Four-point bending mechanical behavior of aged asphalt mixtures containing charcoal

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Abstract

The asphalt coating is the layer responsible for resisting the traffic stresses of a highway. However, the search for new materials to mitigate environmental impacts and improve pavement quality is increasing. Thus, the mechanical behavior of asphalt mixtures was analyzed through the four-point bending test after the molding process and aged, with the participation of residues in the form of charcoal. The frequencies of 1Hz, 3Hz, 5Hz, 10Hz, 20Hz and 1Hz are considered at temperatures of 25°C and 40°C. The aging process contributed to improve the mechanical characteristics of the charcoal mixture at a temperature of 25 ° C, considering that there was an increase in stiffness at frequencies from 1 to 20 Hz, as well as a reduction in phase angle at frequencies of 3 Hz. , 5 Hz, 10 Hz and 20 Hz.

Key words: asphalt mixtures; charcoal; four-point bending;

1. Introduction

The covering of a floor directly receives the efforts from traffic, and it is intended to provide comfort and safety to users (GENTY et al, 2011). Among the materials used for the execution of this layer are:

interlocking floors, bricks, reinforced concrete and bituminous mixtures. Among the hot bituminous asphalt compositions, the Asphalt Concrete (AC) stands out. It can be defined as a suitable mixture of petroleum asphalt cement (PAC), filler, and fine and coarse aggregates. In this composition, aggregates account for approximately 94% to 96% of the weight of the mixture while the binder participates in the formulation with a percentage of about 4% to 6% by weight (GAO, 2014). Considering that asphalt cement is a viscoelastic material, it is affected by small changes in temperature and loading rates (KING, 2004). In this sense, the study of the phase angle and the dynamic modulus becomes important in order to analyze the mechanical behavior of asphalt mixtures, such as the four-point flexural test. The mentioned essay studies a prismatic beam containing four support points (QUITERO, 2016). It is noteworthy that two points are at the extremes and two points are located in the internal region of the beam, being used for the load application. Thus, the bending moment originated in the central third of the beam is constant, conditions to this stretch a state of uniform stress and without shear forces characterizing the pure bending (MARÉ, 2011). It is noteworthy that the aging of such asphalt compositions significantly affects pavement performance (PAN, 2018). In such process a series of chemical reactions occur, like oxidation and volatilization, as well as the influence of external factors such as temperature and oxygen that contribute to the reduction of the coating quality (XIAO-GE, 2015). The present work analyzed the phase angle and complex modulus, as in the studies by King (2004) and Pellinen et al. (2003), according to the four-point bending test of beams containing asphalt mixtures with charcoal shortly after molding and aged for 1 year.

2. Sample Materials and Preparation

The following materials of granite origin were asphalt mixtures: gravel 0 (4.8 mm to 9.5 mm), gravel 1 (9.5 mm to 19 mm) and stone dust (less than 4.8 mm). Also included in the compositions there were sand (fine aggregate), with grains ranging from 0.6 to 2.4mm, and petroleum asphalt cement (PAC).

2.1 Charcoal

The charcoal used in the asphalt formulations came from coal kilns. This material originates from the burning (with temperatures ranging from 300 to 400 ° C) of residues of native Amazonian plant species, such as imbaúba, pau de lacre and others (Figure 1). It was ground by means of a hand grinder, and then passed through a 2mm aperture sieve.

Figure 1. Charcoal

2.2 Dosage

Asphalt mixtures of the asphalt concrete (AC) type of reference and alternative additive with charcoal were obtained, obeying the proportions presented in Table 1.

Table 1: Studied compositions, AC e ACCV.

Asphalt Coating Composites							
Sample	Gravel 0	Gravel 1	Grit	Medium sand	CAP 50/70	Alternative material	Charcoal content
AC	28,2%	14,8%	28,2%	23,8%	5%	-	-
ACCV	28,2%	14,8%	28,2%	23,8%	5%	Carvão	3%

Prismatic beam-shaped specimens were made in a specific, robust and demountable metal mold. In the molding of the CP's a Bovenau P3000 hand hydraulic press was used, with a capacity of 30 tons. The samples were compressed to the preset height according to the compaction test parameters. After the specimens were made, the mechanical behavior was determined by the four-point bending test immediately after molding and after one year of their manufacture (aged beams) at two different temperatures (25°C and 40°C).

