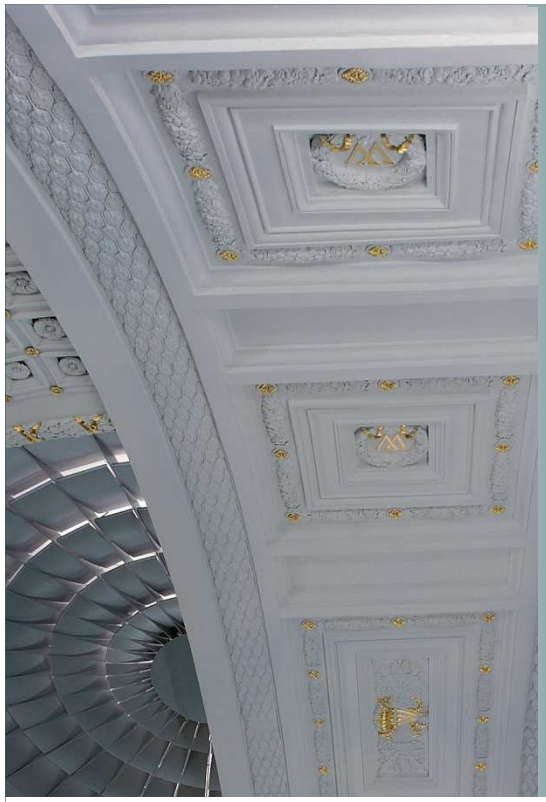
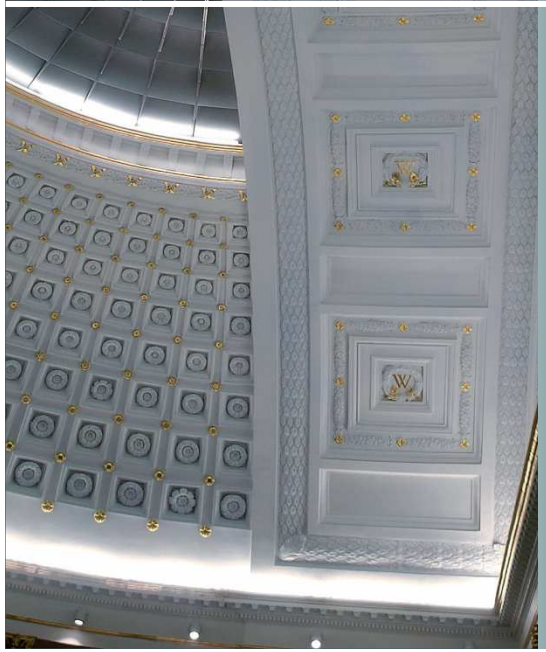




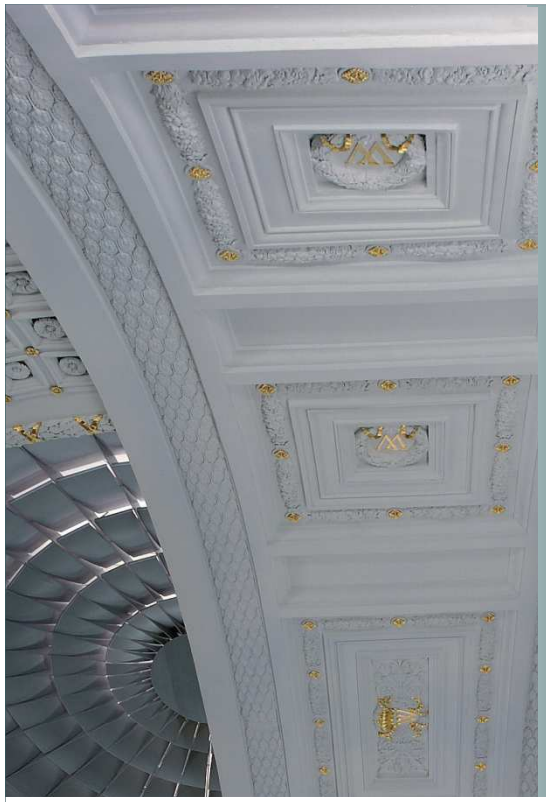
Concrete Repair Science:

