Investigation of cracking characteristics of aged and rejuvenated asphalt binders measured by rheological analysis

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ABSTRACT

The cracking characteristics of asphalt binders are function of several factors, including aging. In the attempt to understand the effects of aging on the cracking resistance of binders, researchers have evaluated several material characteristics and proposed different indices for their analyses. A rheological parameter called Glover-Rowe has recently become attractive because it allows the use of linear viscoelastic properties typically obtained in the DSR to infer the material resistance to cracking. In this study, two asphalt binders (aged and rejuvenated by three additives) were tested in a DSR to determine their linear viscoelastic properties. From those, several different aging indices could be calculated. Chemical tests SARA and Gel Permeation Chromatography were also performed to evaluate the efficiency of the rejuvenators and the chemical changes that occurred due to aging and rejuvenation. The results of the tests were then compared to identify potential correlations between the different parameters evaluated. As expected, the rejuvenators promoted the recovery of the rheological characteristics compared to the aged samples. A tendency to improve the material cracking resistance was also observed as well as the restoration of some chemical fractions lost during aging. The parameters employed in this study are important tools to assist engineers in the selection of materials that are more resistant to aging and consequently to cracking.

Keywords: Asphalt Binder, Cracking, Aging, Rejuvenators, DSR.

1. INTRODUCTION

Asphalt binders experience aging during the construction and service life of flexible pavements mainly because they are subjected to high temperatures and different weather conditions. In order to recover the original binder characteristics, multiple techniques and products have been investigated. In this regard, the addition of alternative rejuvenator agents has been a promising approach since it allows the reuse of aged asphalt binders. These alternative products are especially attractive because they are generally byproducts of industries or even waste materials that can replace the conventional petroleum-based products [1-4]. However, such materials should be carefully analyzed to assess characteristics that are directly linked to the performance of pavements.

Empirical investigations are not sufficient to assess the influence of the different rejuvenators. For that, rheology has been proven to be a remarkable tool to evaluate the asphalt binder behavior. Techniques that adopt results from rheological analyses have been used to evaluate field distresses such as cracking. For instance, researchers developed a parameter called Glover-Rowe (GR) parameter that evaluates cracking performance by relating rheological characteristics to ductility [5-9].

In addition, chemical analyses are also crucial to understand the microscopic scale changes that the materials undergo after aging and rejuvenation. Several studies have analyzed binder chemical characteristics using tests previously developed to investigate the behavior of polymers[10-13].

These types of analyses may facilitate the selection of suitable tests that allow the proper characterization of the materials considering relevant properties. Besides, they may provide tools to engineer asphalt binders by optimizing the product additions and to achieve a desirable performance in the field.

This study aims to investigate rheological and chemical characteristics of virgin, aged, and rejuvenated asphalt binders. Specific objectives of this paper are:

- To investigate aging and rejuvenation processes of different binders and rejuvenator agents;
- To evaluate the binder cracking characteristics at different conditions and to identify the rejuvenator that provides the best recovery with respect to the virgin binder properties;
- To identify possible correlations between cracking resistance and chemical characteristics of the different materials evaluated.

2. EXPERIMENTAL PROGRAM

2.1 Materials

The asphalt binders investigated in this study were a PG 64-22 S and a PG 70-22 S. The materials were tested in three conditions: virgin, aged, and rejuvenated. The aging process was performed at the RTFO and PAV ovens. PAV - aged samples were previously aged at RTFO oven. The four aging conditions evaluated were: RTFO aged, 20hr PAV aged, 60hr PAV aged, and 80 hr PAV aged.

The samples aged at the RTFO followed by 20 hours aging at the PAV were then rejuvenated by the addition of three agents: AR 5, a petroleum-based material widely commercialized in Brazil, and two alternatives: waste cooking oil (WCO) and castor oil (CAO). The optimum content of rejuvenators was selected based on the recovery of the material viscosity determined from tests at a rotational viscometer at 135ºC, 150ºC, and 177ºC. The optimum dosage of each rejuvenator was 12% of AR 5 for the rejuvenation of both binders, 7% of WCO for PG 64-22 S and 8% for PG 70-22 S, and 7% of CAO for PG 64-22 S and 8% for PG 70-22 S.

2.2 Rheological Characterization

The rheological characterization was performed within the limits of linear viscoelasticity in a Dynamic Shear Rheometer (DSR). Dynamic shear modulus (|G*|) and phase angle (δ) were determined at 10ºC, 25ºC, 45ºC, and 60ºC and at frequencies that varied between 0.01 Hz and 25 Hz. Master curves were obtained at a reference temperature of 25ºC using the frequency-temperature superposition principle.

