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MFPA

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# FUNDAMENTAL APPROACH FOR THE CONCEPT OF CONCRETE REPAIR COMPATIBILITY


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… is that repair?

*Somewhere in the world …*

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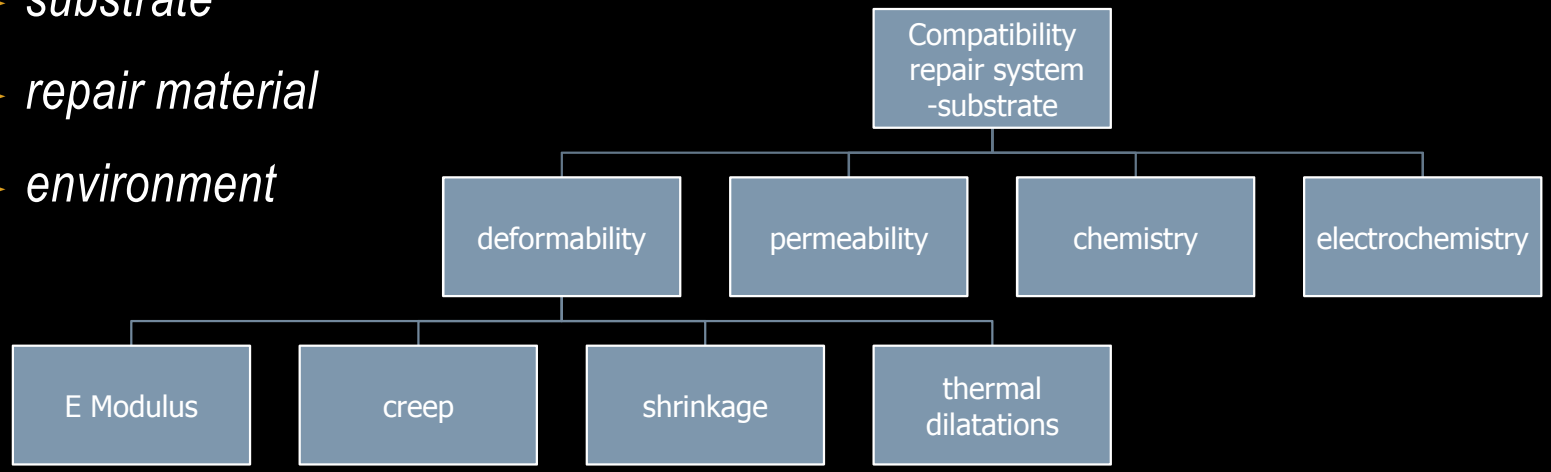
# COMPATIBILITY FOR REPAIR (BISSONNETTE ET AL., 2004)

- is a 3D marriage …
  - *substrate*
  - *repair material*
  - *environment*




… compatibility (*tolerance*) becomes *appetency*: instinctive desire for satisfying a need …

# MAIN PARAMETERS AFFECTING THE QUALITY OF REPAIR *(SILFWERBRAND, 2004)*

- Concrete properties
- Removal deteriorated concrete
- Cleaning after removal
- Surface properties
- Surface preparation
- Bonding agents
- Mechanical devices across the interface
- Concrete placement
- Concrete curing
- Time dependance
- Traffic, ..

