phase was based on up to 300 cycles of gyratory compaction according to EN 12697-31.

Figure 5 displays the different curves of densification with void content vs. number of gyrations, with the four different temperatures (colours) and the three different maturation times (dotted line styles). The maturation time curves for each temperature are close together. However the different temperature curves for a given maturation time are significantly different, with lower void contents as the temperature is increased. The temperature has the most important impact on the results, whereas the maturation time does not significantly impact void content. The higher the temperature, the better the compactability.

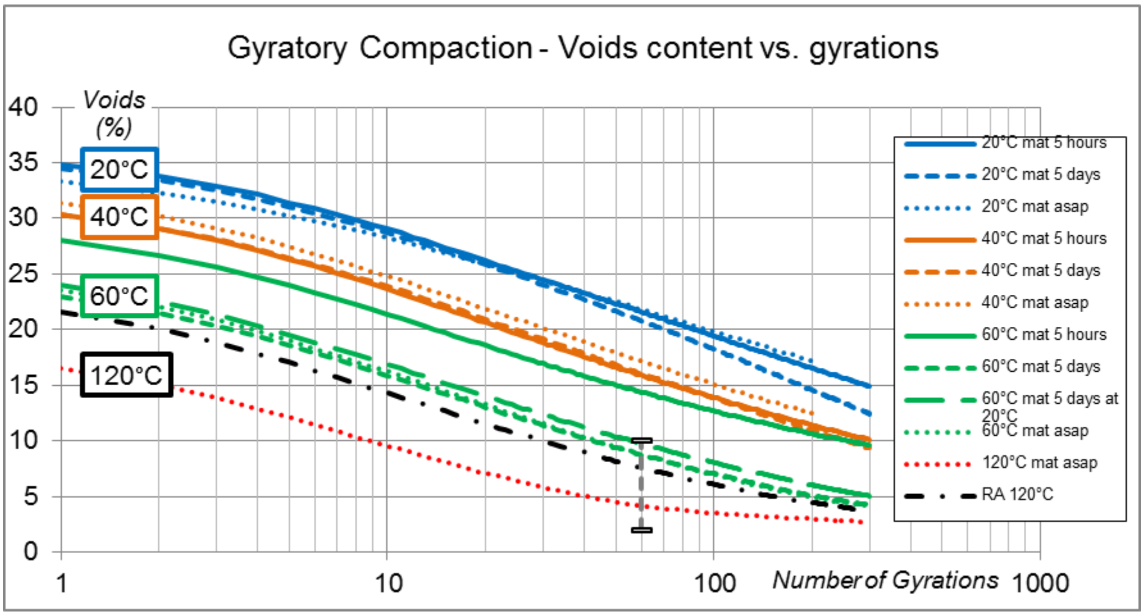

Figure 5. Effect of mixing conditions on gyratory compaction

Table 2 displays void content after 60 gyrations, as recorded for specifications. The results were consistent, with the exception of the mix at 60 °C and after 5 h, which was due to error in sample preparation. These values confirmed that maturation time had a limited effect on void content, whereas the temperature had a consistent effect. At temperatures of 40 °C and above, the void content was close to 15 % or lower, regardless of maturation time. Furthermore, at 120 °C, the mix already achieved a void content close to 4 %, which is usually the target for HMA (as in, for example, for the Superpave mix design). At the same time, the untreated RA did not achieve a proper void content.

Table 2. Results of gyratory compaction after 60 gyrations

Gyratory compaction, void content at 60 gyrations		Mixing temperature			
		20°C	40°C	60°C	120°C
Maturation time	Normal, asap	21.8 %	17.2 %	8.7 %	4.3 %
	5 hours	21.6 %	15.9 %	14.4 %	Not relevant
	5 days	20.8 %	16.1 %	9.8 %	Not relevant
Untreated RA	asap	Not relevant	Not relevant	Not relevant	7.6 %

Pictures of the samples, recorded to assess the aspect of the sample after 300 gyrations, are presented in Figure 6. For the compacted samples at temperatures of 20 °C and 40 °C, the voids content was above 15 % and samples had a rough and not homogeneous aspect. At temperatures of 60 °C and 120 °C, the compacted samples appeared more shiny and dense, with void content below 10 %, as in HMA specifications.

