Asphalt Binder and Mastic Curves Characteristics: Binder Fracture Energy (BFE) Test and Dynamic Shear Rheometer (DSR) Test

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ABSTRACT

The mechanical properties of asphalt mastic influence significantly the overall performance of hot mix asphalt. The fatigue damage and fracture in the hot mix asphalt are strongly related to binder characteristics, filler properties, interaction between the binder and filler, and is a phenomenon affected by microcrack development and growth in the mastic such as crack pinning. This research aims to contribute to a better understanding of the mineral filler effects on the curves of two tests, the Binder Fracture Energy (BFE) Test developed at the University of Florida, and the Dynamic Shear Rheometer. The results show that mastics have similar curve shape of both tests, and cause a vertical shift on the DSR results and a decrease on fracture energy values.

Keywords: fracture energy; fatigue; asphalt binder; mastic; stress strain curve

1. INTRODUCTION

Fatigue damage is strongly related to binder characteristics, filler properties, interaction between the asphalt binder and mineral filler, and a phenomenon that affect microcrack development and growth in the mastic such as crack pinning [1].

For the evaluation of the fracture properties of asphalt binders, the most part of the researches utilize traditional tests methods, as the Dynamic Shear Rheometer (DSR), Bending Beam Rheometer (BBR), Elastic Recovery, Ductility, with the use of traditional parameters, as the complex modulus (G*), the phase angle (δ), or parameters derived from of these tests, as the energy and deformation produced at the maximum stress [2]. It is worth noting that most energy fracture tests to asphalt binders are developed to be utilized at low temperatures.

During the development of the HMA design of the SHRP Program, the thermal cracking at low temperatures was considered an important factor, for being one of main modes of distress development in pavements. So, based in practical consideration, two tests were adopted in the SHPR specification to asphalt binders, in order to characterize the low temperatures properties, the Bending Beam Rheometer (BBR), to evaluate the rheological properties, and the Direct Tension Test (DTT), to characterize the fracture property of asphalt binder [3].

Conceptually, the Direct Tension Test (DTT) is a suitable approach to determine the fracture energy of asphalt binder. However, due to configuration of the specimen, the standard DTT results are in a very large variability and do not represent properly the fracture condition of asphalt binders between the aggregate in the mixture, making the fracture energy determination not accurate. The tensile stress is fairly uniform in the extensive central section, so the specimen can break in any point at this section, which makes impossible the exact measure of the fracture stress on the fracture plane, what is required for fracture energy determination.

The DTT method should be limited to strains up to 10% to avoid the need for correction by reducing the cross section. Increasing the temperature and reducing the elongation rate, the binder fracture occurs with large deformations and is caused by the specimen flow and does not for the rupture.

Researchers at the University of Florida [4] developed a test to determine the accumulated energy until the rupture, which is able to provide the asphalt binder performance to the cracking in intermediate temperatures. The study developed a Direct Tension Test for asphalt binders and a data interpretation method that allows the accurate determination of the fracture energy at intermediate temperatures.

Roque et al. [4] tested a new procedure in a range of asphalt binders, including net binders, polymer modified binders, SBS modified binders and rubberized binders. Each binder was tested at different loading rates and temperatures.

The new test method of the Binder Fracture Energy (BFE) Test was not evaluated for asphalt mastics, so this research aims to contribute to a better understanding of the mineral filler effects over the fatigue cracking at intermediate temperature, through the fracture energy characteristics particularly related to the filler and asphalt binder type and filler content.

There is a correlation between the proportion of fines smaller than 75 μm in the mixture and the asphalt pavement behaviour in service. However, the filler physical-chemical properties, that determine in fact the good or bad performance in the field, should be must be well studied, i.e., there is still much to understand about the mechanism governing the contribution of the fillers to the overall performance of the mixture.

This research aims to contribute to a better understanding of the mineral filler effects on the curves of two tests, the Binder Fracture Energy (BFE) Test developed at the University of Florida, and the Dynamic Shear Rheometer, because each type of binder has its own characteristic of the true stress-true strain curve and master curve, for neat, aged and modified by different materials (polymer, rubber and others) asphalt binder.

2. MATERIALS

Two asphalt binders, with penetration of 50/70 (0.1 mm) and 85/100 (0.1 mm), and three fillers, Portland cement, limestone and hydrated lime were selected for this study. The characteristics of the binders and the fillers are presented in Table 1 and 2, respectively.

