Impact of the Addition of Trinidad Lake Asphalt (TLA) on the Rheological Behavior of an Asphalt Binder

Ricardo Zardin Fengler, Patrícia Hennig Osmari, Leni Figueiredo Mathias Leite, Marcos Antonio Fritzen, Francisco Thiago Sacramento Aragão

(Departament of Civil Engineering, Federal University of Rio de Janeiro - UFRJ/COPPE, Av. Pedro Calmon s/n, Ilha do Fundão, Cidade Universitária, Rio de Janeiro RJ, Brazil, ricardo_z_fengler@hotmail.com, patriciaosmari@gmail.com, lenimathais@yahoo.com.br, marcosantonio_ufrj@yahoo.com.br, fthiago@coc.ufrj.br)

ABSTRACT

The use of modifiers to improve the performance of asphalt materials when subjected to loading and climate effects has become an increasingly common practice in Brazil. Among the modifiers, the natural Trinidad Lake Asphalt (TLA) has characteristics that improve pavement performance. The objective of this work is to evaluate the performance of asphalt binders and mixtures modified by different TLA contents, i.e., 15%, 25%, and 50%. It is intended to verify whether the minimum amount of TLA specified by the national standard DNIT 168 is sufficient for the modification of a conventional binder. The base binder and three TLA-modified binders were tested in a Dynamic Shear Rheometer to characterize their rheological behavior. The rheological index parameters GR and R - value of these binders were also estimated to assess aging and cracking characteristics. Four asphalt mixtures were designed and their resistance to permanent deformation was evaluated. Results indicate that the addition of TLA stiffens the base binder and improves rutting resistance. The cracking resistance of the material is not necessarily affected by the stiffening effect provided by the TLA, especially if a proper amount is added to the virgin binder.

Keywords: Asphalt Cement, Modifiers, Trinidad Lake Asphalt, Rheological Behavior, Asphalt Concrete Performance.

1. INTRODUCTION

In order to improve binder characteristics, the use of modifiers has emerged as an alternative in Brazil. Among these modifiers, the natural asphalt extracted from a lake in Trinidad and Tobago, typically called Trinidad Lake Asphalt (TLA), presents properties that compensate the lack of some desirable features in conventional petroleum-based asphalt binders [1-4]. Similarly to other natural binders, TLA is characterized by its high viscosity and high density [5]. Despite the similarities on physical properties between TLA and conventional binders, the chemical compositions vary significantly [6].

Binders modified by TLA present increased stiffness and adhesion, less tendency to permanent deformation and thermal susceptibility, extended durability by the improvement of aging characteristics and lower solubility by solvents [4,7]. However, the increased stiffness may affect pavement performance and resistance to cracking since it reduces mixture workability, and worsens compaction.

Recently, Brazil has established a new specification, DNIT 168 [8], to standardize technical requirements for TLA modification of asphalt binders. The lowest TLA content required by this standard is 25% by mass of binder.

This study aims to investigate the effects of the addition of three different TLA contents on the characteristics of asphalt binders and mixtures and on their resistance to cracking, permanent deformation, and aging. These contents include the 25% recommended as the lowest amount by DNIT 168 [8], as well as one content above (50%) and one below (15%) this value.

2. MATERIALS AND METHODS

2.1 Materials and Mixture Design

A conventional PG 64-22 S, named CAP 50/70 - 2nd LT, was used in this study. Three percentages of TLA were added to the original binder: 15%, 25%, and 50%. Table 1 presents the respective PG grade by AASHTO M332 [9] of each sample after the modification and its continuous grade by ASTM 7643 [10].

Data for other two binders were added to the paper to enrich the analysis of the materials investigated in this study. One is a binder obtained at the same refinery, referred to as CAP 50/70 - 1st LT. This binder was aged in the Rolling Thin Film Oven (RTFO) and in the Pressure Aging Vessel (PAV) for 20, 60, and 80 hours. The material was named based on its aging level, i.e., virgin, RTFO, 20 hr PAV, 60 hr PAV, and 80 hr PAV. The second one is a binder from another refinery, referred to as CAP 50/70 - REPAR, which was analyzed in the original condition, RTFO aged, RTFO + oven aged (RTFO oven + 120 hours in an oven at 90°C), and RTFO + sun test aged, and named, respectively, as virgin, RTFO, RTFO_OVEN and RTFO_UV [11].