Figure 6. Aspect of the gyratory samples at 20, 40, 60 and 120 °C

The use of the bio-based rejuvenating additive helps to gain reasonable compactability, with a void content ≤ 15 % for temperatures at least 60 °C and above, even and a void content close to 4 % at 120 °C. These values are obtained regardless of the maturation time.

3.3 Effect of mixing conditions on Strength

Based on the results from the gyratory compaction, ITS was also measured for mixtures prepared at 60 °C and 120 °C without curing time. In the first stage, an additional mix was prepared at 20 °C, but this was not really recordable; the values are included for comparison. Some samples of untreated RA were generated at those temperatures but unfortunately did not exhibit sufficient cohesion to be measured through ITS. The results were also compared with those obtained for a reference Hot Asphalt Mixture with no RA. The measurements were made on dry samples and samples soaked in water in order to determine the ITS Ratio addressing water sensitivity.
Figure 7 displays the value of the ITS (dry and wet), as well as ITSR. The results of mixing at 20 °C were very poor and not relevant for any paving material. The mixtures made at 60 °C and 120 °C, both had lower values than HMA. The dry ITS was, on average, 1000 kPa and 1600 kPa with mixing at 60 °C and 120 °C, respectively, compared to 2100 kPa for HMA. These values were reasonable for a cold process despite the significant variability. With respect to water sensitivity, the results were below the 80 % threshold usually set for HMA, but still reasonable, with values > 50 %.

