Influence of viscoelastic properties of cold recycled asphalt mixtures on pavement response

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ABSTRACT

Cold recycled asphalt mixtures (CRAMs) have been widely used in pavement construction and rehabilitation of base course materials. Some studies describe the CRAMs as granular materials, without stiffness dependency regarding temperature or frequency variation, while other researches state that it resembles a viscoelastic material; the CRAMs mechanical behavior is not fully understood. For this paper, dynamic modulus tests were conducted with CRAMs samples. The master curves suggest a viscoelastic behavior for this type of mixture. The dynamic modulus results were used as input data in 3D-Move Analysis software and it was found that the temperature dependency of CRAMs' stiffness influences the pavement response. Therefore, its viscoelastic properties cannot be neglected.

Keywords: Cold recycled asphalt mixtures; Dynamic modulus; Temperature dependency; 3D-Move software.

1. INTRODUCTION AND BACKGROUND

Cold recycled asphalt mixtures (CRAMs) have been extensively used in pavement structures, mainly as base course materials. Since CRAMs are comprised by reclaimed asphalt pavement (RAP) aggregates, and does not require mixture heating for proper mixing procedure, the cold recycling technique provides several sustainable benefits, for instance: lower virgin aggregate consumption, reduction of the polluting gases emission, reduction on aggregate transportation costs (in-situ recycling), and greater reclamation levels of milled aggregates [1, 2].

Nonetheless, the mechanical behaviour of CRAMs is not fully known. The South African approach considers CRAM as granular materials with higher cohesive strength. For construction purposes, the Asphalt Academy Technical Guideline [3] states that CRAMs should be treated as unbound granular materials since they have similar void content. Therefore, no temperature dependency should be expected. Guatimosim also observed stress dependency of CRAMs stabilized with foamed asphalt [4]. For higher confining pressures, greater resilient moduli were obtained, which is a characteristic behavior of granular materials. Other researchers also assume CRAMs as granular materials [5-7].

On the other hand, some studies have investigated the viscoelastic properties of CRAMs. Ebels reported that, albeit CRAMs master curves are flatter than HMA's, the stiffness is temperature dependent [8]. Leandri *et al.* observed similar results and used the dynamic modulus master curves of CRAMs and HMA as input data for pavement structure simulation in

ViscoRoute 2.0 software [9]. It was found that considering the viscoelastic properties of CRAMs, the predicted stresses and strains presented good fit with the measured ones, especially for CRAMs stabilized with asphalt emulsion. Other researchers have also considered the CRAMs as viscoelastic materials [10-12].

Thus, the goal of this paper is to characterize the CRAMs in terms of its viscoelastic characteristics and use these properties for the analysis of pavement response under different temperature conditions. Seeing that different approaches have been used for CRAMs characterization, a better understanding of the mechanical behaviour of this material is necessary. This will provide a more accurate representation of CRAMs behavior, reducing the chances of early distresses during pavement field performance.

2. **MATERIALS AND TEST METHODS**

2.1 Materials

The analysis of the viscoelastic properties was conducted for two CRAMs: (i) Asphalt Emulsion Mixture (AEM) and (ii) Foamed Asphalt Mixture (FAM). The RAP used in both mixtures was obtained from milling of the Fernão Dias Highway (BR-381) in São Paulo, Brazil. Both the AEMs and FAMs met the grading requirements specified by Wirtgen [13]. A Proctor hammer with modified compaction energy was used to produce the specimens with 100 mm diameter and 150 mm height.

The AEM samples were prepared by mixing 98% of RAP and 2% of Portland-limestone cement by dry aggregate weight. A slow-setting cationic emulsion was selected (62.3% of nominal binder content) with 3% emulsion content by dry aggregate weight. The moisture content was 5.5% by dry aggregate weight. The curing procedure proposed by Bessa *et al.* [14] was modified with an additional curing time. The samples were stored unsealed at 60 ºC for 3 days. After that they were sealed and cured for three additional days at 60ºC. Since the core of the samples might have higher moisture content than the border, the additional sealed procedure ensures that the moisture is uniformly distributed within the sample geometry.