TABLE 1 Binders PG and continuous grade

Asphalt Binder	Performance Grade [9]	Continuous Grade [10]
CAP 50/70	64-22 S	64.6-26.1
CAP 50/70 + 15% TLA	64-22 S	69.2-23.9
CAP 50/70 + 25% TLA	70-22 S	71.6-22.6
CAP 50/70 + 50% TLA	76-16 H	81.1-16.3

A limestone was used as the aggregate in the composition of all mixtures evaluated. The aggregate gradation was determined according to AASHTO M323 [12] to meet the requirements for a 19.0 mm Superpave blend, as shown in Figure 1. A reference asphalt mixture was prepared with the virgin binder and three additional mixtures were prepared with the TLA - modified binder. The binder content was 4.7% for all asphalt mixtures investigated in this study.

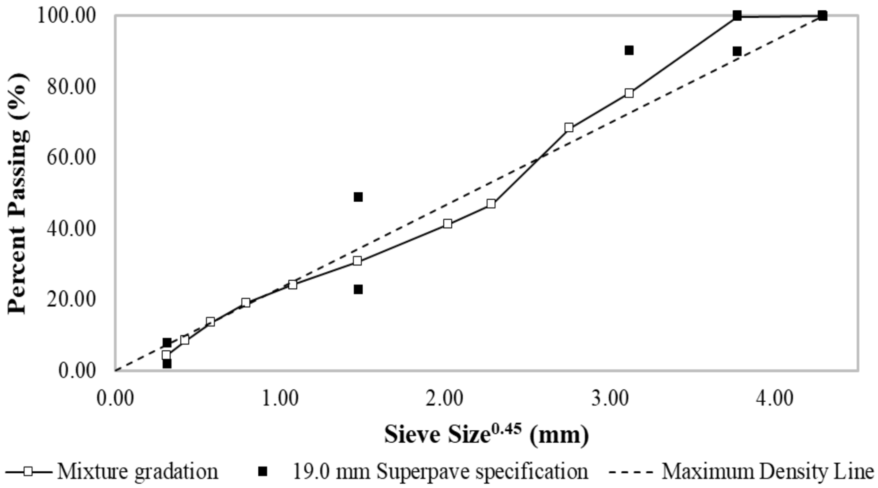

FIGURE 1 Mixture gradation

2.1 Binder Testing

The binders were tested in a Dynamic Shear Rheometer (DSR) to characterize their rheological behavior in three conditions: virgin, RTFO aged, RTFO aged + PAV aged.

Asphalt master curves were obtained by DSR measurements of dynamic shear modulus (|G*|) and phase angle (δ) at a reference temperature of 25°C using the frequency - temperature superposition principle.

The Glover-Rowe parameter was determined to investigate cracking characteristics. It was calculated using the expression $|G^*|(\cos \delta)^2/(\sin \delta)$ [13]. |G*| and δ were determined at 15°C and at 0.005 rad/sec, and plotted on black space diagrams of |G*| versus δ. The limits for cracking analysis are 180 kPa for cracking warning and 600 kPa for block cracking [14].

R - value and crossover frequency (ωc) were determined by |G*| and δ data from the frequency sweep tests. The results were plotted on the ωc versus R - value space. The R - value is the difference between the log of the vitreous modulus and the log of |G*| at the crossover frequency.

The resistance of the binders to permanent deformation was evaluated by multiple stress creep and recovery (MSCR) tests based on the non-recoverable compliance (J_{nr}). The analysis was performed on a DSR at 64°C, the high PG temperature of the original binder evaluated in this study.

2.2 Hot Mix Asphalt Performance Tests

The resistance of the mixtures to permanent deformation was evaluated based on the flow number (FN) test, performed following the Brazilian standard ABNT NBR 16505 [15]. The FN is obtained as an average for three replicates and corresponds to the number of cycles in which the sample starts to present shear at constant volume.

