Evaluation of the UV aging tests effect on asphalt binders using Glover Rowe parameter

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ABSTRACT

At first, PAV test accounts for long-term aging for 10 years in pavement service, but now it is capable to not perform more than 3 years aging. Therefore, studies had done, increasing PAV time to 40, 60 and 80 hours or considering the ultraviolet effect on aging, especially important in tropical countries. The actual work shows the stiffening increase of unmodified and modified asphalt binder samples using different long-term aging tests, employing solar radiation. The aging path of these samples measured by rheological parameter Glover Rowe (GR). This parameter is associated to limits for cracking beginning and significant cracking, allowing comparison between the aging tests and asphalt binders. Parameter GR based on complex modulus and phase angle at 15ºC and 0.005 rad/s. Samples had submitted to RTFOT, followed to three different tests: Suntest, Weatherometer, both using ultraviolet radiation and the last test consist of binder thin film weathering exposed directly to solar light. Parameter GR assess performance of new accelerated aging tests and can evaluate the performance of asphalt binders in respect to aging process.

Keywords: GR parameter, Asphalt binder, Long term Aging, Rheology, Solar radiation

1. INTRODUCTION

Several aging tests for asphalt binders had already proposed to simulate the long-term aging process. The factors that play an important role in field aging are air pressure, temperature and time. After twenty-five years of pressure aging vessel test as long-term aging test in SUPERPAVE specification, some researchers revealed the disability of PAV to simulate adequately 5 to 10 years aging. After 20 hours, PAV-aged materials have not yet reached the advanced state of deterioration [1]. There is a subject in Expert Task Group of Federal Highway administration considering the increase aging time of PAV test to be more representative. In the years 2000, researchers begin to study the effect of sunlight or ultraviolet radiation in long-term aging [2, 3, 4]. They used weatherometer with UV radiation for many hours or UV radiation oven test for thin bitumen films. They found these aging tests relevant to emulate better the field aging, the bitumen after UV aging test presented higher viscosities and carbonyl indices. Mouillet reported that the UV radiation increase the rate of oxidation and verified that the evolution kinetics due to a pure thermal oxidation or a photo-oxidation processes are different. The field aging had better evaluated by photo-oxidation than by pure thermal oxidation. Moreover, the UV exposure may affect the bitumen's properties more strongly than the PAV test. This standardized ageing method in laboratory probably underestimates the real evolution of the binder in a bituminous mixture used in surface course [5]. In tropical countries, this factor is much more valuable than in Europe and Asia.

Three different long-term simulations had studied in Brazil, using three different tests: Weatherometer and Suntest, both using ultraviolet radiation and the last test consists of binder thin film weathering exposed directly to solar light [6, 7, 8]. The Brazilian studies also revealed that thermal process is less severe than photo-oxidation according several results: AFM images, carbonyl indices, rheological parameters and chemical composition. This paper shows the stiffness paths of asphalt binder samples submitted to these three different aging tests using the Glover Rowe (GR) parameter.

The use of linear visco-elastic analysis methods for the characterization of asphalt binders has gained popularity since the wide introduction of rheometers in the early/mid 1990s. The use of the G*x sin (delta) parameter for fatigue cracking has been suggested as lacking the validation with field performance. Proposed aging functions such as GR Damage Parameter were compared to lab results on Black Space Diagrams. They found that the location of GR in Black Space is an important performance measurement for cracking. However, the initial quality of the asphalt as determined in Black Space is just as important to performance as rheological changes in modulus and phase angle occurring during aging. Oxidation not only increases binder modulus, but also has a dramatic negative impact on binder phase angle and BBR m-value. Lower phase angles result in less binder fluidity, lack of healing, and more rapid accumulation of damage. To demonstrate the evolution of damage, the researchers evaluated long-term PAV-aged binders from three different crude sources using the Dynamic Shear Rheometer (DSR) and the Bending Beam Rheometer (BBR) [6]. Age-induced rheological changes were then compared on Black Space Diagrams plotting log G* vs phase angle [7]. Analysis of the Glover-Rowe parameter from model parameters had shown relation to cracking in airfield pavements and with silo storage time increase. The same parameter had used by other researchers to assess the quality of RAP and rejuvenating agents. [9, 10, 11].