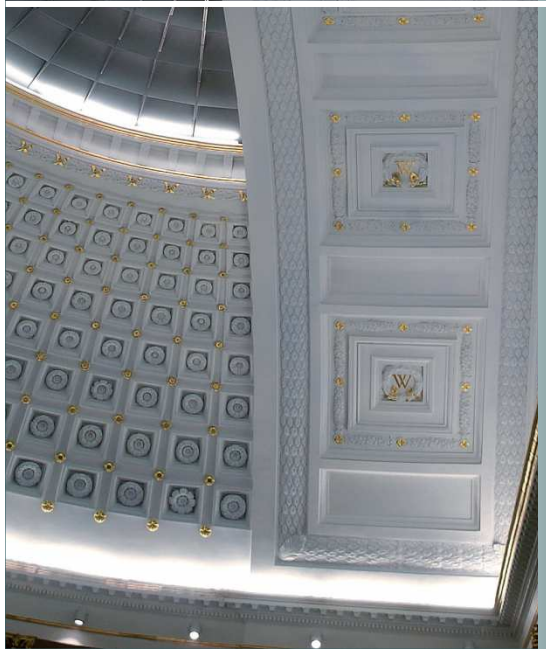
new trends

Cooperation between the University of Liege

and the Politechnika Warsawska

November 29th, 2010





Surfology: new investigations techniques and approaches

A. Garbacz, Politechnika Warszawska

L. Courard, Université de Liège

November 29th, 2010

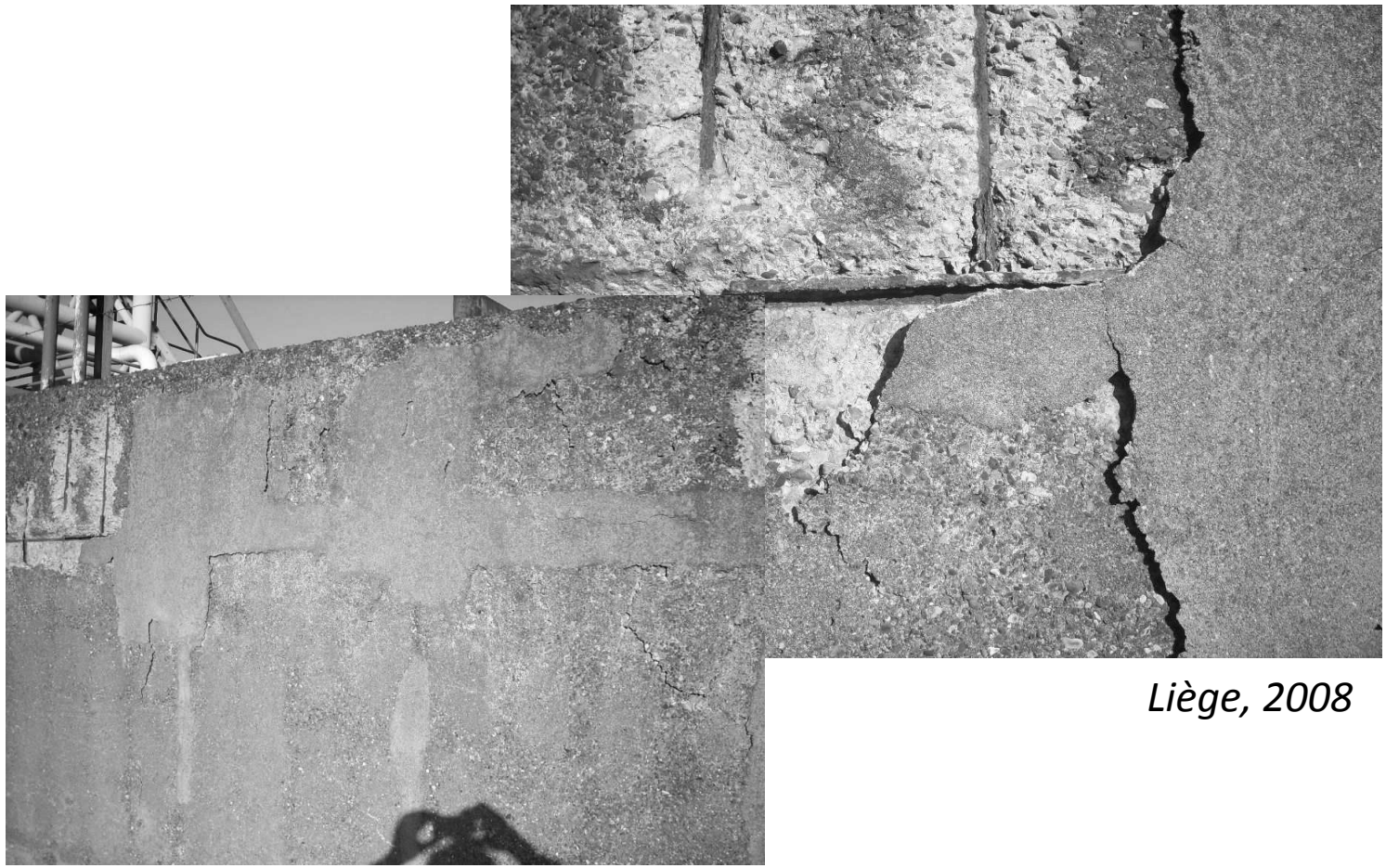
Surfology:
techniques and principles

1. Concrete Repair
   Needs for knowledge
2. Surfology
   Definitions
3. How to quantify surfology?
   Roughness, thermodynamic equilibriums, water
4. Why is surfology needed?
   Repair engineering, adhesion

