Evaluation of Binder Blending on Warm Mix Recycling

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ABSTRACT

Over the past few years, the use of recycled asphalt mixtures with high contents of reclaimed asphalt pavement (RAP) has become attractive for its environmental benefits, and the possibility of reducing costs. However, the production of such type of mixtures without compromising mixture performance is still a challenge. While on cold recycling the RAP is normally considered a "black rock", on hot and warm recycling part of the RAP binder is activated, but it is hard to determine the amount of it that actually interacts with the virgin binder. For that reason, mix design is many times not done properly, and the performance of the recycled mixture is uncertain. In this paper, a staged extraction laboratory procedure was used to evaluate binder homogeneity in a plant-produced warm recycled mixture with 25% RAP. The obtained binder “layers” were analyzed using the Dynamic Shear Rheometer, by means of the frequency-temperature sweep, MSCR, and LAS tests. The used procedure proved to be an option for determining binder homogeneity in recycled mixtures, providing important information about the degree of blending in the mixture, which is useful for the design of recycled mixtures with improved performance.

Keywords: asphalt recycling, degree of blending, staged extraction, RAP.

1. INTRODUCTION AND BACKGROUND

Due to its environmental benefits and the possibility of reducing costs, reclaimed asphalt pavement (RAP) has become a valuable material for the paving industry. RAP can be used in several applications, such as granular bases or subbases and stabilized base materials, but it is through hot and warm mix recycling that it has the potential to replace more expensive materials such as the virgin asphalt binders [1]. In these processes, the aged binder present in the RAP is heated and remobilized, hence less virgin binder is necessary in the mixture. However, the use of high contents of reclaimed material without compromising the performance of recycled mixtures is still a challenge, and one reason for that is the lack of understanding about the mechanisms involved in the mixing between RAP and virgin materials [2]. In this regard, one of the major concerns is the degree of blending between recycled and fresh binders. During mix design, the virgin binder content is established assuming 100% blending between these materials, although studies have shown that what actually happens is the partial blending [3–6].

One method that has been used by some researchers to evaluate the degree of blending is named staged extraction or progressive extraction, in which the asphalt mixture is washed with solvent sequentially, extracting the binder layer by layer so that the homogeneity of the binder film can be evaluated [7]. Despite the success of these studies, in each of them different laboratory procedures were used, with different equipment, making it difficult for other researchers to reproduce them in a reliable way. With that in mind, a previous study by Gaspar et al. [8] aimed to establish a methodology for the staged extraction using standard reflux extraction equipment, but it was concluded that the duration of each extraction step needed to be adjusted in order to obtain more comparable results. Based in this scenario, the aim of the present study was to evaluate the ability of the staged extraction procedure, with adjusted extraction times, to identify binder homogeneity in a plant-produced warm recycled mixture with 25% RAP, which is related to the degree of blending between RAP and virgin binders.

2. MATERIALS AND METHODS

2.1 Materials

For this experiment a plant-produced Warm Mix Asphalt was used, consisting of basalt aggregates, unmodified asphalt binder (penetration grade 30/45), RAP, and surfactant additive (added to the asphalt binder at a ratio of 0.4% by weight). Hydrated lime was also used as a filler and anti-stripping agent. Characteristics of the asphalt binder are presented in Table 1.

TABLE 1 Characteristics of Asphalt Binder

Parameter		Brazilian specification (DNIT 095/2006)
Penetration at 25°C (0.1 mm)	37	30-45
Softening point (°C)	53	min. 52
Flash point (°C)	350	min. 235
Density at 25°C (g/cm³)	1.008	-
Brookfield viscosity at 135°C (cP)	528	min. 374
Brookfield viscosity at 150°C (cP)	248	min. 203
Brookfield viscosity at 177°C (cP)	84	76-285

The RAP characterization was carried out in the laboratory after homogenization. The binder content was found to be 5.0%, determined through the ignition method (ASTM D6307-16 Method B). The RAP content in the mixture was 25%, and the designed binder content in the final recycled mixture was 4.7% of total mix weight. During mix design, full blending was assumed between the fresh binder and the RAP binder, resulting in a Replaced Virgin Binder (RVB) ratio of 26.6%, calculated as described by Lo Presti et al. [2]. Therefore, 1.2% of the binder was present in the RAP and 3.5% of virgin binder was added.

