The University of Nottingham

Moisture-induced damage in asphalt

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Introduction

- **Durability** is one of the most important properties of an asphalt mixture.
- A key factor affecting the durability of asphalt pavements is **moisture damage**.

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Moisture damage phenomenon

- Complicated mode of asphalt mixture distress ⇨ loss of stiffness and structural strength
- Mechanisms - loss of adhesion between aggregate and bitumen
- Mechanisms - loss of cohesive strength in bitumen and/or bitumen-filler mastic
- Due to presence and action of moisture (liquid and vapour)

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DAMAGE

MOISTURE

Detrimental effects of moisture & water

Directly caused by moisture damage

- Corrugations
- Pumping & bleeding
- Ravelling
- Stripping

Increased in extent and severity by moisture damage

- Cracking
- Potholing
- Patch deterioration
- Rutting

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How can we assess moisture damage in the laboratory?

- Tests on loose mix
- Static Immersion Test (AASHTO T182, ASTM D1664)
- Boiling Water Test (ASTM D3625)
- Total Water Immersion Test (TWIT)
- Ultrasonic Water Bath Technique
- Rolling Bottle method (BSEN 12697-11)

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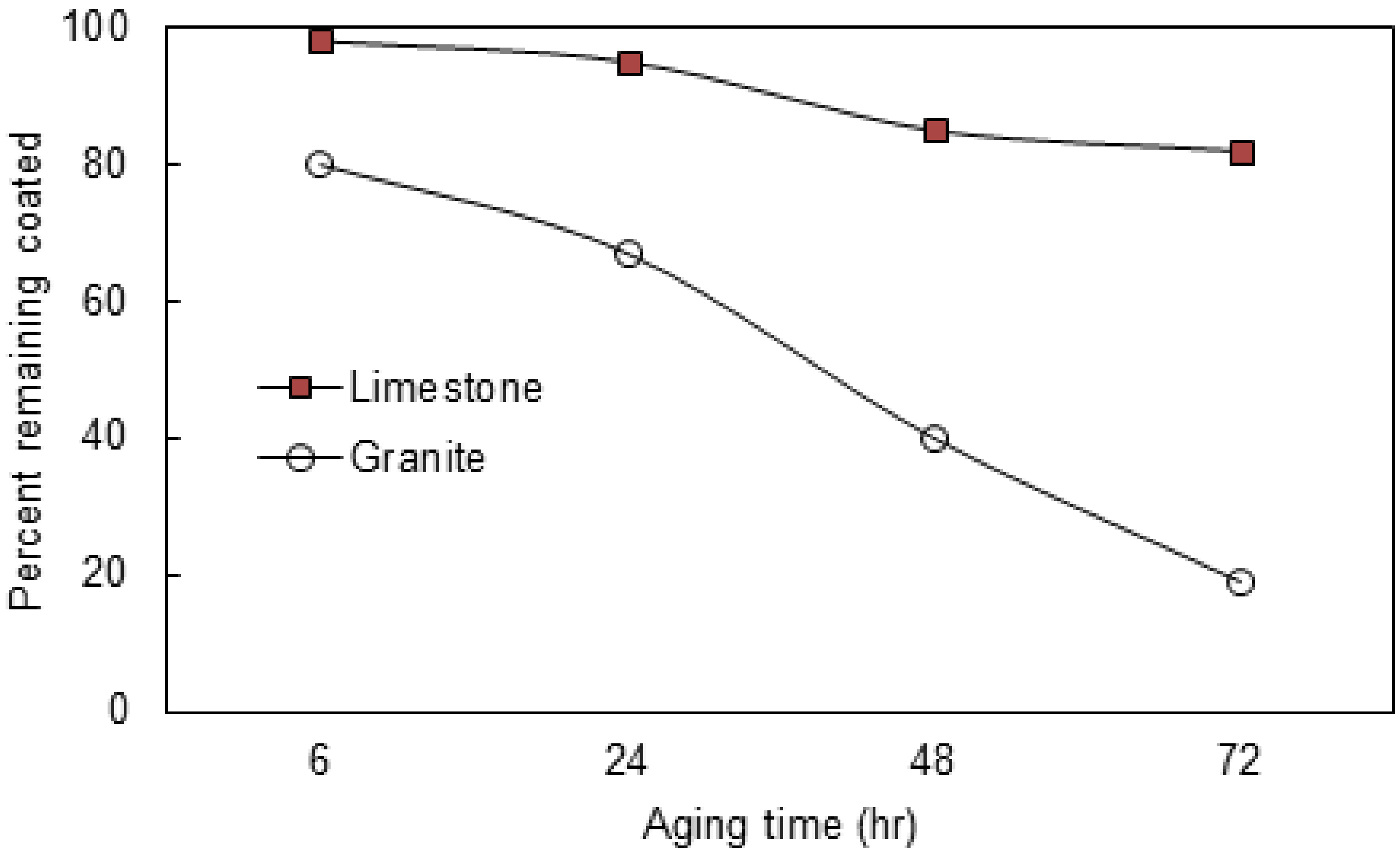
Rolling Bottle method



J. Grenfell et al., Assessing asphalt mixture moisture susceptibility through intrinsic adhesion, bitumen stripping and mechanical damage, Road Materials and Pavement Design, 2014 Vol. 15, No. 1, 131–152, http://dx.doi.org/10.1080/14680629.2013.863162

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How can we assess moisture damage in the laboratory?