Predominant factors

**Method of concrete removal**

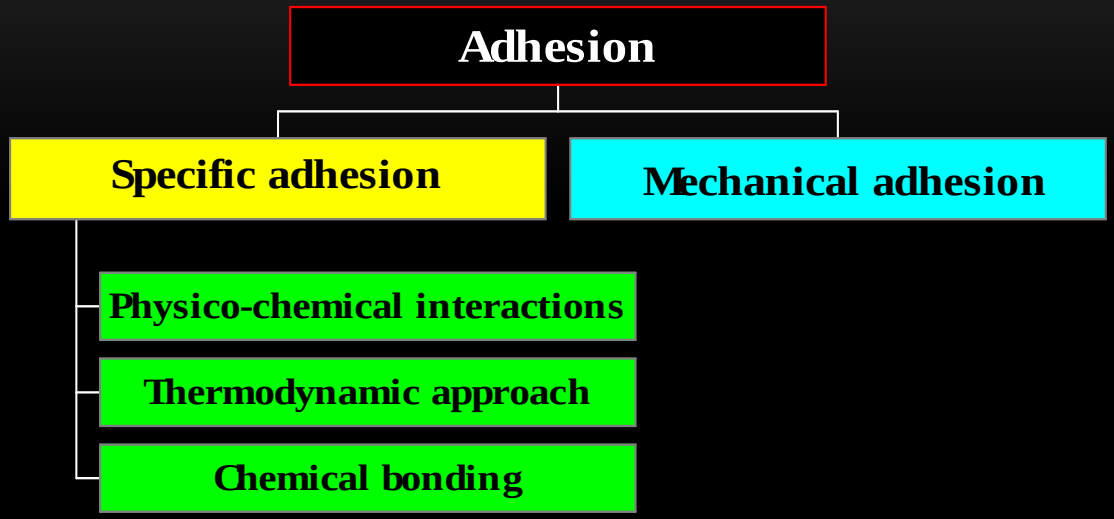
**Absence of laitance layer**

**Cleanliness before to concrete placement**

**Compaction of the overlay**

**Curing of the overlay**

# OBJECTIVE: ADHESION

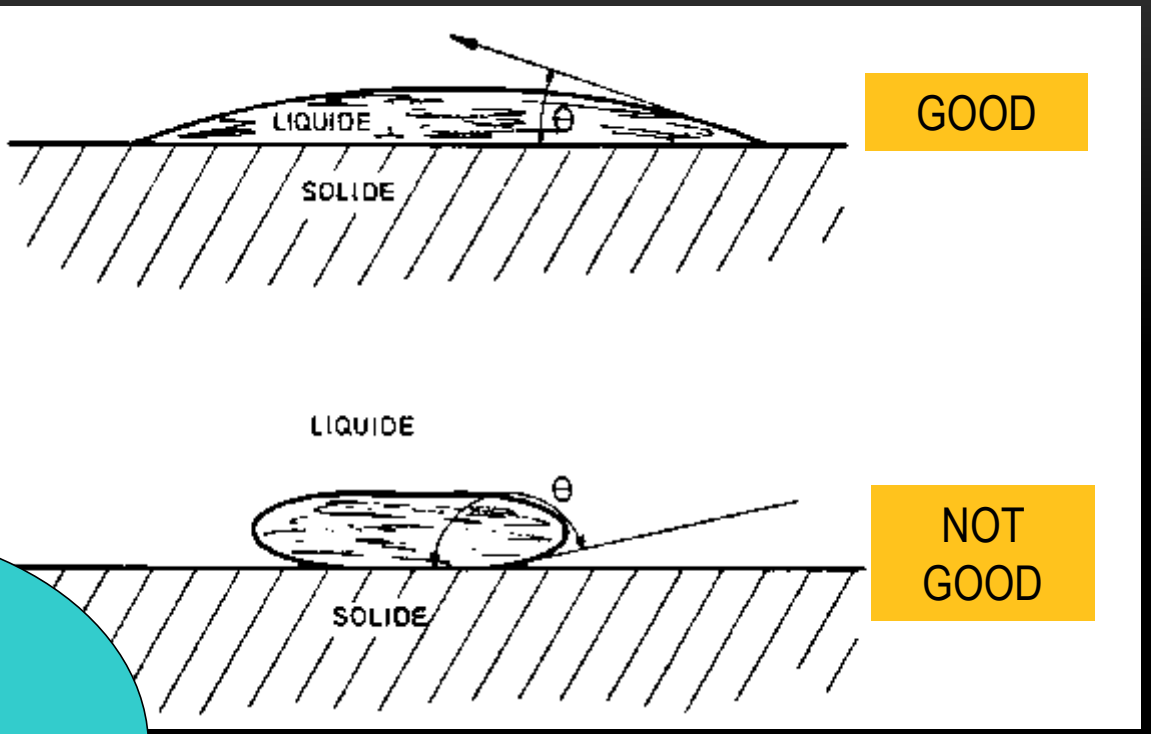


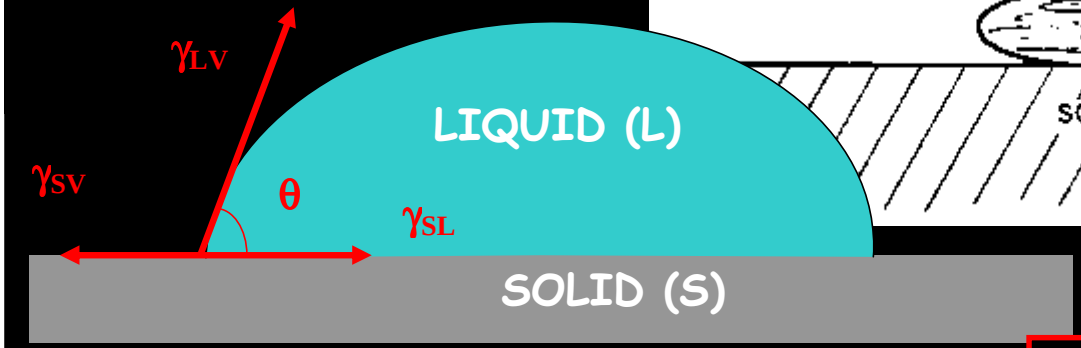

**Condition 1 : spreading and wettability**

**Condition 2 : physico-chemical interactions**

**Condition 3 : mechanical interlocking**

# Condition 1 :
spreading




$$\gamma_{SV} = \gamma_{SL} + \gamma_{LV} \cos\theta$$

Better wettability of the solid by the liquid if contact angle is LOW

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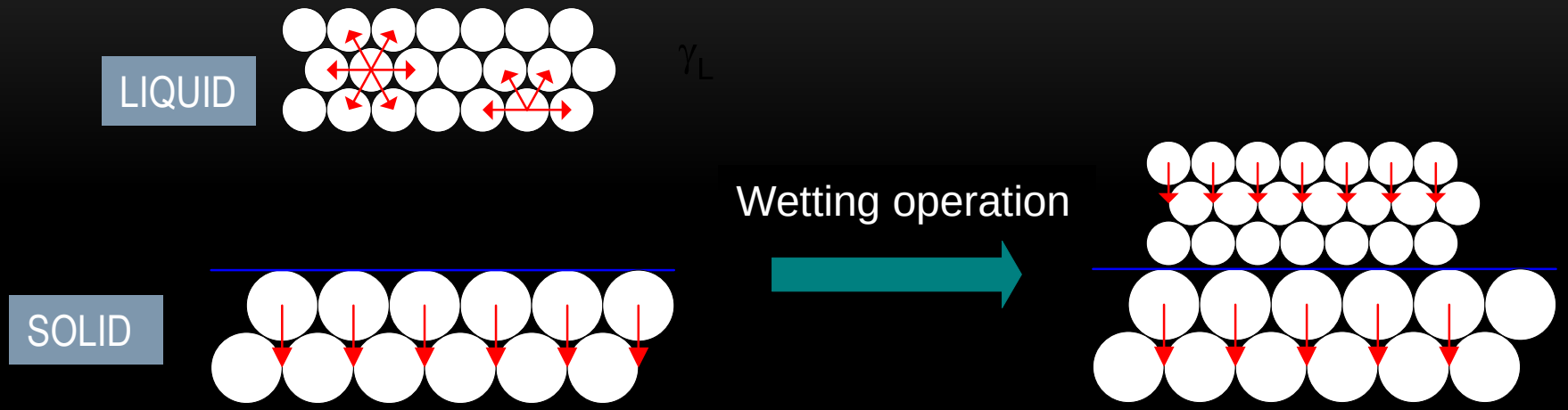
# INTERFACIAL FREE ENERGY