The FAMs have an aggregate blend of 68% of RAP, 30% of fine aggregate blend and 2% of Portland-limestone cement by dry aggregate weight. The addition of fine aggregate blend is required for FAMs, because the asphalt binder dispersion occurs exclusively throughout the finer particles of FAMs. Therefore, for a proper dispersion of asphalt binder, the amount of finer particles required is greater than AEMs, in which the dispersion of the asphalt binder occurs preferentially throughout the finer particles (Asphalt Academy, 2009). The bitumen for the foaming process has 85/100 penetration grade with 3% bitumen content by dry aggregate weight. For the foaming process, 2.6% of foaming water was necessary, and 6.5% for moisture content by dry aggregate weight was selected for compaction. The FAMs samples were cured at 40 ºC, unsealed, until they reached 60% of the OMC [4]. After that, the specimens were sealed and kept at room temperature of 25 ºC.

2.2 Laboratory test

To evaluate the viscoelastic properties of AEMs and FAMs, the dynamic modulus test was conducted (AASHTO TP79-12) after complete the curing process [15].

Six frequencies were used (25, 10, 5, 1, 0.5 and 0.1 Hz) along with four temperatures (54, 37.8, 21.1 and 4.4 ºC).

For the dynamic modulus master curve, the sigmoidal model parameters δ, α, β and γ were calculated, as shown in Eq. (1). The f_r parameter is the reduced frequency.

$$\log|E^*| = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log(f_r)}} \quad (1)$$

2.3 3D-Move Analysis simulation

The 3D-Move software is a continuum-based finite-layer approach to evaluate the pavement response to moving loads with different speeds, tire-pavement contact areas, and temperature conditions [16]. The 3D-Move software has been used to validate pavement responses and to compare field with pavement-modelled data [17-20].

The test sites in Fernão Dias Highway with AEMs and FAMs as base courses were reproduced at 3D-Move software. The pavement structures with AEM (Figure 1a) and FAM (Figure 1b) are illustrated along with the input parameters of the materials used in the simulation, as Poisson ratio and thickness. It is worth noting that the structure under the milled pavement is referred in this paper as “remaining structure”. The Light Weight Deflectometer test was performed in the remaining structure and the resulting modulus of 118 MPa was used as input for the simulation.

For the tire-pavement contact configuration, a circular contact area was selected, with radius of 0.107 m and tire pressure of 560 kPa. For load application, a semi-axle configuration was used with 20 kN/tire uniformly distributed. The semi-axle load is also illustrated in Figure 1. A low speed of 40km/h was selected in order to simulate the worst case scenario for traffic loading.