- Tests on compacted mixtures
  - AASHTO T283
  - SATS Test
- Essentially conditioning tests
- Measure stiffness before and after
- Complex interactions (especially in the case of the SATS test)

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Saturation Ageing Tensile Stiffness (SATS) Procedure

- Pressure, temperature & moisture conditioning system
- Combined ageing / moisture damage conditioning procedure
- Able to accurately replicate moisture damage stiffness reduction in the field

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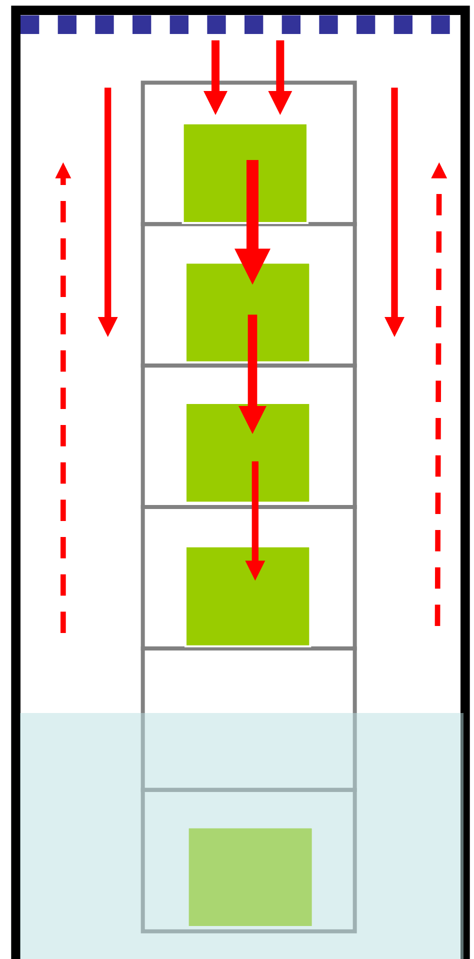
Specimen layout and moisture conditioning

Initial Saturation Level

55%
55%
55%
55%
55%



Final Saturation Level

66%
49%
26%
6%
80%

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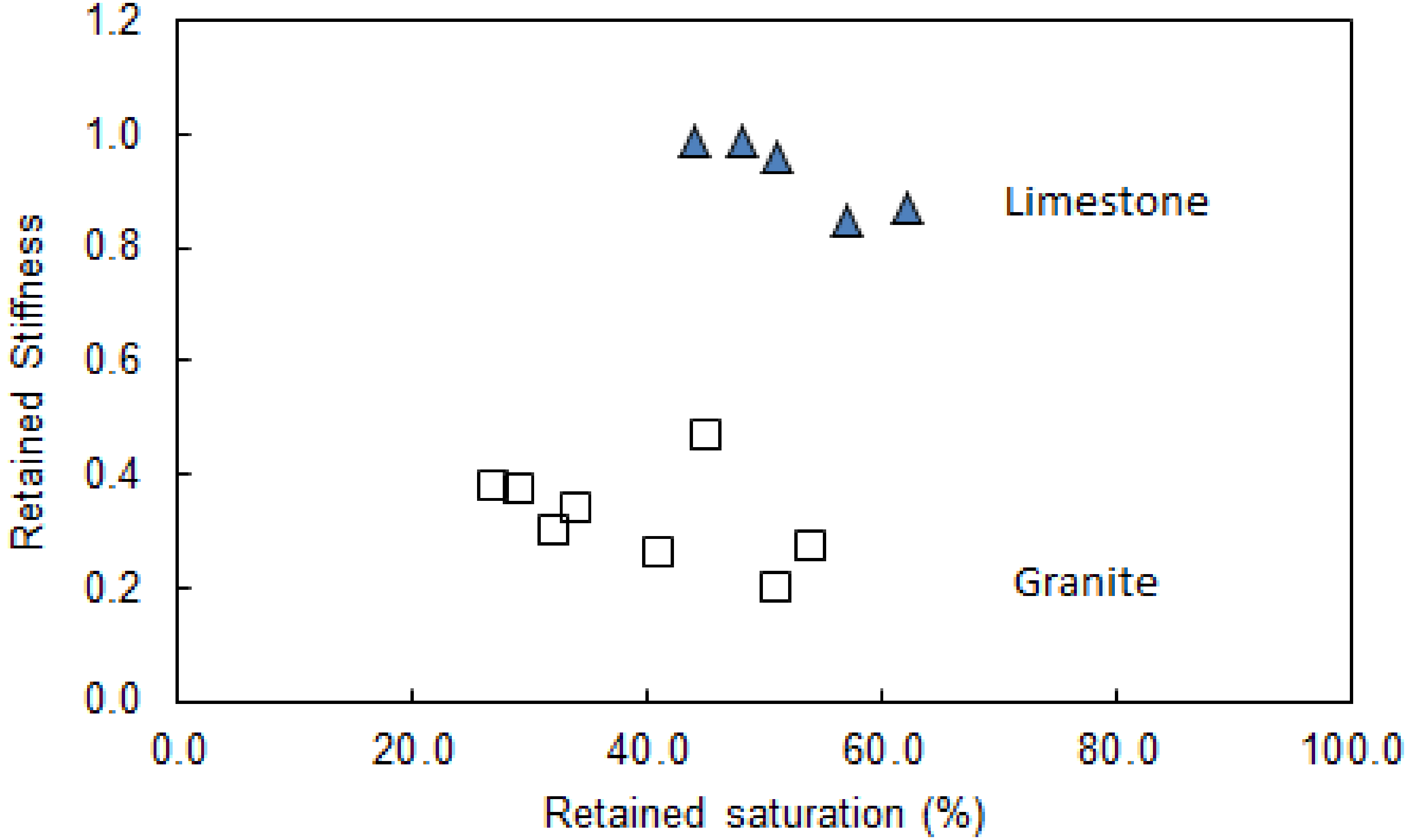
Comparison of SATS retained stiffness with retained saturation for 50 pen mixtures