- Geometric average (OWENDS et WENDT)

$$\gamma_{SL} = \gamma_L + \gamma_S - 2\left(\gamma_L^d \cdot \gamma_S^d\right)^{1/2} - 2\left(\gamma_L^p \cdot \gamma_S^p\right)^{1/2}$$

- Harmonic average (WU)

$$\gamma_{SL} = \gamma_L + \gamma_S - 4\frac{\gamma_L^d \gamma_S^d}{\gamma_L^d + \gamma_S^d} - 4\frac{\gamma_L^p \gamma_S^p}{\gamma_L^p + \gamma_S^p}$$

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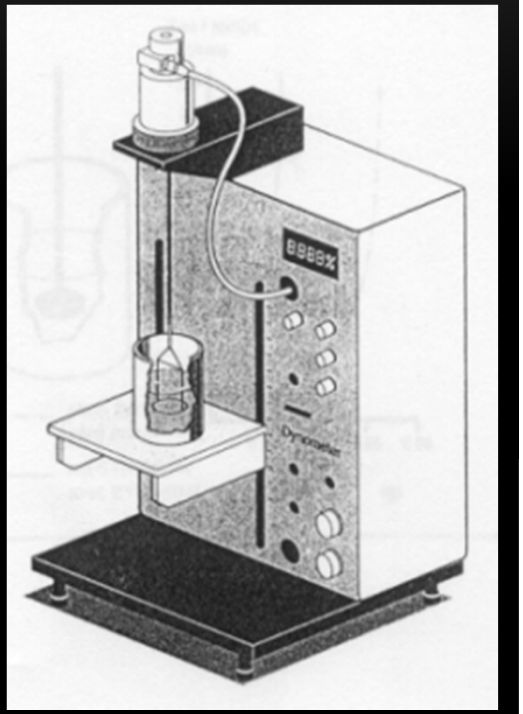
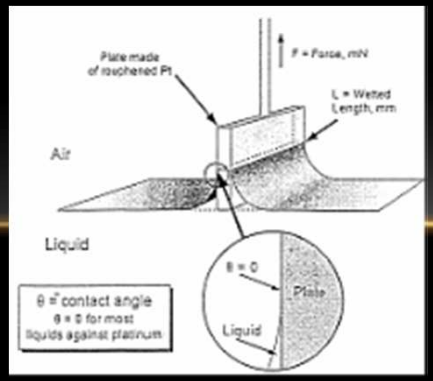
# SURFACE ENERGY OF LIQUIDS

| Reference | Temperature [°C] | Surface free energy [mN/m] |
|---|---|---|
| Distilled water | 23.2 | 71.1 |
| Melamine (macromolecules) | 23.5 | 66.3 |
| Melamine | 23.3 | 70.3 |
| Naphtalen | 23.2 | 67.3 |
| Vinyl copolymer | 23.3 | 49.1 |
| Maleic acid | 23.2 | 67.8 |
| Natrium ligno-sulfonate | 23.3 | 66.3 |
| Cement based slurry (no admixture) | 23.3 | 70.6 |
| Dimethylformamide | 23.1 | 36.3 |
| 2-dimethylethanolamine | 22.9 | 27.95 |
| 3-dimethylamino-1,2-propanediol | 22.8 | 36.1 |
| Tetramethylen sulfone | 23 | 49.6 |
| α-bromonaphtalen | 23.1 | 42.5 |



De Nouyï ring




Wilhelmy plate

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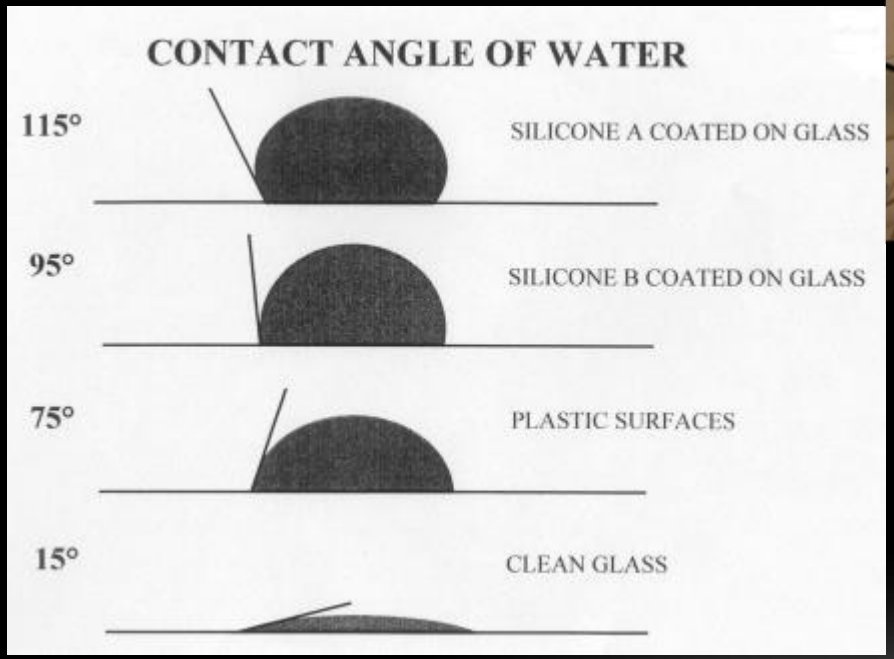
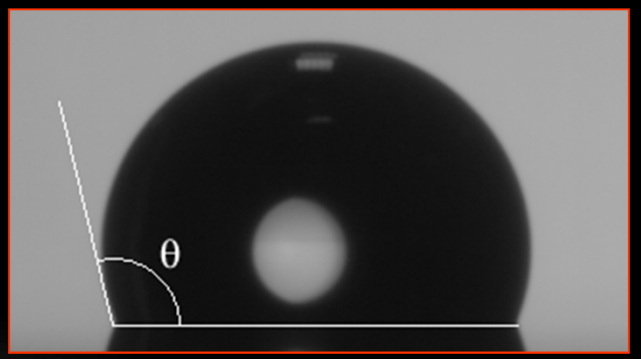
# CONTACT ANGLE