3. Test method

The asphalt mixtures made in the shape of beams and tested in the IPC Four Point Bending Apparatus (Figure 2) were subjected to two central loads of the same intensity. Thus, considering that the PC is supported at its ends, the equipment submits the beam to a flexion at 04 points, that is, a structural system in which the central section of the PC presents pure flexion. Therefore, no shear stresses occur.

Figure 2: four point bending test equipment.

It is noteworthy that the IPC Global equipment consists of a pneumatic system for the application of loads, it has transducers for data acquisition and a computer personal unit (CPU) that allow the total control of the experiment by users and the recording of data acquired. The beam is seated on supports that allow free rotation and horizontal displacement, but restrict the vertical movement of the specimen. The frequencies of 1Hz, 3Hz, 5Hz, 10Hz, 20Hz and 1Hz, temperatures of 25 ° C and 40C, maximum strain amplitude of 50 μm / m and one cycle with 100 repetitions for each frequency analyzed were considered. It is noteworthy that through the four-point bending test it is possible to analyze the mechanical behavior of the structure by studying the phase angle and the complex modulus (stiffness modulus). This gives the possibility of obtaining the behavior of the asphalt compositions in terms of elasticity and viscosity. In determining such parameters, stiffness can be defined as an intrinsic property of asphalt concrete, related to the slope of the stress strain curve (MARÉ, 2011), which depends on a number of factors that influence the achievement of these results such as loading rate, temperature and age of the concrete. sample (PAN, 2018). The four-point bending system consists of a prismatic beam containing four support points, with two points at the extremes and two points located in the inner region of the beam and used for load application. Thus, the bending moment originated in the central third of the beam is constant, which conditions to this stretch a state of uniform stress and without shear forces characterizing the pure bending, as it can be observed in Figure 3.

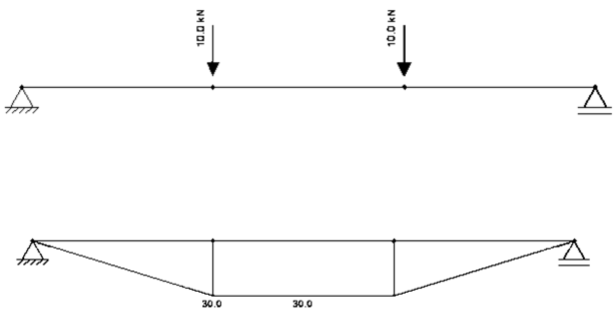


Figure 3: Isostatic beam subjected to pure bending.

Thus, by subjecting in this system a specimen to load pulses, the response they produce in terms of deformation is analyzed. Therefore, the stresses and equivalent deformations are sinusoidal, and the distance between the sinusoid peaks corresponds to the period of the wave motion. It is noteworthy that in the four-point flexion test to be performed, we seek to simulate sections of pavements subjected to vehicle movement. Then, the beam is subjected to load pulses at a certain frequency that produce deformations, as shown in Figure 4. Considering that the loads are applied at different frequencies, both the stresses and the resulting deformations have sinusoidal behavior. parameters ϵ_0, σ_0, δ, ie strain amplitude, stress amplitude and phase angle (amplitude from 0 ° to 90 °), respectively.

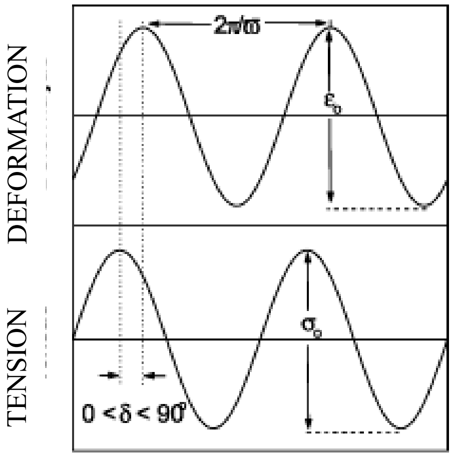


Figure 4: Answer example: stress pulse and its deformation.