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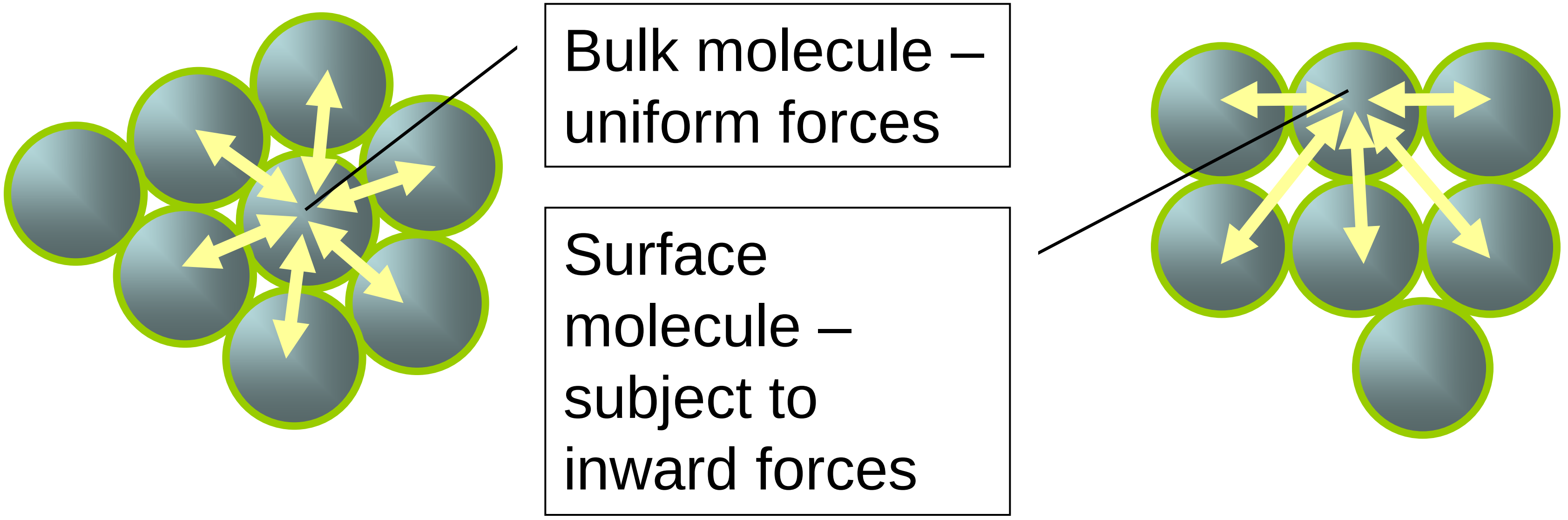
Adhesion Theories – Physio-Chemical

Surface Energy - Definition

Energy required to form a unit area of new surface



Physical Meaning

Work done to remove a molecule from bulk to surface

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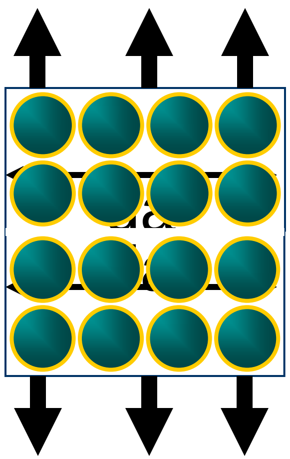
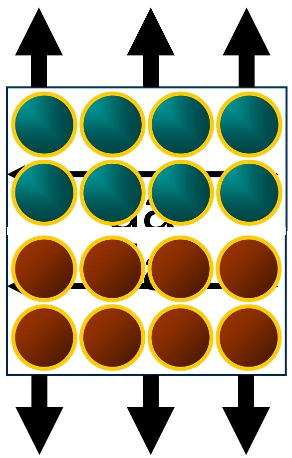
Adhesion Theories – Physio-Chemical





→ Cohesive Fracture Energy = **2**γ

→ Adhesive Fracture Energy = $\gamma_1 + \gamma_2 - \gamma_{12}$

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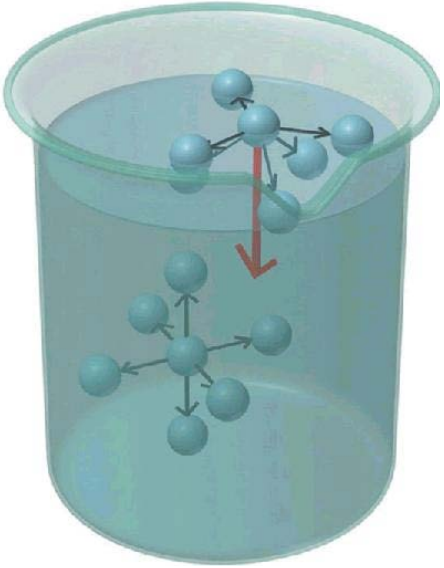
Surface Free Energy

- Surface free energy is defined as the energy/work required to create a new unit surface area of the material in vacuum
  - Surface energy of a bitumen-aggregate combination consist of two components
    - Non Polar (apolar) component
    - Acid-base component



$$\gamma^{Total} = \gamma^{LW} + \gamma^{AB}$$ (Unit; ergs/cm²)

Where:

γ^{LW} = Liftshitz-Van der Waals component

γ^{AB} = Acid-Base component

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Surface Free Energy

- Good and Van Oss postulated:

$$\gamma^{AB} = 2\sqrt{\gamma^{+}\gamma^{-}}$$

Where,

γ^{+} = Lewis acid component of surface interaction

γ^{-} = Lewis base component of surface interaction

- Three-component (acid-base) theory of SFE:

$$\gamma = \gamma^{LW} + 2\sqrt{\gamma^{+}\gamma^{-}}$$

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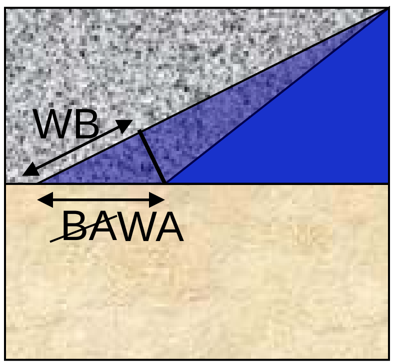
Adhesion Theories – Physio-Chemical

Three Phase System – Bitumen-Aggregate-Water



A = lost bitumen-aggregate interface ($-\gamma_{AB}$)
B = new water-asphalt interface (γ_{WB})
C = new water-aggregate interface (γ_{WA})

Total energy used

$$\Delta\gamma_{WAB} = \gamma_{WB} + \gamma_{WA} - \gamma_{AB}$$

≤ 0 !! (Almost always)

= fn (3 surface energy components of each material)

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Surface Energy Approaches

- It has to be remembered that these approaches and calculations only give intrinsic adhesion properties. This means they do not take into account such things as:
  - Interlock
  - Surface roughness of aggregate
  - Dustiness of aggregate

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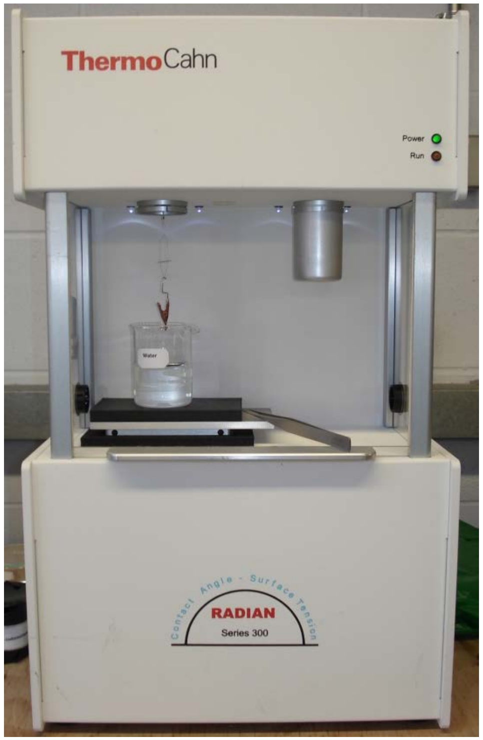
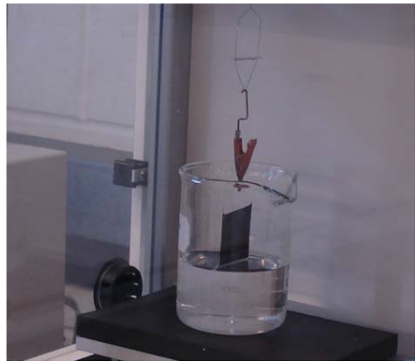
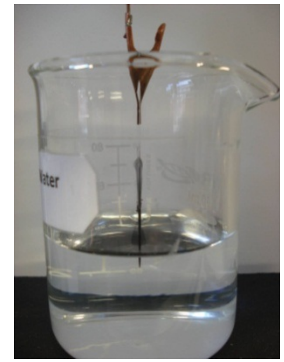
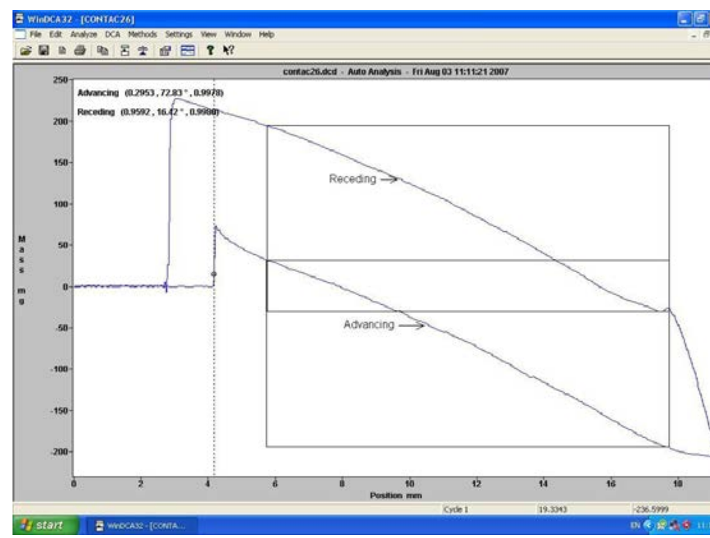
Wilhelmy Plate Method



