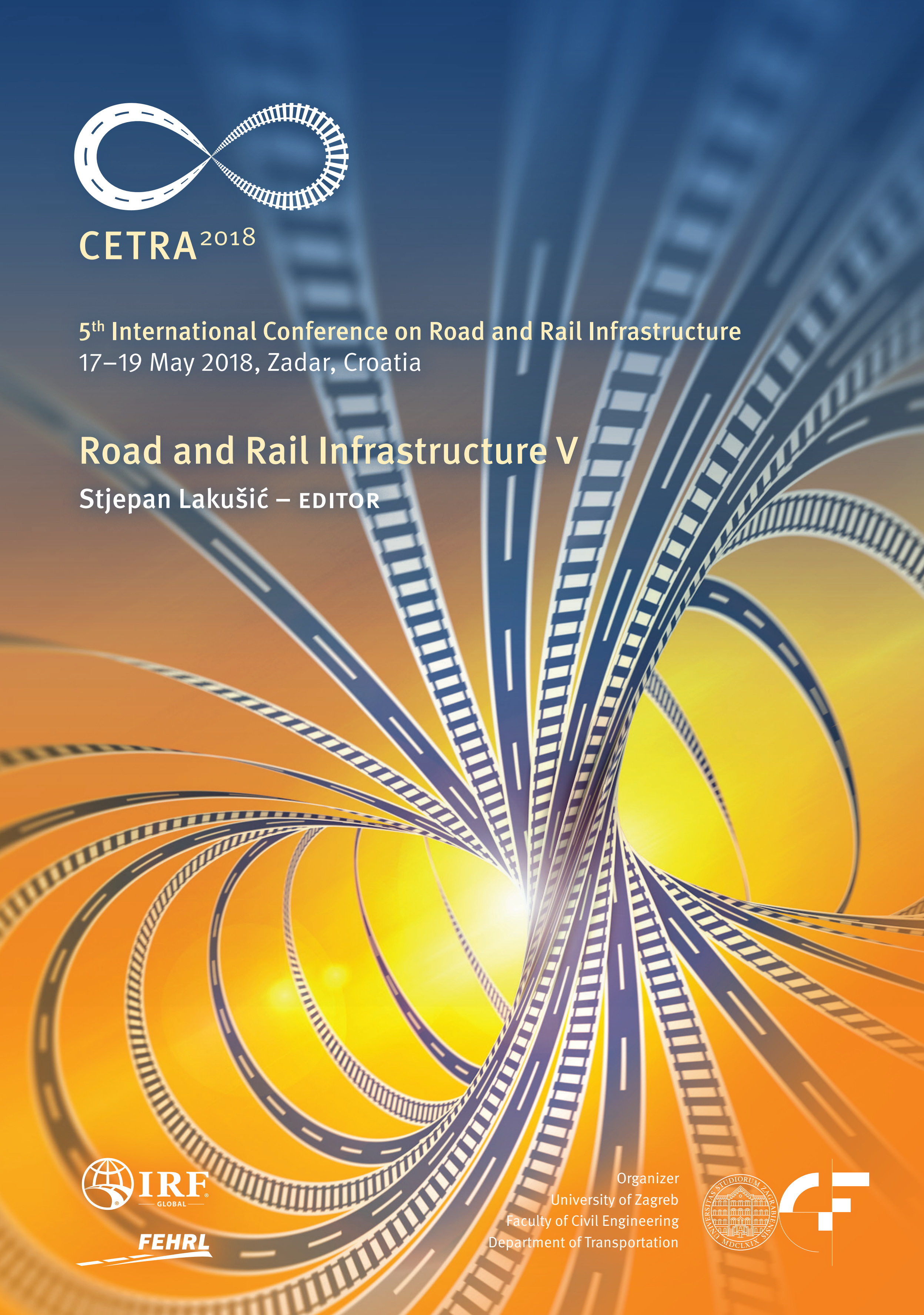

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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

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STUDY OF THE RELATIONSHIP BETWEEN THE AGGREGATES GRADATION, BINDER PROPERTIES AND DENSIFICATION INDEXES FOR AN ASPHALT CONCRETE RUTTING RESISTANCE

