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Flexural Tensile Strength of Asphalt Composites with Calcined Clay under Four-Point Bending

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Abstract

Replacing natural aggregates for employment in pavement applications has been exhaustively proposed in order to reduce the unsustainable consumption of these materials. An option widely studied in the Amazon Region is the Sintered Calcined Clay Aggregate (SCCA), a promising alternative to the historical scarcity of rocky material, given the region geology, primarily for the strong occurrence of clays. The aim of this research is to study the use of calcined clay aggregates to create an alternative mixture for asphalt coating of urban paved roads. The influence of temperature variation on the mechanical behavior of SCCA asphalt concrete was also evaluated in order to simulate high-temperature zones. Four-point bending tests were performed on prismatic specimens compacted in controlled conditions with the aim to determine the Flexural Tensile Strength. Superpave method was used for the design of asphalt mixes. The test results from this study indicated that the FTS increases with frequency and decreases with temperature. On the other hand, increasing temperature promotes a tendency of stabilization of the FTS, in which the saturation of the asphalt binder can be observed, due to its viscoelastic nature.

Keywords: Four-point bending; flexural tensile strength; pavement construction; calcined clay aggregate.

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1. Introduction

Flexible road pavement is a multi-layer complex system where hot asphalt mixtures are widely used [1]. In those mixtures, aggregates provide resistance against repeated traffic loads caused by vehicle motion under different environmental conditions and the asphalt binder is responsible for its adhesion and viscoelastic properties [2,3]. In this context, the State of Amazonas in northern Brazil faces such a great challenge when it comes to roadway engineering [4]. The federative entity is located in a region that presents a chronic deficiency in providing coarse aggregates for this purpose, due to its geological disposal, intensified by the environmental and legislative restrictions [5]. Moreover, the historical scarcity combined with the large distance between natural deposits of rocky materials and urban areas increases the costs of paving construction, which makes urgent the searching for suitable alternative inputs under economics and environmental prisms [6,7]. From this point of view, sustainable solutions gain notoriety. Several studies have been conducted to evaluate the feasibility of alternative aggregates with potential to attend the mechanical requirements for asphalt pavement construction, associated to sustainable aspects [8-14]. Besides that, Authors in [15,16] state that using recycled material promotes sustainability in roadway construction by reducing consumption of energy and emission of greenhouse gases produced on natural aggregates mining process. Parallel to this, many studies have utilized sintered calcined clay aggregates, henceforth called SCCA, as conventional aggregates substitutes in bituminous mixtures. Also deserve mention those studies whose regard the reuse of waste materials from ceramics industry [17-20]. On this field of research, Authors in [21] used calcined clay aggregates manufactured in a rotary kiln as a coarse aggregate of asphalt concretes and surface treatments in order to compare the results of Skid Resistance Value (SRV) and Surface Texture Depth (STD) with those acquired for asphalt mixtures produced using limestone aggregate. The results indicated that the SCCA could be used as coarse aggregate for both types of pavement, asphalt concrete and surface treatment, conferring more durability to the mixtures, once that better SRV and STD results were achieved in comparison with those from limestone aggregate. Authors in [5] and [22] have focused their attention on comparing the mechanical behavior of asphalt mixtures using calcined clay aggregates and pebbles as coarse aggregates. The first authors examined the tensile strength, resilient modulus and fatigue parameters of the two mixtures, regarding the effect of temperature. The results showed a superior overall performance of the asphalt compositions with the clay aggregates, when compared to formulations with the pebbles, within the temperature range of 25 °C to 60°C. On the other hand, Authors in [22] carried out four-point bending tests to obtain the dynamic modulus and phase angle of SCCA asphalt concrete. The tests were conducted on a frequency series of 1, 3, 10 and 20Hz, within the temperature range similar to the previously mentioned authors of 25 °C to 55 °C. Considering the local conditions of temperature and traffic, the dynamic modulus presented abrupt change, showing a drop of up to 93.3% in value, with the surface appearing very susceptible to permanent deformation. Nonetheless, another aspect that co-exist with the problem of aggregate disponibility is the temperature. During their service life, asphalt pavements will be exposed to different temperatures of service [23,24]. Hence, it is interesting to note the mechanical response of hot asphalt mixtures under these circumstances. In general, technical standards indicate temperatures around 25ºC to study the mechanical performance of asphalt composites. Exceptions are present, such as ASTM D 3497 [25], which guides the performance of dynamic module tests at temperatures of 5, 25ºC and, notably, 40ºC. The incompatibility of these standards, related to tests temperatures, becomes evident when it comes to the environmental conditions of Brazil, including the Amazon region. In the specific case of Manaus-AM, study developed by [26] shows that, in the hottest months of the year, the surface temperature of asphalt coatings can reach 60ºC. In this respect, the binder, fundamental component in asphalt coating structure, has viscoelastic characteristics that should be considered, once that its consistency and deformation are variable with the increasing of temperature and the stages of cyclic loading. Therefore, at high temperatures, this material behaves as a viscous fluid [27]. In contrast, at low temperatures, the viscous influence portion decreases until the composite works as an elastic solid for loads applied in short time intervals [28-30]. Notwithstanding, the combination of all these factors leads to a significant change in rheological properties of the asphalt binder, which consequently modifies the composite stiffness [31,32]. On the other hand, regardless of some authors argue that indirect tensile tests are effective at characterizing bituminous mixtures stiffness [33,34], Authors in [35] state that the use of a single temperature and load frequency neglects the viscoelastic nature of asphalt mix and its temperature susceptibility, inherited from the asphalt binder. Considering it, mechanistic pavement design requires estimation that takes into account the asphalt concrete mechanical response under dynamic loading and a representative environmental configuration, conditions that simulate a more realistic scenario. Although there are a variety of studies where stiffness measurement is done by considering cyclic solicitations [36-38], these studies address different aspects of loading conditions analysis that should be further approached when it comes to propagation of flexural tensile solicitations on laboratory manufactured prismatic specimens, mainly because different procedures and sample sizes may conduct to different test results, and according to [39], no clear correlation is found between flexural strength and indirect tensile strength. Furthermore, little information has been published about hot asphalt mixtures with calcined clay aggregates tested under four-point bending (4PB). Given these concerns, this research aims to evaluate the influence of temperature variation on the mechanical behavior of asphalt mixtures, with major emphasis on analyzing the Flexural Tensile Strength of prismatic beams produced with calcined clay aggregates, due to the region shortage of stone material, under four-point bending tests. The testing methodology was based on [40] guidelines, preconizing a series of temperature and cyclic loading compatible with the climatic and traffic conditions of the Amazon Region urban areas. The tests were conducted in a controlled strain mode of 50 μm/m ratio.