The asphalt binder cracking characteristics were investigated by the analysis of the GR parameter and were plotted on the black space diagrams of |G*| versus δ. GR is calculated by $|G^*|(\cos \delta)^2/(\sin \delta)$. |G*| and δ were determined at 15 °C and 0.005 rad/sec. The limits for cracking analysis are 180 kPa for cracking warning and 600 kPa for block cracking [9].

2.3 Chemical Chracterization

The saturates, asphaltenes, resins, and aromatics (SARA) fractions were separated by using an Iatroscan Thin-Layer Chromatograph with Flame Ionization Detection (TLC-FID). The Gel Permeation Chromatography (GPC) analysis classified the binders into three categories by their molecular weights: large molecular size (LMS), medium molecular size (MMS), and small molecular size (SMS).

3. RESULTS AND DISCUSSION

3.1 Rheological Characterization

Figure 1 presents results of |G*| for the virgin, 20 hr PAV aged, and rejuvenated binders evaluated in this study. It can be observed that |G*| increased after aging and decreased after the addition of the rejuvenators, as expected [4]. Although the addition of AR 5 provided the best recovery of |G*|, the alternative rejuvenators presented promising results.

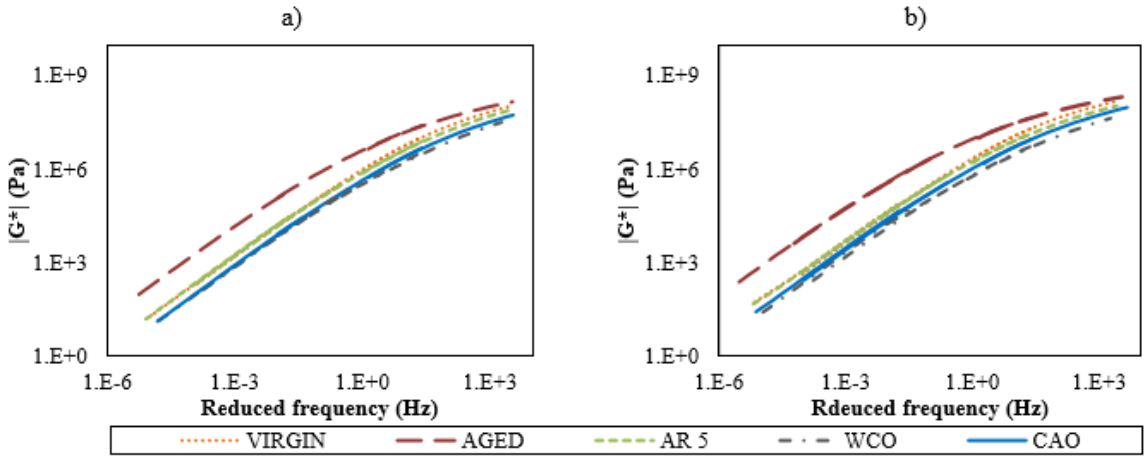

FIGURE 1 Dynamic shear modulus master curve at 25°C for the virgin, 20 hs PAV aged, and rejuvenated a) PG 64-22 S and b) PG 70-22 S binders

Figure 2 presents the GR parameter for both binders at virgin, aged, and rejuvenated conditions. As expected, the virgin binder results were positioned at the right bottom corner of the graph and as the material aged the GR parameters moved to the upper left part [7, 14, 15]. The virgin PG 64-22 S presented a lower GR than the PG 70-22 S at the same condition. The PG 64-22 S was less susceptible to aging and only reached the damage cracking zone after 80 hours of PAV aging. On the other hand, the PG 70-22 S has reached the damage zone at 20 hours of PAV aging and also the block cracking zone for longer aging times. This behavior was not foreseeable from the comparison between the results of Figures 1 and 2 since both binders presented significant differences on their aging trends in the GR evaluation. Thus, the aging provided by the laboratory ovens may not be representative of the field aging.