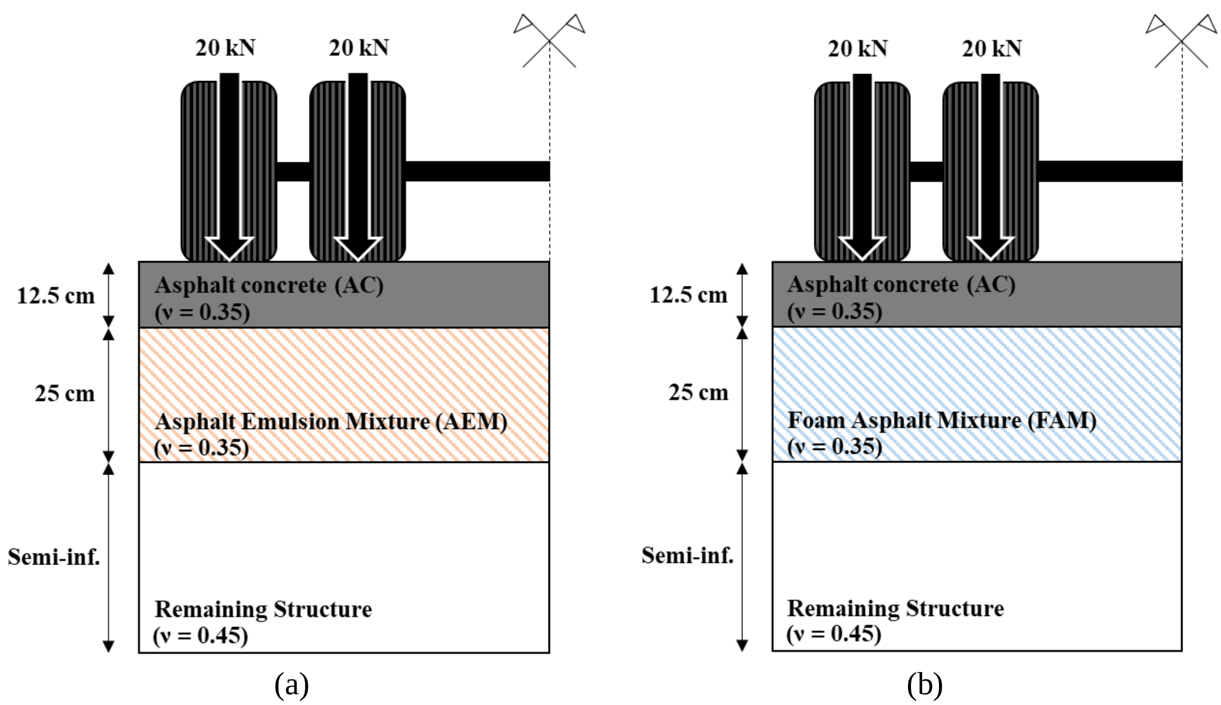


FIGURE 1 Pavement structure with (a) AEM and (b) FAM as base courses

To evaluate the effect of temperature dependency of the test sites with AEM and FAM in pavement response, three temperature conditions were used: (i) W30B20, (ii) W25B15 e (iii) W20B10. The “W” and “B” letters correspond respectively to the wearing (AC) and base courses

(AEM and FAM); the numbers represent the temperatures, in Celsius, used in the simulation for each layer.

The viscoelastic properties obtained from laboratory tests were used as input data for 3D-Move Analysis simulation. The AC, AEM and FAM were characterized in terms of its dynamic modulus master curves. For the binder input data, a dynamic shear rheometer was used and the |G*| and δ parameters were determined at different temperatures and frequencies.

3. RESULTS

3.1 Viscoelastic properties

Figure 2 presents the dynamic modulus master curves for the AC, AEM and FAM at the reference temperature of 21.1ºC. At low reduced frequencies, the AC presents the lowest dynamic modulus values. However, at high reduced frequencies, the AC dynamic modulus is higher than the one from the CRAMs. It indicates that the AC is more thermo-sensitive than the CRAMs.