Evaluating that asphalt mixtures have viscous characteristics, the parameter called phase angle is responsible for measuring the elasticity or viscosity of the material, considering the gap between the peaks of the stress and strain sinusoidal graphs (LYTTON, 2000). So, when the value of this parameter is closer to 90º, the material has viscous characteristics and it is therefore called Newtonian. If the phase angle value is close to 0 °, the material has elastic characteristics, in this case, it is called hookeno. Thus, period (T) is defined as the distance between the sinusoid peaks, which can be calculated by considering Equations 1, 2 and 3.

$$\omega = 2\pi f \quad (1)$$

$$T = \frac{1}{f} \quad (2)$$

$$T = \frac{2\pi}{\omega} \quad (3)$$

According to Otto (2009), the mathematical equations related to the applied stress and the equivalent strain are derived from the study of Simple Harmonic Motion (SHM) and can be expressed respectively by equations 4 and 5. Thus, when subjected to a stress σ (t) the material, due to its viscoelastic characteristic, responds as a lagged deformation ϵ (t) δ:

$$\sigma\,(t) = \sigma_0 . sen(\omega t) = Im\,(\sigma^*) \rightarrow \sigma^* = \sigma\,_0 e^{i\omega t} \quad (4)$$

$$\epsilon\,(t) = \epsilon_0 . sen(\omega t\, +\, \delta) = Im\,(\epsilon^*) \rightarrow \epsilon^* = \varepsilon\,_0 e^{i(\omega t - \delta)} \quad (5)$$

Where:

σ_0 = tension amplitude;

ϵ_0 = deformation amplitude;

ω = pulsation (rad/s);

δ = phase angle;

t = time;

i = $\sqrt{-1}$

In this context, the δ lag makes it possible to analyze the viscous character of the material. If δ = 0, the material is considered elastic. According to Quintero (2016), the relationship between stresses and complex deformations is defined as a complex module, according to Equation 6.

$$E^*(t) = \frac{\sigma^*}{\varepsilon^*} \tag{6}$$

Where:

E^*= stiffnnes modulus;

σ^*=complex tension sinusoidal;

ε^*= complex amplitude of deformation sinusoidal;

Thus, the complex module can be represented by a real and an imaginary part, being physically interpreted as the vector sum between the elastic component (real part) and the viscous component (imaginary part) of the module. Then, from Equation 6, it is possible to describe the viscoelastic behavior in the frequency domain of asphalt mixtures, according to Equation 7, 8 and 9.

$$E^*(t) = \frac{\sigma_0}{\epsilon_o} e^{i\varphi} = \frac{\sigma_0}{\epsilon_0}(cos\varphi + isen\varphi) = E' + iE'' \tag{7}$$

$$E' = \frac{\sigma_0}{\epsilon_0}.cos\delta \tag{8}$$

$$E'' = \frac{\sigma_0}{\epsilon_0}.sen\delta \tag{9}$$

It is noteworthy that the value inherent to the plot E´ represents the elastic portion of the material being called storage modulus or elastic modulus. The value relative to E "corresponds to the portion inherent in the viscous portion of the material being called loss modulus or viscous modulus. Thus, considering that Equation 7 represents a complex number, it can also be represented graphically, as observed. See Figure 5.

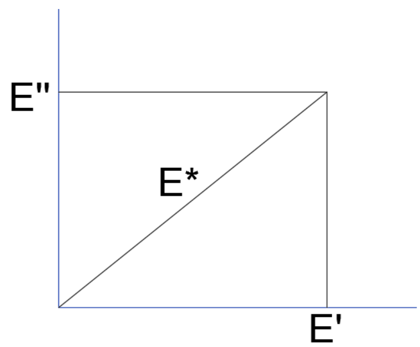


Figure 5: Graphical representation of the complex module.

Therefore, it is noted that the phase angle can be calculated by the tangent of the angle formed between the elastic portion (E´) and the viscous part of the material (E ”) resulting in Equation 10. In addition, the complex module can be calculated by Equation 11 as the square root of the sum of the squares of the elastic and viscous part of the material.

$$tg\delta = \frac{E^{"}}{E'} \qquad (10)$$

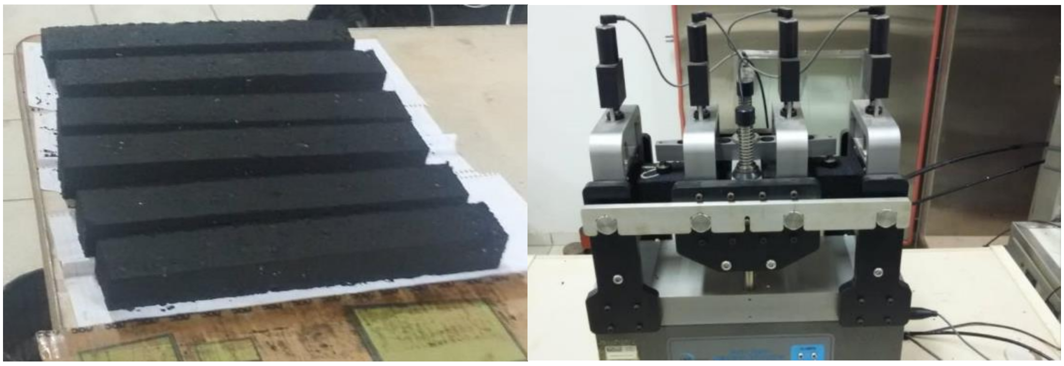
$$|E^{*}| = \sqrt{E_1^2 + E_2^2} \qquad (11)$$