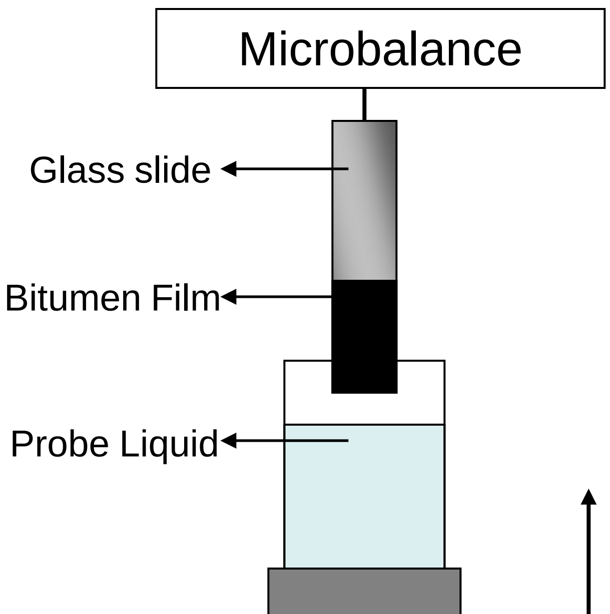






Wilhelmy Plate Method

Wilhelmy Plate Method



<u>In air:</u>

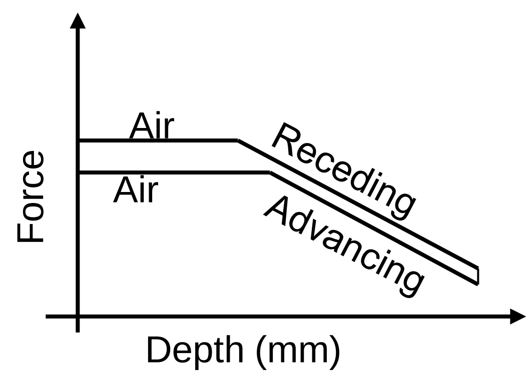
Weight of Slide

<u>In liquid:</u>

Weight of Slide – Buoyancy – Adhesion

Buoyancy: $\boxed{\text{Volume} * \text{liquid density} * g}$

Adhesion: $\boxed{\text{Perimeter} * \gamma_{liquid} * \cos\theta}$



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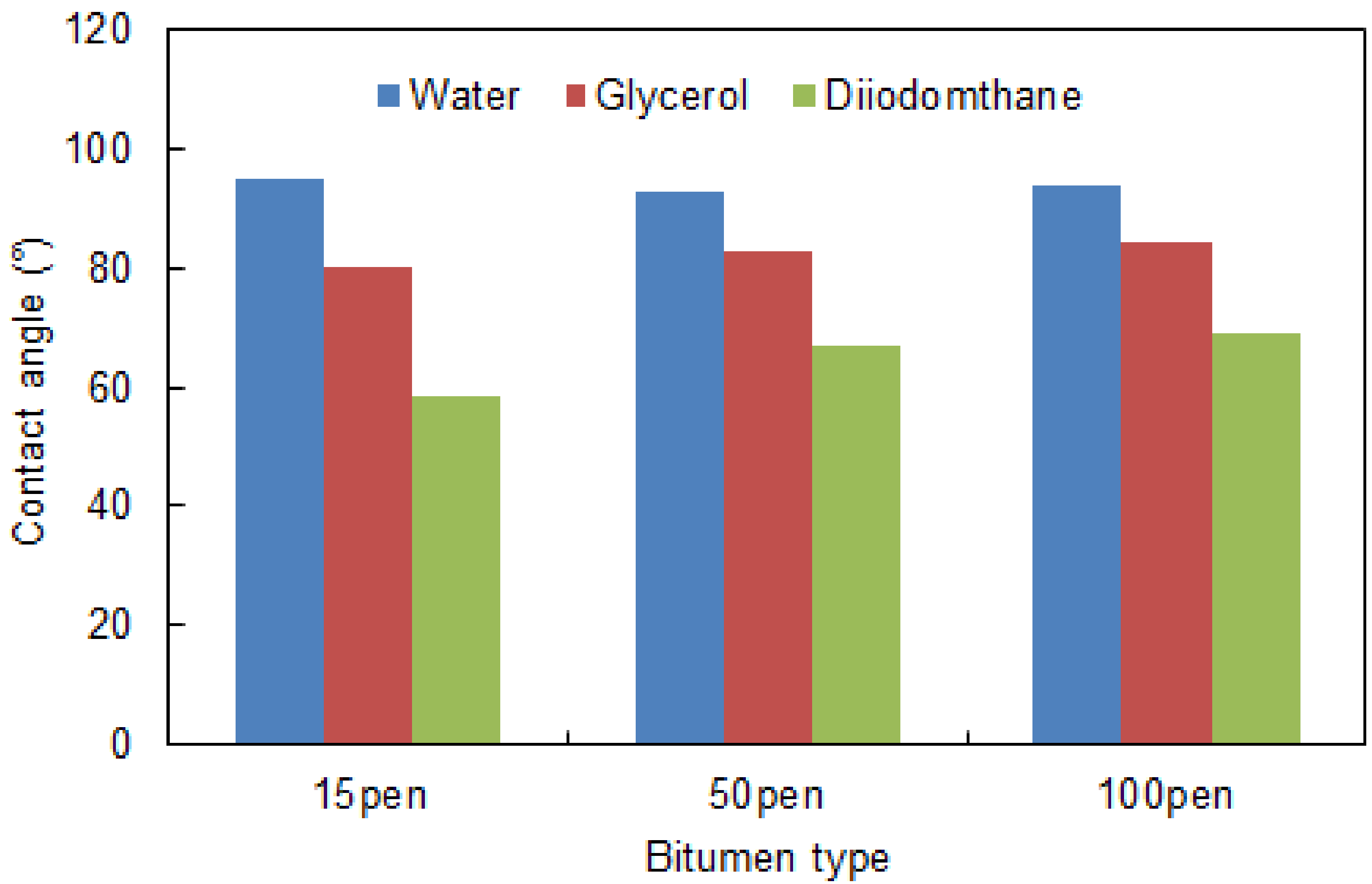
Contact angle of probe liquids obtained from the DCA test



