Comparing Fatigue Life of a WMA and HMA Using the Four Point Bending Beam Test

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ABSTRACT

Warm Mix Asphalt (WMA) has had increasing use over the last years due to its advantages such as reduced Green House Gas emission, lower consumption of energy, reduced compaction temperature, amongst others. Surfactant additives improve compaction even at temperatures below those typically used with Hot Mix Asphalt (HMA). Many papers have studied WMA, but there is still a lack of concrete results regarding the behaviour of these mixtures in the long-term performance. Considering that fatigue is one of the key distress problems in Brazilian pavements, this paper aims at comparing the fatigue life assessment of a WMA and a HMA. Both mixtures were produced with the same materials differing only by the addition of the surfactant and temperatures of production and compaction. Fatigue tests were performed using four points bending apparatus under controlled deformation loading mode of 400, 500 and 600 microstrains. The results demonstrate a higher fatigue lifecycle for WMA in contrast to conventional HMA, particularly for low deformation levels. This behaviour may be credited to the higher flexural stiffness of the conventional HMA mixtures yielding to a reduction in their fatigue lifecycle.

Keywords: Warm Mix Asphalt, Fatigue, Controlled Strain, Flexural Stiffness.

1. INTRODUCTION

Increased scientific awareness about the effects of climate change have motivated all fields of engineering to search for more sustainable products and take into consideration the rational use of natural resources. The road engineering field is no different, and new techniques and products have been developed aiming at reducing the environment impact in road maintenance efforts. In addition, scientific studies aiming at reducing the temperature of asphalt mix production have increased all over the world.

Reducing the temperature of hot mix asphalt (HMA) can generate a variety of positive aspects such as extending paving seasons in cold climates regions, energy savings linked to lower fuel consumption in plants, healthier working environments, and concrete support to the struggle against the effects of climate change as it contributes for a reduction of greenhouse gas emissions [1-2].

Furthermore, reduced heat exposure during asphalt mix production is another benefit to be considered. HMA temperatures for mixing average 150°C. At this temperature, particles that are already in the asphalt binder have the potential to evaporate, causing oxidation and consequently reducing material’s drop-in performance.

Different techniques are used to generate temperature reduction in asphalt mixes; the majority uses additive blended in binder. Surfactant additives proved to be effective and easy to use in warm mix production [1-4].

Surfactant additives have their origin from surface-active agents. These agents act in the interface between aggregates and the asphalt binder provoking better lubricity between both and, hence, enabling an easier binder coating over aggregates at lower than conventional temperatures. The addition of WMA surfactant additive enables a decrease in the compaction temperature of about, at least, 30°C without significant loss in workability and improving particle homogeneity in the mixes [5].

In order to ensure the use of WMA is increased, its performance characteristics needs to be similar to the ones found at HMA, provided that practice has already proved its use effective as far as application is concerned

Fatigue cracking phenomenon, caused by the intermittent repetition of traffic loads in the road structure, is one of the major distress mechanisms that affects asphalt pavement performance. It must be considered at the asphalt mixture design and be used at the asphalt surface of a road pavement. [6].

Based on the afore mentioned, this paper aims at studying the fatigue behaviour connected to a WMA and a HMA using the Four Point Bending Beam (4PBB)Apparatus. In this test, a bi-supported prismatic test beam is subjected to vertical loads in the centre two-thirds of the beam, leading to a uniform bending moment in the central part of the sample between the two loading points, with zero normal and shear stresses. This is a suitable test to represent the field behaviour in relation to the fatigue strength of asphalt mix [7]

The beam specimens to this test are usually extracted from the field or molded using slabs and cut in the laboratory [8].

The flexural fatigue tests could be conducted in 4PBB under controlled strain or stress modes. However, at the controlled stress tests, deformation increases with stiffness reduction. At the controlled strain test, tension is reduced throughout the test [9-10].

Fatigue tests are typically interpreted with the use of curves that are related to the level of stress or strain with the number of cycles until the failure of the samples by an exponential function called Law or Fatigue Model (Wöhler Curves). The failure criteria vary as the samples may be conducted until a 50% reduction from the initial stiffness, until the complete failure, until they reach a determined number of cycles, until an increase in the rate of energy dissipation stops being linear, amongst others.

The more relevant parameters on the fatigue behaviour are the strain level and the material stiffness, so a model that takes into account these parameters could be a good approximation for an increased prediction accuracy on the performance of asphalt mixtures.

As a result of the study, a single model for both mixtures HMA and WMA were obtained, using variables such as initial flexural stiffness and strain from the 4PBB Test.