First developed by Glover [12] who derived a fatigue cracking parameter, G'/(η'/G'), from a Maxwell model. He correlated this parameter to binder ductility (15°C, 1 cm/min), tied to age-induced cracking during field pavement studies. Brittle binders can be tolerated in stiff pavement systems. Thus, an appropriate limiting G'/(η'/G') value depends on the stiffness of the pavement system. For a stiff pavement system, Glover parameter values of 0.003 MPa/s (ductility = 3 at 15ºC, 1 cm/min) can be tolerated, but this value may be an approximate limit for avoiding age-related failure. For pavements with high deflections, Glover parameter of 0.0009 (ductility = 5) was tentatively taken to be an approximate limit. Rowe [13] re-defined the Glover parameter in terms of |G*| and δ based on analysis of a Black Space diagram and suggested use of the parameter $|G^*| \times (\cos\delta)^2/\sin\delta$, termed Glover-Rowe (GR) parameter, in place of the original Glover parameter. Rowe proposed measuring the G-R parameter based on construction of a master curve from frequency sweep testing at 5°C, 15°C, and 25°C in the DSR and interpolating to find the value of G-R at 15°C and 0.005 rad/sec to assess binder brittleness. A higher GR value indicates increased brittleness. It had proposed that a G-R parameter value of 180 kPa corresponds to damage onset whereas a GR value exceeding 450 kPa corresponds to significant cracking based on a study relating binder ductility to field block cracking and surface raveling.

The correspondence between Glover and GR parameter is shown above:

- Damage onset (5 cm ductility): $|G^*| \times (\cos\delta)^2/\sin\delta$ 180 kPa
- Significant cracking (3 cm ductility): $|G^*| \times (\cos\delta)^2/\sin\delta$, 450kPa

Later, GR parameter related to significant cracking changed to 600 kPa [14]. Figure 1 shows the Use of Black Space Diagram to Predict Age-Induced Cracking, employing GR parameter.

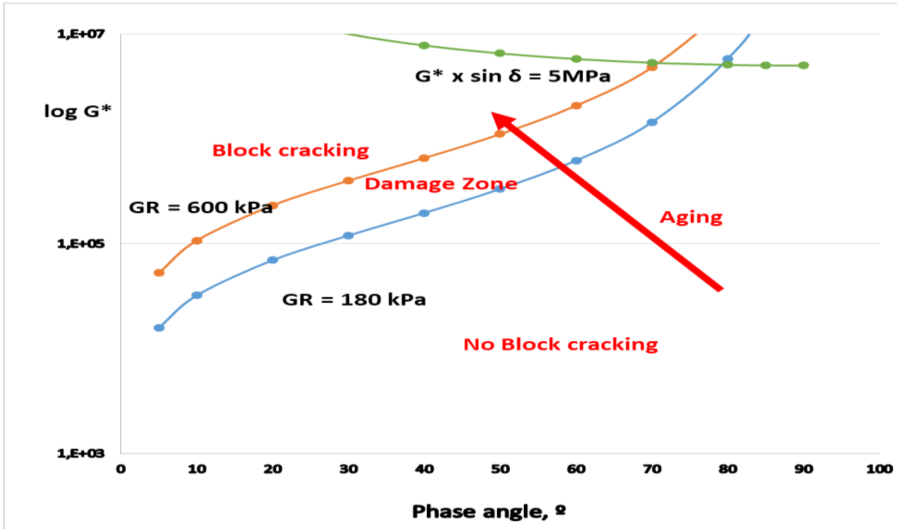

FIGURE 1 - Black Space Diagram to Predict Age-Induced Cracking

2. MATERIALS AND METHODS

The three Brazilian studies employed asphalt binder samples of modified and non modified asphalt. Cravo [7] studied the behavior of two asphalt cements penetration graded 50/70 from different crude sources and production processes (straight run distillation - sample A and deasphalting residue + diluent – sample B). Dantas [8] studied two asphalt cements penetration graded (straight run distillation 30/45 – sample C) and (straight run distillation 50/70 – sample D) of different crudes. Moreover she studied three modified asphalts: SBS polymer asphalt (sample E), ground tire rubber asphalt (sample F) and TLA modified asphalt (sample G). Araujo [6] studied two samples of asphalt binder: 50/70 straight run (sample H) and SBS modified asphalt (sample I). The properties of these samples of asphalt binder are presented on Table 1.