1.1. Flexural tensile strength in four-point bending tests

When a load is applied over an asphalt coating layer, it generates a stress that is initially homogenously distributed [24]. This condition commonly occurs during the ordinary traffic dynamics, precisely when a vehicle passes over a flexible pavement, as shown in Figure 1(a). When it happens, Moreno-Navarro & Rubio-Gámez [24] explains that this stress induces a mechanical reaction in the material in the form of strain, which is commonly lower in elastic materials or high in the case of viscous materials. In this respect, bituminous mixtures are more susceptible to molecular re-orientation, where the strains are considered to be permanent at high temperatures. Given that, asphalt composites present behave more elastically or more viscously in relation to the frequency of the load or the temperature of service. Consequently, the stress transmitted by the traffic loading will induce strains that could be reversible, or by molecular movements, which mainly produce plastic deformations. *Given this possibility, bending tests consist in a reasonable representative modeling of pavement conditions that can be further assessed to better understand this phenomenon. In 4PB tests, tensile stresses are determined by monitoring the loads and the vertical displacements on a flexed beam. Hereupon, the experiment* *is conducted on a prismatic beam with four supporting pins. Two of the pins are internal, where the loads are applied. The other two supports are articulated and positioned at the ends, allowing them to rotate without vertical displacement. This structural form allows the central span of the beam to be in pure bending, as shown in Figure 1(b), which approaches the premises for the general beam equations development [41-46]. Furthermore, this system admits that the deformations in the center of the beam are free of stress concentration points, once the loads are concentrated in the middle thirds. In short, this experimental arrangement reduces uncertainty and error propagation and reduces the dispersion of results.*