The higher the contact angle between a solid and a liquid, the lower the potential for the two to adhere to each other

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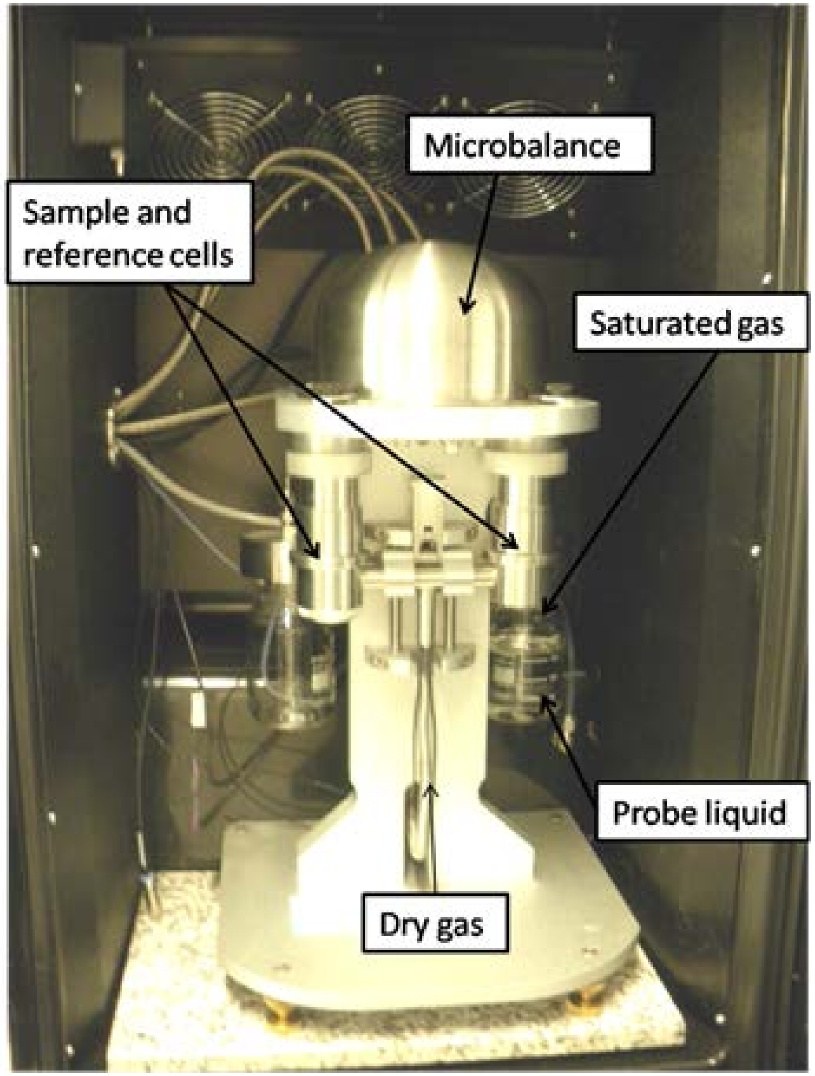
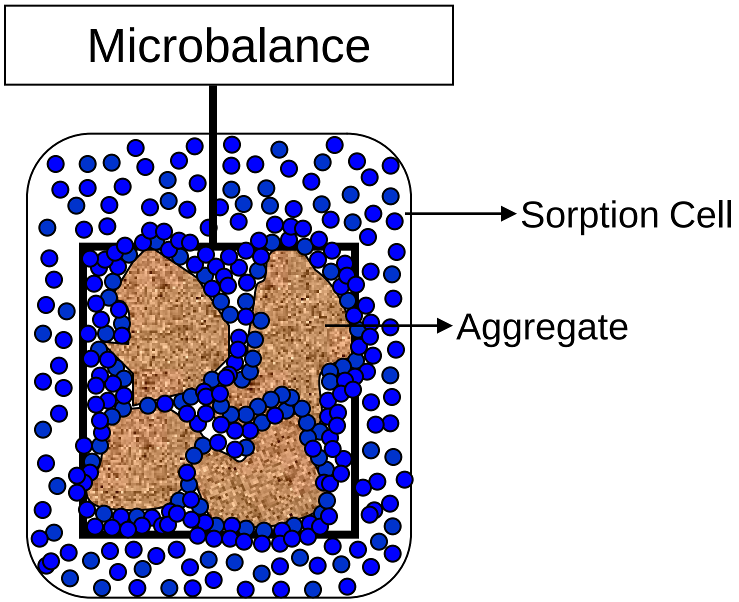
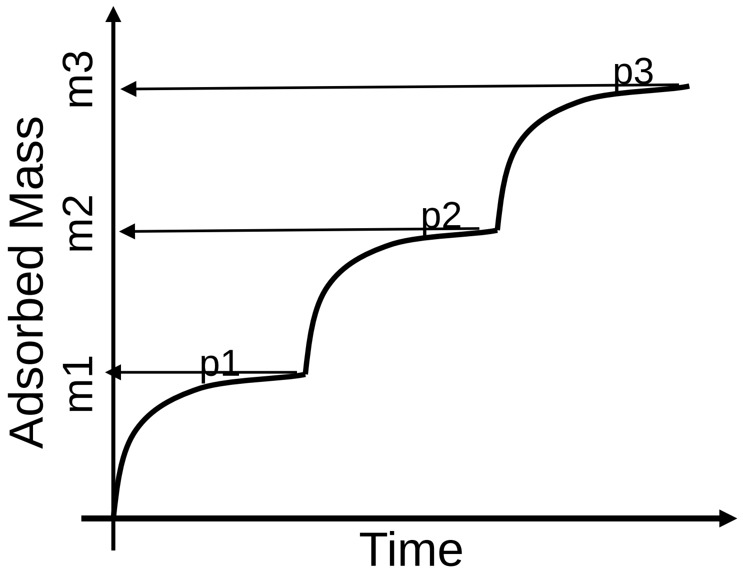
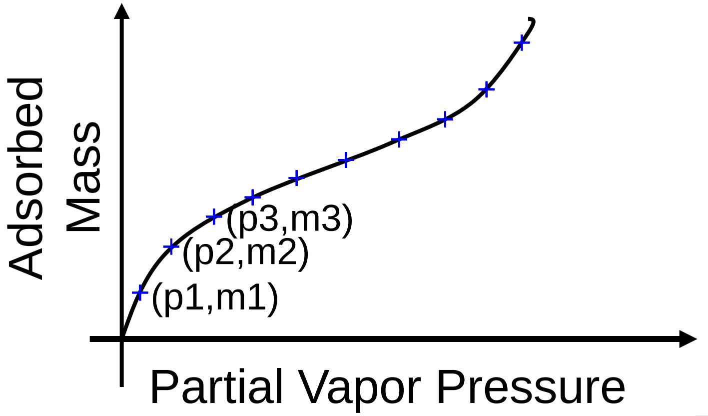
Dynamic Vapour Sorption (DVS)