The mixture was produced in a batch plant adapted for processing recycled pavement materials. RAP was introduced in the mix at ambient temperature, being heated by contact with superheated virgin aggregates (at 180°C), and mixing was carried out at 140°C. Mixing time was increased to 60 seconds (the usual at this plant was 20 seconds) in order to minimize residual moisture in the RAP. Samples of the loose mixture were collected and taken to the laboratory for the experimental procedures. Further information about the materials characterization and mix design are available at Lopes et al. [9].

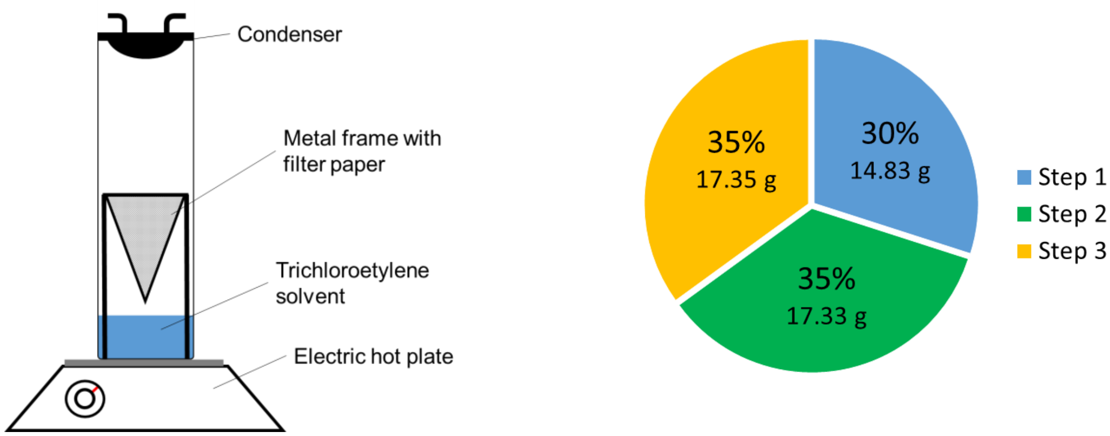
Another warm asphalt mixture was produced without RAP, with the same materials, binder content and aggregate gradation, in the same plant. This mixture (labelled as “0% RAP”) and the pure RAP were also collected and subjected to binder extraction, through the standard reflux method (ASTM D2171-11 Method B), and recovery, through Abson method (ASTM D1856-09). These extracted binders were subjected to rheological tests as described ahead, just as the binders obtained from the staged extraction procedure.

2.2 Staged Extraction and Recovery

The staged extraction procedure used was an adjustment of the reflux extraction method (ASTM D2171-11 Method B), using the same apparatus (with one cone frame only), but interrupting the extraction twice before the mixture was completely washed. At each interruption, the solution of trichloroethylene and extracted binder was collected and replaced by clean solvent. This way, the binder covering the aggregates in the mixture is extracted in three different layers. The outermost layer is removed in the first wash, and the innermost layer is extracted in the third wash. The objective of this procedure is to identify differences between the extracted layers and evaluate the homogeneity of the binder in the asphalt mixture, which is related to the degree of blending between the RAP binder and the virgin binder.

This procedure, inspired by previous studies found in the literature [4,7,10–13], is an attempt to extract different layers of the binder in a more controlled way, using standardized equipment and adapting an already widespread method. The process used here was introduced in another study by Gaspar et al. [8], where it is described in more detail, and illustrated in Figure 1(a). It was concluded that the duration of each step of the extraction (of 30 minutes, in that case) should be adjusted, since more than half of the binder was extracted in the first wash, leaving very little for the third wash. Because of that, the recovery of the third layer of binder was difficult, and some solvent might have remained in the binder.