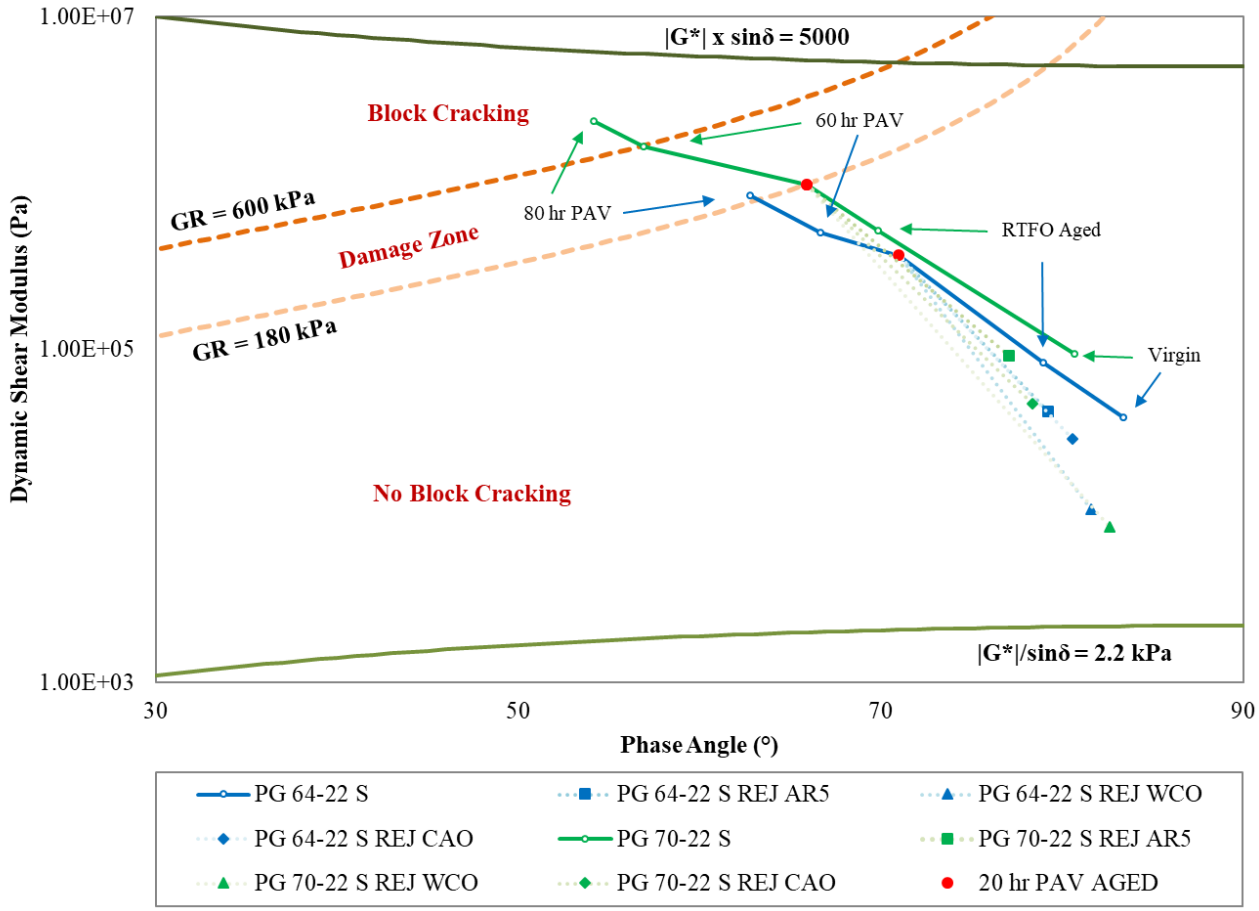

FIGURE 2 Black Space Diagram presenting the cracking zones and the GR parameter for each condition investigated in this study

The rejuvenation process provided a recovery of the GR parameter to levels similar to those of the virgin condition, as expected [16]. The addition of AR 5 and CAO presented higher GR than WCO for both binders and the addition of CAO to the PG 64-22 S has shown the most similar cracking performance to the virgin condition. This indicates that the cracking performance can be similar regardless of the nature of the rejuvenators. On the other hand, this trend is different than the behavior observed at the master curves from Figure 1 where both alternative rejuvenators resulted in lower |G*| than that of the samples rejuvenated by AR 5. Therefore, it is important to emphasize the significant relevance of parameters that allow researchers not only to evaluate binder linear viscoelastic characteristics but also to properly predict distresses such as cracking.

3.2 Chemical Characterization

Table 1 shows results of the chemical tests SARA and GPC for the virgin, 20 hs PAV aged, and rejuvenated binders. Only the amount of aromatics and asphaltenes from SARA and LMS from GPC were evaluated in this study. The percentage of aromatics decreased with aging for both binders, while asphaltenes increased as in several studies [4, 10, 12, 13]. Also, the SARA fractions presented a partial recovery when the rejuvenated samples presented an

increased amount of aromatics and a decrease of asphaltenes as in Yu *et al.* [4]. Similarly to another research [10], the aging process led to an increase of LMS.

TABLE 1 Results of the chemical characterizations from SARA, and GPC tests

Material		SARA		GPC
		Aromatic (%)	Asphaltene (%)	LMS (%)
PG 64-22 S	Virgin	52.1	21.7	3.6
	Aged (20 hr PAV)	39.4	25	5.6
	AR 5	41.7	18.3	4.7
	WCO	36.0	23.4	5.2
	CAO	34.9	24.8	5.4
PG 70-22 S	Virgin	50.2	21.9	3.1
	Aged (20 hr PAV)	35.4	27.1	6
	AR 5	41	23.7	5.7
	WCO	36.7	21.1	5.9
	CAO	34.9	24.8	5.1

3.3 Correlations between rheological and chemical characterizations

Figure 3 presents results of the correlations between the rheological GR parameter and chemical characteristics of the virgin, aged, and rejuvenated samples for both asphalt binders investigated in this study. The comparison between those characteristics revealed that asphaltene content of 20 hours PAV aged samples reached a maximum value that decreased after rejuvenation, but did not achieve the amount in the corresponding virgin binder. The same trend was observed for the amount of LMS, which increased from virgin to aged condition for both asphalt binders and decreased after rejuvenation, without reaching the lower values of the virgin samples for any rejuvenator.