Repairing concrete

Needs for knowledge

Surfology:
needs for knowledge

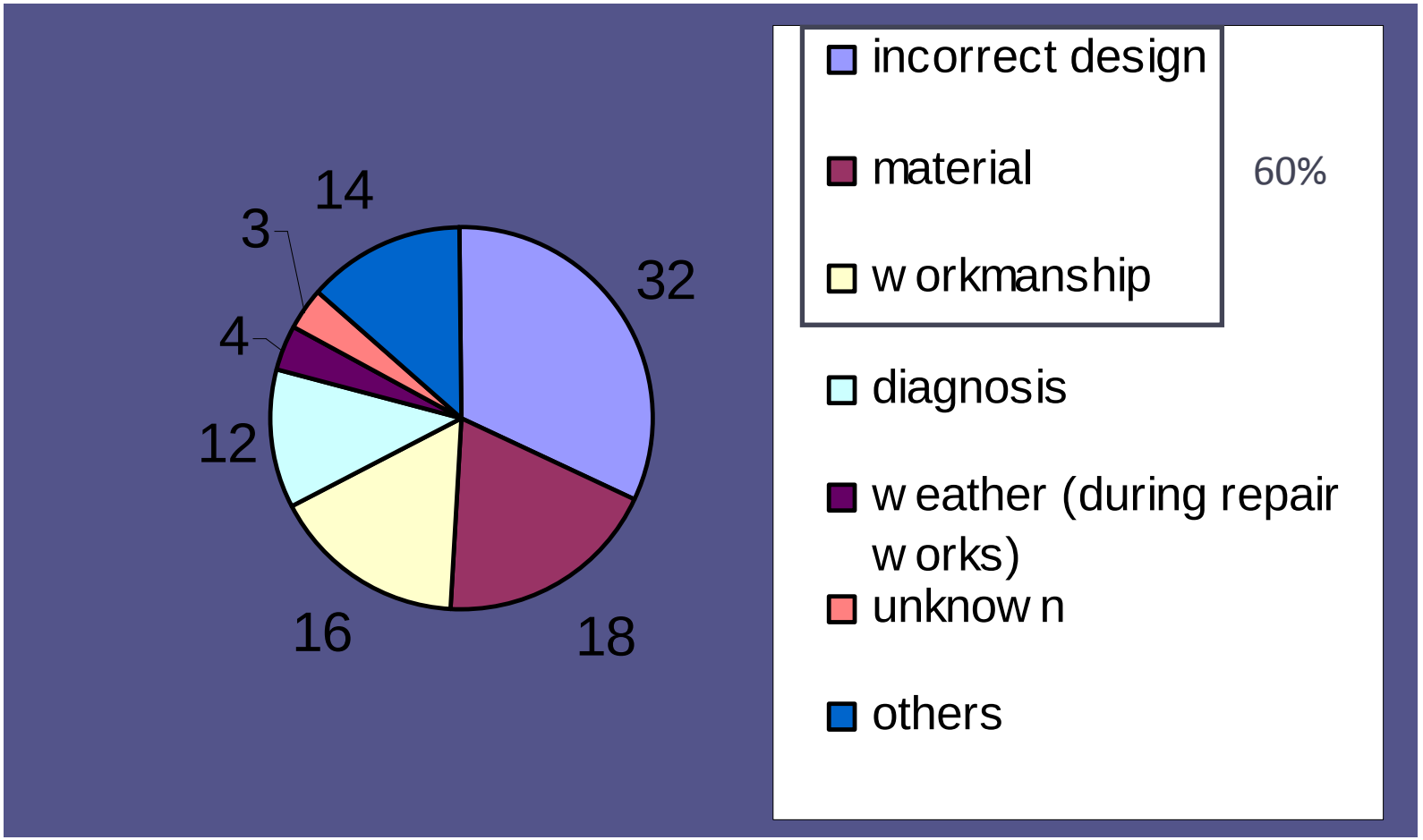


Liège, 2008

Surfology:
needs for knowledge

Nowy swiat, Warsaw, 2009

Surfology:
needs for knowledge



Causes of repair failure by corrosion, cracking, debonding (Tilly, 2004)

Surfology:
needs for knowledge

The reliability and durability of a repaired concrete substrate and its remaining service life depends on the behavior of the repair material, which is controlled by the **compatibility** between the two materials making up the repair system.