2. MATERIALS

The study was carried out with typical materials used in Brazilian highways, ergo, national standards were applied. The materials characteristics are shown below.

2.1 Asphalt Binder

The asphalt binder used was a type 50/70 (pen gradation). Such binder has no modifiers, only the surfactant in the warm mixes, which allows the additive effect to become evident.

The addition of the surfactant used in this research do not change significantly the asphalt binder characteristics measured, which could influence the fatigue life. In Table 1 are presented both conditions with and without the additive, according to Brazilian specifications [11].

TABLE 1 Results of Binder Characterization

PROPERTIES	BRAZILIAN SPECIFICATION	BINDER 50/70	BINDER + SURFACTANT (WMA ADDITIVE)
SOFTENING POINT	46min	49	48
PENETRATION	50-70	67	57
SPECIFIC GRAVITY	--	0.957	1.017
BROOKFIELD VISCOSITY 135°C (cP)	274 min	408	480
BROOKFIELD VISCOSITY 150°C (cP)	112 min	237	242
BROOKFIELD VISCOSITY 177°C (cP)	57-285	90	91

Important to notice that the temperature reduction for WMA production shall only be carried out for mixing and compaction. Binder has to be pre-heated at the same temperature for both mixes.

2.2 Surfactant additive

The surfactant used was Ingevity Evotherm® M1, that is available in liquid form and can be added directly in the binder to a ratio of 0.4% by total weight of binder, as per supplier recommendation. Due to convenience, provided no changes in the production line of asphalt mix is required, this type of additive is of growing use [12].

Typically, such use allows 30°C reduction in mix and compaction temperatures and provides a better densification on the field.

2.3 Aggregates

The aggregates used are of basaltic origin, from a quarry located in southern Brazil (Santo Antonio da Patrulha/RS). The particle size distribution is of a dense graded mixture, with maximum nominal size of 19 mm, according to Brazilian standards [13].

2.4 Mixture parameters

Both mixtures, HMA and WMA, were designed using the Marshall methodology, using the same aggregate gradation and binder type, only varying incorporation of WMA surfactant additive.

The characteristics obtained for both mixtures are shown in Table 2 and evidence no significant change in the parameters. HMA was mixed at 153°C and compacted at 143°C, while WMA was mixed and compacted at 30°C below (123°C and 113°C, respectively).

TABLE 2 Final Characteristics of the Asphalt Mixtures.

PROPERTIES	STANDARD DNIT –031/2006	HMA NO ADDITIVE	WMA WITH ADDITIVE
BINDER CONTENT (%)	--	5.7	5.7
AIR VOIDS (%)	3-5	4.3	4.2
VOIDS W/ASPHALT (%)	72-82	76.9	78.2
GMM (kN/m³)	--	25.06	25.04
GMB (kN/m³)	--	23.98	24.04

3. METHODOLOGY

A 4PBB Beam Test was used to investigate the fatigue life of the two asphalt mixes presented in this study.

To obtain the beams of asphalt mixture, a methodology of molding and compaction of the slabs in laboratory was selected [8]. After this process, the slabs were sawn in order to obtain the beams in required sizes, and these samples tested to verify the apparent density and degree of compaction.

The tests were carried out under controlled deformation mode of loading. All tests were conducted at 10 Hz frequency, in a sinusoidal load wave shape, at the temperature of 20°C attending to AASHTO T-321 [14]. Three different levels of peak-to-peak strain were tested, 400, 500 and 600 microstrains for three samples for each level. The failure criterion used was the 50% reduction in the initial flexural stiffness, measured in the 50th cycle.

Fatigue life models were determined considering initial stiffness and tensile strain for the two asphalt mixtures studied, allowing to compare both behaviour.

4. RESULTS

Table 3 show the four points bending beam fatigue results, the flexural stiffness and the air voids for all HMA and WMA samples.

TABLE 3 Four points bending beam fatigue results.