4. Discussion of results

AC beams were molded according to two designs, the reference composition and alternative mixture with the participation of charcoal (ACCV), according to the contents informed in Table 2. It is worth remembering that such formulations were tested in two steps, soon after molding and after one year of manufacture (aged beams). The first, at the temperature normally used in articles (Kok, 2012) and (Lytton, 2000) equal to 25 ° C, and the second, at a temperature around 40 ° C, representative of field conditions. Figure 6 shows the asphalt concrete beams, before and after positioning in the equipment, to perform the flexion experiment. The visco-elastic behavior of the studied AC beams, before and after the aging process, can be verified in Figures 7 to 10. The non-alignment of the graphs referring to the peaks force x time and displacement x time is observed. The viscous influence of petroleum asphalt cement is outlined.

Table 2: Asphalt concrete specimens for 4-point bending test

COMPOSITION	SAMPLE	TYPE OF ASPHALTIC MIXTURE	ALTERNATIVE MATERIAL	CONTENT	TEMPERATURE
ASPHALTIC MIXTURES	AC	Asphalt concrete	--	--	25 °C / 40 °C
	ACCV	Asphalt concrete	CHARCOAL	3%	25 °C / 40 °C



(a) (b)

Figure 6: Asphalt concrete beams: (a) before test. (b) positioned on the flexion equipment at 4 points.

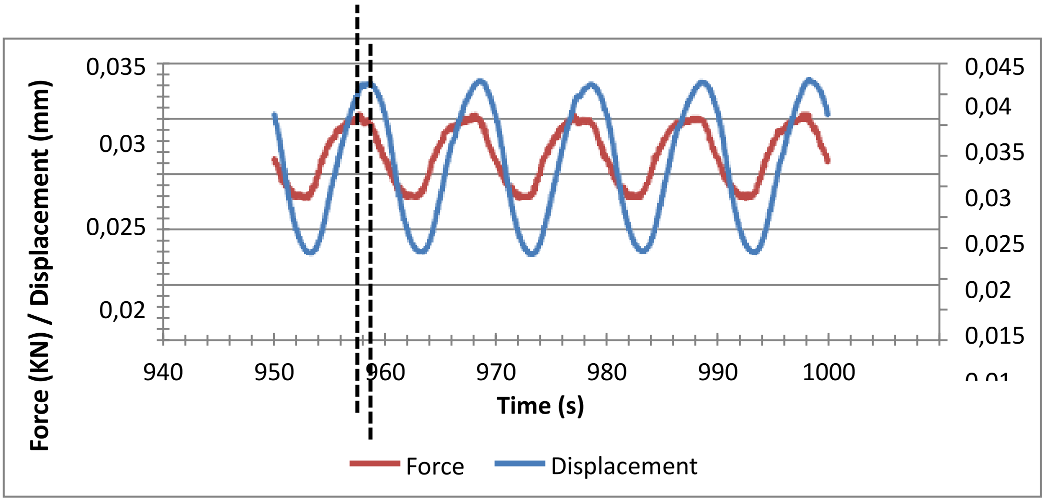


Figure 7: Force and displacement for non-aged AC beams.

