THE EFFECT OF AGGREGATE-BINDER ADHESION IN FATIGUE AND MOISTURE DAMAGE RESISTANCE IN ASPHALT MIXTURES

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ABSTRACT

This laboratory study investigates the effect of aggregate-binder adhesion on the moisture damage and fatigue life of asphalt mixtures. Three mixtures with the same aggregate gradation and approximate volumetrics were investigated: one with pure binder, another with the same binder and a commercial antistripping agent, and a third one with the same binder and grounded plastic bags as an additive to improve aggregate-binder interface properties. Adhesion was analyzed following the Brazilian standard NBR 12583/17 and subsequent digital image processing (DIP). Moisture damage was also investigated considering NBR 15617/15, and fatigue life of the mixes was determined by the diametral compression test under controlled stress. The aggregate area covered by the binder, as determined by DIP a correlation with moisture damage results. The results showed that both the commercial antistripping agent and the plastic bags produce an increase in the resistance of asphalt mixtures against moisture damage and also an increase in fatigue life when compared to the mixture with pure binder.

Keywords: Adhesion, stripping, cracking fatigue, moisture damage.

1. INTRODUCTION

According to a national research conducted in 2016, Brazil has 211,468 km of paved roads, of which 103,259 km, or 17.3%, exhibit cracking on their asphalt pavements [1].

Traffic weather, and the compatibility of the materials within the surface coarse mixture can accelerate the formation of cracks, mostly caused by fatigue associated to repeated loads.

The decreased adhesion at the aggregate-binder interface affects the structural quality of the pavement. When water penetrates the interface, there is a tendency of bituminous-film rupture (film surrounding the aggregate), and with repeated loading, microcracks begin, potentially evolving to fatigue cracking.

This study investigates how aggregate-binder adhesion can contribute to fatigue cracking of asphalts mixtures tested in the laboratory. Adhesion, was investigated by means of testing mixtures with the same aggregate gradation and similar volumetrics, but differing with respect to their additive. The following configurations were tested: aggregate and pure binder, aggregate and the same binder modified by an antistripping agent, and aggregate heated along with grounded plastic bag from waste and subsequently mixed with the same pure binder of the former mixes. The materials are further detailed ahead along with the experiments performed.

The DIP analysis of the adhesion test has the capacity to transform a qualitative result into a quantitative result, which may help in correlations with different tests related to the subject and with physic-chemical properties of the materials composing the asphalt mixture.

2. MATERIALS AND METHODS

The aggregate used is phonolitic and the asphalt binder is processed by Petrobras/Lubnor in the state of Ceará. The characterization of these materials is described in Table 1.

TABLE 1 Characterization of Materials

Characterization of asphaltic binder	
Penetration, 25ºC [dmm]	50
Softening Point [ºC]	49
Temperature Susceptible	-1.4
Rotational Viscosity, 135ºC [Cp]	395
Mixing Temperature [ºC]	160 – 166
Compaction Temperature [ºC]	148 – 152

Characterization of aggregates		
Test	Coarse	Fine
Los Angeles abrasion [%]	20.26	-
Absorption [%]	0.874	1.218
Adhesion	Unsatisfactory	
Actual Density	-	2.547
Apparent density	2.394	-

Three asphalt mixtures were investigated using the Superpave Methodology. Mixture M1-P (P from Pure binder) was produced with pure binder, whereas mixture M1-M (M from Modifier) with a 0.2% commercial adhesion antistripping agent, and mixture M1-R (R from Recycled) with grounded plastic bags (PB) from waste. Fine PB material reached 1 cm² ± 0.5 cm², and it was placed upon the aggregates heated at 160ºC. These residues were added at a content of 1.0% of the total mass of the mixture. This technique enabled PB to melt over the aggregates prior the subsequent addition of the asphalt binder. The mixing temperature was 160°C and the compaction temperature was 150°C. Figure 1 presents the sole aggregate gradation curve used and Table 2 presents the volumetric parameters of the investigated mixtures.

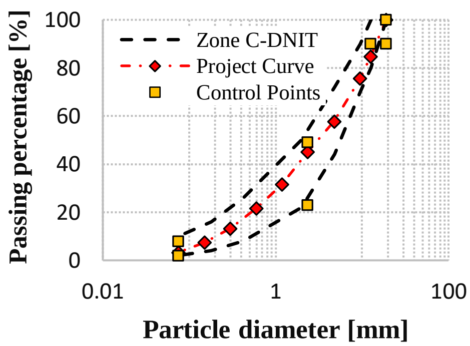


FIGURE 1 Aggregate Gradation Curve

TABLE 2 Volumetric Parameters of the Specimens

	Mixtures		
	M1-P	M1-R	M1-M
Optimum binder content CA [%]	5.0	5.0	4.5
Air voids [%]	3.73	4.14	3.80
Bulk specific gravity [g/cm^3]	2.253	2.186	2.214

The adhesion of the mixtures was measured following NBR 12583/17, and analysis of the bitumen-coated aggregate area was also determined by digital image processing (DIP). Moisture damage was analyzed following NBR 15617/15, and laboratory fatigue life was measured by the diametral compression test under controlled stress. Testing procedures are briefly described ahead.