STRAIN (μƐ)	VV (%)		INITIAL FLEXURAL STIFFNESS (MPa)		CYCLES TO FAILURE (Nf)	
	HMA	WMA	HMA	WMA	HMA	WMA
400	3.9	3.4	5405	4503	8.48E+05	9.25E+05
	3.5	3.5	4887	3803	8.41E+05	1.73E+06
	3.7	4.0	4807	3600	4.93E+05	2.54E+06
500	5.1	4.3	4700	4161	3.01E+05	2.78E+05
	5.2	5.0	3789	3831	5.57E+05	3.29E+05
	5.1	5.2	4462	3723	1.76E+05	6.01E+05
600	4.7	4.4	4130	3915	1.70E+05	1.26E+05
	4.8	4.5	4820	5778	8.02E+04	1.01E+05
	4.7	4.5	4163	3669	1.01E+05	1.82E+05

The results indicate a higher fatigue life for the warm mixes, predominantly in the lower strain level (400 microstrains) where the fatigue life was more than twice longer. The longer fatigue is associated to lower flexural stiffness, indicating a great sensibility to this parameter.

As the mixtures have the same materials and the final characteristics are quite similar, the aim was a single model that includes the imposed strain and the flexural stiffness, covering both performances (Eq. (1)).

$$N_f = a \; x \left({}^{1}/_{\varepsilon_t}\right)^{b} x \left({}^{1}/_{S_i}\right)^{c} \qquad (1)$$

where N_f is the number of cycles to failure; ε_t is the strain level; S_i is the initial flexural stiffness; a, b and c are the fitting coefficients.

The coefficients were adjusted using the Microsoft Excel solver function, optimizing to minimize the error between the model and the measured data.

The fitting coefficients for the WMA data had a better adjust, thus the same coefficients were also used for the HMA adjust. In general, a strong correlation was obtained from this model with a R-square value of 0.994 for WMA and 0.807 for HMA. The Figure 1 shows the measured data and the model adjusted for both mixtures.

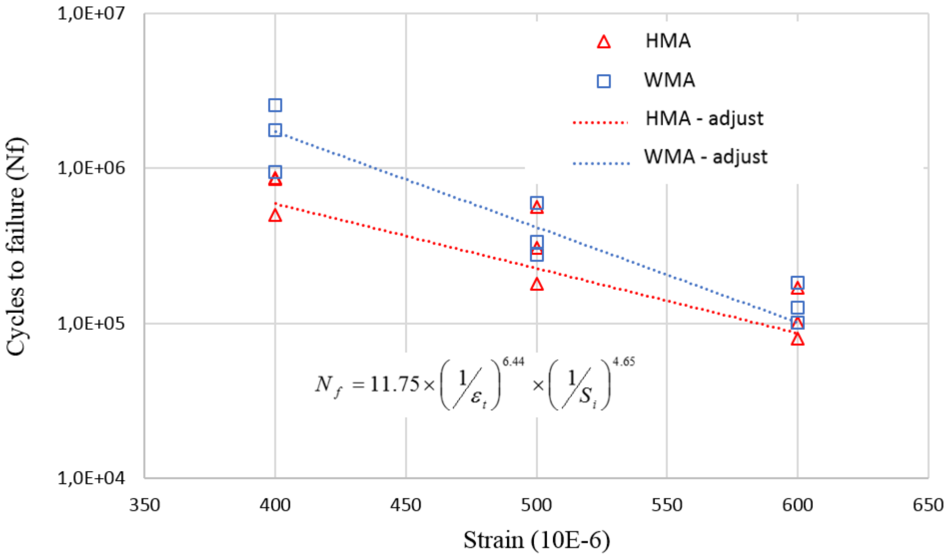

FIGURE 1 Measured Data and Model Adjusted.

5. CONCLUSIONS

The results demonstrate a fatigue lifecycle is higher for WMA in comparison to HMA, particularly for the low strain levels. This behaviour may be credited to the higher flexural stiffness of the HMA, leading to reduced fatigue lifecycle. At controlled strains tests, the stiffer the mixture, the higher is the stress imposed by the equipment to reach the desired strain level, leading to higher damage on the sample.

Arguably, the higher stiffness in the HMA can be connected to the short-term aging from the asphalt binder during the production of the mixtures, exactly because of its exposure to higher temperatures. This makes the oxidation process to be accelerated turning the asphalt binder stiffer and fragile. The surfactant used does not seem to affect the WMA behaviour, except for the reduced stiffness. Likewise, this change in stiffness is probably due its reduced exposure to higher temperatures.

The model showed a good correlation for the studied mixtures. It indicates that the hot and warm mixes (with surfactant) designed with the same materials have a fatigue behaviour with the same tendency, but clearly sensitive to the stiffness variation. A model that takes into account this parameter, as the presented in this research, is potentially suitable to predict the fatigue response of both warm and hot mixes if adjusted to just one of the conditions, since the stiffness of the other is known.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude for the Lapav-UFRGS and all other laboratory partners for their technical contribution and financial support to the research group.

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