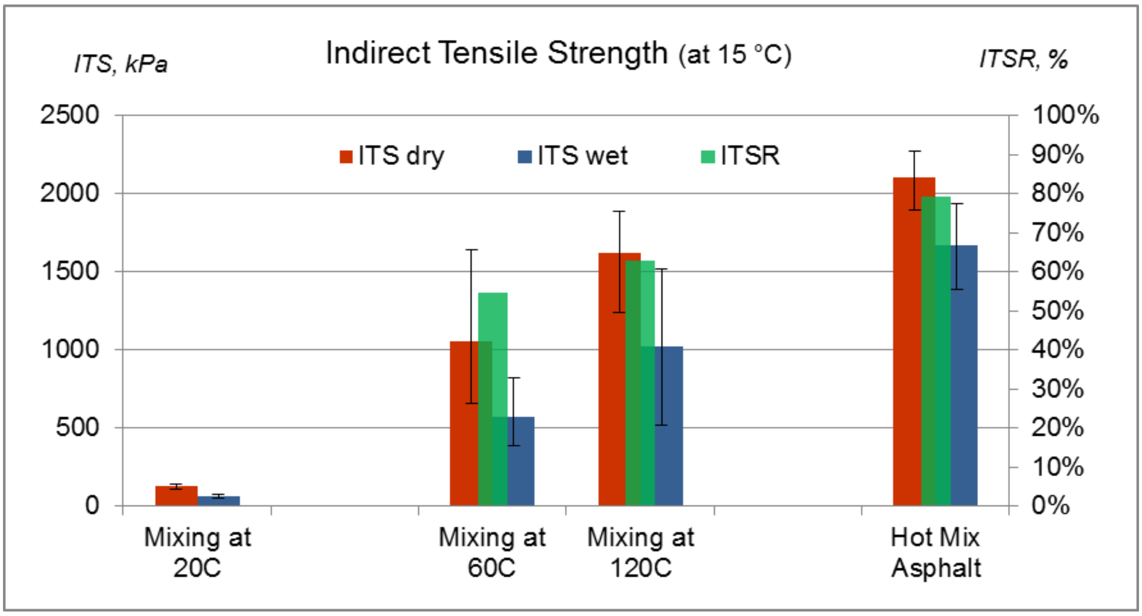

Figure 7. Effect of mixing temperature on Indirect Tensile Strength

4 DISCUSSION

This study aimed at determining the effect of a bio-based rejuvenator additive at different processing conditions. Although it was specifically developed for RA reuse in hot in-plant processes [6, 7], its efficacy in pre-treating RA suggested a different route for recycling RA. The reuse of RA in a hot process aims to yield a final product with specifications at least equal to those defined for standard HMA. In other processes, such as cold mix or half-warm mix, the mix is made with bitumen emulsion or foamed bitumen; however the mechanical characteristics are usually of a lower level than for HMA.
The specifications for HMA are described, among others, with volumetric analysis based on gyratory compaction and mechanical characteristics such as strength values, water sensitivity, permanent deformation, equivalent elastic modulus, fatigue resistance, or low temperature cracking susceptibility. These are supported, for example, by the Superpave mix design approach, AASHTO M323 [8], or by the European standard EN 12697 series [9].
The specifications for cold mix or cold recycling are not as well described as for HMA. These types of mixtures are more likely used for remote areas or secondary roads where traffic is not intensive. In these cases, the required performances of the materials are defined at least to ensure good waterproofing of the road and reasonable mechanical characteristics to withstand low traffic loading under various climate conditions. Research projects involving the characterisation of cold recycled asphalt mixture have already been undertaken.
Today the most comprehensive studies and research on Bituminous Stabilised Materials (BSM) or Granular Emulsion Mixes (GEMS) have been carried out in South Africa. With the variable nature of aggregates used, ranging from natural granular aggregates to old asphalt pavement, the Sabita Manual 14 [10] helps to define specifications. For cold mixes with emulsion, the void content should be no more than 15 % in order to prevent excessive strength loss due to the possible ingress of water into the material, and no less than 5 % in order to allow the emulsion to break and the mix to cure. Some values for the ITS, are also provided, but at a test temperature of 23 °C with a minimum of 100 kPa.

Some European studies have examined cold mixing and cold recycling using emulsions. One such study was the SCORE project (2002–2005), which investigated Superior COld REcycling [11]. This study evaluated the mechanical characteristics of RA treated with emulsion with an optimum void content no more than 15 %. This study was followed by the ENVIROAD project, which used the outcomes to assess the Performance assessment of Cold Recycling in Place. The Re-Road project (FP7 2007-2013) aimed to develop knowledge and innovative technologies for enhanced end-of-life strategies for asphalt road infrastructure [12]. One part of this project dealt with cold recycling.

In Nordic countries, cold mixing and cold recycling has been widely used for years. Some research has been carried out by VTI on the characteristics of cold recycling materials from lab mix design and as well in-field coring [13]. Some trends and specifications have been drawn based on void content and Strength values. Results from cores out of the field show void contents between 6 % and 15 %, and ITS values ranging from 400 kPa to almost 900 k Pa; however, in this case, the ITS was performed at 10 °C and most often soft bitumen (70/100) is used as the reference.

In France, a draft standard, NFP 98-121, set in 2012, gives some specification. Among other parameters, it provides indications for the following:

- Void content up to 22%
- Strength from Duriez test at 18 ºC > 1,5 MPa and r/R > 0,55
- Complex modulus at 15 ºC and 10 Hz > 1500 MPa

There is no universal set of specifications for cold asphalt mixtures; this varies with region or country. However, the trend is to define a cold or half-warm asphalt mixture as a pavement material manufactured at lower temperature than HMA and with lower characteristics. The mixture can be made with bitumen emulsion, manufactured at ambient temperature or up to 60–80 °C; or with fluxed bitumen, manufactured half-warm at a temperature up to 120 °C. These applications require a curing time to achieve the proper characteristics for the mixture. The differences compared with HMA, as regularly reported in literature, are:

- higher void contents, up to 15 %,
- up to 2-fold lower mechanical characteristics (in terms of strength or modulus)

In this study, based on a preliminary screen, treatment with the specific bio-based rejuvenator additive clearly demonstrated a tangible effect on RA even at ambient temperature, compared to untreated RA. The additive mobilised the overall grading of RA by breaking down the granulated mortar lumps in the loose mineral gradation of RA. Furthermore, some cohesion was already apparent even within a few hours.

The more comprehensive assessment of various cold to half-warm mixing conditions provided interesting values, through gyratory compaction and ITS values.