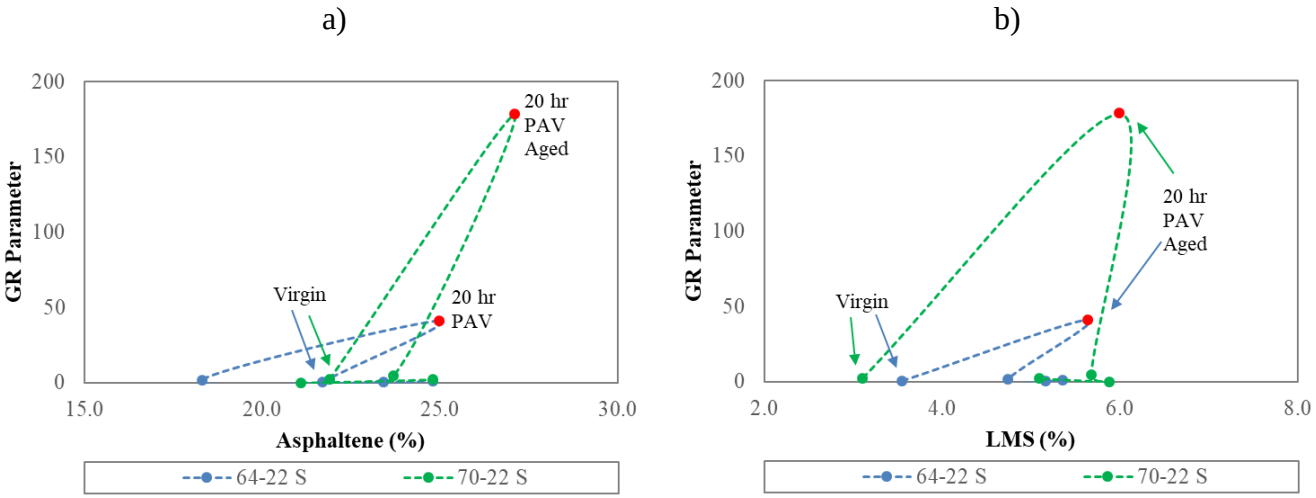

FIGURE 3 Correlations between GR parameter and a) asphaltene from SARA test and b) LMS from GPC test for both asphalt binders

The adoption of chemical procedures primarily used for hydrocarbons in asphalt binder samples that contain triglycerides, components of the alternative oils, could be the reason for this

behavior. These chemical tests explain the low asphaltene content of the AR 5 rejuvenated sample, but not its high value of LMS. Therefore, it is important to identify a chemical procedure that is able to explain the chemical phenomena during recycling when vegetable oils are used as rejuvenators. For instance, the new method SARA-AD developed at Western Research Institute splits asphalt binder in several fractions and can be more efficient to clarify this misunderstanding.

4. SUMMARY AND CONCLUSIONS

This paper evaluated rheological and chemical characteristics of two asphalt binders in the virgin, aged, and rejuvenated conditions. In the study, three rejuvenators were used: the petroleum - based AR 5 and the alternative waste cooking and castor oils. Rheological tests were performed in order to obtain master curves and calculate the GR parameter to evaluate the cracking characteristics of the samples. The chemical tests SARA and GPC were performed to identify changes in the chemical composition of the binders resulting from aging and rejuvenation. Finally, the results from both characterizations were compared to evaluate the possible correlation between cracking and chemical characteristics of the materials.

From the results and analyses, it could be concluded that:

- The addition of the commercial and alternative rejuvenators to the aged binders generally provided a good recovery of the characteristics of the corresponding virgin binders.
- The GR results approached the cracking zones as the materials aged, however the block cracking zone was only reached by the binder PG 70-22 S. This indicates that the laboratory aging provided by RTFO and PAV was not enough to simulate field aging so different aging techniques may be required to analyze such materials.
- It was not found a clear correlation between the rheological GR parameters and the chemical results. Thus, different chemical characteristics should be pursued to allow a better understanding of binder chemical fractions to relate them to the pavement performance.

This paper is part of a broader research under development by the authors that attempts to analyze chemical and rheological characteristics of asphalt binders and relate them to their damage - related properties. The parameters employed in this study are important tools to assist engineers in the selection of materials that are more resistant to aging and consequently to cracking.

5. REFERENCES

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