2.1 NBR 12583/17

NBR 12583/17 has traditionally been used in Brazil access the aggregate-binder adhesion. It uses a sample of heated aggregate (12.5/19.0 mm) weighing 500 ± 1g and 17.5 ± 0.5g of asphalt cement at a temperature of 100°C for aggregates and 120ºC for the AC. The mixture is homogenized until the bituminous film completely coats the aggregates, and it is then cooled maintaining the aggregates separated one from another. Upon cooling, the mixture is placed in a beaker completely submerged in distilled water and then heated in the oven at 40ºC for 72 hours. After this period, the mix is removed from the beaker and a visual inspection is performed. If the film continues to completely coat the aggregates, the result is considered satisfactory. If one notes displacement of the film, the result is considered unsatisfactory. Therefore, results are reported on a qualitative and subjective basis.

2.1.1 Coated Area Analysis

In order to also have a quantitative and objective analysis, a pixel counting methodology was developed in this research to determine the coated area of bituminous film after the adhesion test. After the test, the loose mix is placed on a white paper sheet and photographed using a 12 megapixel camera (resolution of 1280 x 720). The aggregates of the mix are then rotated, and three images are taken, since the test has a three-dimensional result and an image is two-dimensional. Pictures are then taken to Matlab R2017 and histogram evaluation techniques are used to find thresholds, image segmentation, recognition, classification, and image analysis.

DIP allows counting pixels within the aggregates and the asphalt binder. With Equation (1), it is possible to find the bitumen film coating area (A_{DIP}), where P_B denotes the number of pixels of the binder and P_A the number of pixels of the aggregates.

$$A_{DIP} = \frac{P_B}{P_A} \cdot 100 \tag{1}$$

2.2 Moisture Damage - NBR 15617/15

Mixture specimens are compacted to 7±1% air voids and then divided into 2 groups. In the first group, three specimens are submitted to evaluate the indirect tensile strength (ITS) by diametral compression following NBR 15087/12. In the second group, three more specimens are placed under high humidity severity conditions. Specimens are submerged in water and saturated under vacuum until they reach a saturation level between 55-80%. They are then kept in the freezer at -18°C for 16h, taken to a hot water bath at 60°C for 16h, and finally for temperature stabilization at 25ºC for 2h. After this procedure, specimens are subjected to the ITS test. The indirect tensile strength ratio (TSR), expressed in percentage, is determined by Equation (2), where ITS_C(MPa) is the indirect tensile strength of the conditioned specimens and ITS(MPa) is the indirect tensile strength of the non-conditioned specimens.

$$TSR = \frac{ITS_C}{ITS} \cdot 100 \tag{2}$$

2.3 Fatigue

The laboratorial test to evaluate the fatigue life most commonly performed in Brazil is the diametral compression under controlled stress (CS), in which the load is applied by the pneumatic equipment at a frequency of 1 Hz (0.1s load and 0.9s rest period).

The fatigue life is expressed by Equation (3), where N is the number of loads to specimen failure, $\Delta\sigma$ the difference between compression and tension stress in the middle of the sample, and k and n constants determined from the experimental results.