TABLE 1 Physical Properties of the Asphalt Binder

Property	Method ASTM	Result		Unit
		AC 50/70	AC 85/100	
Penetration	D 5	50	102	0,1 mm
Softening Point	D 36	48.6	43,5	° C
Brookfield Viscosity @ 135°C	D 4402	377	252.5	cp
Brookfield Viscosity @150°C	D 4403	187	130	cp
Brookfield Viscosity @177°C	D 4404	69	52.5	cp

TABLE 2 Mineral Filler Properties

Mineral Filler	Specific gravity (g/cm^3)	Specific Surface (cm^2/g)
limestone	2.749	2800 – 3500
hydrated lime	2.350	5000 - 15000
Portland cement	3.030	2200 – 2750

3. METHODS

The tests were performed in unaged binders and mastics and also in aged binders and mastics. Due to the lack of information and researches about which is the more suitable aging method for mastics, the aging was performed by two ways: (1) the standard procedure, applying 100 °C for 20 hours and; (2) a modified procedure, applying 60°C for 100 hours, stirring the sample every 20 hours.

The mastics samples were subjected to the dog bone direct tension test, at the unaged and at the aged condition. Portland cement and limestone filler were used, at the ratio (f/a) of 0.6 and 1.2; and with hydrated lime, at the ratio (f/a) of 0.3 and 0.6.

Specimens were moulded to obtain the Dog Bone shape according to "Standard Method of Test for Determining the Fracture Properties of Asphalt Binder in Direct Tension Test (DTT), AASHTO Designation: T 314-02". The Binder Fracture Energy (BFE) Test was performed according to Roque et al. (7).

In this study, Dynamic Shear Rheometer (DSR) were also performed to evaluate fracture energy and fatigue parameter ($G^*.\sin \delta$). The DSR tests were performed according to ASTM D 7175 – 05 ("Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer"). DSR tests were performed in unaged asphalt mastic composed by Portland cement and limestone at the ratio (f/a) of 0.6, 0.9 and 1.2, and by the hydrated lime at the ratio (f/a) of 0.6 and 0.9. The complex modulus (G^*) and phase angle (δ) were obtained at the temperature of 25˚C.

3.1 Stress Strain Curves

According to the research of Roque et al. [4], each type of binder has its own characteristic of the true stress-true strain curve: unmodified binders (PG 76-22 PAV), that present only one stress peak and low fracture energy ; SBS polymer modified binders (PG 64-22 Recovered), exhibited a second stress peak with high fracture energy; rubber modified binders (ARB-12), have the first stress peak followed by an inflexion instead of a second stress peak; hybrid binders – modified both with rubber and polymer (Wright, Hudson and Geotech), the curve present a second stress peak due the presence of the polymer.

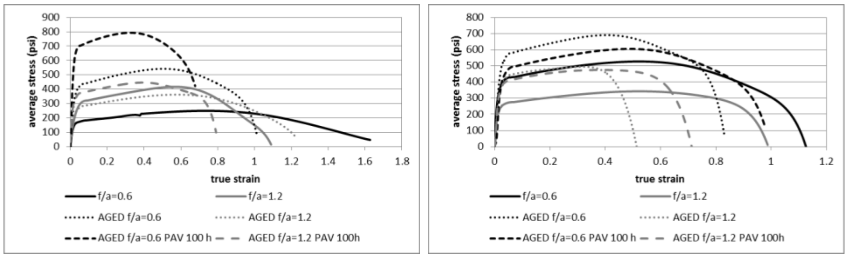
4. RESULTS

4.1 Strees Strain Curves

Figures 1 (a) and (b) show the stress versus strain curve, for the mastics composed by the Portland cements and 50/70 and 85/100 PEN, respectively. These curves have the same shape from the unaged and unmodified binder curves, with only one stress peak followed by a relatively steep drop in the true stress-true strain curve.

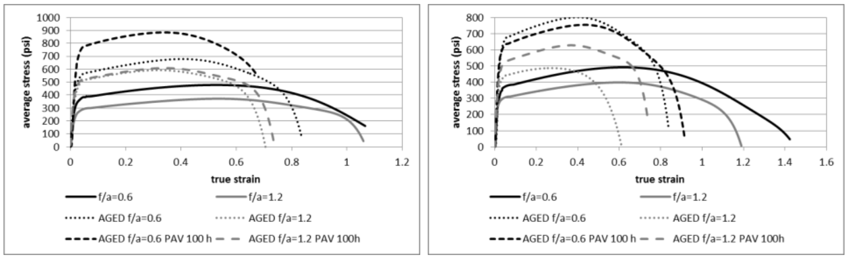
Figures 2 (a) and (b) show the stress versus strain curve, for the mastics composed by the limestone and 50/70 and 85/100 PEN, respectively. These curves have the same shape from the unaged and unmodified binder curves, as the mastic composed by the Portland cement.