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Abstract

Permanent deformation is one of the most common asphalt pavements pathologies in Brazilian and may be directly related with aggregates structure and asphalt binder used in the mixture. The objective of this paper is to study the rutting potential, based on laboratory tests, of a typical Hot Mix Asphalt (HMA) used in the state of Goias, in the Central-West region of Brazil. The asphalt binder used was CAP 50/70, classified according to the penetration test, and the aggregates derive from micaxist rocks. Characterization tests were performed for the aggregates and asphalt binder according to Brazilian and ASTM specifications. The mixture was designed in accordance with the Superpave methodology. The mixture volumetric properties, as well the Static Indirect Tensile Strength and Resilient Modulus were determined. The Flow Number was obtained to analyze the permanent deformation and was correlated with parameters of aggregate gradation curve, as well the results of the Multiple Stress Creep Recovery test for the binder. Correlations with the compaction indexes were also investigated. In addition, the master curve of the HMA was determined to verify a possible relationship between the dynamic modulus and the permanent deformation. The mixture with micaxist presented a low value of Flow Number, indicating possible problems of rutting that mainly can be associated with non-adequacy in any of the evaluated parameters from aggregate gradation curve. Thus, a correct analysis of aggregate size range for mix components impacts in the rutting behavior.

Keywords: Flow Number, rutting, hot mix asphalt, gradation curve

1 Introduction

Permanent deformation is one of the most common types of distress of asphalt pavement surface courses in Brazil. This problem is generated by irrecoverable strains caused by vertical compression [1, 2]. The primary deformation mechanism is the shear failure caused by the high surface loads applied by the dynamic traffic, especially at high temperatures. Permanent deformation may be due to poor compaction during the road construction, mixture instability, problems with mixture design or low structural capacity. Rutting on the pavement surface layer can cause others problems as aquaplaning with risk of accident [3].

Many studies have focused on this issue by analyzing the relationship between densification, Multiple Creep Stress Recovery (MSCR) properties, grain size aggregates and Flow Number (FN) [4-6]. Aragão et al. [7] analyzed several asphalt mixtures designed with Superpave methodology and showed that the aggregate's morphological properties presented strong relation with the rutting resistance. One way to evaluate the concrete asphalt rut resistance in laboratory is given by the FN obtained with a repeated-load test. The analysis of FN data

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test can be done using the Francken model as discussed by Dongre et al. [8]. Other studies also show correlations between rutting and FN as a function of the repetitions of Equivalent Single Axle Load (ESAL).

The main objective of this paper is to evaluate the influence of aggregate gradation, asphalt binder properties, gyratory compactor parameters and the Flow Number on the rutting resistance of a Hot Mix Asphalt (HMA) commonly used in the Central-West region of Brazil.

2 Materials and methods

The present study was carried out in Goiania, Goias, Brazil. The materials selected are commonly used for asphalt concrete mixture in this region: the asphalt binder is designated as CAP 50/70, classified by penetration grade, and the aggregates were obtained from micaxist rocks and are divided in 5 fractions (gravel 1, gravel 0, sand, fines and mineral filler). Laboratory tests were performed to characterize these materials using Brazilian and ASTM International standards. The binder was aged in the Rolling Thin-Film Oven (RTFOT) at a temperature of 163 °C for 85 minutes and other conventional characterization tests were performed. The binder was also classified by the performance grade (PG) using the Dynamic Shear Rheometer (DSR), considering the PG determination only for the highest temperature which is most relevant for the Brazilian typical climatic conditions. The grain size distribution adopted for the aggregate mixture was the Gradation Curve C defined by a Brazilian specification [9]. The Bailey Method and Dominant Aggregate Size Range (DASR) model were used to analyze the asphalt mixture performance in terms of permanent deformation.