TABLE 1 – Properties of asphalt binders samples

Binders	A	B	C	D	E	F	G	H	I
Brazilian Grade	50/70	50/70	30/45	50/70	30/45	E 65/90	AB 8	50/70	E 55/75
PG grade	58 S	64 S	64H	64S	64H	64V	64H	64S	64H

In order to estimate GR parameter aging path of each asphalt binder sample, the samples of these three studies in different aging states were analyzed in DSR rheometer. Therefore, they were submitted to master curve from frequency sweep testing at 5°C, 15°C, and 25°C in the DSR, interpolating to find the value of GR at 15°C and 0.005 rad/sec. Cravo [7] employed the samples: virgin, RTFOT aging, RTFOT + Thermal aging and RTFOT + Suntest aging. Suntest is a solar radiation simulator with xenon lamp supplied by Atlas, entitled Suntest CPS. Lamp intensity of 700 W/m^2 irradiates an asphalt binder film of 0.7mm thickness during 120 hours at 90ºC. Thermal aging is the same film thickness, temperature and aging time but without UV radiation. Dantas [6] employed the samples: virgin, RTFOT, RTFOT + sun light for six months and RTFOT + sun light for 12 months. Solar radiation and rain exposition was done in asphalt binder film of 1mm thickness. The asphalt binder films were applied on metal plates, being the plates placed on laboratory roof. Araujo [8] employed RTFOT aged samples plus wheaterometer aging with UV lamp at 60ºC for 10, 50 and 100 hours. The asphalt binder film of 0.6 mm thickness was applied on granite plate. The plates were placed in weatherometer Q Sun XE-1.

3. DISCUSSION OF RESULTS

The GR parameters of Araujo study were estimated at different times aging with UV radiation after RTFOT aging. The results are plotted in Figure 2. They revealed that the UV weatherometer aging is severe enough to place the two samples modified and not modified within the damage zone after 100 hours aging time. The behavior of the two samples was very similar after 50 hours. The concentration of SBS seems to be low to protect the sample against UV aging. Its aging path is located in a more elastic region.

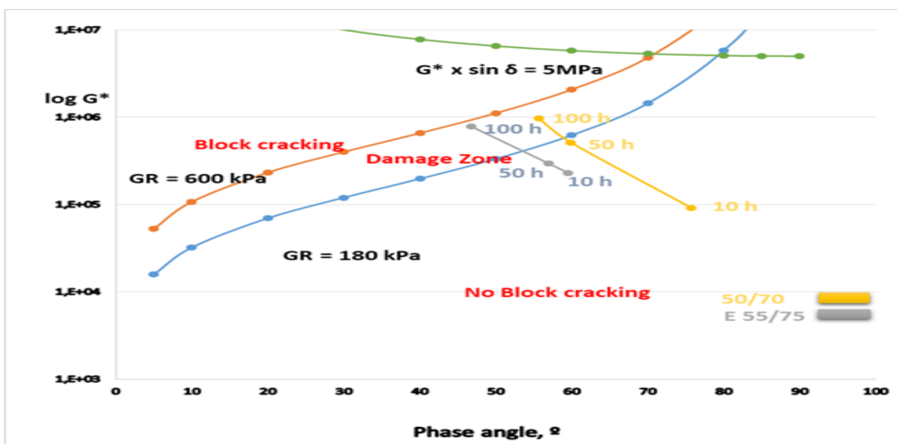

FIGURE 2 - Black Space Diagram of samples submitted to UV wheatherometer aging

The GR parameters of Dantas study are plotted in Figure 3. It showed that sun light aging can not afford to place all the aged samples after 12 months in damage zone. This aging sort is still weak to simulate the solar radiation effect during pavement service. Only TLA asphalt binder ended within damage zone. The study allowed the comparison of aging performance of different asphalt binders. SBS E 65/90 is the mostly modified of Brazilian specification. It had the best aging behavior. The two elastic asphalt binder presented their aging paths in elastic region. The path aging of two asphalt cements are similar, placed in more viscous region. TLA asphalt binder is in between the asphalt cement's zone and the elastomer-modified binder's zone.

The GR parameters of Cravo study are plotted in Figure 4. It showed that UV Suntest aging allow a better simulation of service pavement aging. The two samples after 120 hours at 90ºC Suntest aging are placed in damage and block cracking zone.