(Czarnecki, 2004)

… the heterogeneity of the components in a composite repaired structure requires an **understanding of the interaction** of the existing materials and the repair materials …

(Vaysburd et al., 2004)

Surfology

Definitions

Surfology: definitions

*scientific and technological approaches related to the design, the production and the application of surface layers to improve properties of the substrate, particularly resistance to corrosion and abrasion and aesthetic properties as well **

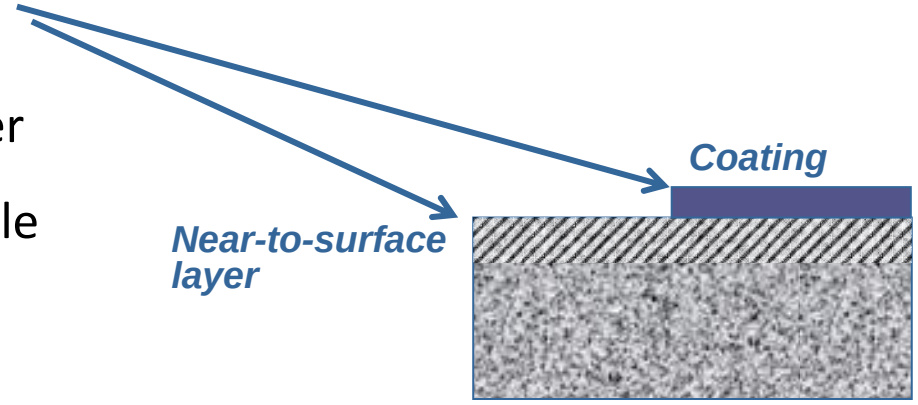
surface engineering covers:

all phenomena involved with a

modification of near-to-surface layer

and/or application of coating suitable

for a given application



(Burakowski T., Wierzchoń T. 1999. Surface engineering of metals. Principles. Equipment. Techn., CRC Press)

Surfology: definitions

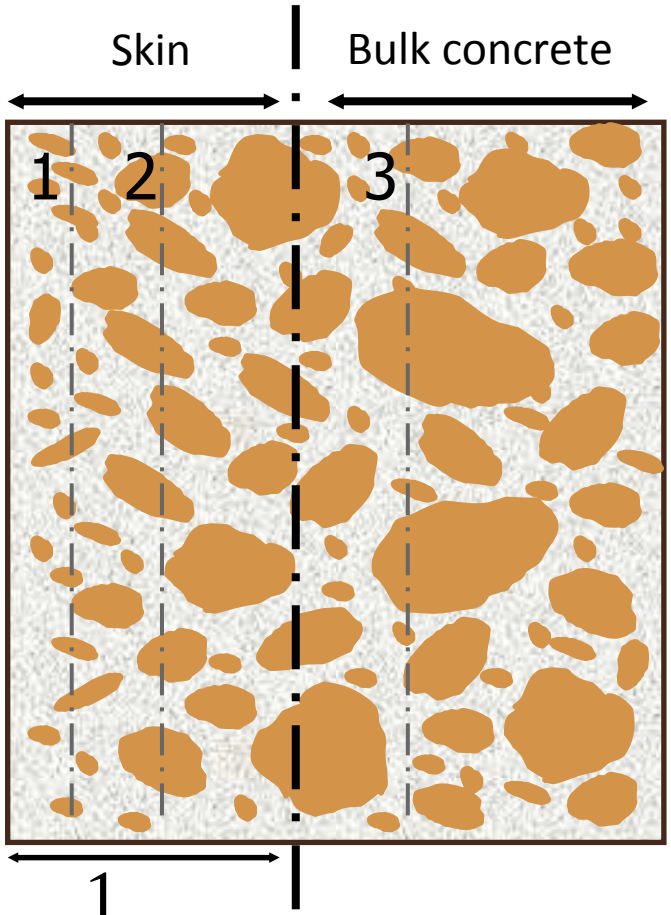
Surface engineering in the case of concrete structures:

- *to reach a desired durability of new structures,*
- *repair existing structures.*

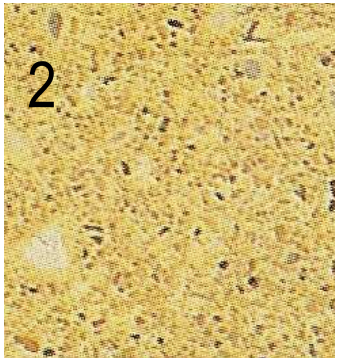
European Standards EN 1504

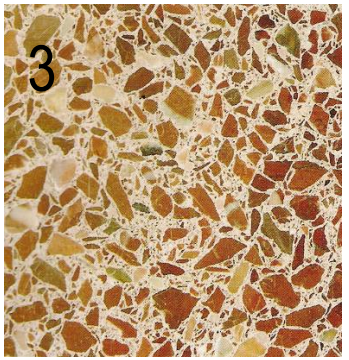
- *improvement of near-to-surface layer quality by hydrophobic treatment or impregnation,*
- *removal of deteriorated concrete and repair with fresh mortar,*
- *application of adhesive coating to improve barrier properties.*

Surfology: definitions



$$\approx \frac{1}{2} d$$ with d : maximum size of aggregates





Surfology: definitions

Creation and stability of the interface

SUBSTRATE
- surface energy
- roughness
- porosity
- capillary succion
- saturation level
- mechanical characteristics
- interstitial water