Dynamic Vapour Sorption (DVS)







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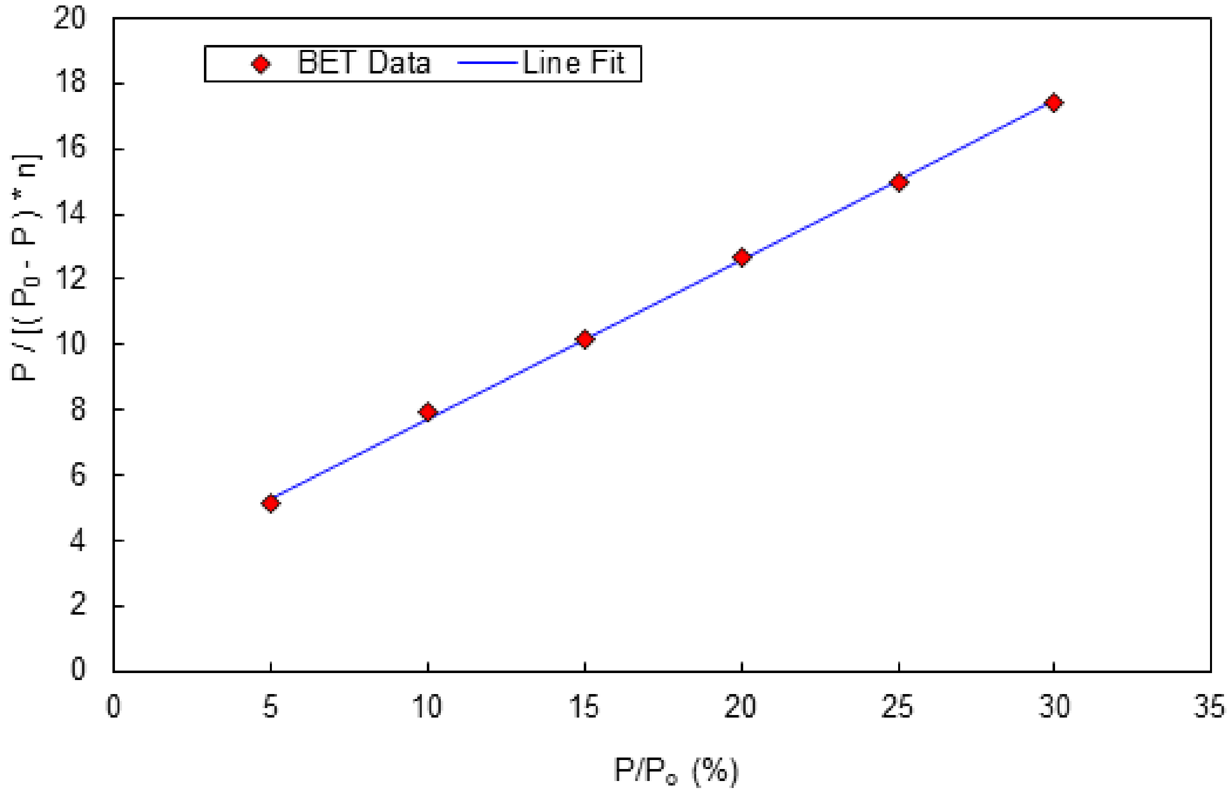
DVS Results



BET model was used to fit the sorption isotherms up to 35% partial vapour pressure. The slope and intercept of the BET plots were used to estimate the parameters n_m and c that used to calculate surface area of the aggregate.