In this paper, staged extraction was conducted with 20 minutes for the first wash and 30 minutes for the second wash, counted from the moment that the solvent began to drip from the bottom of the metal cone. The third step was carried on until the mixture was completely washed. With these extraction times, the amount of binder extracted in each step was approximately the same, as presented in Figure 1(b), which is the ideal situation. The amount of binder lost through the process was ignored. The amount of asphalt mixture used was 1.5 kg, divided in 3 reflux extraction sets. The asphalt binders from the obtained solutions were recovered using the Abson method, and evaluated through rheological tests.



(a) (b)

FIGURE 1 (a) Illustration of Extraction Apparatus [8] and (b) Weight of Asphalt Binder Extracted at Each Step

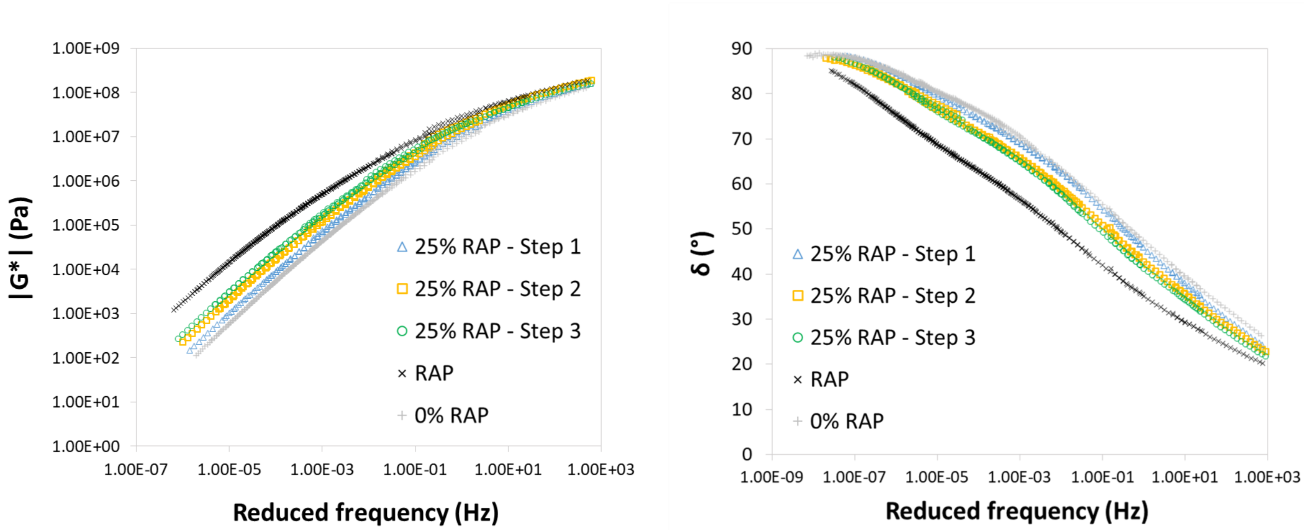
2.3 Rheological Tests

The binders recovered from the 25% RAP mixture, after the staged extraction procedure, and from the 0% RAP mixture and the pure RAP, using the standard extraction method, were tested using the Dynamic Shear Rheometer (DSR). Frequency and temperature sweep tests were carried out from 1 rad/s to 150 rad/s and from 5°C to 76°C. Two parallel-plate geometries were used: 8 mm diameter from 5°C to 40°C, with 2 mm gap, and 25 mm diameter from 40°C to 76°C, with 1 mm gap. Tests were carried in strain-controlled mode at 0.1% strain, in order to keep the materials behavior within the linear viscoelastic region. The obtained data was used to produce the master curves of the complex shear modulus and phase angle, at reference temperature of 15°C.