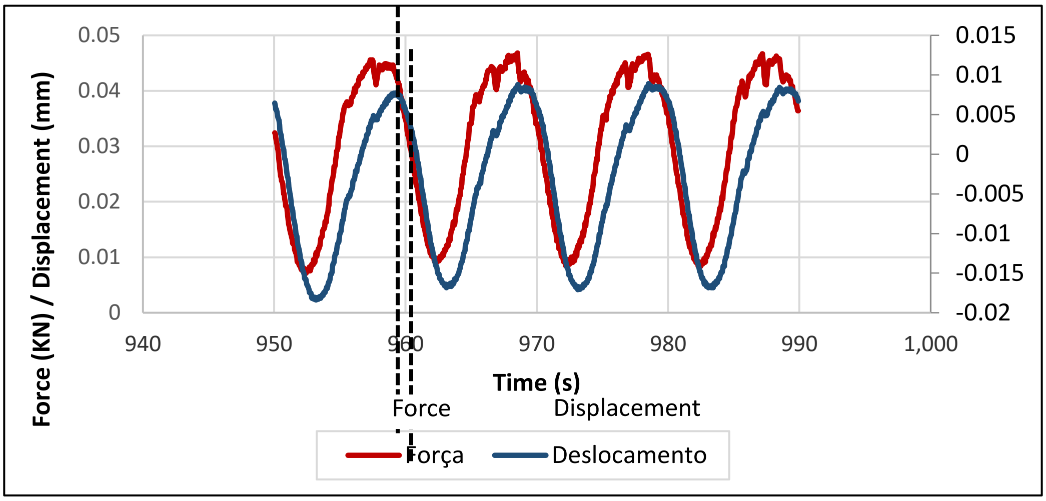


Figure 8: Force and Displacement for Aged AC Beams.

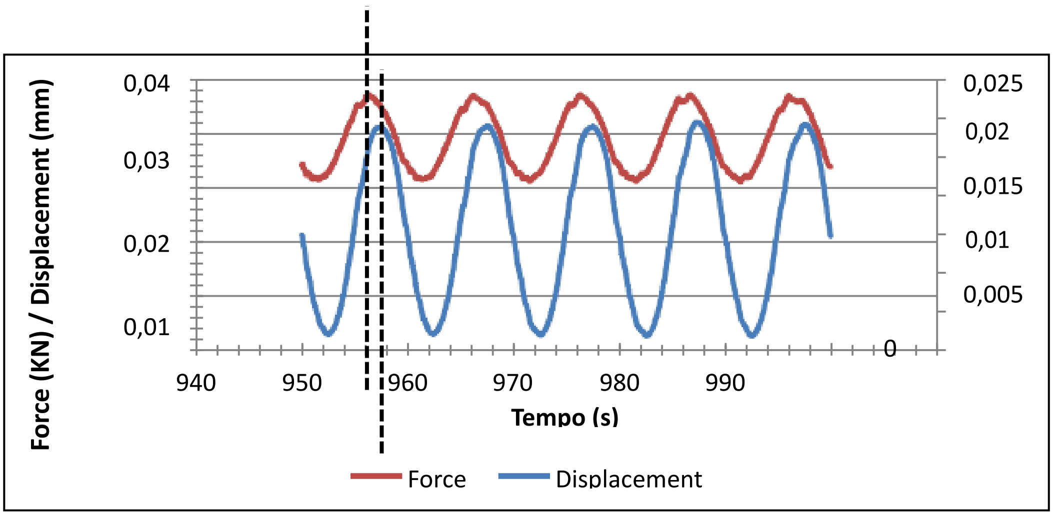


Figure 9: Force and displacement for non-aged ACCV beams.

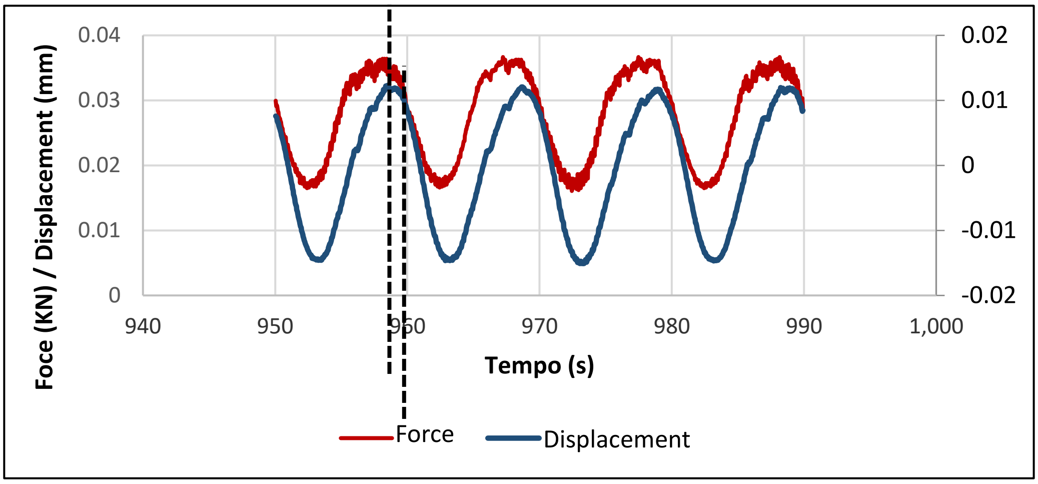


Figure 10: Force and displacement for aged ACCV beams.