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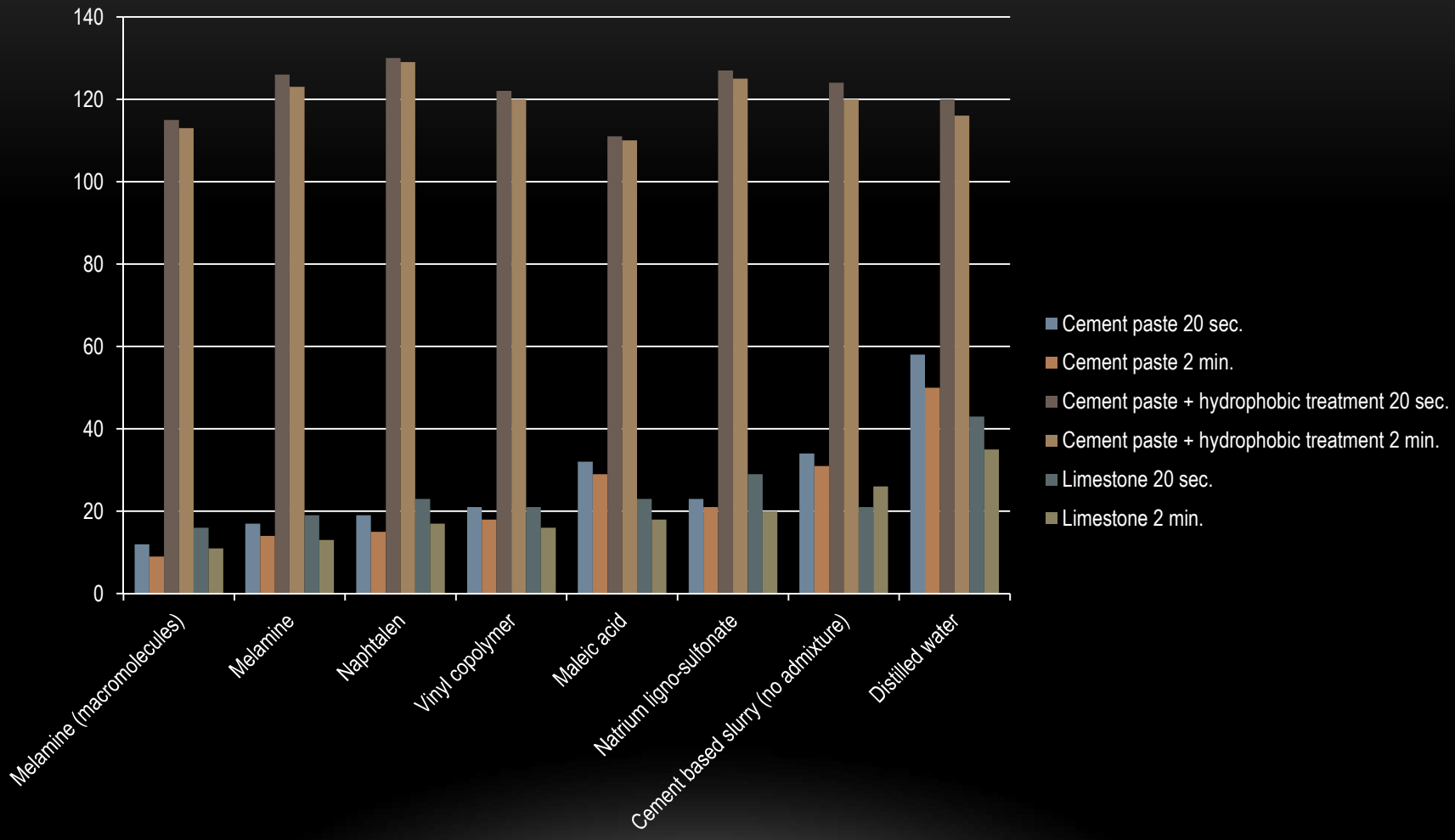
# CONTACT ANGLE

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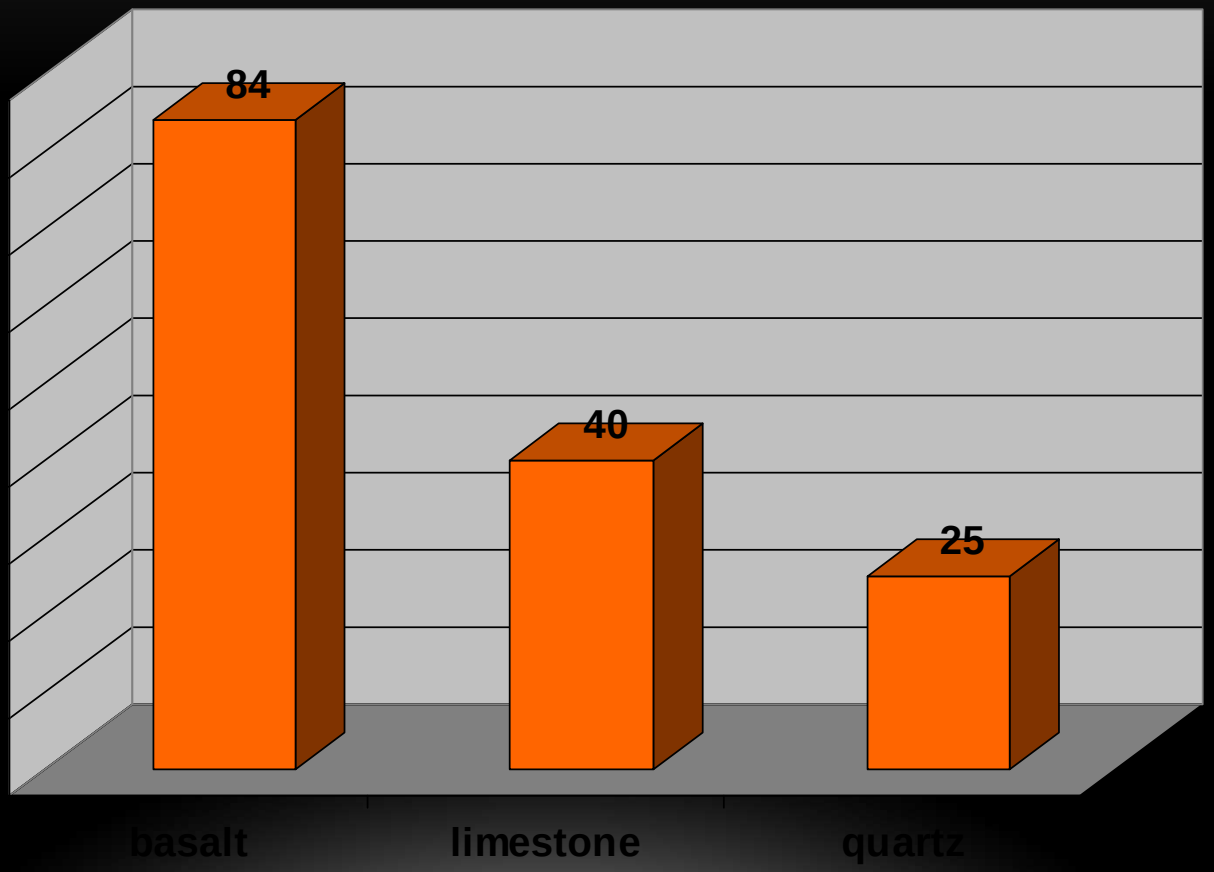
# CONTACT ANGLE