Figures 3 (a) and (b) show the stress versus strain curve, for the mastics composed by the hydrated lime and 50/70 and 85/100 PEN, respectively. These curves have the same shape from the unaged and unmodified binder curves, as the mastic composed by the Portland cement and the limestone.



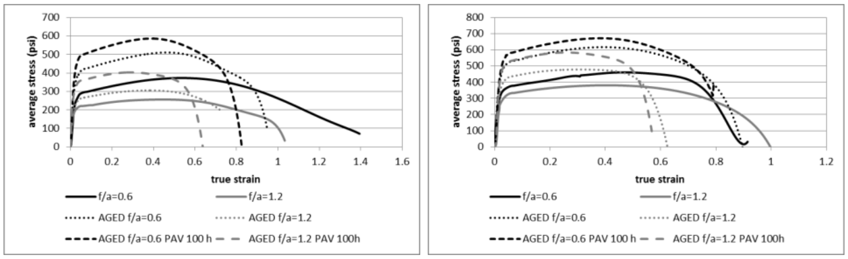
(a) **(b)**

FIGURE 1 True stress versus true strain for asphalt mastic composed by Portland cement and (a) 50/70 PEN and (b) 85/100 PEN



(a) (b)

FIGURE 2 True stress versus true strain for asphalt mastic composed by limestone and (a) 50/70 PEN and (b) 85/100 PEN

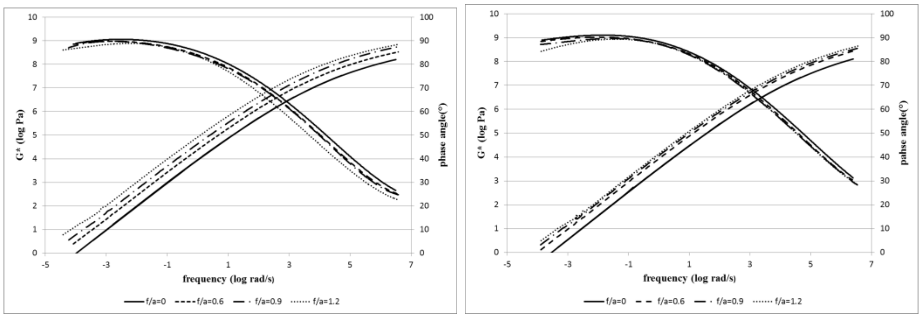


(a) (b)

FIGURE 3 True stress versus true strain for asphalt mastic composed by hydrated lime and (a) 50/70 PEN and (b) 85/100 PEN

4.2 Dynamic Shear Rheometer (DSR)

Figures 4, 5 and 6 present the master curves of G* and δ to the mastics composed by the 50/70 PEN (a) and 85/100 PEN (b), related to the filler/asphalt ratio, to the Portland cement, limestone and hydrated lime, respectively. The reference temperature is 40 °C.



(a) (b)

FIGURE 4 Master curve of G* and δ in function of frequency, to mastics composed by the Portland cement, in function of the f/a ratio and (a) 50/70 PEN and (b) 85/100 PEN

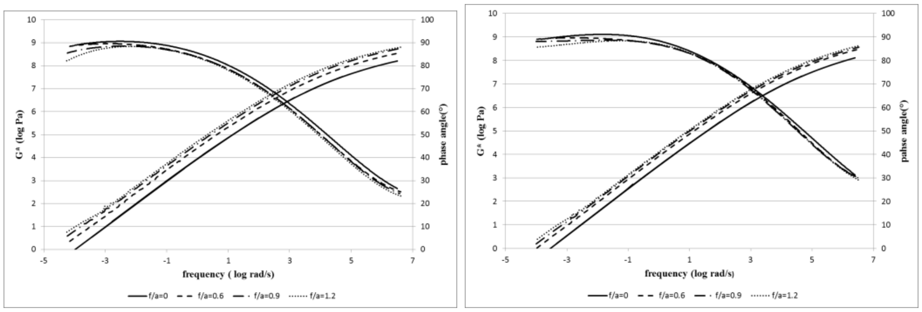


FIGURE 5 Master curve of G* and δ in function of frequency, to mastics composed by the limestone, in function of the f/a ratio and (a) 50/70 PEN and (b) 85/100 PEN