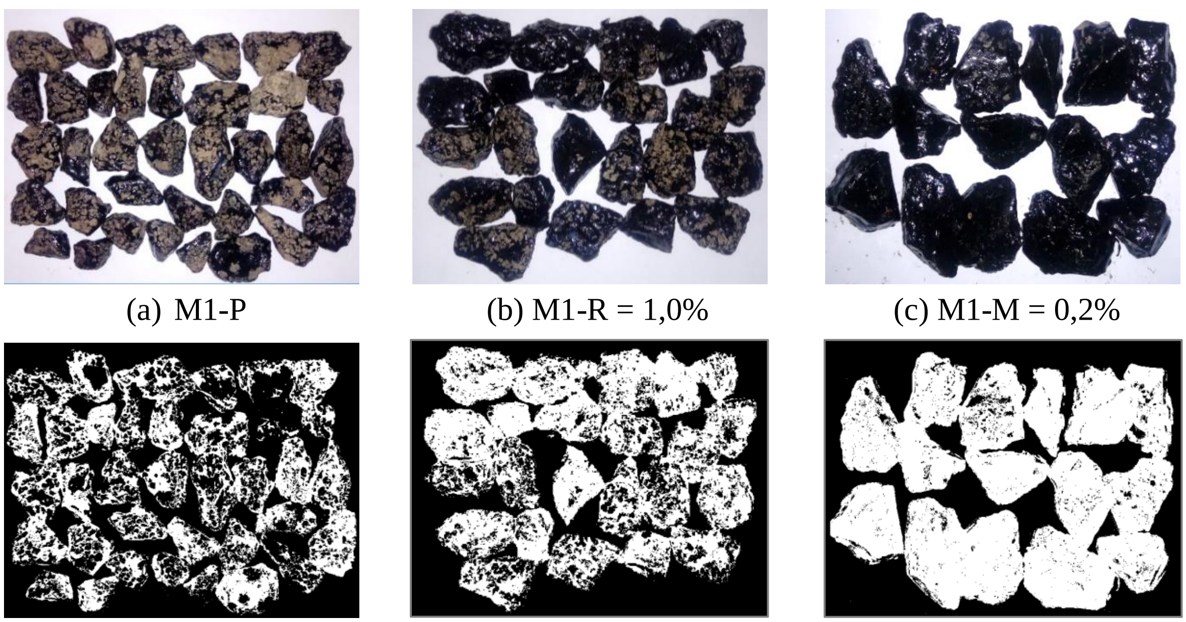
$$N = k \cdot \left(\frac{1}{\Delta\sigma}\right)^{n} \tag{3}$$

In this study, it is tested the levels of stress of 20, 30 and 40% of the ITS at 25ºC. For each stress level, three specimens of each mixture were tested and then a fatigue curve was plotted.

3. RESULTS AND DISCUSSIONS

3.1 Adhesion - NBR 12583/17

Figures 2 (a), (b) and (c) show images of the tested mixes after the adhesion test. The results obtained after DIP are shown in Figures 2 (d), (e) and (f), respectively.



(a) M1-P (b) M1-R = 1,0% (c) M1-M = 0,2%

(d) DIP – M1-P (e) DIP – M1-R (f) DIP – M1-M

FIGURE 2 Images Before and After Digital Processing.

With DIP analysis it was determined that M1-P mixture had the worst aggregate-binder adhesion, as expected since no additive was used. Mixture M1-M presented the best result, while M1-R presented an intermediate result, as shown in Table 3, which indicates the potential of using a waste such as grounded plastic bag as an antistripping agent.

TABLE 3 Determined Area by DIP

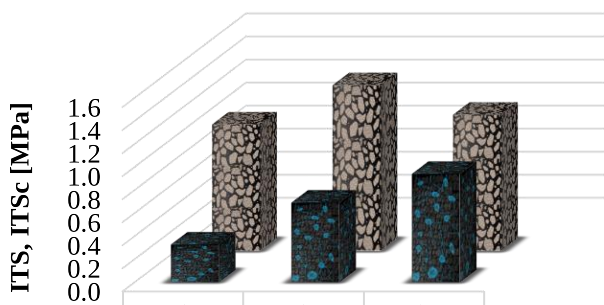
Mixtures	Threshold	$\overline{P_L}$	$\overline{P_A}$	A_{PDI} [%]
M1-P	0.200 | 0.785	137,650	274,130	50.21
M1-R	0.200 | 0.645	215,060	309,540	69.48
M1-M	0.330 | 0.580	371,269	397,780	93.33

It is important to notice that the PB only start completely melting over the aggregate at a temperature of 140ºC, and that the adhesion test performed recommends the aggregate and binder temperatures at 100ºC and 120ºC, respectively. Therefore, the PB melts only partially over the aggregate. The authors verified that the coated area after the adhesion test increases even further with the increase in the temperature of the aggregate.

3.2 Moisture Damage - NBR 15617/15

The results following NBR 15617/15 demonstrate that the antistripping agent increased considerably the compatibility of the materials, reducing the moisture damage.

Considering only ITS of the first three non-moisture-conditioned mixtures, the addition of the antistripping agent by itself did not produce a significant increase on its ITS. From M1-R results, one note PB produces a considerable increase of ITS, when compared to M1-P and M1-M, as shown in Figure 3. However, M1-M is much more efficient in combating moisture damage, when compared to other mixtures. This is because positive charges of antistripping agent increase the binding strength at the aggregate-binder interface, making moisture infiltration difficult.