The asphalt binders were also evaluated by means of the Multiple Stress Creep and Recovery (MSCR) test and the Linear Amplitude Sweep (LAS) test. These two tests are used to evaluate rutting and fatigue potential of asphalt binders, respectively, and were used in this paper aiming to verify if any of them were able to capture different behaviors of each extracted layer of asphalt binder obtained through the staged extraction procedure. The MSCR tests were conducted at 70°C and 76°C, and stress levels of 0.1 kPa and 3.2 kPa, following the standard procedure ASTM D7405-15. The LAS tests followed the AASHTO TP 101-14 standard, and were performed at 20°C.

3. RESULTS AND DISCUSSION

3.1 Temperature-Frequency Sweep



(a) (b)

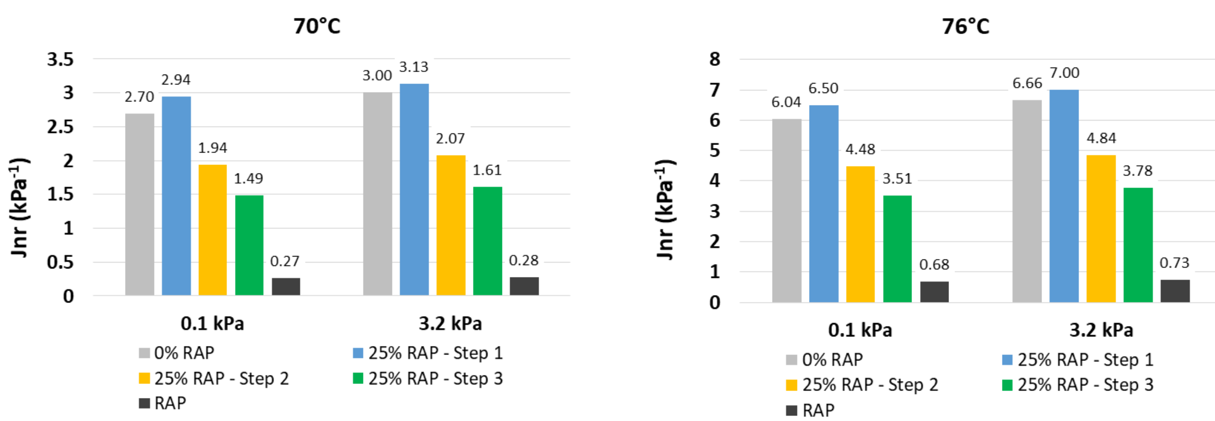
FIGURE 2 Master Curves (T=15°C) of (a) Dynamic Shear Modulus and (b) Phase Angle

The master curves of dynamic shear modulus (|G*|), and phase angle (δ) produced for the tested binders are shown in Figure 2. The RAP binder showed higher stiffness and lower phase angle values for the whole range of frequencies, a result of the aging along the years in service. On the other hand, the 0% RAP binder was the less stiff and elastic one (lower G* and higher δ), what was also expected since this binder suffered only short-term aging during the plant mixing and is not blended with the RAP binder. The difference of aging between these two binders is also recognizable through the shape of the |G*| master curve. More oxidized materials show a more gradual transition from elastic behavior to steady-state flow, what translates in a flatter master curve [14].

The binders of the 25% RAP mixture, obtained from staged extraction, showed intermediate |G*| and δ values, in relation to the other two binders, and it is possible to observe a tendency between them. The first layer of the extraction shows a behavior that is close to the 0% RAP binder and, as the extraction goes on, |G*| increases, δ decreases and the |G*| master curve becomes flatter. This observation is consistent with the hypothesis that the blending between RAP and virgin binders is gradual, and confirms that the staged extraction is capable of separating different layers of the binder that covers the aggregates. Therefore, the innermost layer extracted, obtained in the third extraction step, is stiffer and more elastic, because it has a higher amount of oxidized material in its composition.