- Epoxy resin on *aggregates* *(Fiebrich,1994)*



# SURFACE FREE ENERGY OF SOLIDS

$$1 + \cos\ \theta = \frac{2}{\gamma_L}\left[\left(\gamma_S^d\ \gamma_L^d\right)^{1/2} + \left(\gamma_S^p\ \gamma_L^p\right)^{1/2}\right]$$

| Support | Surface free energy [mN/m] | | |
|---|---|---|---|
| | $\gamma_S^d$ | $\gamma_S^p$ | $\gamma_S$ |
| Cement + paste | 31.65 | 1.69 | 44.34 |
| Cement paste + hydrophobic treatment | 14.86 | 0.01 | 14.87 |
| Limestone | 37.08 | 12.40 | 49.48 |
| Glass | 20.54 | 22.85 | 43.39 |
| Silicon paper | 12.59 | 5.41 | 18 |

*Evaluation of $\gamma_S$: indirect and difficult!*

# SELECTION CRITERIA

- work of adhesion
- spreading
- interfacial energy
- critical energy of solid surfaces

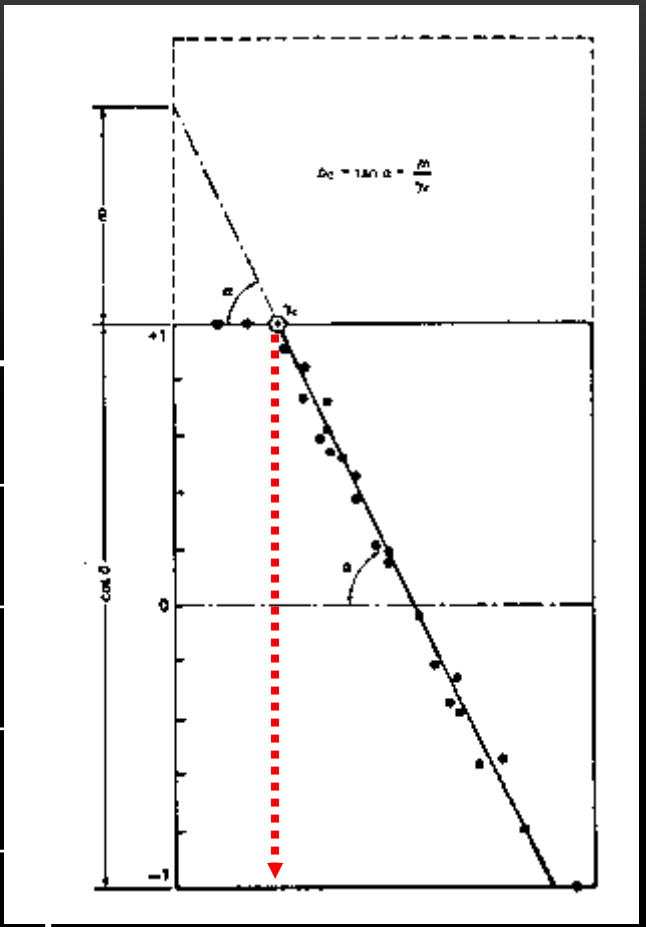
$$W_a = \gamma_l + \gamma_s - \gamma_{sl}$$

**Work of adhesion (mJ/m²) for different cement slurries on concrete**

| Liquid | Cement paste | Limestone | Concrete |
|---|---|---|---|
| Melamine (macromolecules) | 99.76 | 103.49 | 102.18 |
| Melamine | 102.36 | 106.14 | 104.82 |
| Naphtalen | 102.99 | 107.15 | 105.7 |
| Vinyl copolymer | 84.04 | 86.98 | 85.95 |
| Maleic acid | 100.58 | 104.31 | 103 |
| Natrium ligno-sulfonate | 98.58 | 102.13 | 100.89 |
| Cement slurry (no admixture) | 106.69 | 111.18 | 109.61 |
| Water | 102.49 | 106.23 | - |

**Critical surface energy** is the maximum surface free energy of liquid that will spread on specific solid surface

| Substrate | Critical surface energy (mN/m) |
|---|---|
| Cement paste | 25.5 |
| Limestone | 42.5 |
| Epoxy resin (EP) | 43-44 |
| PolyVinyl Chloride (PVC) | 39 |
| PolyEthylen (PE) | 31 |
| PolyTetraFluorEthylen (PTFE) | 18.5 |