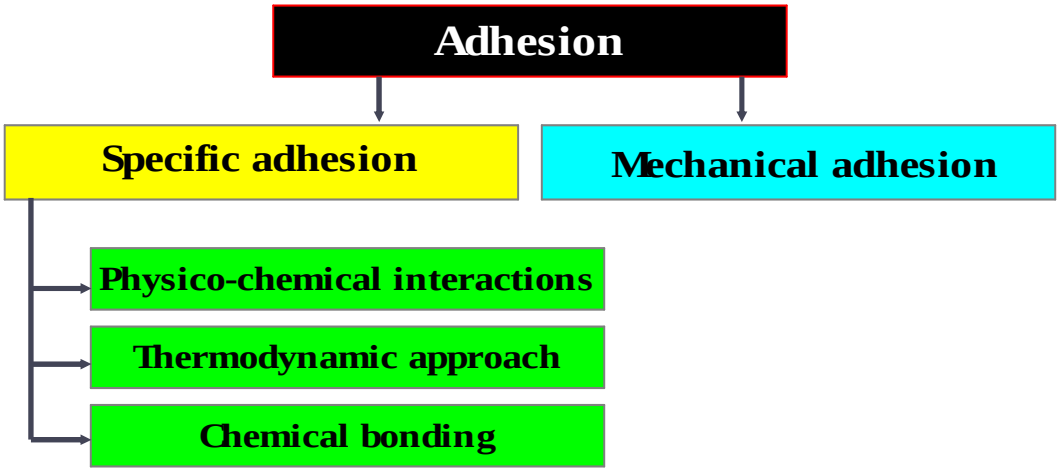
NEW LAYER
- surface energy
- binder setting
- kinetics of contact
- thermal dilatations
- shrinkage
- porosity, capillarity
- mechanical characteristics