3. RESULTS AND DISCUSSION

3.1 Master Curves, Black Space Diagram and the Glover-Rowe Damage Parameter

Figure 2 presents results of |G*| master curves for the virgin condition of the four binders evaluated in this study. It can be observed that the stiffness of the binders is directly proportional to the amount of TLA. Similar trends were observed for other aging conditions, such as RTFO aged and RTFO + PAV aged. In these aging conditions, the binders were stiffer than in the virgin condition, as expected [16].

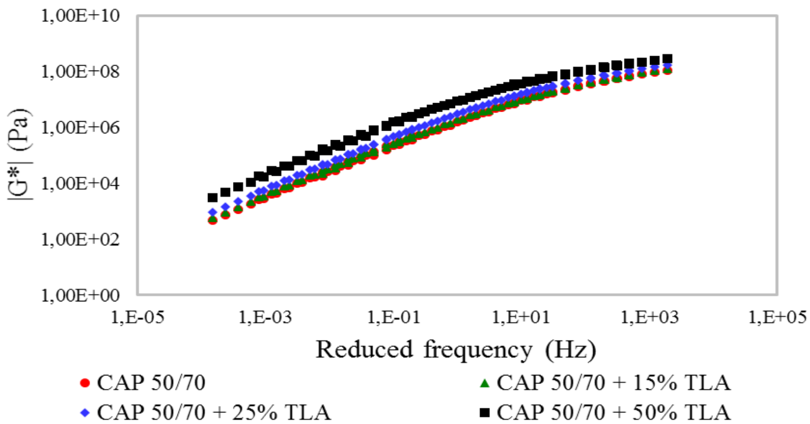

FIGURE 2 Dynamic shear modulus master curve by reduced frequency at 25°C

Figure 3 shows GR parameter data for five materials, four from this study and one from the additional binder obtained at the same refinery (CAP 50/70 - 1st LT). As the materials age, the rheological characteristics move from the lower right to the upper left on the black space diagram. The additional binder has better initial properties than other ones, nevertheless it appears to deteriorate more rapidly after RTFO + 20 hours PAV aging. Due to its better initial quality, this binder did not reach the damage zone after RTFO + 60 hours PAV aging.

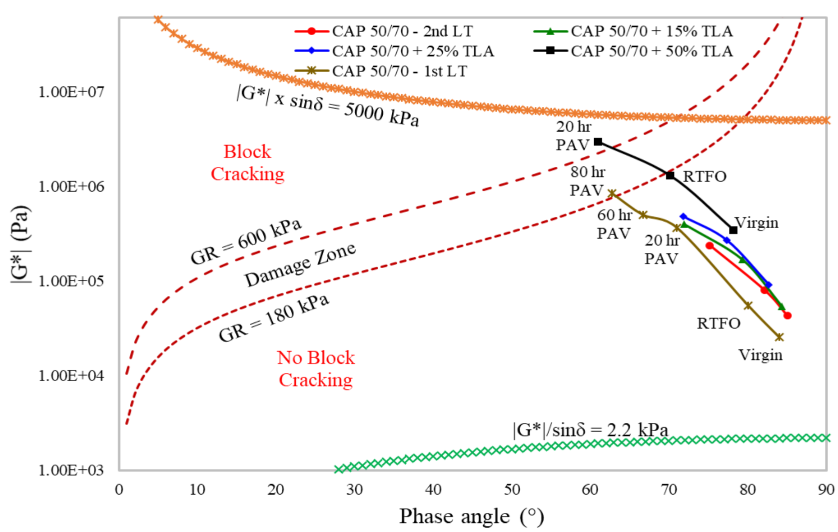

FIGURE 3 Black Space Diagram indicating the GR parameter

The TLA addition to the binder investigated in this study results in increments of the GR parameter as the content increases. Thus, the materials tend to approach the damage zone regardless of the aging condition. The GR parameter analysis of the binders aged by RTFO + 20 hours PAV showed that the 50% TLA addition made the material reach the damage zone and remain in the block cracking region. This is due to the greater stiffness resulting from the addition of a high TLA content. Similar results were obtained by Anderson et al. [13], where stiffer binders presented the same block cracking trend.