Considering the results of the reference beams (without and with aging) shown, the force sine showed maximum peaks of the order of 0.03 kN and 0.045 kN, respectively. Regarding the displacement sinusoid, the resulting values were equal to 0.04 mm and 0.009 mm, respectively. Considering the non-aged and aged beams containing charcoal (ACCV), the sinusoid graphs presented maximum peaks close to 0.036kN. Concerning the displacement sine, the values resulted in 0.02mm and 0.014mm for the aged and non-aged beams, respectively. Concerning the average phase angles for the non-aged and aged beams, these are shown, for each frequency range and at temperatures of 25 ° C and 40 ° C, in Figures 11 and 12. In the non-aged asphalt concrete (AC) beams At 25 ° C, the highest phase angles were recorded for the lowest frequencies (1Hz, 3Hz and 5Hz). Similar behavior was obtained by Xiao-ge (2015). However, in the case of aging beams the highest phase angles occur at the highest frequencies (10 Hz and 20 Hz). Regarding the non-aged ACCV composite and at 25 ° C, compared to the aged ACCV composite at the same temperature, a larger phase angle was noted only at the frequency of 1 Hz, approximately 7.89%. In the other frequencies there was a reduction according to the following percentages: 35.71%, 62.50%, 66.67% and 50% for the partial frequencies of 3Hz, 5Hz, 10Hz and 20Hz.

After raising the test temperature to 40 °C, it was noted that the phase angles for the aged AC mixtures increased compared to the non-aged mixtures. It is noteworthy that the difference is of the order of 16.67%, 63.15%, 78.37%, 84.21% and 85.71% for frequencies from 1 to 20 Hz, respectively. Regarding aged, compared to non-aged ACCV composites, this parameter decreased at 1 Hz frequency (23.68%). In addition, there is a percentage increase of 73.33%, 76.67%, 87.09% and 95.12% in the frequencies of 3 Hz, 5 Hz, 10 Hz and 20 Hz, respectively.

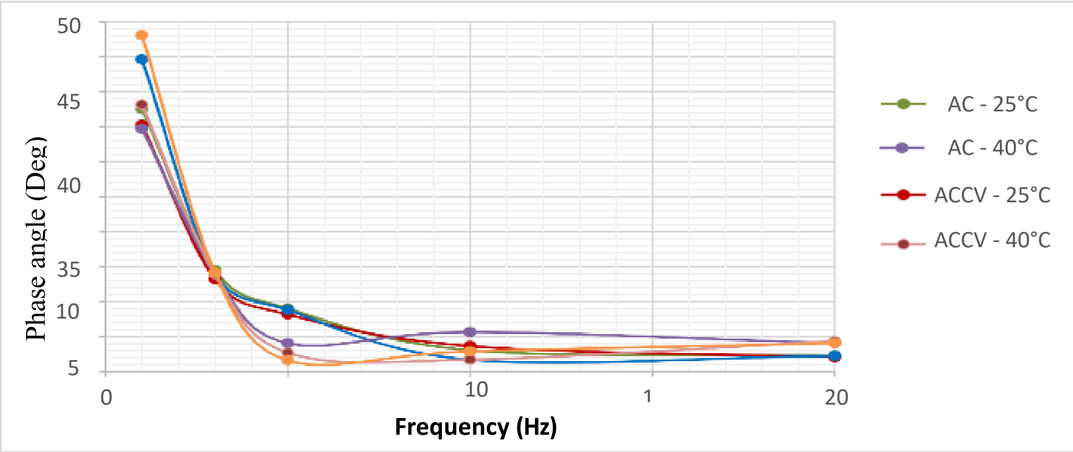


Figure 11: Phase angle of AC and ACCV asphalt concrete beams before aging.