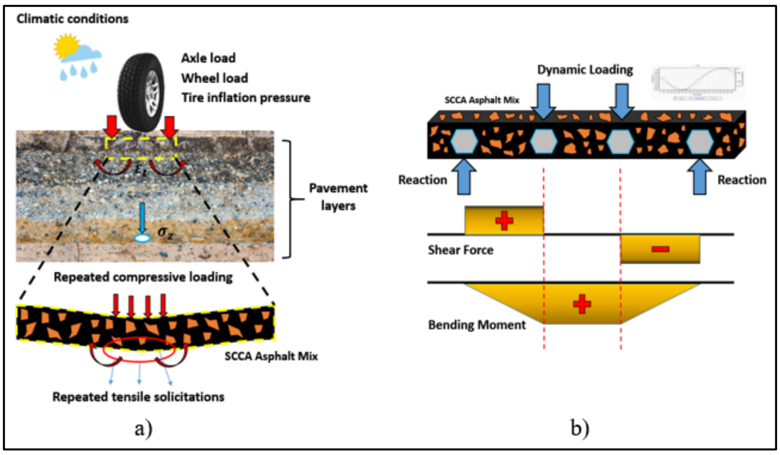

Figure 1: a) Scheme of asphalt coating layer deformation, submitted to climatic and traffic solicitations. b) Four-point bending test beam model and characteristics shear force and bending moment diagrams.

For stresses calculus, the flexure formula was used, which is one of the general beam equations, known as the Euler-Bernoulli theory, given by Equation (1).

$$\sigma_x = -\frac{M_z(x)y}{I_z}, \quad (1)$$

where:

M_Z = bending moment in *z* direction; *y* = point ordinate where the stresses are intended to be calculated; I_Z = cross section inertia moment in *z* direction.

The tension reaches its maximum on the convex surface of the beam, whose ordinate is given by $y = -h/2$ and the bending moment by $M_Z = Pa/2$. The boundary conditions of a four-point bending system predict $a = +L/3$. Substituting these values in Equation (1), the maximum stress for the beam can be found, expressed by Equation (2). Finally, considering a prismatic specimen with known inertia, results:

$$\sigma_x = \frac{PL}{bh^2}, \quad (2)$$

where:

σ_x = flexural tensile strength; P = force amplitude; L = beam length; b = beam width; h = beam height.

2. Materials and methods

2.1. Materials and dosage criteria

The sintered calcined clay aggregates were confectioned from a typical soil of Urucu Petroleum Province, located approximately 650km from Manaus, in Coari-AM, coordinates S04°59'01.68" W065°19'59.20". Initially, solid bricks were produced in a ceramic company in the municipality of Iranduba-AM, with 60x110x200mm format and two ø16 mm longitudinal holes, following the traditional methods of ceramic production. The calcination temperature was 900ºC, approximately. Crushing process was conducted in another company, in order to obtain the intended aggregate size. The reason why sintered calcined clay aggregate, shown in Figure 2, was chosen is due to scarcity of surface rock raw materials in the Amazon region. As mentioned, this regional scenario makes gravel acquisition expensive. Moreover, the clay soil used to produce the alternative aggregate is abundant in the region, thus avoiding the need to dredge riverbeds to remove pebbles, the most commonly material exerted on gravel replacement. Residual sand (fine aggregate) and Portland cement (mineral filler) complete the manufactured composite participants, due to their availability on the regional market. Asphalt cement AC 50-70 was also employed.

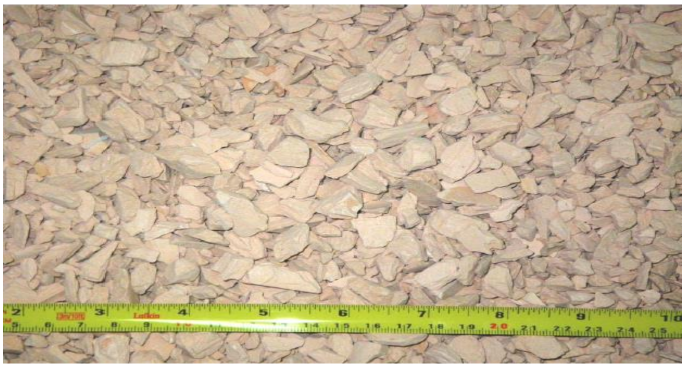

Figure 2: Sinterized Calcined Clay Aggregate (SCCA) after controlled calcination and crushing process.