Surface free energy $\gamma_L$

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# Selection criteria

***CONCLUSION***: good adhesion needs INTIMATE CONTACT (→ good wetting) which means:

☺$\gamma_S$ maximum: to avoid dust, oil or to promote surface treatment

☺$\gamma_{SL}$ minimum: adhesive performances

***BUT***: necessary but not sufficient:

☺kinetics of contact: surface roughness and viscosity of repair system

☺mechanical aspects of adhesion

# Perturbancy for PCC repair mortars


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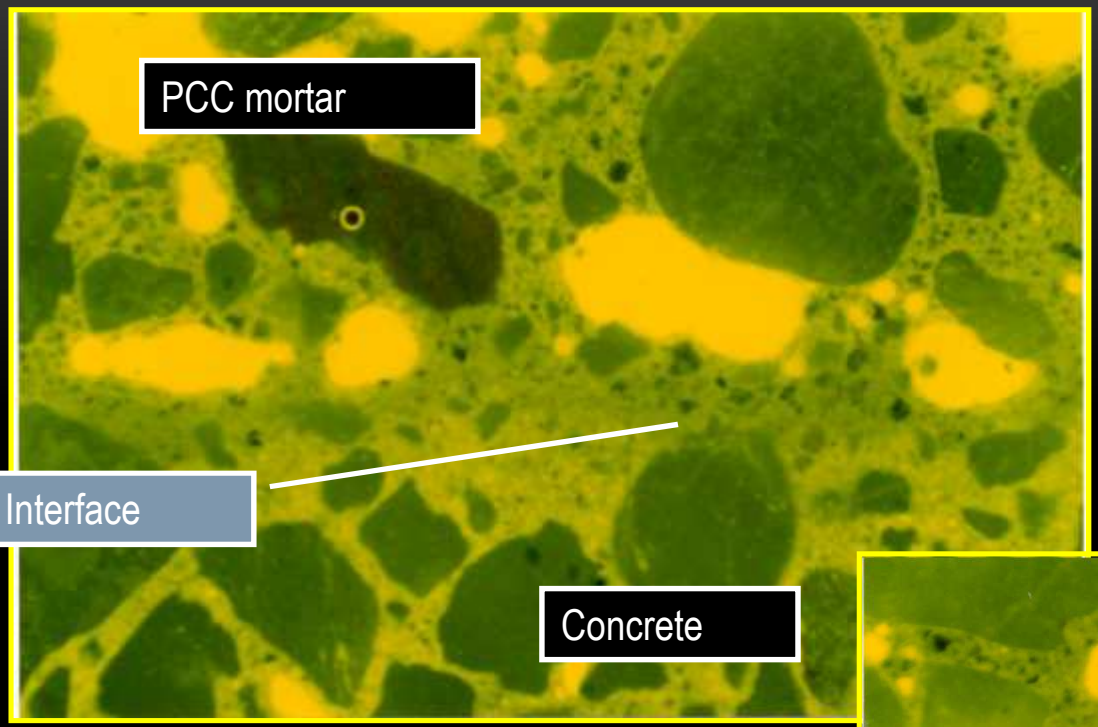
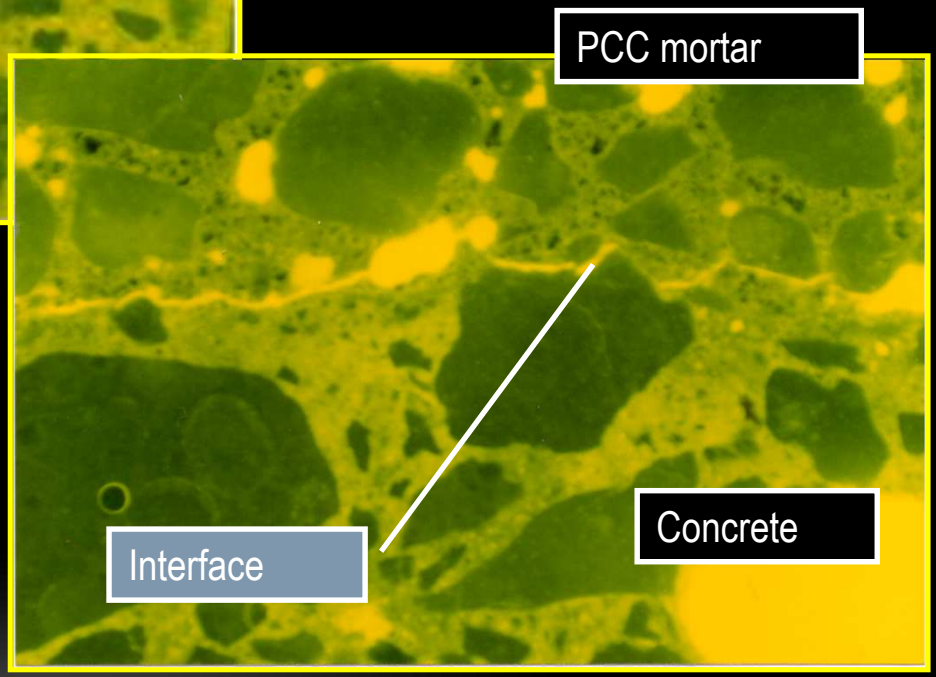
PCC repair mortars