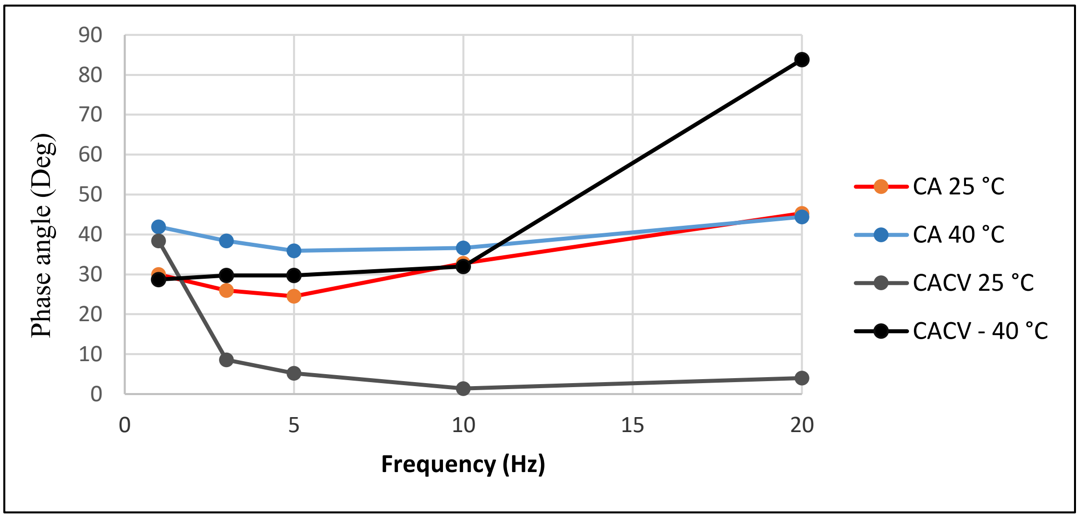


Figure 12: Phase angle of AC and ACCV asphalt concrete beams after aging.

Concerning the complex modulus, for asphalt mixtures, the average results for the non-aged and aged beams are shown in the graphs of Figures 13 and 14. It can be observed at the temperature of 25°C and from the stiffness point of view whether found that aged AC was more advantageous when compared to aged AC, with an increase of 56.67%, 55.66%, 54.82%, 50.91% and 47.81% for the test frequencies of 1 to 20Hz. In turn, aged ACCV showed an increase of stiffness in the order of 23.30%, 10.61%, 12.62%, 10.09% and 8.21% compared to the non-aged ACCV. These conclusions were also obtained by Young (2014) when studying asphalt mixtures. Specific to the 04 point bending test at 40 ° C, it was noted that the values of the modulus of stiffness for the aged beams without additives are higher than those coming from the non-aged beams in the order of 38.71%, 51, 17%, 61.87%, 62.34% and 56.70%, with reference to frequencies from 1 to 20Hz. However, it is found that ACCV composites at this temperature have the most advantageous results with respect to non-aged formulations. Results for the 1Hz, 3Hz and 5Hz frequencies will show a respective percentage change of 10.53%, 16.00% and 22.22%. However, there was a decrease in stiffness in the 10 Hz and 20 Hz partials, 19.35% and 25.45%. In general, the CA and ACCV asphalt mixtures recorded the values of the complex modulus progressively by increasing the test frequencies, as shown in Figures 13 and 14.

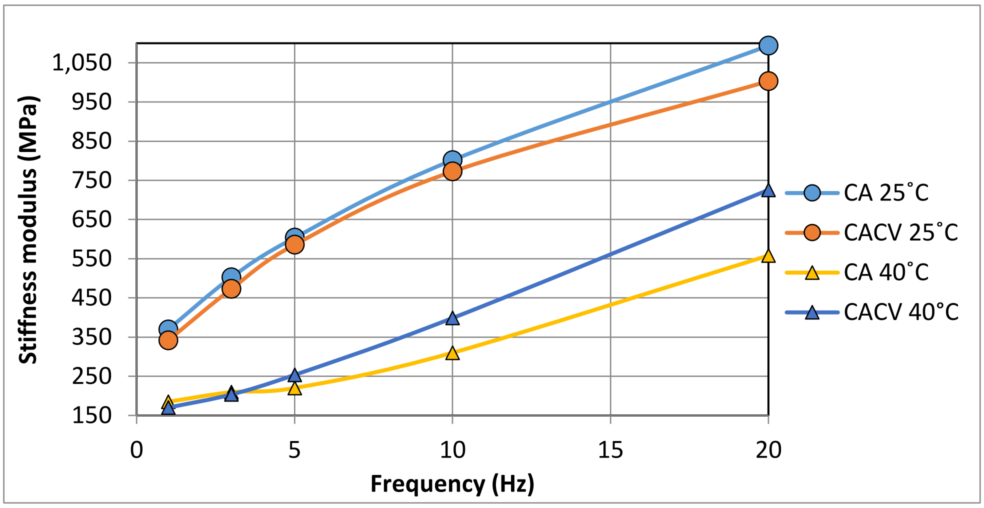


Figure 13: Complex modulus x frequency of non-aged AC and ACCV asphalt mixtures.

