Adhesion at Asphalt-Aggregate Interface Through Surface Energy

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Outline

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• Introduction
• Problem
• Materials and Methods
• Results ans analysis
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Motivation

Cocuy Snowcapped

Bogotá. D.C.

La Guajira (Caribbean Coast)

Nuquí (Pacific Ocean)

Sumapaz Páramo
Introduction

COLOMBIAN HIGHWAY NETWORK GENERAL CONDITION

Creek Street “LA FELICIDAD”

Downpour

Longest Continental mountain range: LOS ANDES

Other Treatments L=736,91Km

Introductory Information:
- Downpour
- Creek Street “LA FELICIDAD”
- Longest Continental mountain range: LOS ANDES
- Other Treatments L=736,91Km

Graphs and Data:
- Full Road Network (Figure 1)
  - Full Road Network (Based on L=10015,66km)
  - 25% Paved
  - 75% Unpaved

- Paved Road Network (Figure 2)
  - Paved Road Network (Based on L=6966,89km)
  - 23% Really Good
  - 77% Bad
  - 52% vs. 48%

- Unpaved Road Network (Figure 3)
  - Unpaved Road Network (Based on L=2311,86km)
  - 1,33% Really Good
  - 1,02% Good
  - 1,67% Tolerable
  - 12,11% Bad
  - 8,73% Really Bad
  - 23% vs. 77%
Degradation of mechanical properties due to moisture damage (liquid or water vapor)

Loss of adhesion between the aggregate and the binder

Loss of cohesive resistance of asphalt by the presence of water

Problem

MOISTURE DAMAGE

Loss of functionality

STRIPPING
MOISTURE DAMAGE = $\tau_h / \tau_s$

$\text{TSR vs. MIST}$

$k$: conductividad (watt/m$^\circ$K)
$\delta$: densidad (kg/m$^3$)
$C$: calor específico (Julio/kg$^\circ$K)
Difusividad térmica = $\alpha$ (m$^2$/s)

$\alpha = k / (\delta \times C)$
Surface energy of the solid $\gamma_s$
Surface energy of the liquid $\gamma_L$
Interfacial solid-liquid energy $\gamma_{SL}$
Cohesion Work $W_c = 2\gamma$

Contact angle to determine cohesion and adhesion

\[ W_a = W_{SL} = \gamma_s + \gamma_L - \gamma_{SL} \]

\[ \gamma_L \times (1 + \cos\theta) = 2 \times \sqrt{\gamma_{SL} \times \gamma_{LW}} + 2 \times \sqrt{\gamma_s^+ \times \gamma_L^-} + 2 \times \sqrt{\gamma_s^- \times \gamma_L^+} \]

Where:

- $\gamma_{LW}$: Lifshitz-Van Der Waals apolar component
- $\gamma^-$: Lewis basic parameter
- $\gamma^+$: Lewis acid parameter

\[ W_a = \gamma_L(1 + \cos\theta) \]

Where:

Contact angle is $\theta$ and it value can vary how is shown below.

- $\theta = 0^\circ$
- $\theta = 90^\circ$
- $\theta = 180^\circ$

- $W_c = W_a$
- $W_c = 2W_a$
- $W_a = 0$

(a) footprint is ≥ 50%, Cohesive Failure
(b) footprint is < 50%, Adhesive Failure
Materials and Methods

- Asphalt: penetration 60-70 (0,1 mm) (PG 64-22)
- BBS test
- Electronic Goniometer
- Surface Free Energy: Formamide (F), Deionized Water (H2O) and Ethylene Glycol (E).

<table>
<thead>
<tr>
<th>Test</th>
<th>Aggregate 1 (sandstone)</th>
<th>Aggregate 2 (sandstone)</th>
<th>Aggregate 3 (alluvial limestone)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent density</td>
<td>2.46</td>
<td>2.43</td>
<td>2.74</td>
</tr>
<tr>
<td>Absorption (%)</td>
<td>2.36</td>
<td>3.33</td>
<td>0.36</td>
</tr>
</tbody>
</table>
# Results and Analysis

<table>
<thead>
<tr>
<th>Type of Aggregate</th>
<th>Contact Angle</th>
<th>Coefficient of variation (Cv) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate 1</td>
<td>155,9°</td>
<td>3,13</td>
</tr>
<tr>
<td>Aggregate 2</td>
<td>159,2°</td>
<td>2,21</td>
</tr>
<tr>
<td>Aggregate 3</td>
<td>161,4°</td>
<td>2,22</td>
</tr>
</tbody>
</table>