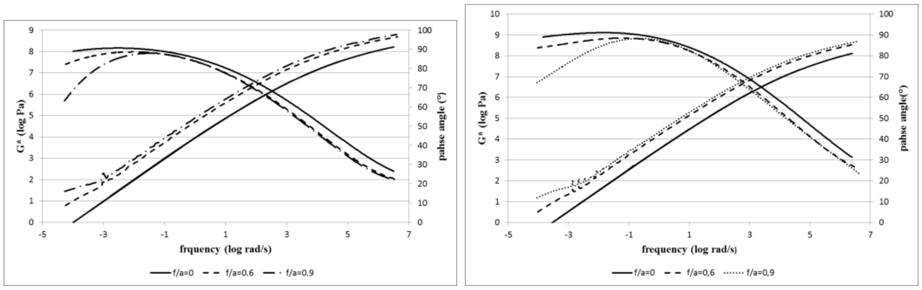


FIGURE 6 Master curve of G* and δ in function of frequency, to mastics composed by the hydrated lime, in function of the f/a ratio and (a) 50/70 PEN and (b) 85/100 PEN

It can be observed that in the development of the master curve of G with the frequency, the material present complex modulus value next to the vitreo modulus at low temperatures (high frequency) and have the stiffness decrease as the temperature increase (lower frequency).

The curve shape is of asphalt binders, that the modulus increase linearly with the loading frequency from the low frequency until the intermediate, and tends asymptotically to the modulus of 10^9 Pa (vitreo modulus).

The filler addition increase the G* values and decrease the δ, making the asphalt binder stiffer and more elastic. The stiffness increase is observed to every loading frequency or temperature. The filler addition causes a vertical shift on the stiffness scale, fairly uniform along the frequency scale, and decrease with the frequency increase (temperature decrease), indicating that the stiffener effect of the filler is more significant at high temperatures, which may reflect in an increase in the resistance to the permanent deformation of hot asphalt mixtures.

Analyzing the phase angle (δ) results, the elasticity increase with the filler addition, what is observed by the decrease of the phase angle values. The asphaltic mastic phase angle increased with the temperature, a tendency of variation similar to the asphalt binders. The filler addition provokes the phase angle reduction, making the mastic more elastic.

The filler amount effect (f/a ratio) is slightly different for each filler. To the mastic composed by the hydrated lime, the phase angle reduction is more notorious to low frequencies, for both type of asphalt binders; mastic composed by the limestone also presented a phase angle reduction large at low frequencies, however, this behavior is very subtler; mastics composed by the Portland cement, the phase angle reduction is more significant for high frequencies, when combined to the 50/70 PEN, and for lower frequencies, when combines to the 85/100 PEN.

Mastics composed by the 50/70 PEN presents G* values higher, when compared to the 85/100 PEN. The hydrated lime is the filler that present the larger stiffener capacity, with both asphalt binders; the Portland cement present higher stiffener values when combined to the 50/70 PEN, once combined to the 85/100 PEN, present stiffening similar to the limestone, showing the mastic behavior depends of the physical-chemical interaction between filler and asphalt binder [5]. The stiffening effect of the hydrated lime can be attributes the particle shape and the superficial texture, besides presenting a high potential physical chemical activity with the asphalt binder [6].

3. CONCLUSION AND FINAL COMMENTS

Fracture energy is an important property related to fatigue resistance of binders and has a strong influence on the cracking performance of flexible pavement. A new binder fracture energy test was developed by Roque et al. [5] based on nonlinear 3-D Finite Element Analysis (FEA) to determine the stress and the strain on the fracture plane, assuring accurate determination of fracture energy.

The main objective of this research is analyse the stress strain curve of asphalt mastics, from the Binder Fracture Energy (BFE) Test, and compare to curves of asphalt binders, observing the behaviour and shape of the curves. It’s also studied the behaviour of the curves of the rheological properties, particularly from the Dynamic Shear Rheometer, the complex modulus (G*) and phase angle (δ), to evaluate if the mastic present the behaviour of a modified binder.

The addition of filler to the asphalt binder decreases the fracture energy and consequently reduces the cracking resistance at intermediate temperatures. Hydrated lime is the type of filler that reduced the fracture energy the most, even at low contents for both asphalt binders.

Asphalt mastics have the same curve shape of unmodified binders of the DBDT, that present only one stress peak and low fracture energy; and of the DSR test, that the filler addition causes a vertical shift on the stiffness scale, fairly uniform along the frequency scale, and decrease with the frequency increase (temperature decrease).

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