3.2 Christensen-Anderson Model (CAM)

Figure 4 shows data for the binder investigated in this study, the additional binder obtained at the same refinery, and the binder aged by the sun test. The binders from this study showed that the crossover frequency decreases with aging, while the R - value increases. This means that there is an increase in the stiffness of the material with its oxidation. As for the effect of TLA content, both the crossover frequency and the R - value decreased as more TLA was added.

Different trends were observed for the rheological indexes GR and R - value. Whereas the GR index for the CAP 50/70 - REPAR did not reach the damage zone after the sun test aging, this binder presented the highest R - value, as shown in Figure 4. On the other hand CAP 50/70 + 50% TLA presented the lowest R - values for all the aging conditions. It seems that the R - value can describe well the aging paths but it has the disadvantage of not reaching the damage zone. This asphalt binder is stiff due to the high TLA content, but is still unclear if it is stiff enough to cause significant cracking.

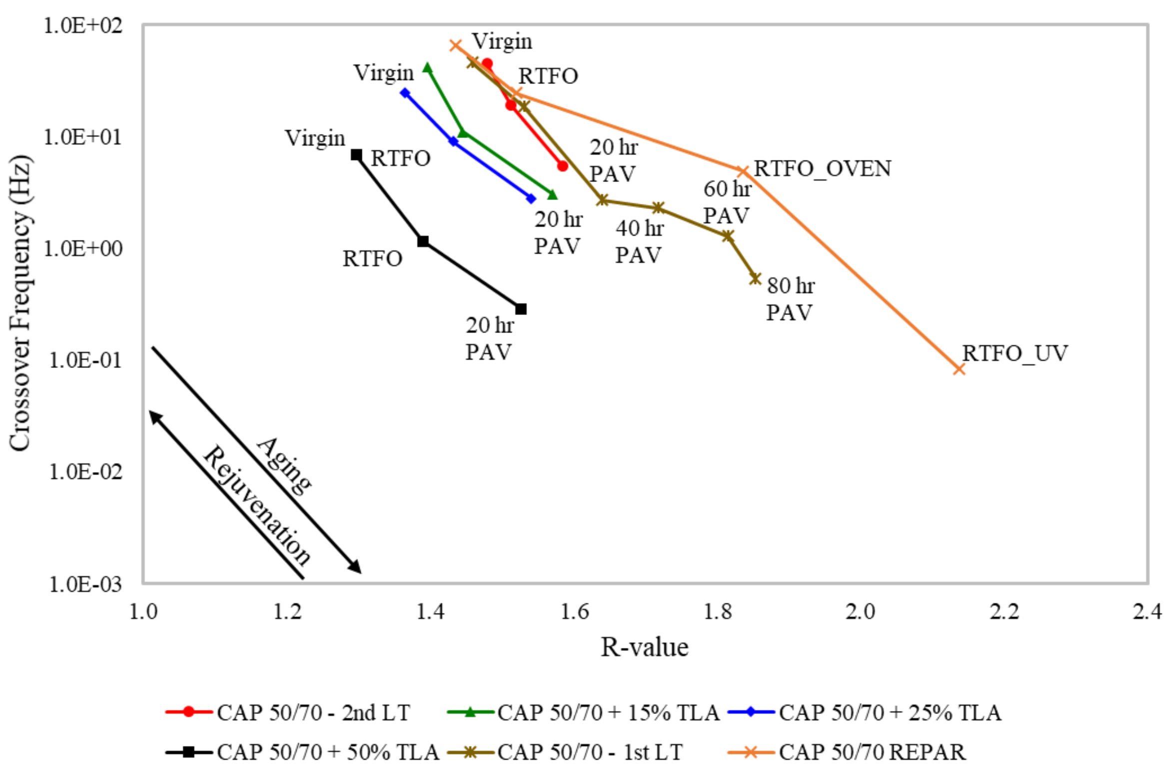

FIGURE 4 Crossover Frequency – R-value space

3.3 Rutting Resistance - Flow Number Test

Figure 5 a) shows the results of FN for the mixtures evaluated in the study. As expected [4,17,18], the addition of TLA greatly increased the resistance to permanent deformation of the mixtures as a consequence to the increased stiffness resulting from the use of this modifier. The significant increase of FN corroborates the results of GR parameters that showed a greater propensity to break with increased amounts of TLA. Figure 5 b) shows the strong correlation between mixture FN and corresponding binder $J_{nr3.2}$ for the materials evaluated in this study.