Adhesion: > 2 MPa




PCC repair mortars

Adhesion: < 0.3 MPa

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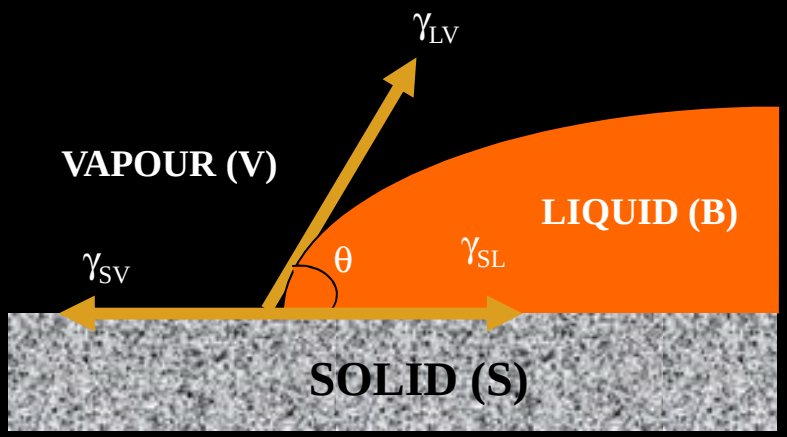
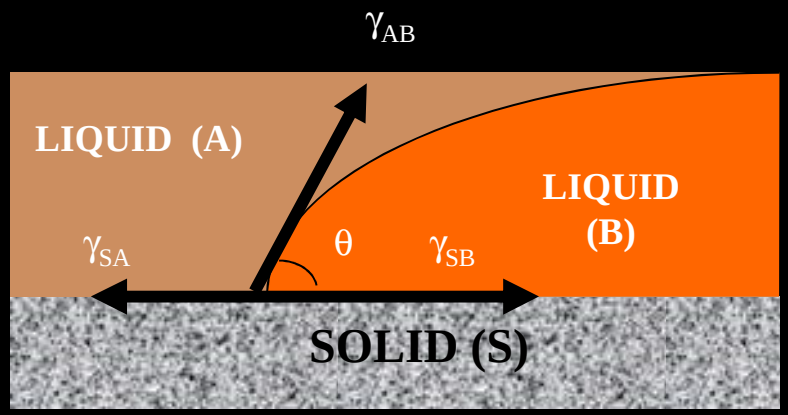
# DISTURBANCE OF EQUILIBRIUM: WATER

$$\gamma_{SV} = \gamma_{SB} + \gamma_{BV} \cdot \cos\theta$$

$$\gamma_{SA} = \gamma_{SB} + \gamma_{AB} \cdot \cos\theta$$

$$\begin{cases} \gamma_S = \gamma_{SA} + \gamma_A \cdot \cos\theta_A \\ \gamma_S = \gamma_{SB} + \gamma_B \cdot \cos\theta_B \end{cases}$$




Equilibrium : the difference between tensions of adhesion is inferior to interfacial tension

$$\gamma_B \cdot \cos\theta_B - \gamma_A \cdot \cos\theta_A < \gamma_{AB}$$

No equilibrium : liquid B will expulse liquid A

$$\gamma_B \cdot \cos\theta_B - \gamma_A \cdot \cos\theta_A > \gamma_{AB}$$

**the liquid with the higher tension of adhesion will expulse the other one from the surface**

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# WORK OF ADHESION: interfaces without ($W_A$) and with ($W_{AL}$) water

$$W_A = \gamma_A \cdot (1 + \cos \theta_A)$$

A = air

L = water

| Interface | $W_A$ (mJ/m²) | $W_{AL}$ (mJ/m²) |
|---|---|---|
| Mortar/concrete | 87.8 | No sense |
| Acrylic/Concrete | 74.1 | 22.7 |
| Acrylic/Acrylic | 80.4 | 53.7 |
| Acrylic/Hydrophobic treatment | 52.2 | 66.7 |
| Epoxy/Concrete | 79.6 | 21.8 |
| Epoxy/Epoxy | 92.4 | 53 |
| Epoxy/Hydrophobic treatment | 56 | 42.2 |

Loss of adhesion when water

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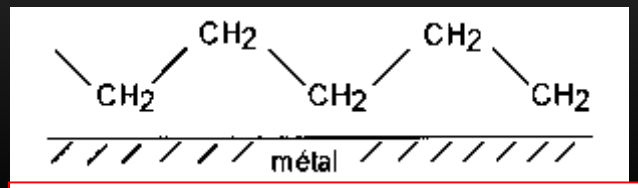
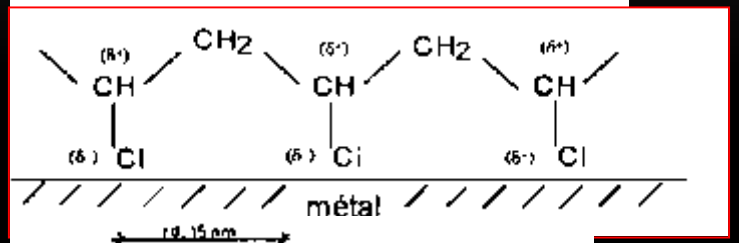
# Condition 2 : physico-chemical interactions