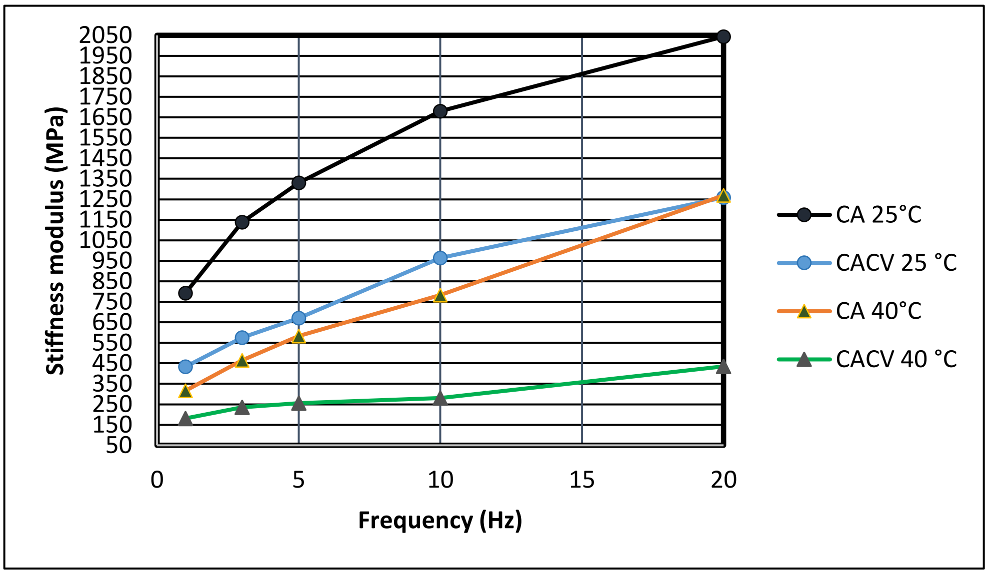


Figure 14: Complex modulus x frequency of aged AC and ACCV asphalt mixtures.

5. Conclusions

Charcoal was used as a participant in non-aged and aged composites intended for the asphalt floor covering layer. Regarding the phase angle, for the compositions without the presence of this alternative material, it was observed that in the most usual and studied temperature in the literature (25 ° C) there was an increase in their values when there is the aging of the beams, especially considering the frequencies. 10 Hz and 20 Hz. Regarding the mixtures containing charcoal, it was found that aging resulted in the reduction of the phase angle value for the frequencies of 3 Hz, 5 Hz, 10 Hz and 20 Hz. However, increasing the temperature to 40 ° C , this parameter for the aged mixtures, both AC and ACCV, increased with a maximum value in the frequency of 20 Hz of the order of 85.71% and 95.12%, respectively. Regarding the stiffness of the beams made of asphalt concrete, it was noted that for the temperature of the order of 25 ° C the aged mixture, with and without additive, provided superior complex modulus to the non-aged beams. For the

AC composition the largest percentage difference occurred at the lower frequencies of 1 Hz (56.67%) and 3 Hz (55.66%), while for the ACCV the percentage difference is higher in the 1 Hz (23 Hz) pair. , 30%,) and 3 Hz (12.62%). Considering the temperature of the order of 40 ° C, it was found that the aged AC presented greater rigidity than the non-aged formulation, with greater difference in the frequency of 10 Hz (62.34%). Regarding the ACCV composite and at this temperature, the stiffness showed an increase of 10.53%, 16.00% and 22.22% in the 1 Hz, 3 Hz and 5 Hz frequencies, respectively, but showed a reduction in the 10 Hz frequencies. and 20 Hz. From the above, the aging process contributed to improve the mechanical characteristics of the ACCV mixture at room temperature (25 ° C), considering that the phase angle reduction and stiffness increase occurred. However, at 40 ° C, the composition with the participation of charcoal showed an increase in phase angle and a reduction in stiffness, especially considering the higher frequencies (10 Hz and 20 Hz).

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