## Table of Results

<table>
<thead>
<tr>
<th>Type of rock</th>
<th>Dry Condition</th>
<th>Wet Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Asphalt covered area average</td>
<td>Type of failure</td>
</tr>
<tr>
<td>Aggregate 1 (sandstone)</td>
<td>98,60%</td>
<td>cohesive</td>
</tr>
<tr>
<td>Aggregate 2 (sandstone)</td>
<td>94,92%</td>
<td>cohesive</td>
</tr>
<tr>
<td>Aggregate 3 (limestone)</td>
<td>88,60%</td>
<td>cohesive</td>
</tr>
</tbody>
</table>

![Graph showing the comparison between Dry and Wet conditions for different types of aggregate.](image)
### Results and Analysis

#### Summary of Total Free Surface Energy (TFSE) and its Components

<table>
<thead>
<tr>
<th>Surface</th>
<th>Acid (+) and Basic (-) Components (ergs/cm²)</th>
<th>Acid-Basic Component $\gamma_{AB}$ (ergs/cm²)</th>
<th>Apolar Component $\gamma_{LW}$ (ergs/cm²)</th>
<th>TFSE $\gamma$ (ergs/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt</td>
<td>$\gamma^-$ 0,098</td>
<td>1,886</td>
<td>8,998</td>
<td>10,883</td>
</tr>
<tr>
<td></td>
<td>$\gamma^+$ 9,111</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregates 1 (Sandstone 1)</td>
<td>$\gamma^-$ 56,223</td>
<td>14,199</td>
<td>65,849</td>
<td>80,047</td>
</tr>
<tr>
<td></td>
<td>$\gamma^+$ 0,896</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregates 2 (sandstone 2)</td>
<td>$\gamma^-$ 50,440</td>
<td>23,784</td>
<td>78,607</td>
<td>102,391</td>
</tr>
<tr>
<td></td>
<td>$\gamma^+$ 2,804</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregates 3 (Limestone)</td>
<td>$\gamma^-$ 52,161</td>
<td>30,459</td>
<td>80,060</td>
<td>110,519</td>
</tr>
<tr>
<td></td>
<td>$\gamma^+$ 4,447</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Humidity Damage Index (HDI) of the asphalt-aggregate interface and Total Free Surface Energy (TFSE)

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Type of Aggregate (ρ=2,46; Abs=3,36%)</th>
<th>TFSE</th>
<th>HDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate 1</td>
<td>sandstone</td>
<td>80,047</td>
<td>0,361</td>
</tr>
<tr>
<td>Aggregate 2</td>
<td>sandstone (ρ=2,43; Abs=3,33%)</td>
<td>102,391</td>
<td>0,410</td>
</tr>
<tr>
<td>Aggregate 3</td>
<td>limestone (ρ=2,46; Abs=0,36%)</td>
<td>110,519</td>
<td>0,421</td>
</tr>
</tbody>
</table>

Values of HDI > 1,5: mixtures highly resistant to moisture damage in the field, Values between 1,5 and 0,5: mixtures of medium resistance to moisture damage, Values under 0,5: highly susceptible to moisture damage in the field.

ρ: Apparent Density; Abs=Absorption
Relationship between *Humidity Damage Index* (HDI) of the asphalt-aggregate interface and *Total Free Surface Energy* (TFSE)

Results and Analysis
Conclusions

- **Absorption** is a physical property of aggregates that significantly affects the asphalt-aggregate adhesion. At higher absorption, the difficulty to separate the asphalt from the aggregate, at wet condition, increases, it was the case for aggregates 1 and 2, which were high porosity sandstones.

- The asphalt-aggregate interface studied showed increases in tensile strength in the Bitumen Bond Strength (BBS) test in wet conditions, compared to the tensile strength obtained in the dry condition. Although the increase in this tensile strength was not significant, it showed that water do not have any influence in the decreasing of the required release energy.

- The three aggregates studied were classified according to the HDI as very susceptible to moisture. However, aggregate 2 (sandstone) had the most uniform behavior with respect to the tensile force in the BBS test, as well as a higher average of traction of detachment and less loss of asphalt in the adhesion analysis. In this way, it can be said that this last aggregate was the best to be affected by the humidity.

- According to Figure 5, we can conclude that the mineralogy of aggregates has more influence at the *Humidity Damage Index* (HDI) than *Total Free Surface Energy* (TFSE), This phenomenon can be observed in aggregates 1 and 2, which to have similar density and absorption, but are sandstones with different origin and mineralogy.

- The results obtained justify the need to carefully select the paving materials so that the asphalt-aggregate bond has a higher adhesion work in the dry state compared to the wet adhesion work to reduce the susceptibility to moisture damage of the asphalt mixture.

- Because the materials studied are classified as highly susceptible to moisture damage, it is advisable to use modifiers to increase the affinity between aggregate and asphalt and to reduce water ingress to the interface
Thank you!

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