The aggregates (SCCA and residual sand) were submitted to the following tests:

(a) Particle-size distribution test (ASTM C 136, 1995);

(b) Apparent specific gravity (Gsa), Bulk specific gravity (Gsb) and Absorption test:

(i) ASTM C 127 (1988), for coarse aggregate;

(ii) ASTM C 128 (1993), for fine aggregate.

(c) Bulk specific gravity in the condition Saturated Surface Dry (Gsbssd) (ASTM C 127, 1988), for coarse aggregate;

(d) Los Angeles abrasion (LA), for coarse aggregate (ASTM C 131, 1996);

(e) Rodded Unit Weight (Wur) and Loose Unit Weight (Wul) (AASHTO T 19, 1997).

AC 50-70, sold in Manaus by the Isaac Sabbá Refinery (UN-REMAN), took part in the mixtures, and was analyzed by the National Agency of Oil, Natural Gas and Biofuels guidelines. Considering the mineral dosage, the design criteria established by the Strategic Highway Research Program (SHRP, 1994a; 1994b), known as Superpave method, was applied to determine the percentage of the components, which consider a limited particle size interval, according to the control points defined by the maximum nominal size of the aggregate. For this purpose, the determination of binder content followed the cited methodology, which is conducted by using the Superpave Gyratory Compactor, shown in Figure 3(a). Prior to the compaction process, the compositions remained for two hours in a kiln, at 155ºC, in order to simulate the short-term aging effect. Five specimens (beams) were compacted into a prototype made for this purpose, formed by a base were sidepieces are fixed, as shown in Figure 3(b). Figure 3(c) illustrates the compaction system, where the upper rigid metal piece is set inside the mold and receives the compaction effort. Sample's geometry is prismatic with length (L) 400.0 mm, width (b) 64.5 mm and average height (h) of 51.6 mm. The mechanical tests were carried out on *IPC Global Pneumatic Standalone 4 Point Bending* apparatus. The outfit consists of a servopneumatic system, where the force is transmitted for two internal supports, equipped with transducers for data acquisition and a control unit connected to a personal computer that enables setting configuration and recording acquired data, as shown in Figure 3(d). The equipment was inserted into a climatic chamber with temperature variation capability, illustrated in Figure 3(e). Sinusoidal charge pulses were performed on 1, 3 and 10Hz. For each frequency, the corresponding force and displacement amplitude were measured and collected from the machine report generated by the equipment. A 50µm/m controlled strain mode was applied, condition that, according to [47], does not cause damages to the specimens. The test temperatures were gradually changed for each sample, with increments of 5°C from 25°C to a maximum of 50°C.

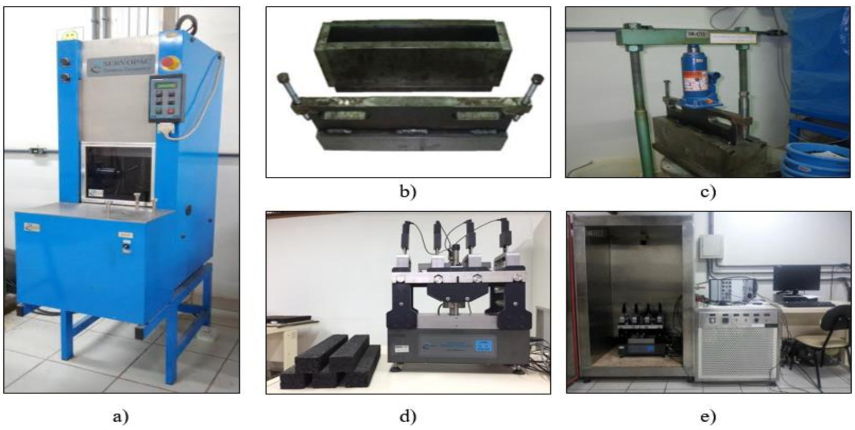

Figure 3: a) Superpave Gyratory Compactor (GEOTEC/UFAM). b) Molding apparatus [22]. c) Compaction system [22]. d) *IPC Global* Four-Point Bending apparatus. e) Data acquisition system, including climatic chamber and *IPC Global* 4PB equipment [22].

3. Results and discussion

3.1. Materials

Table 1 presents the physical properties of the aggregates used in this investigation. Table 2 indicates the asphalt cement characterization. In this respect, the binder used in this study was characterized by Isaac Sabbá Refinery (REMAN), according to the National Agency of Petroleum, Natural Gas and Biofuels, which applies the ASTM standards. Table 3 and Figure 4 indicate the design specifications of asphalt mixes, precisely the proportion of each mixture component in percent and mass content, as well as the suitability of the design aggregates gradation recommended by Superpave criteria, considering the upper and lower limits and the restricted zone.