With gyratory compaction, the curing time between mixing and compaction has no significant effect on how the materials can be compacted and on densification curves. The curves at a given temperature and different curing times almost overlapped. However, the mixing temperature has a more prominent effect. Considering a void content of 15 % after 60 gyrations as a potential specification for cold mix, this level can be easily reached at temperatures of 60 °C and higher. At 120 °C, it reached the compaction level seen with HMA, as supported by the Superpave approach M323 [8].

With respect to ITS, there are no standard values for comparison with cold mix. However, compared to the values observed for a standard HMA of 2000–2500 kPa, the mixes manufactured at 60 °C and 120 °C showed that reasonable values such as 500 to 1000 kPa could be achieved with cold mix or cold recycling. Moreover, these values were obtained without the need of curing time.

All these results taken together provide some very promising data to define a new way to recycle RA at a half-warm temperature between 60 °C and 120 °C. Compared to the option of cold recycling, it can, at the least, provide the same level of characteristics, but without the need for curing or maturation time. This provides additional value for road construction by eliminating delays before the road can be released to traffic.

This new outcome can be utilized in at least, but not limited to, three new applications, as follows:

Warm in-plant recycling: RA is processed in a drum to be dried and warmed at a temperature between 60 °C and 120 °C and later mixed for a few minutes with the rejuvenating additive that mobilises and restores the binder from the RA. Obviously, the higher the temperature, the better the results.

Hot in-place recycling: the road is heated up from the surface remixed/rejuvenated and repaved. Hot in-place recycling has shown that RA produced in situ has a temperature between 180 °C from the surface to 80 °C at the bottom of the layer to be recycled. In this case, the rejuvenation enables achieving the right level of compaction even in this range of temperature.

Pre-treatment of RA stockpile: the rejuvenating additive can be spread directly on RA either after mechanical treatment (crushing, screening) or on the stockpile. In this application, it is most likely that during summer the temperature of the stockpile can easily achieve a temperature as high as 40 °C to 60 °C. The treated RA can be used immediately after treatment for processing in an asphalt mix plant or directly for job site applications.

5 CONCLUSION

The study presented hereby displays the results of evaluating the effect of a bio-based rejuvenating additive on Reclaimed Asphalt for a half-warm manufacturing process. Because RA contains aged binder that is harder than standard bituminous binder, it requires elevated temperatures in order to "mobilise" the binder. At ambient or lower temperatures, RA is usually considered as gravel material with no cohesion/strength in an asphalt mixture. Cold asphalt mix or cold recycling processes use lower temperatures than hot or warm mix processes, in combination with bitumen emulsion or foamed bitumen. Consequently such mixes require curing/maturation times in order for the water to evaporate and the materials to build up strength, and do not reach the same levels of mechanical characteristics.

This study was based on an initial screening evaluation consisting of mixing at ambient temperature in the laboratory, pouring in a mould, allowing it to remain for a specified time, and then removing the mould. The mixes that were treated with the rejuvenating additive showed better cohesion, enabling the sample to remain in a cylindrical shape. Furthermore, the aspect of the treated RA indicated mobilisation of the RA, with a more shiny appearance and a greater proportion of loose sand granulated material.

Subsequently, a more standard evaluation was carried out with gyratory compaction and ITS measurements by varying mixing conditions, such as temperature and maturation time. Maturation time has very limited influence on compactability, whereas the temperature has a significant effect. Even at 60 °C, the void content after 60 gyrations was < 15 %, and at 120 °C it was close to 4 %. Similarly, at 60 °C and above, the ITS values were ≥1000 MPa.

This shows that recycling RA in a half-warm process between 60 °C and 120 °C with the bio-based rejuvenating additive is possible, and can provide a reasonable level of compaction and strength. Although, as expected, these values do not meet the specifications for HMA, they are in the same range of magnitude expected for cold or half-warm asphalt mixtures made with RA and/or virgin aggregates. The potential applications are for mixtures made with RA in warm in-plant recycling with a temperature starting at 60 °C, or hot in-place recycling where the produced RA has a variable temperature, as well as in pre-treatment of the RA stockpile at the mix plant.

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