Multiple Stress Creep Recovery (MSCR) tests were carried out to evaluate the binder influence on the mixture rutting. In this test, 10 shear cycles, each one lasting 1 second of creep loading and 9 seconds out of creep recovery were applied. Two consecutive loading stages were used: a shear stress load of 100 kPa (for low traffic) and other stress of 3,200 kPa (for heavy traffic). The test temperature ranged from 52 and 70 °C with increments of 6 degrees. Before de MSCR test, the binder was aged using the RTFOT. The HMA design followed the Superpave specifications. The number of gyrations used for the samples compaction was: 8 (initial), 100 (design) and 160 (maximum). During the gyratory compaction, the Construction Densification Index (CDI) e Traffic Densification Index (TDI) were determined. The mix design data were defined for the mixture that presented 4 % of air voids [10]. After compaction, the laboratory tests were performed in the designed HMA using a Servo-Hydraulic Universal Test Machine (UTM-30): Indirect Dynamic Tensile Test (IDT), Flow Number (FN) and Dynamic Modulus (DM), with 3 samples replicates for each test. Indirect tensile strength (ITS) tests under static loading were also carried out at a temperature of 25 °C [11].

The IDT tests were carried out at the temperature of 25 °C and samples were subjected to a conditioning stage of 4 hours according to the Brazilian protocol to find the Resilient Modulus (RM) [12]. For the Flow Number test, a deviation stress of 204 kPa, a contact load of 10.2 kPa and a temperature of 60 °C were applied [4]. The FN samples were prepared on the gyratory compactor with 7.0 ± 0.5 % of air voids, 150 mm in height and 100 mm in diameter, and the results were obtained using the Francken model. The master curve of the mixture was defined by the Dynamic Modulus test, with the average value of 3 samples evaluated for the temperatures of 4.4, 21.1, 37.8, 54.4 °C and for the frequencies of 20, 10, 5, 1, 0.5, 0.1 Hz. The samples with dimensions of 150 mm x 100 mm were prepared in the gyratory compactor. The sigmoidal model was adopted for the dynamic modulus curves:

$$\mathrm{Log}\left|E^*\right| = \delta + \frac{\alpha}{1+\exp(\beta+\gamma \mathrm{Log}(Tr))} \tag{1}$$

where Tr is the reduced frequency, and δ, α, β, χ are parameters obtained using the least square fitting.

A quadratic model was used for the shift factor as a function of the reference temperature:

$$\mathrm{Log}\alpha_t(\mathrm{Ti}) = a\mathrm{Ti}^2 + b\mathrm{Ti} + c \tag{2}$$

in which a, b and c are fitting coefficients and Ti is the temperature of reference.

3 Results and discussions

3.1 Laboratory tests for asphalt binder

A summary of the test results obtained for the binder is shown in Table 1. These data show that CAP 50/70 meets the requirements of the specifications and was classified as a PG 58-XX. The "XX" symbol was used in the PG identification, because it is not common to test low temperatures in Brazil. The MSCR test results are shown in Table 2. The greater the non-recoverable creep compliance value (J_{nr}), the lower the capacity of the binder to recover from the deformations imposed by the traffic. The binder CAP 50/70 at a temperature of 64 °C can support a standard traffic, characterized by ESAL $> 1\text{x}10^7$ and average traffic speed greater than 70 km/h. For temperatures of 70 °C and above, the binder does not show elastic strain recovery for both stresses levels. Results from other studies using CAP 50/70 and other binders are shown in Table 3 for comparison. One can note that in all cases the CAP 50/70 can present poor rutting performance, because of high values of J_{nr} and low elastic strain recovery. The FN tests carried out with CAP 50/70 mixtures also presented low values, corroborating the MSCR results. However, it is important to emphasize that the aggregate skeleton also contributes to the FN values and this aspect should be properly evaluated.

Table 1 Characterization laboratory tests results for asphalt binder (CAP 50/70)

Property	Value	Standard
Bulk Specific Gravity [g/cm^3]	1.002	NBR 6296 (ABNT, 2012)
Relative density [g/cm^3]	1.005	NBR 6296 (ABNT, 2012)
Softening point [°C]	47.67	NBR 6560 (ABNT, 2008)
Penetration [0,1 mm]	61	NBR 6567 (ABNT, 2007)
Rotational Viscosity 135° – Spindle 21 [cP]	387.2	NBR 15184 (ABNT, 2004)
DSR G*/ senδ @ 58 °C	2.586	T 315 (AASHTO, 2012)
RTFOT – Mass Loss [%]	0.12	D 2872 (ASTM, 2004)
RTFOT – Retained penetration [%]	66	NBR 6567 (ABNT, 2007)
RTFOT – Softening Point Increase [°C]	3.3	NBR 6560 (ABNT, 2008)
RTFOT – Rotational viscosity 135° [cP]	471	NBR 15184 (ABNT, 2004)
RTFOT – DSR G*/senδ @ 58 °C	5.066	T 315 (AASHTO, 2012)