Table 1: Routine test results for mineral aggregates.

Test	Material		Standard
	SCCA	Sand	
Gsa, g/cm³	2.571	2.692	ASTM C 127, C 128
Gsb, g/cm³	1.855	2.632	
Absorption, %	15.0	0.0	
Gsbssd, g/cm³	2.133	-	ASTM C 127
LA, %	70.0	-	ASTM C 131
Wur, kg/m³	1126.35	1675.90	AASHTO T 19
Wul, kg/m³	1062.00	-	

Table 2: Asphalt cement characterization.

Parameter	Unit	Result	Standard
Penetration at 25°C, 100g, 5s	mm	50 – 70	ASTM D 5
Softening point, min	°C	46	ASTM D 36
Saybolt viscosity			
at 135°C, min	s	141	
at 150°C, min	s	50	ASTM E 102
at 170°C, min	s	30 – 50	
Brookfield viscosity			
at 135°C, min	s	274	
at 150°C, min	s	112	ASTM D 4402
at 177°C, min	s	57 – 285	
Thermal susceptibility index	-	(-1.5) – (+0.7)	-
Fire point Cleveland open cup, min	°C	235	ASTM D 92
Solubility in trichloroethylene, min	%	99.5	ASTM D 2042
Ductility at 25 °C, min	cm	60	ASTM D 113
Heat and air effect at 163°C for 85min			
Mass change	%	0.5	ASTM D 36
Ductility at 25°C, min	cm	20	ASTM D 113
Softening point	°C	8	ASTM D 36
Retained penetration, min	%	55	ASTM D 5

Table 3: Design of asphalt mixes.

Criteria (Superpave)	Material			
	SCCA	Sand	Portland cement	AC 50/70
Percent content, %	55.24	30.29	3.56	10.9
Mass content, g	1311.2	719.1	84.6	258.7

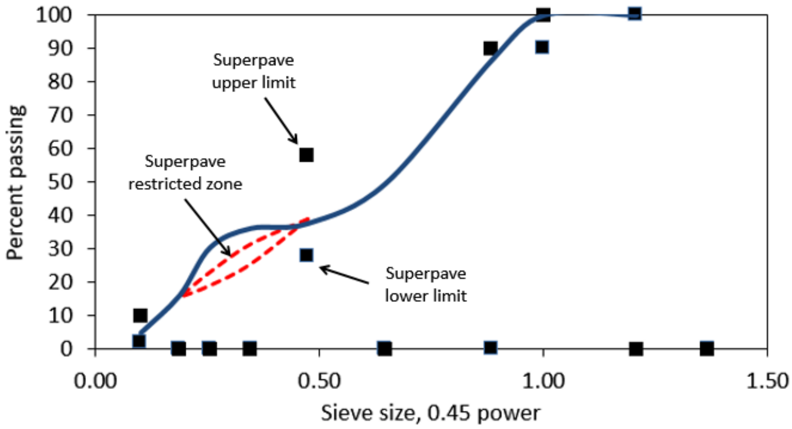

Figure 4: Aggregate gradation.

By means of Table 1, it is verified that SCCA is a light aggregate, whose specific gravities values were lower than the respective values generally found for natural materials, such as crushed stone and pebble. The alternative aggregate also indicated a high absorption potential, leading to an optimal asphalt cement consumption of 10.9% (Table 3), given the considerable porosity of the material, which reflects an absorption of 15%. In these terms, Gómez-Meijide & Pérez (2014) [48] found similar results, confirming that the optimal asphalt cement content for mixtures made with CDW aggregates (high porosity) is greater than those that employs mineral aggregates. Regarding the "Los Angeles" Abrasion Test, the results indicated wear of 70%, above the maximum value of 45%, prescribed by Brazilian standards. In principle, such value would preclude its application as a coarse aggregate in asphalt mixtures. However, studies with SCCA [4,49,50] and different typologies of alternative coarse aggregates, such as construction and demolition waste [12,51,52] showed satisfactory mechanical strength in asphalt concretes, in particular with lower potential to develop permanent deformations. Therefore, the feasibility of using SCCA should be inquired, not only in terms of wear, but above all, from the perspective of mechanical behavior. It is also noteworthy that the aforementioned standard exceptionally allows coarse aggregates with values greater than 45%, if they had shown satisfactory performance in previous use.