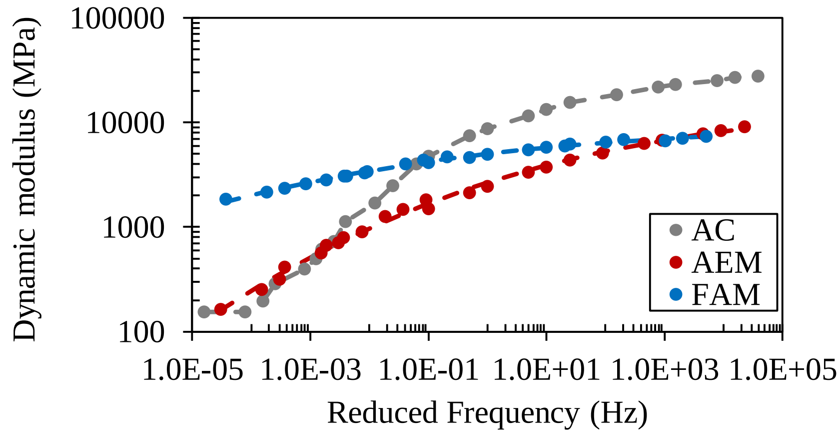


FIGURE 2 Dynamic modulus master curves of AC, AEM and FAM mixtures

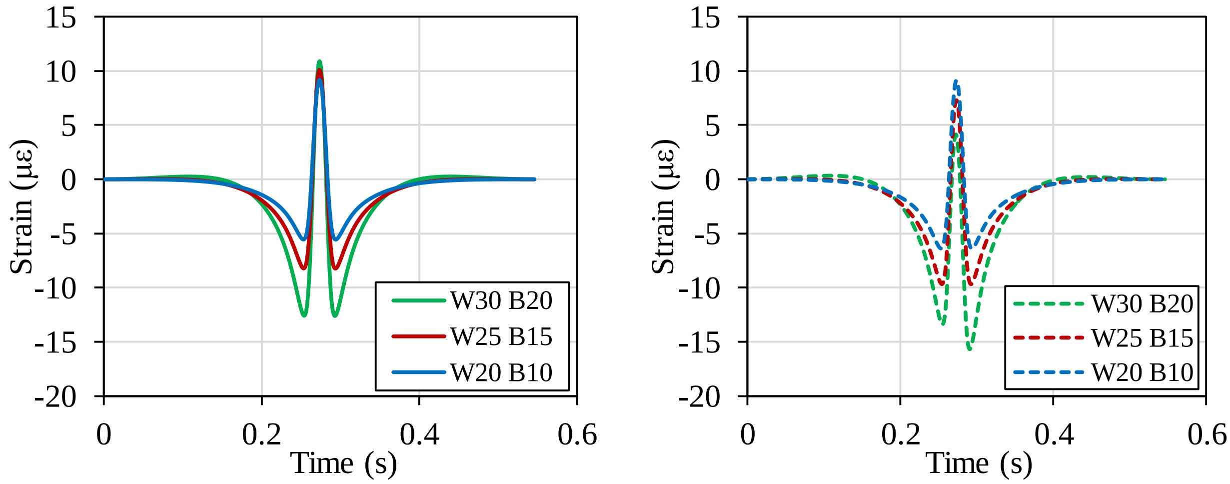
Comparing the CRAMs' master curves, despite both mixtures presented good fit with the sigmoidal model, the master curves are quite distinct from each other, with the FAM's master curve less thermo-sensitive than the AEM's. At high reduced frequencies, or low temperatures, the dynamic modulus of both mixtures is similar. On the other hand, at low reduced frequencies, or high temperatures, the dynamic modulus of FAMs is higher than AEMs'. This behavior was also observed in the literature [9] and could be explained comparing the gradation curves of each material. At higher temperatures, the bitumen becomes more fluid and the mechanical properties of the samples are dominated by the aggregate gradation. Considering FAMs have a higher content of finer aggregates, the smaller particles fill in the voids created by the coarse particles, creating a more imbricated aggregate skeleton. It is important to note that a finer gradation is required for FAMs to ensure proper bitumen dispersion during mixing procedure, as mentioned before [3].

AEMs' master curve also suggests that the aggregate composition influences the dynamic modulus results. Since RAP is a combination of aggregates and aged bitumen, the total bitumen content within the mixture increases as RAP content increases. Considering AEM have higher RAP content (98%) than FAM (68%), the binder content of the former is greater than the latter.

Therefore, as temperature increases, the AEMs' stiffness decreases faster, which describes the master curve higher slope for this type of mixture. For the FAMs, as the binder content is lower, the temperature increase will not significantly reduce its stiffness. It is important to note that despite the significant difference in RAP content between CRMs, the AEM and FAM are different mixtures, with distinct gradation curves, aggregate blending, and bitumen content.

3.2 3D-Move results

To evaluate the influence of temperature on pavement response, analysis of the strain at the bottom of the wearing course was conducted. This was done considering that most of the fatigue models for flexible pavement uses the tensile strain as an input data. Figure 3 presents the strain results at different temperature conditions for the test sites with AEM (Figure 3a) and FAM (Figure 3b) right under the outer tire centerline. The positive values correspond to the tensile strain and the negative values correspond to the compression strain.