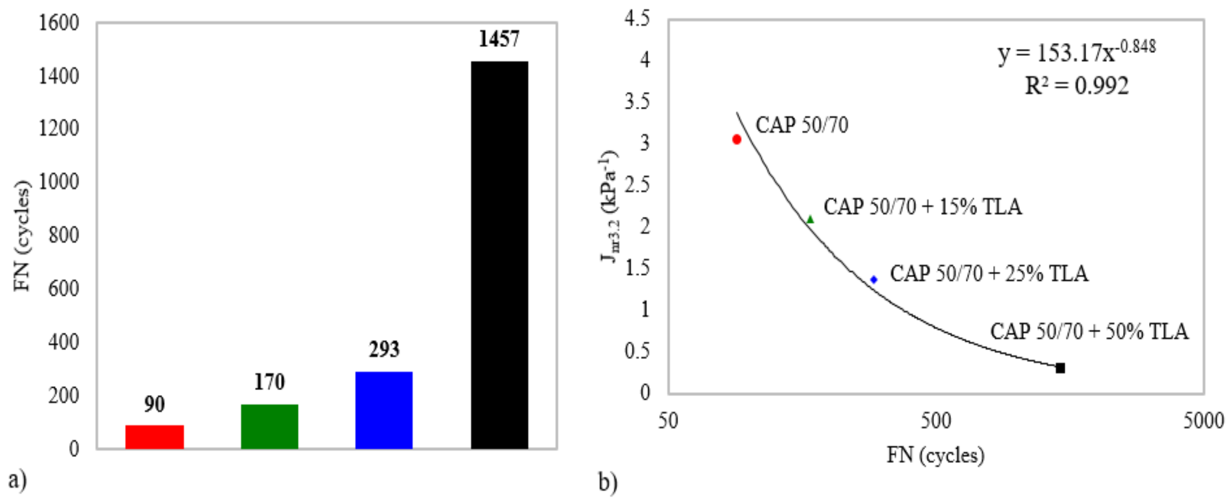

FIGURE 5 a) Rutting resistance of the asphalt mixtures evaluated in this study; b) Correlation between permanent deformation parameter $J_{nr3.2}$ and FN

4. CONCLUSIONS

Based on the testing and the data analysis, the following conclusions were made:

- The master curves indicated that the stiffness of the binders evaluated was directly proportional to the amount of TLA used.
- The GR parameter indicated that as the TLA content and the aging time increased, the materials showed a tendency to present accentuated cracking. Furthermore, the stiffness increased considerably after RTFO + PAV aging on binders modified by 50% of TLA, which led the material to exhibit block cracking.
- The rheological parameters analyzed in the crossover frequency versus R - value space indicated that the addition of TLA increased the binder stiffness and decreased the aging intensity.
- TLA addition improved the binder and the mixture resistance to permanent deformation. A strong correlation was found between mixture flow number and binder $J_{nr3.2}$.
- The Brazilian specification DNIT 168 requires the addition of at least 25% of TLA. This seems to be a satisfactory content based on the results shown in this paper. The lowest TLA content (15%) evaluated did not change considerably the material characteristics. On the other hand, the use of 50% of TLA changed significantly the material behavior and was the only content that presented block cracking characteristics in the rheological characterization of the binders.

5. REFERENCES

[1] SPECHT, L.P., BABADOPULOS, L. F. A. L., BENEDETTO, H., SAUZÉAT, C., SOARES, J. B. Application of the theory of viscoelasticity to evaluate the resilient modulus test in asphalt mixes, Construction and Building Materials, 149, pp. 648-658. 2017.