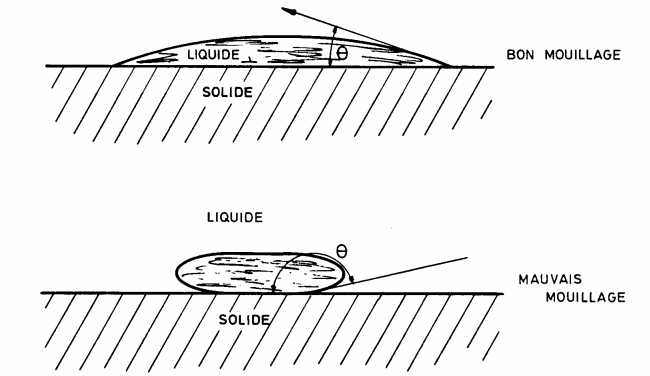
ENVIRONMENT

hydrothermal conditions of substrate and air curing conditions

HUMAN FACTORS

Surfology: definitions

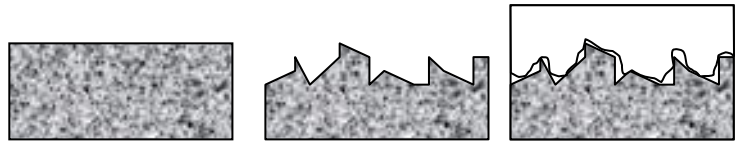




Condition 1 : spreading and wettability

Condition 2 : physico-chemical interactions

Condition 3 : mechanical interlocking



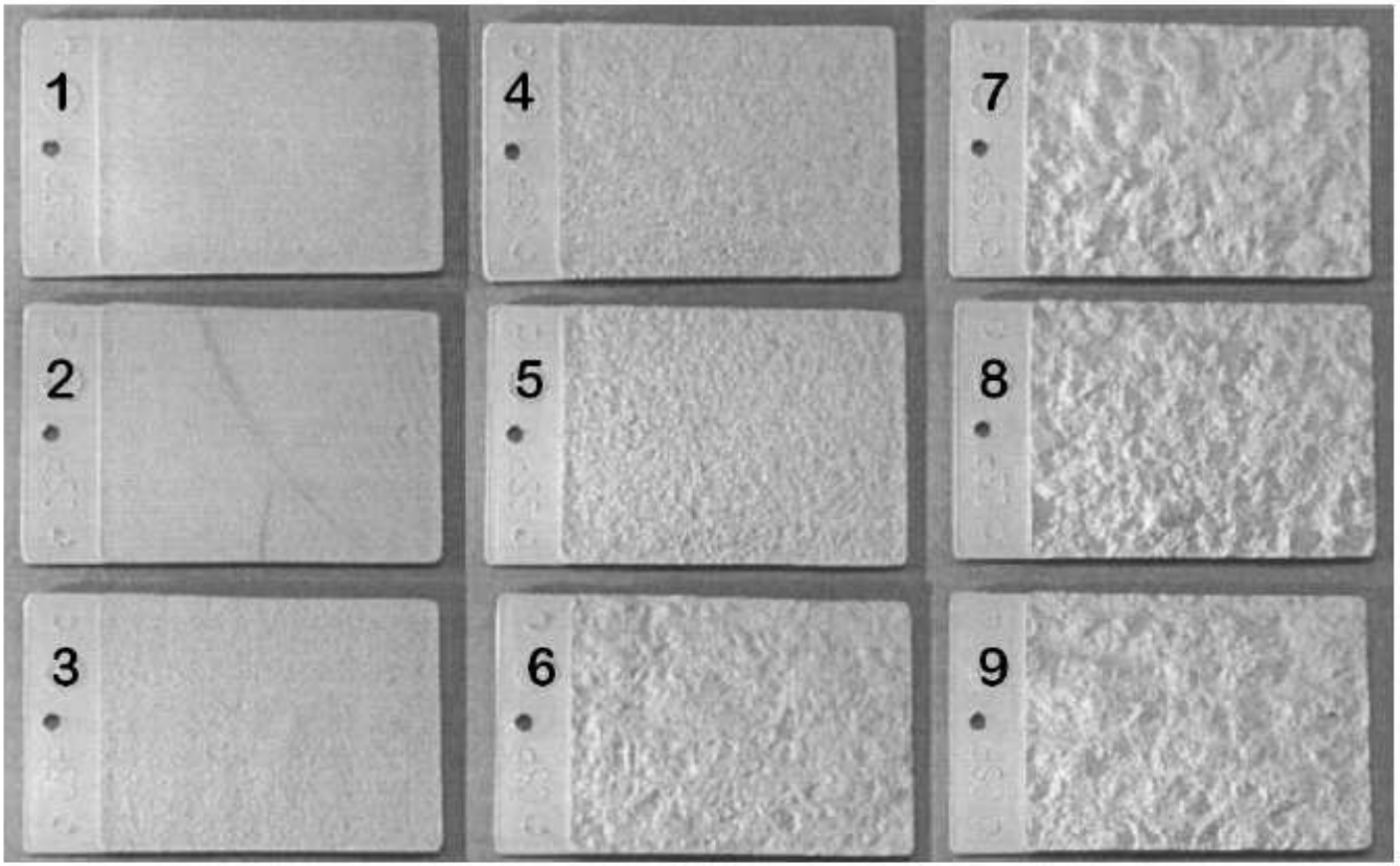
Geometric profile Real profile Effective profile

Surfology

How to quantify surfology?