	M1-P	M1-R	M1-M
ITSc [MPa]	0.33	0.69	0.94
ITS [MPa]	1.10	1.44	1.18
TSR [%]	30	48	79

FIGURE 3 Moisture Damage of Asphaltic Mixtures

3.3 Relation Between Adhesion and Moisture Damage

Figure 4 shows the relation of the quantitative results of the adhesion determined by DIP as presented in Table 3 with the results of the moisture damage as indicated in Figure 3. Despite the reduce number of mixtures thus far in this research, one note a stronger correlation between the areas determined by DIP with the $ITSc$ of the conditioned specimens, which is not observed for the non-conditioned specimens.

Considering the three analyzed mixtures and a minimum TSR of 70% [2], a criterion of A_{DIP}≥86% could be established to classify mixtures with minimally desirable adhesion, giving adequate moisture damage resistance.

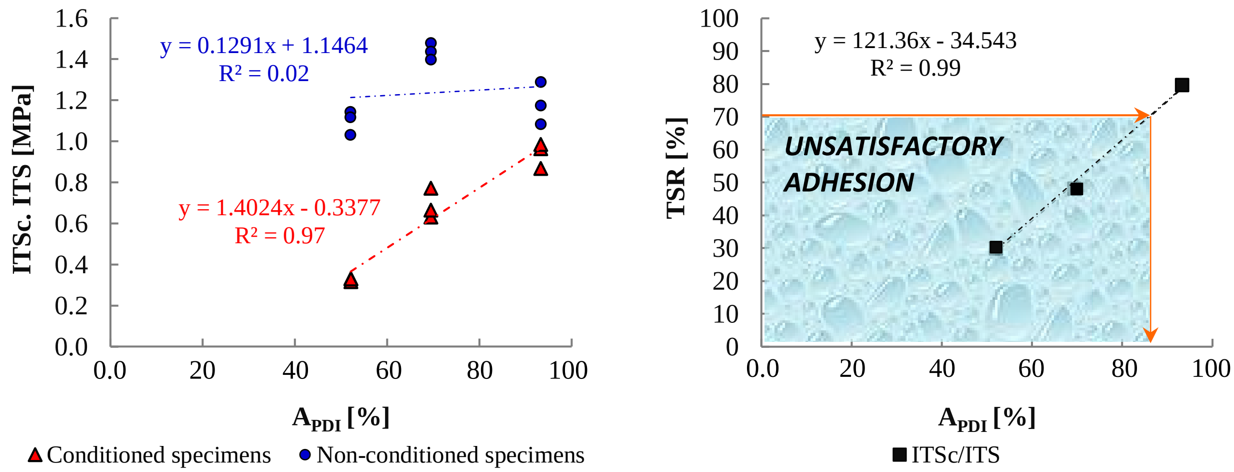


FIGURE 4 Relation Between Adhesion and Moisture Damage

3.4 Fatigue

Figure 5 and the experimental fatigue coefficients in Table 4 show that M1-M and M1-P present similar trends. Because M1-R has a higher *ITS* (1.44MPa) than the other two mixtures, the applied target load was higher and consequently the difference of stresses obtained was higher. This is a bias of the diametral compression test under controlled stress [3].

The number of loads to failure for M1-R was much higher when compared to the other two mixtures. It is observed that the antistripping agent increased the fatigue life when compared to the mix with pure binder.

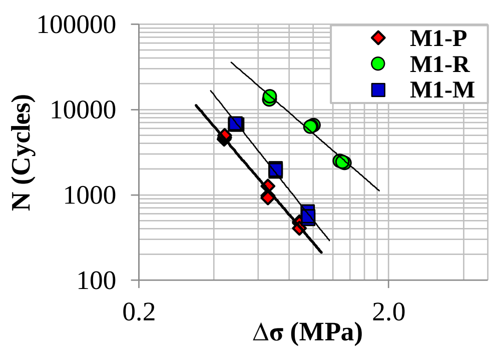


FIGURE 5 Fatigue Life Curves

TABLE 4 Fatigue Test Data

	M1-P	M1-R	M1-M
k	2.72E+2	5.21E+3	5.47E+2
n	3.432	2.538	3.695
R-squared	0.98	0.97	0.99

3. CONCLUSIONS

Both the grounded PB and the investigated antistripping agent decreased the displacement of the bituminous film, the latter with greater effectiveness. The digital image processing makes it possible to objectively determine the bituminous film coated area after the adhesion test and this measurement apparently may be used to access the results of moisture damage. Further investigation is necessary with a larger number of mixtures.

It is noticed that the commercial antistripping agent strongly contributes to prevent moisture damage. The mixture containing this additive had a satisfactory coated area, produced the best response with respect to moisture-conditioned, and also presented a potential to increase fatigue life.

Considering the PBs, it was noticed a trend of considerable improvement related to an increase in fatigue life. This study identified the potential of the investigated waste both to prevent moisture related damage and to increase fatigue life.

4. REFERENCES

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