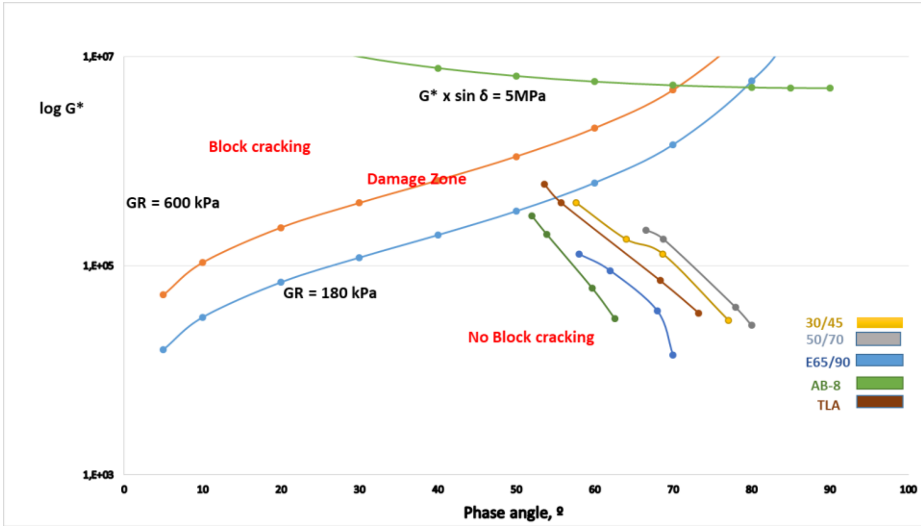

FIGURE 3 - Black Space Diagram of samples submitted to solar radiation aging

The thermal aging was not sufficient to put the aged samples in cracking zone, showing the UV effect severity. The process production source of them was responsible to classify the aging behavior of straight run sample better than deasphalting residue. This same conclusion had already revealed by Cravo, using another parameters [7].

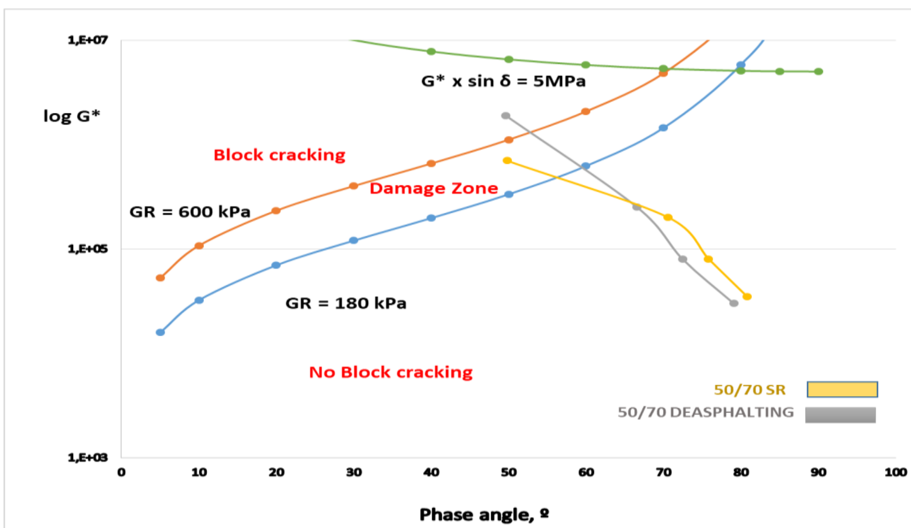

FIGURE 4 - Black Space Diagram of samples submitted to UV Suntest aging

4. CONCLUSIONS

The three aging studies presented different GR aging paths. The weatherometer aging for 100hours was not enough to place asphalt binders samples in the blocking crack zone. This method should be extended for more time or lesser film thickness. The sun light aging for 12 months on thin asphalt film was also insufficient to put the asphalt binders samples in the blocking and damage zone. These two procedures showed behavior differences between elastomeric modified asphalts and asphalt cements, in terms of Black space diagram location. The more elastic binders are placed on left side, the more elastic zone.

The Suntest was the best aging procedure, placing after 120 hours aging the asphalt cement samples in the damage and blocking zone. It revealed still the better aging resistance of straight run asphalt cements.

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