Roughness evaluation

Surfology: roughness



Reference ICRI plates and comparison with roughness on site

Surfology: roughness

Surface Rough Index

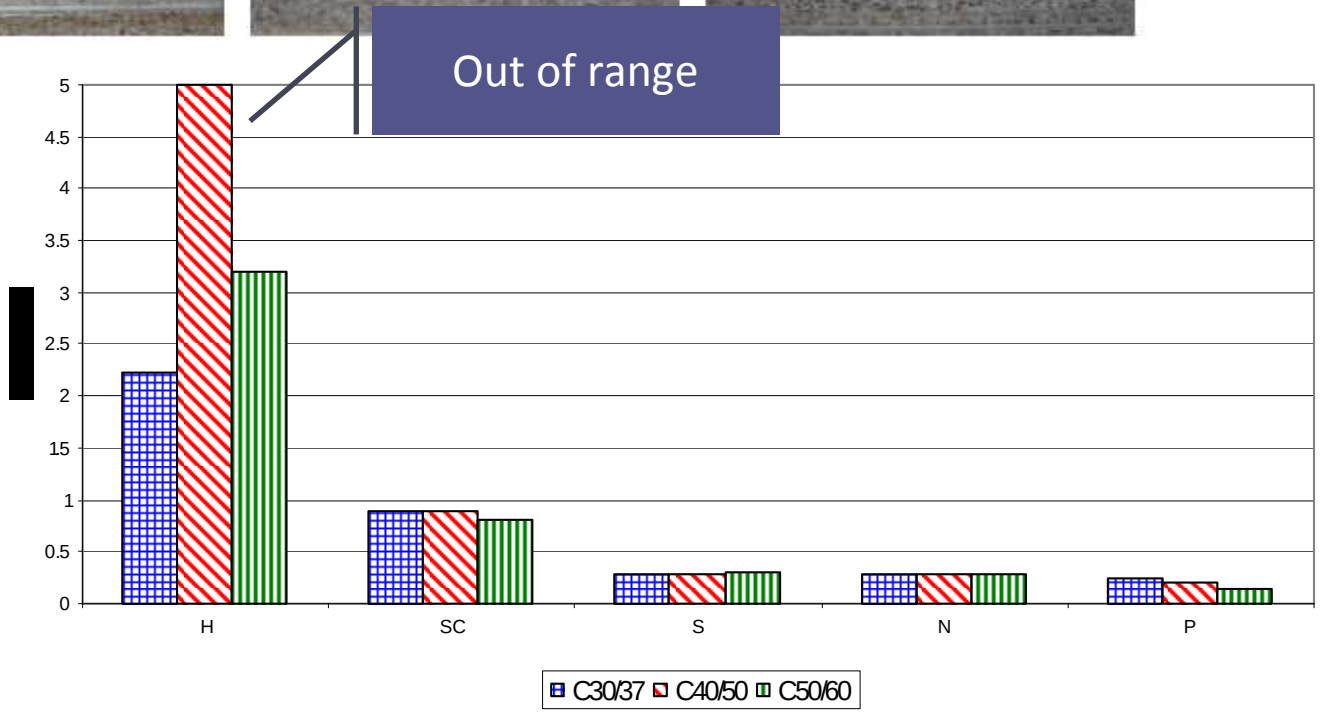
$SRI = 4V/\pi D^2$

H = water-jetting

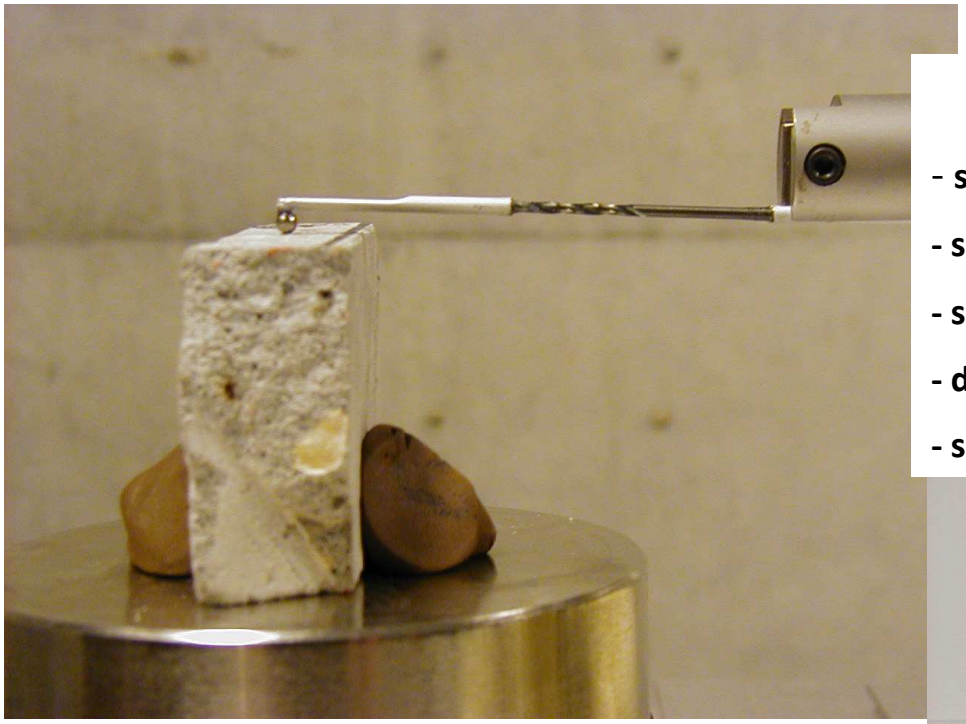
SC = scabbling

S = sandblasting

P = polishing



Surfology: roughness



Technical characteristics

- **system capacity: 1000 by 1000mm**
- **surface of measurement : 30 by 30mm**
- **shape of the stylus: spherical**
- **diameter of the stylus: 6µm and 1.5mm**
- **step of measurement: 300µm**

(Courard, Garbacz and Gorka 2004)

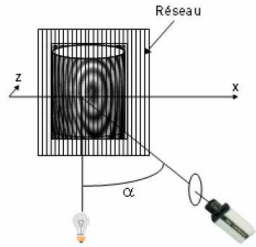
Surfology:
roughness and waviness

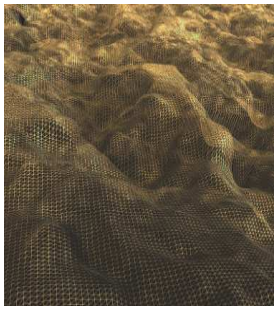
Equipments to measure surface texture

Mechanical profiling
Measuring area : 200x200 mm
Shape of the stylus: truncated cone
Diameter of the stylus: 1 mm
Path of measurement: 1 mm

Atos I 3D Digitizer
Fringe patterns
Measuring area:
120×100 - 1000×800 mm^2
Spatial resolution: 0,04-1 mm