3.2 MSCR Test

The non-recoverable compliances (J_{nr}) obtained in the MSCR tests are shown in Figure 3 for both temperatures and stress levels, and the same tendency found previously could be identified between the staged extraction binders. The three 25% RAP binders showed considerably different J_{nr} values, indicating that the high temperature performance of the materials is significantly influenced by the amount of RAP binder blended in each of the extracted layers. Differently from what was observed in Gaspar et al. [8], the adjustment of the extraction times in the present study was able to ensure that the amount of binder obtained in each step was almost the same and, as a result, the MSCR test could better distinguish them. The lowest values of compliance were obtained for the RAP binder, as it is stiffer than the others, and the 0% RAP binder had slightly lower J_{nr} values than the Step 1 binder, what was probably related to test variability.



(a) (b)

FIGURE 3 Results of the MSCR tests at (a) 70°C and (b) 76°C

3.3 LAS Test

The main outcome of the LAS test is a curve that expresses fatigue life in cycles (N_f) as a function of strain, that is presented in Figure 4 for each of the studied binders. Fatigue life is expected to be lower for a stiffer binder than that of a softer binder. However, the results showed higher N_f for the RAP binder than the 0% RAP binder for lower levels of strain. As it was concluded by Harvey and Tsai [15], increased stiffness caused by long-term aging is not necessarily detrimental to fatigue life, and the same could be observed in the present results. Nevertheless, the strain susceptibility, represented by the slope of the fatigue curve, is higher for the RAP binder than the others. Unlike what happened in the previous tests, the LAS test was not able to capture the difference of binder blending between the staged extraction binders, and their fatigue curves did not follow the same tendency that was found earlier in this study.

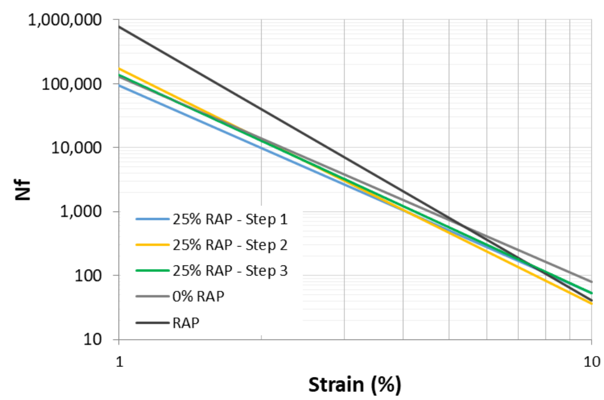


FIGURE 4 Fatigue Life Curves Obtained in the LAS Tests

4. SUMMARY AND CONCLUSIONS

This paper evaluates a staged extraction laboratory procedure used to investigate the binder (RAP binder and new binder) homogeneity in a plant-produced warm recycled mixture with 25% RAP. Based on the findings of this study, the following conclusions were drawn:

- The adjustment of the duration of each step of the staged extraction procedure, separating the binder in three approximately equal layers, is important to ensure that enough binder is recovered in each step and to improve the distinction between them. This way, the procedure can offer a better idea about the homogeneity of the binder, which is related to how the RAP binder is blended within the mixture.
- Master curves of complex modulus and phase angle are useful tools to distinguish the behavior of the binder layers obtained through the staged extraction procedure, and show a tendency of higher modulus, flatter modulus master curve and lower phase angle for binders with higher amounts of blended RAP binder.
- The MSCR test also shows a tendency of lower compliance for binders with higher amount of RAP, and is able to capture the heterogeneity in the recycled mixture studied. The same cannot be said about the LAS test, which results could not be related to the degree of RAP blending in each layer.
- Although further studies are necessary, staged extraction associated with rheological tests seems to be a promising solution to determine the degree of blending on hot and warm recycled mixtures, based on the heterogeneity of the extracted layers.

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