3.2. Mechanical tests

The 4PB apparatus provided, for each temperature and frequency configuration, a machine report containing the force required to produce the displacement programmed in all situations (controlled deformation), as shown in Table 5. Given these results and the geometric characteristics of the five compacted beams (Table 4), the flexural tensile strength (FTS) was calculated by Equation (2), whose average values and respective variations are shown in Table 6 and in Figures 5 and 6.

Table 4: Tested specimens (beams) characteristics.

Sample	Mass [g]	Length [mm]	Width [mm]	Height [mm]	Volume [cm³]	Density [g/cm³]
1	2443.0			51.3	1324.4	1.845
2	2461.0			51.9	1338.2	1.839
3	2449.0	400	64.5	51.5	1327.8	1.844
4	2465.0			51.7	1333.0	1.849
5	2454.0			51.8	1337.3	1.835

Table 5: Average flexural tensile force, in Newton, for each temperature (T) and frequency, and corresponding coefficient of variation (CV).

T [°C]	1 Hz		3 Hz		10 Hz	
	Force [N]	CV [%]	Force [N]	CV [%]	Force [N]	CV [%]
25	32.0	3.13	40.0	1.77	44.8	4.84
30	25.0	4.00	31.6	3.61	39.6	5.24
35	17.0	9.30	21.8	8.21	30.0	6.24
40	9.4	12.13	13.0	12.16	18.2	13.12
45	5.8	14.43	7.8	14.04	11.4	10.00
50	4.0	17.68	5.8	18.89	8.0	23.39

Table 6: Average **f**lexural tensile strength (FTS), in kilopascals, for each temperature and frequency, and corresponding coefficient of variation (CV).

T [°C]	1 Hz		3 Hz		10 Hz	
	FTS [kPa]	CV [%]	FTS [kPa]	CV [%]	FTS [kPa]	CV [%]
25	75.6	2.53	94.5	1.74	105.8	4.85
30	59.1	3.60	74.6	3.02	93.6	5.35
35	40.2	9.22	51.5	8.21	70.9	6.11
40	22.2	11.58	30.7	11.49	43.0	12.43
45	13.7	14.47	18.4	13.74	26.9	10.00
50	9.4	17.25	13.7	18.41	18.9	23.09

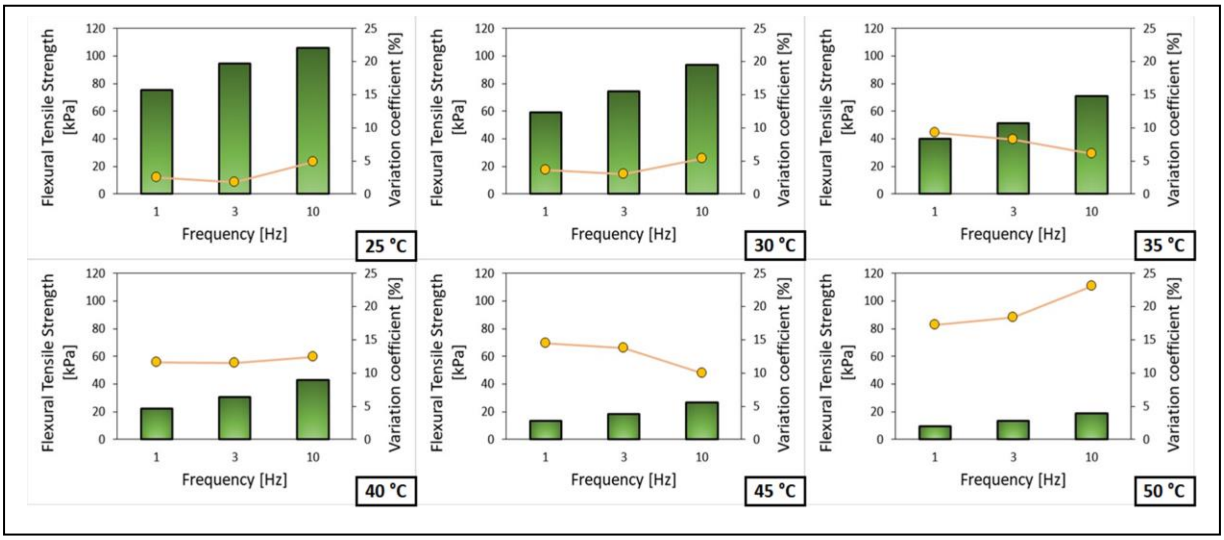

Figure 5: Flexural tensile strength, in kilopascals (kPa), registered in 4PB mechanical tests and corresponding statistic variation coefficient.