[2] COLPO, G. B., MOCELIN, D. M., BRITO, L. T. B., CERATTI, J. A. P. Estudo do comportamento à fadiga de misturas asfálticas com ligante asfáltico modificado por polímero e asfalto TLA, Congreso Ibero Latinoamericano del Asfalto – CILA, Bariloche, Argentina, pp. 1-12. 2015.

[3] KLINSKY, L. M. G., BARDINI, V. S. S., FURLAN, A. P., FABBRI, G. T. P. Reaproveitamento de areia de fundição residual em misturas de areia asfalto usinada a quente, Revista Transportes, 20(4), pp. 27-34. 2012.

[4] CAVALCANTI, L. S. Efeito de alguns modificadores de ligantes na vida de fadiga e deformação permanente de misturas asfálticas, Dissertação de Mestrado, COPPE/UFRJ, Rio de Janeiro, RJ, Brasil. 2010.

[5] MEYER, R. F., ATTANASI, E. D., FREEMAN, P.A. Heavy oil and natural bitumen resources in geological basins of the world, U.S. Geological Survey Open-File Report 2007-1084, Reston, Virginia. 2007.

[6] CONCAWE. Bitumens and bitumen derivatives. Product dossier no. 92/104, 49, Brussels. 1992.

[7] CERATTI, J. A. P., BERNUCCI, L. B., SOARES, J. B. Utilização de ligantes asfálticos em serviços de pavimentação. 146, ABEDA, Rio de Janeiro. 2015.

[8] DEPARTAMENTO NACIONAL DE INFRAESTRUTURAS DE TRANSPORTES. DNIT-EM 168: Cimento asfáltico de petróleo modificado por asfalto natural do tipo TLA (Trinidad Lake Asphalt) – Especificação de material. Rio de Janeiro. 2013.

[9] AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS. AASHTO M 332: Standard specification for performance-graded asphalt binder using multiple stress creep and recovery (MSCR) test. Washington DC. 2014.

[10] AMERICAN SOCIETY FOR TESTING AND MATERIALS. ASTM 7643: Standard practice for determining the continuous grading temperatures and continuous grades for PG graded asphalt binders. West Conshohocken. 2016.

[11] CRAVO, M. C. C. Efeitos do envelhecimento térmico e fotoquímico em ligantes asfálticos, mástique e matriz de agregados finos, Tese de Doutorado, COPPE/UFRJ, Rio de Janeiro, RJ, Brasil. 2016.

[12] AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS. ASSHTO M 323: Standard specification for superpave volumetric mix design. Washington DC. 2012.

[13] ANDERSON, M., KING, G., HANSON, D., BLANKENSHP, P. Evaluation of the relationship between asphalt binder properties and non-load related cracking, Journal of the Association of Asphalt Paving Technologist, 80, pp. 615-661. 2011.

[14] ROWE, G. M. ΔTc - Some thoughts on the historical development. Presentation from the Asphalt Binder ETG Meeting, Salt Lake City, UT, April 25-28. 2016.

[15] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 16505: Misturas asfálticas – resistência à deformação permanente utilizando o ensaio uniaxial de carga repetida. Rio de Janeiro. 2016.

[16] DANTAS, L. N. Estudo do envelhecimento de ligante asfálticos, Tese de Doutorado, COPPE/UFRJ, Rio de Janeiro, RJ, Brasil. 2015.

[17] BARROS, L. M. Deformação permanente de misturas asfálticas: avaliação de desempenho conforme critério de Flow Number de misturas quentes e mornas, Dissertação de Mestrado, UFRGS, Porto Alegre, RS, Brasil. 2017.

[18] TIMM, D. H., ROBBINS, M. M., WILLIS, J. R., TRAN, N., TAYLOR, A. J. Field and laboratory study of Trinidad lake asphalt mixtures at the NCAT test track, National Center for Asphalt Technology NCAT Report #14-05, Auburn University, pp. 1-114. 2014.