Table 2 MSCR results

Property	100 [Pa]				3,200 [Pa]			
	52 °C	58 °C	64 °C	70 °C	52 °C	58 °C	64 °C	70 °C
Average recovery strain [%]	7.99	5.49	1.58	0.00	3.65	2.97	1.22	0.00
Non-recoverable creep compliance; J_{nr} [kPa^{-1}]	0.65	1.68	4.13	9.86	0.71	1.79	4.13	11.14
Traffic level [13]	–	–	–	–	Very Heavy	Heavy	Standard	–
Maximum J_{nr} [kPa^{-1}] [13]					1.00	2.00	4.50	

Table 3 Other studies MSCR and FN results for 3,200 Pa

Reference	Binder	PG [°C]	Average recovery train [%]	Non-recoverable creep compliance J_{nr} [kPa^{-1}]	Stress sensitive J_{nr}, diff [%]	FN [cycles]
This study	CAP 50/70	58	3.0	1.8	13.0	118
Bastos et al. (2017) [7]	CAP 50/70	70	2.0	2.8	16.0	30
	CAP 30/45	70	0.8	3.8	6.0	1214
	CAP 60/85	70	80	0.4	25.0	1487
Nascimento et al. (2015) [5]	CAP 50/70	64	-	3.5	4.1	117
	CAP 60/85	70	38.3	1.7	51.8	5484

3.2 Laboratory tests for aggregates

The aggregate characterization test results are shown in Table 4. High values of sand content were found due to high filler content in the fine aggregates. Both coarse and fine aggregates satisfy the Superpave shape specifications. The aggregate gradation adopted for the HMA mix design was chosen based on the range that is mostly used in the region, the Gradation Curve C [9]. The nominal maximum aggregate size is 19 mm and the maximum size is 25 mm. The aggregate gradation curve in the Superpave 0.45 power chart is shown in Fig. 1, where it is possible to observe that the grading curve satisfies all control points of the AASHTO specification [10]. Furthermore, the gradation curve showed a downward slope in the fine aggregate section, which according to Vavrik et al. [14] indicates an excess in the fine aggregate portion and can lead to HMA rutting.

Table 4 Aggregates characterization results

Property	Gravel 1	Gravel 0	Powder	Sand	Standard
Bulk Specific Gravity [g/cm³]	2.777	2.776	2.789	2.802	NBR NM 053 (ABNT, 2009)
Sand content [%]	–	–	68.16	57.36	ME 54 (DNER, 1997)
Flat and elongated particles – sieve 9.5 mm [%]	1.73	–	–	–	D4791 (ASTM, 2007)
Fine aggregate angularity [%]	–	–	53.1	–	C1252 (ASTM, 2003)
Shape Index – Coarse Aggregate – Grad. C [%]	0.91	–	–	–	ME 086 (DNER, 1994)

The aggregate distribution can be analyzed using the Bailey Method, based on Vavrik et al. [14] recommendations to avoid problems with permanent deformation. This method uses two principles based on the relationship between aggregate gradation and mixture volumetric indexes: aggregate packing and definition of coarse and fine aggregate. Three ratios are defined: CA (Coarse Aggregate) expresses the volume of Coarse Aggregates as percentage of its loose unit weight; FA_c (Coarse Portion of Fine Aggregate) is ratio of the coarse part of the Fine Aggregate fraction; and FA_f (Fine Portion of Fine Aggregate) the ratio of the fine part of the Fine Aggregate fraction. These ratios for the Gradation Curve C are presented in Table 5 and it is possible to note that they are not satisfactory because the values are not meeting the range proposed by Vavrik et al. [14]. These results agree with the "S" shape observed in Fig. 1. Mixtures with high values of CA can present poor compaction and rutting with the traffic load. High values of FA_c and low values of FA_f point to high fines percentage that reduces the volume of air void (V_a) and the volume of voids in mineral aggregate (VMA).