Energy Ratios

$$ER_1 = \left| \frac{W_{BA}^{a}}{W_{BWA}^{a}} \right|$$

Where:

W_{BA}^{a} = adhesive bond energy values in the dry condition

W_{BWA}^{a} = adhesive bond energy values in the presence of water

$$ER_2 = \left| \frac{W_{BA}^{a} - W_{BB}}{W_{BWA}^{a}} \right|$$

Where:

$W_{BA}^{a} - W_{BB}$ is a wetability relationship

$W_{BA}^{a} \& W_{BB}$ represent bitumen-aggregate dry bond strength and bitumen cohesion respectively

Bond energy parameters (compatibility ratios)

ER_1				
Bitumen	Limestone A	Limestone B	Granite A	Granite B
15 pen	2.89	1.75	1.37	3.41
50 pen	2.52	1.64	1.20	2.93
100 pen	1.39	1.36	**<u>0.70</u>**	1.54
ER_2				
15 pen	1.56	0.61	0.76	1.86
50 pen	1.31	0.58	0.64	1.56
100 pen	0.82	0.66	**<u>0.44</u>**	0.94
ER_1*SSA				
15 pen	**<u>0.49</u>**	1.38	0.61	**<u>0.36</u>**
50 pen	**<u>0.43</u>**	1.29	0.53	**<u>0.31</u>**
100 pen	**<u>0.24</u>**	1.07	**<u>0.33</u>**	**<u>0.16</u>**
ER_2*SSA				
15 pen	**<u>0.27</u>**	0.48	**<u>0.34</u>**	**<u>0.20</u>**
50 pen	**<u>0.22</u>**	0.46	**<u>0.28</u>**	**<u>0.16</u>**
100 pen	**<u>0.14</u>**	0.52	**<u>0.19</u>**	**<u>0.10</u>**

Bond energy parameters (compatibility ratios) for aggregate-bitumen combinations. The aggregate-bitumen combinations that are classified as ‘poor’ are shown in bold and underlined.

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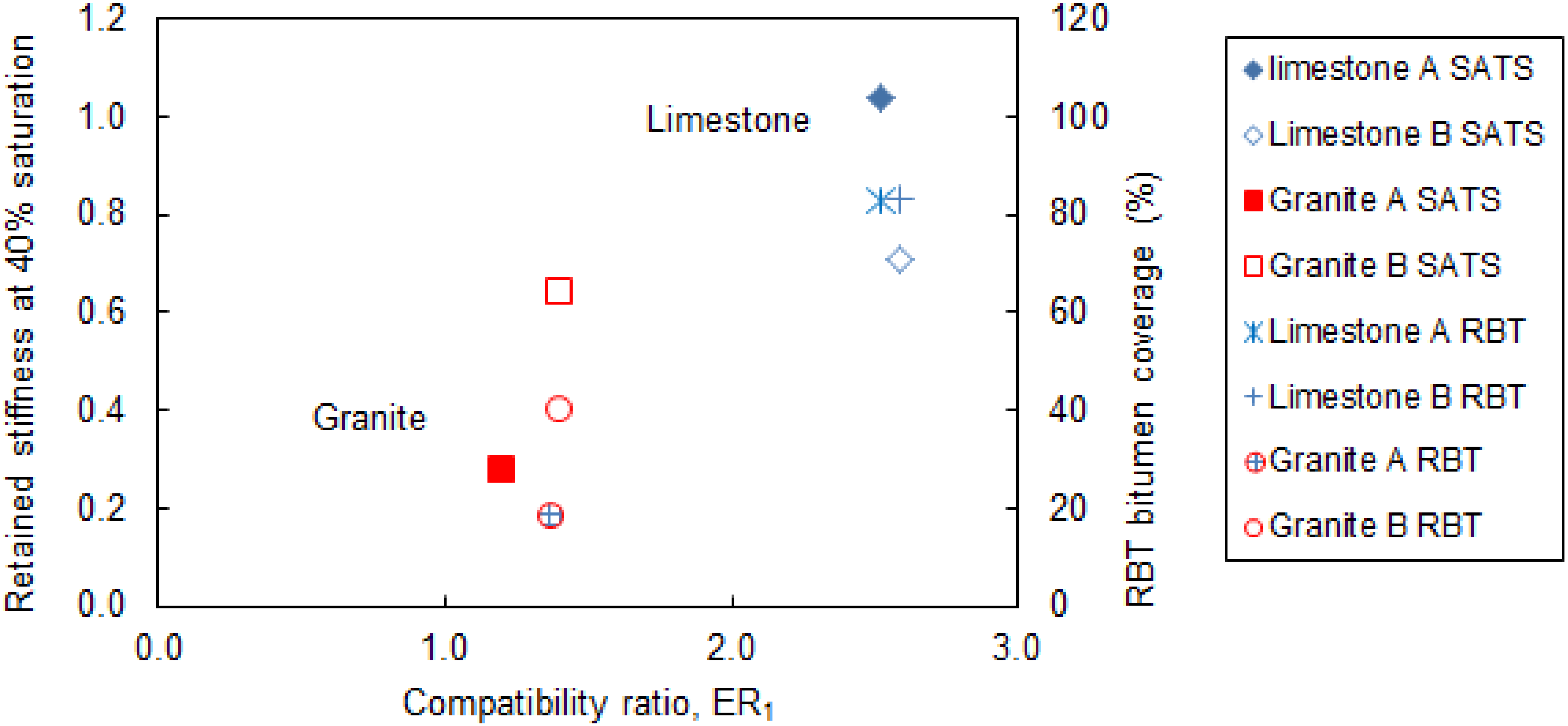
Plots of SATS results and RBT results as a function of bond energy ratio ER_1



Both SATS and RBT ranked limestone mixtures higher (higher retained stiffness and higher bitumen coverage) than granite mixtures which is in agreement with compatibility ratio obtained from surface energy measurements.

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Conclusions

- RBT and SATS are useful in evaluating moisture damage in asphalt mixtures as the ranking obtained in these empirical tests are similar to surface energy characteristics of the asphalt mixtures.

- Surface energy properties of the materials combined with the parameters obtained by conventional moisture sensitivity assessment techniques can also contribute towards the development of a material screening protocol.

- This can be used to determine the best combinations of bitumen and aggregates for the local road material providing better bitumen-aggregate adhesion and less susceptibility to moisture damage/stripping.

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