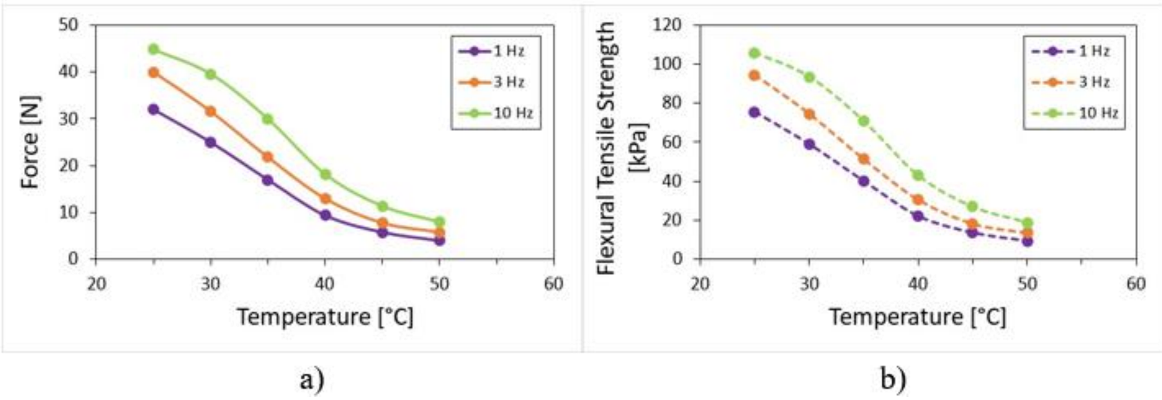

Figure 6: Convergence of force (a) and flexural tensile strength (b) with temperature increasing.