(a) (b)

FIGURE 3 – Tensile strains at the bottom of the asphalt concrete layer with (a) AEM and (b) FAM base courses

Figure 3 shows that as temperature increases the compression strain also increases for both pavement structures. At high temperatures, the AC stiffness reduces and the stress level at the bottom of the wearing course increases. Loulizi *et al.* obtained similar results from instrumented pavement sections data in the state of Virginia, United States [21]. Therefore, with the increase of stress level, the compression strain also increases.

On the other hand, the trend in tensile strain results differ from AEM and FAM simulations. In order to evaluate stiffness of the pavement layers from isochronous curves, Brown's model was used to determine the frequency related to the simulated vehicle speed. Brown's model is presented in Eq. (2), in which *t* is the loading time (s), *d* is the depth (0.124 m) and *v* is the vehicle speed (40 km/h).

$$\log(t) = 0.5d - 0.2 - 0.94\log(v) \qquad (2)$$

Since the loading time in Eq. (2) is the inverse of the angular frequency of the sinusoidal applied load, the corresponding frequency of 7.0 Hz was then calculated. Therefore, the frequency of 5 Hz of the dynamic modulus test is the most similar to the frequency obtained from Brown's model. Figure 4 shows the isochronous curves for the materials at 5 Hz.

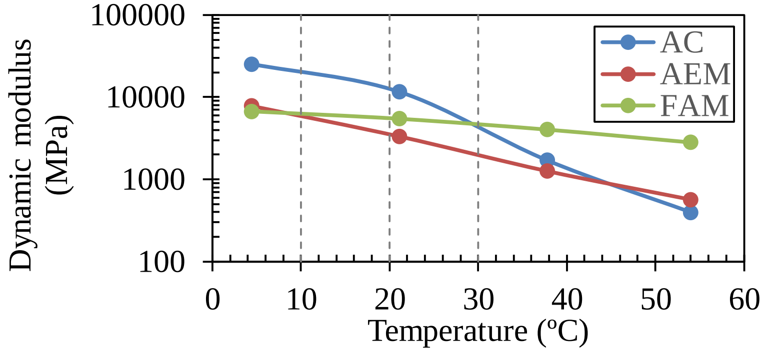


FIGURE 4 Isochronous curves at 5 Hz

Since AEMs are more thermo-sensitive, its stiffness decreasing rate is greater than FAMs at higher temperatures. This trend can be more easily observed in Figure 4 for the simulated temperatures. Therefore, as temperature rises, the AEM stiffness reduces, resulting in greater tensile strain results, as seen in Figure 3a.

On the other hand, Figure 3b shows a different trend for tensile strain values at the FAM pavement structure. As temperature increases, the tensile strain on the bottom of AC layer decreases. It can be explained by FAMs' stiffness values from Figure 4. At the temperature condition of W20B10, the AC layer stiffness (10000 MPa) is greater than FAM's (5000 MPa). However, when temperature rises to 30ºC in the wearing course and to 20ºC in the base course, the FAM's stiffness (6000 MPa) becomes higher than AC's (3000 MPa), since FAMs are less thermo-sensitive. This result suggests that as temperature raises the FAM will become increasingly stiffer than AC, reducing the tensile stress at the bottom of AC layer. Thus, the tensile strain will also reduce.

4. CONCLUSIONS

The paper herein presents the viscoelastic properties of CRaMs, and used these properties as input data for 3D-Move Analysis simulation. The following conclusions can be drawn:

- Both AEM and FAM are thermo-sensitive materials and its viscoelastic properties cannot be neglected.
- The finer gradation of FAM compared to AEM explains the flatter shape of FAM's dynamic modulus master curve. Besides, the higher RAP content in AEM may contribute to the AEM's stiffness greater temperature dependency.
- From 3D-Move results, the increase in temperature cause an increase in compression strain at the bottom of the AC layer for pavement structures with AEM and FAM.
- As temperature increases, the tensile strain on the bottom of AC layer also increases for AEM pavement structure. On the other hand, the tensile strain decreases for FAM pavement structure. This could be explained by the different temperature dependency characteristics of the base course materials evaluated.
- Considering CRAMs as elastic materials hinders the temperature effect on the stiffness of these materials. This could lead to incorrect tensile strain results, which are commonly adopted as fatigue model input data.

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