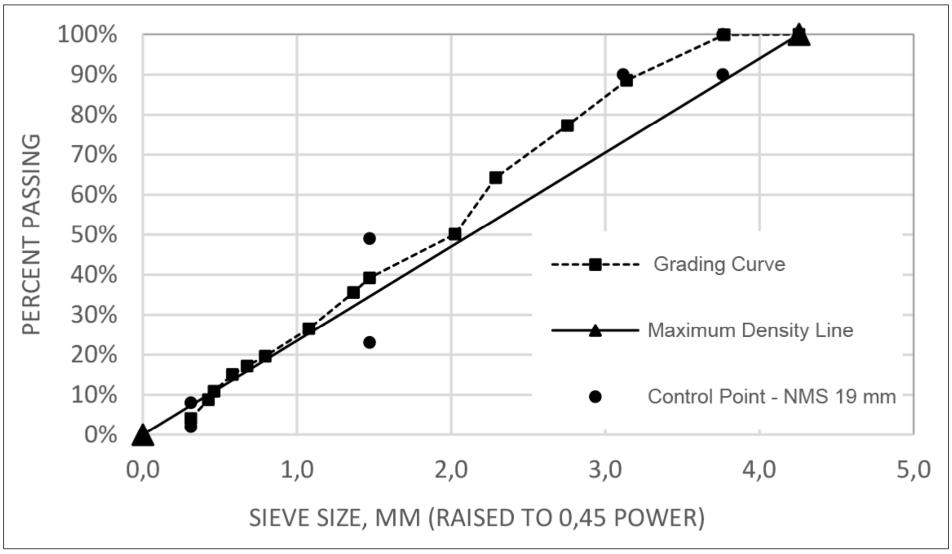


Figure 1 Aggregate gradation curve

Table 5 Bailey Method and DASR parameters

Parameters	**Bailey Method**			**DASR**	
	CA	FAc	FAf	DASR particles	DASR porosity [%]
	1.16	0.57	0.15	2.36 – 1.18	76.7
Range [14]	0.60 – 1.00	0.35 – 0.50	0.35 – 0.50		

The DASR model is used to evaluate particles interactions that form the aggregate skeleton [15]. Dominant particles of coarse aggregate in the DASR create a contact network and produce voids, and when the fraction of fine aggregate is low, there is not a good interaction among particles. After the DASR particles diagram is defined, the porosity is computed and these parameters are used to categorize the mixture into three different groups with respect to their expected rutting performance: Good (DASR porosity between 38 and 48 %), Marginal (DASR porosity between 48 and 52 %), and Bad (DASR porosity greater than 52 %) [16]. This analysis was applied for the Gradation Curve C micaxist aggregate, and the DASR porosity obtained is shown in Table 5. The results indicate that a bad performance is expected and the mixture shows excessive rutting potential. Bastos [17] indicate that the DASR porosity has a good correlation with FN results.

3.3 HMA volumetric parameters

The volumetric parameters obtained for the HMA after gyratory compaction is shown in Table 6. All mixture volumetric indexes and dust proportion satisfy the specifications prescribed by Superpave [10]. However, the voids filled with asphalt (VFA) is higher than the specified range (65-75 %), which indicates excessive voids filled with asphalt.

Table 6 HMA volumetric parameters

G_{mm}	G_{mb}	V_a [%]	VMA [%]	VFA [%]	AC [%]	Dust Proportion	CDI	TDI_m
2.540	2.437	4.0	15.6	75	5.6	0.73	43	250

Note:
G_{mm} = maximum specific gravity of paving mixture sample; G_{mb} = bulk specific gravity of compacted paving mixture sample; V_a = percentage of air voids in compacted mixture; VMA = voids in mineral aggregate; VFA = voids filled with asphalt; AC = asphalt content; CDI = construction densification index; TDI_m = modified traffic densification index.