From Table 5, it can be seen that the force imposed by the four-point bending equipment to achieve the programmed strain ratio increases with the frequency. The results indicate that at 25°C and 1Hz, the parameter reached 32N and increased to 40 and 44.8N, when subjected to 3 and 10Hz, respectively, at the same temperature. Briefly, there was a 40% percentage increment from the first to the last frequency. On the other hand, changing the optics of the analysis, the opposite is observed when analyzing the behavior of the force under temperature variation. Focusing on the 1Hz column, it can be seen that this parameter presented a percentage decrease of 87.5%, from 32 to 4N. The behavior is maintained for the other frequencies. Respecting the coefficients of variation, Table 5 also shows how the measurement of the force is difficult when the temperature increases. At 25 and 30°C, the values of the five repetitions did not deviate from the average, with variations below 6%, being the largest obtained for the frequency of 10Hz, indicating a change of 5.35%. At the highest temperature, 50°C, the divergence exceeds 15% around the average, for all frequencies applied in the tests. As expected, similar behavior was observed for the flexural tensile strength results, shown in Table 6, once that this parameter is directly proportional to the applied force. At 25°C and 1Hz, the average FTS reached 75.6 kPa and increased to 94.5 and 105.8 kPa, after variation to 3 and 10Hz, respectively, at the same temperature. Under these conditions, there was also a percentage increase of approximately 40% from the first to the last frequency. On the other hand, as the temperature increases, FTS decreases. From this point of view, at 1Hz, FTS showed a percentage decrease of 87.6%, very close to the one obtained for the force, varying from 75.6 kPa to 9.4 kPa. A visual inspection of Figure 5 indicates the pattern attributed to FTS for each condition of analysis. For a single temperature, the green bars increase with the frequency. However, when the temperature increases, the bars tend to reduce the representative FTS values. In addition, Figure 5 also shows the graphical behavior of the statistic variation coefficients (yellow lines) obtained in the analysis, corroborating that FTS results tend to deviate from the average, with a maximum of 23.39% for 50°C. In this context, it is interesting to mention the study conducted by [53] that despite employing different methodology in their study, strength properties of different asphalt mixtures were investigated to better understand thermal cracking phenomenon. The authors analyzed the flexural strength by using the Bending Beam Test (BBT), where a beam subjected to three points bending is considered, loaded in the middle. The nominal stress is defined as the maximum stress according to elastic bending theory, resulting in a flexural strength 50% greater than 4PB hypothesis [53,54]. Laboratory tests were conducted on three types of asphalt mixtures: two asphalt concretes for wearing course layer and one asphalt concrete for the binder course layer, performed at -20 and 10 °C. Although the aim of their work had been directed for low-temperature regions, it is pertinent to note that the results indicated that, for all the asphalt mixtures that were tested in the BBT, the flexural strength also decreased with the temperature. For example, for the mixture employing SBS-polymer modified bitumen 45/80–55 at the temperature of -20 °C, the parameter reached 9.13 MPa. When the test was performed at 10°C, a reduction of 74% was observed, decreasing from 9.13 to 2.37 MPa. In a new visual analysis, now observing Figure 6, there is a notable saturation tendency of the asphalt composite when the temperature increases. Furthermore, the two-parameter curves, force and FTS shown in Figure 6(a) and 6(b) respectively, present a convergence with the amount of temperature, condition in which the asphalt mixture becomes more viscous. This occurrence is proven given the inflection points of the curves between temperatures of 40°C and 45°C. After this temperature range, the stresses drop is attenuated and tends to stabilize, as mentioned. Therefore, it can be inferred that high temperatures are responsible to reduce the mechanical resistance of the SCCA asphalt concrete, providing low stress absorption. This configuration demonstrates that a great transfer of these efforts clearly occurs to the pavement sublayers, supposing that under such temperatures, the behavior of the mixture is governed by the viscous characteristics of the asphalt binder. In brief, asphalt mixtures are studied at temperatures around 25 °C, but in some tropical regions, case of Manaus-AM, the average temperature which the asphalt pavement is submitted is much higher in the warmer months of the year. Thus, given the temperature and traffic conditions, the flexural tensile strength of SCCA asphalt coatings would show a range from 94.5 kPa (25°C, 3Hz equivalent to a 40 km/h traffic) to 9.4 kPa (50°C, 1 Hz equivalent to a 20 km/h traffic), which corresponds to a decrease of approximately 90% [55]. Allied to the regional problem of stone aggregate disponibility for the construction of flexible pavement structures, the effect of temperature exerts crucial importance on the mechanical response of the alternative composite, therefore explaining the high occurrence of plastic deformations in the asphalt coatings of Amazonas municipalities.

4. Conclusion

This paper studied the feasibility of using sintered calcined clay aggregates to produce hot asphalt mixtures for paving urban roads as a solution to reduce the environmental impact derived from mining process of crushed stone and pebble, natural aggregates employed on Amazon Region paving construction. For this purpose, the performance of asphalt concrete prismatic specimens were assessed under four-point bending. Based on the results, the following conclusions can be drawn:

- Flexural force imposed by 4PB apparatus on the specimens increases with the frequency and decreases with the temperature. Same behavior is attested for the flexural tensile strength;
- Temperature increasing promotes a stabilization tendency of the flexural tensile strength due to the saturation of the asphalt binder. When the temperature increases, the material gets less viscous;
- At reduced stress due to high temperatures, the SCCA mixture provides low stress absorption. Thus, in high-temperature regions, case of the Amazonas State, asphalt pavement temperatures can exceed 45 °C. Under these conditions, the asphalt coating has a lower resistance, which can cause overloading of the lower pavement layers;
- In the light of temperature and traffic conditions, the FTS of asphalt coatings would show a range from 94.5 kPa to 9.4 kPa, which corresponds to a drop of approximately 90%. This explains the strong occurrence of plastic deformation in the asphalt coatings of the region.

5. Recommendations

In order to complement this study, further research can be considered as follows:

- Compare FTS values obtained in the Four-Point Bending tests with other type of mechanical test, such as the Bending Beam Test, considering the calcined clay aggregate formulation;
- Produce asphalt beams with other type of coarse aggregate with the aim to compare FTS values in the large thermic range employed in this paper;
- Study the effect of temperature in the mechanical parameters of SCCA mixtures such as complex and resilient modulus, phase angle and fatigue properties, employing modified bitumen.

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