Van der Waals

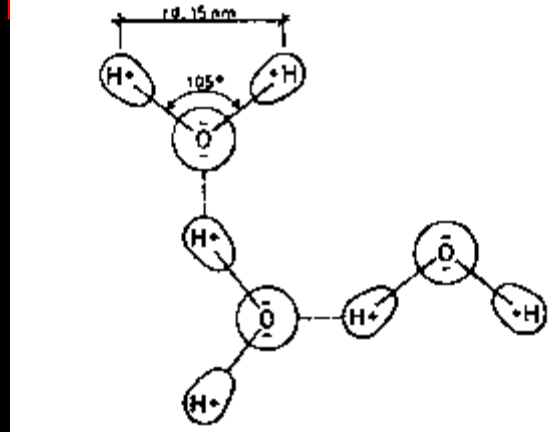
Hydrogen bond

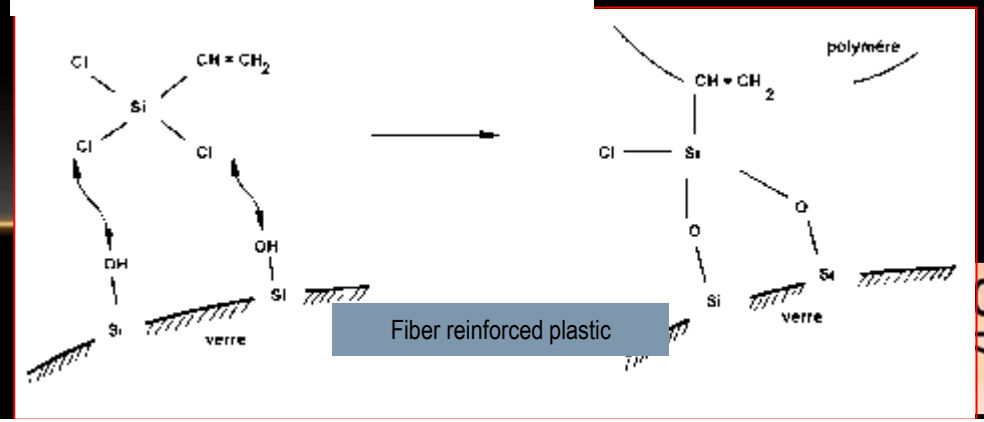
Chemical bonds



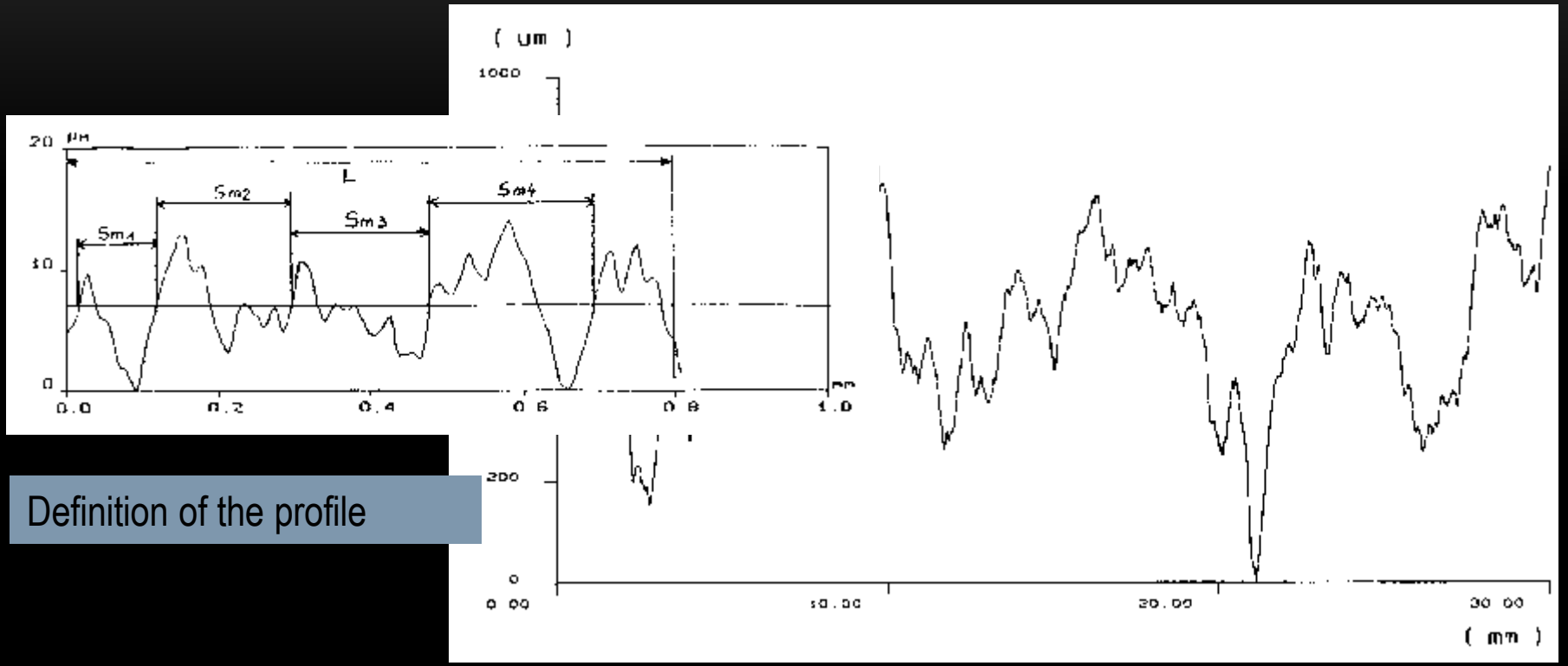

polarization



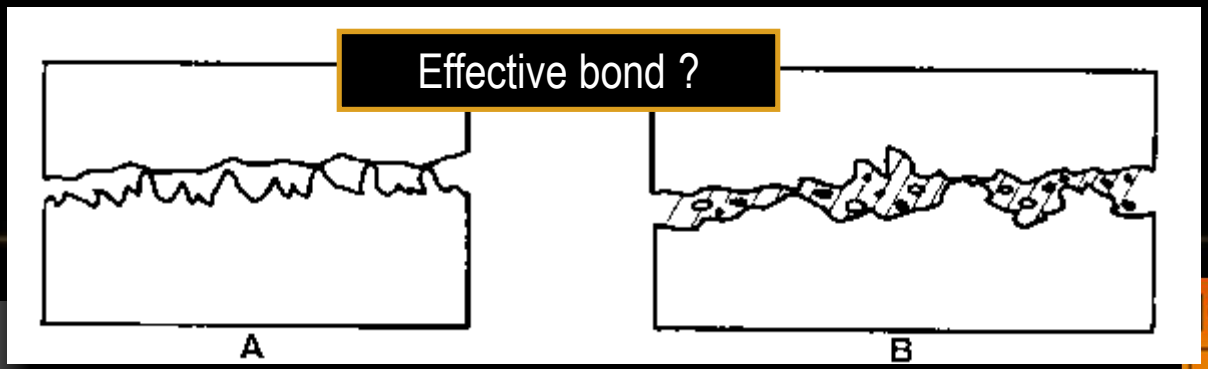



Fiber reinforced plastic

# Condition 3 : mechanical interlocking




Definition of the profile

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# CONCLUSIONS

Fundamental approach let us to explain and understand adhesion process and development

Adhesion is depending on surface free energy of liquids and solids into contact

Adhesion is dramatically affected by water, dust, oil, …

*Contact quality has to be promoted in order to have chance of a good adhesion between repair material and concrete substrate*

# ACKNOLEDGMENTS

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