Bahia et al. [18] indicated that mixtures with high CDI values present more resistance to densification in the final pavement life and are most desirable for asphalt pavements construction. Faheen et al. [19] state that higher TDI values indicate better HMA rutting resistance. Nascimento [4] correlated CDI and TDI with FN and indicated that, for medium traffic, CDI has to be higher than 50 and TDI higher than 250; for heavy traffic, the minimum values are 50 for CDI and 400 for TDI. Thus, the HMA studied in this research presented low values for CDI and TDI.

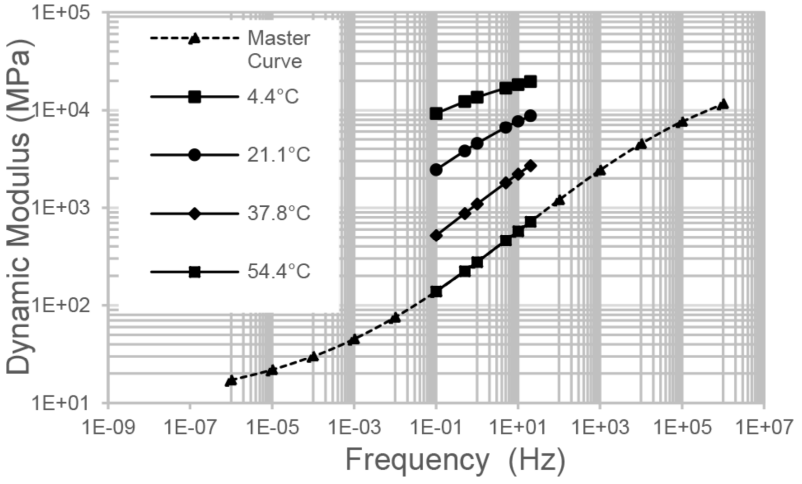
3.4 Mechanical tests

The results for static and dynamic indirect tensile tests as well the relation between the static Tensile Resistance (TR) and the Resilient Modulus (RM) are presented in Table 7. These results can be considered satisfactory. The FN results are also shown in Table 7 and suggest that the HMA rut resistance is compatible with low and medium traffic according to the criteria suggested in [4, 20]. In the case of heavy traffic, the studied mixture shows a high rutting potential, which indicates the need to improve the grain size distribution or to modify the asphalt binder.

Table 7 TR, RM and FN tests results

Parameter	TR [MPa]	RM [MPa]	RM/TR	FN [cycles]	FN Index [microstrain/cycle]
Average	1.401	7658	5467	118	69.11
Standard deviation	0.07	259.63	–	–	–
Coefficient of variation [%]	4.92	3.39	–	–	–

The master curve of the mixture for 54.4 °C is shown in Fig. 2. Studies published by Nascimento [4] and Witczak et al. [21] pointed that high values for the relation between the complex modulus and the phase angle (|E*|/senδ) indicate low rutting potential in the wheel track. Witczak et al. [21] compared several |E*|/senδ values for 54.4 °C and wheel track rutting of experimental segments. They found a value of approximately 400 for the highest deformations (in the order of 50 mm), and 1550 for deformations of approximately 5 mm. The HMA studied in this paper presented |E*|/senδ (for a 5 Hz frequency) equal 836. Witczak et al. [21] found wheel track rutting values less than 20 mm for this condition.



δ	0.96
α	3.65
β	0.38
γ	0.35
A	0.00
B	-0.16
C	7.13
Phase angle (°)	33.37
|E*|@ 5 Hz	460
|E*|/senδ@ 5 Hz	836

Figure 2 Master curve for 54.4 °C

4 Conclusions

This paper showed the HMA commonly used in the Central-West region of Brazil, produced with binder CAP 50/70 and Gradation C micaxist aggregates, presents low asphalt binder recovery capacity, grain size problems, bad aggregate packing, and limited compaction index. All these results indicate that this mixture might have problems with rutting and this hypothesis was corroborated by the FN results. New studies are recommended by changing the HMA materials (asphalt binder and aggregates) and using Bailey and DASR methods to improve the aggregate grain size distribution.

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