Mathematical treatment

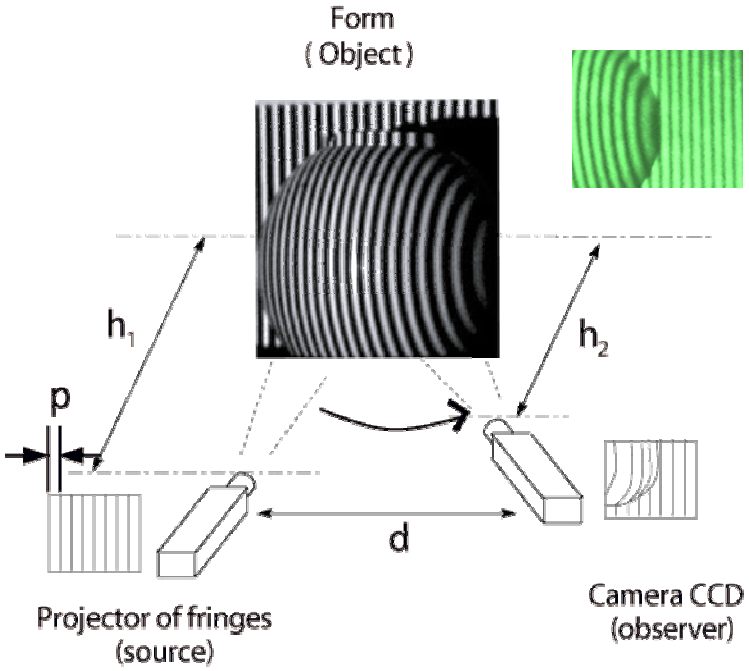


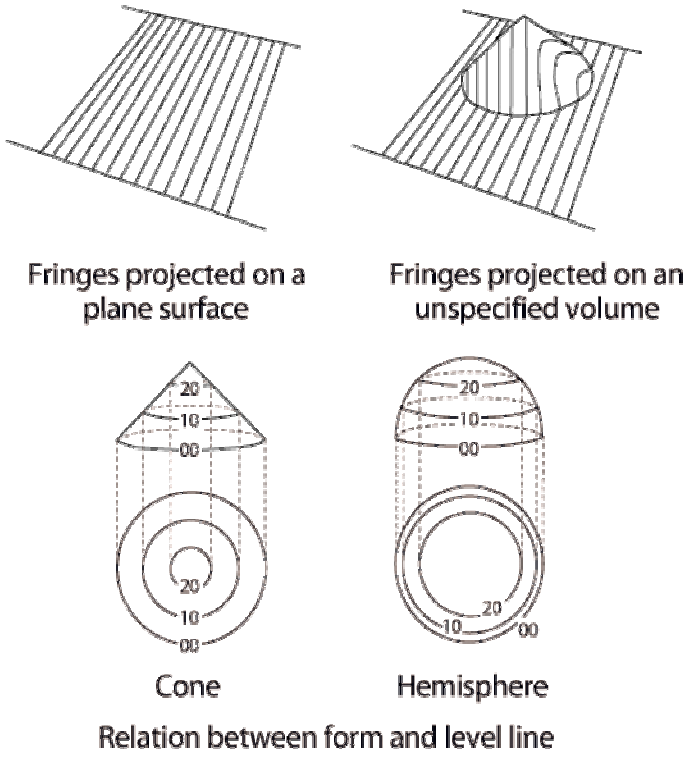


(Schwall, Courard, Belair, Perez, Bissonnette and Piotrowski 2007)

Surfology: roughness

Deformation of parallel and periodic fringes (level line)



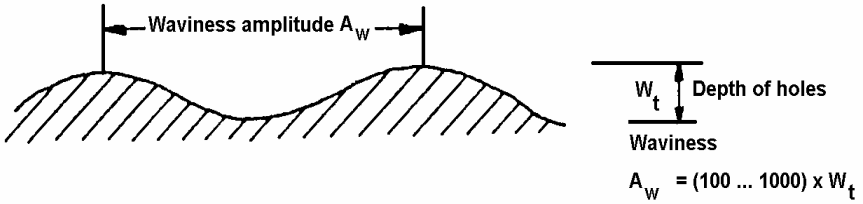


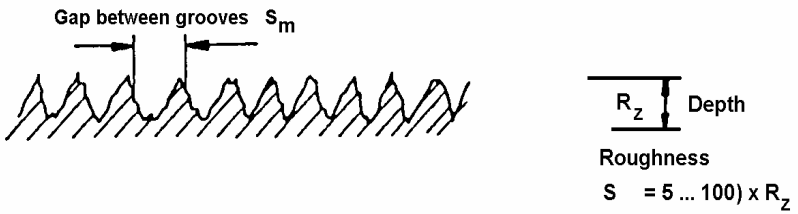
(Perez, Courard, Bissonnette, Garbacz and Gorka 2006)

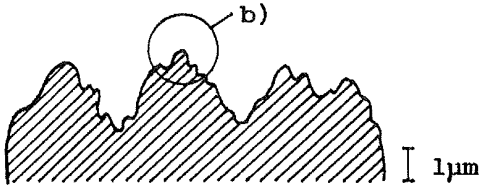
Surfology: roughness

Definition of description parameters

- Filtration process: standard
  - Meso-waviness
  - Waviness
  - Micro-roughness
  - Nano-roughness



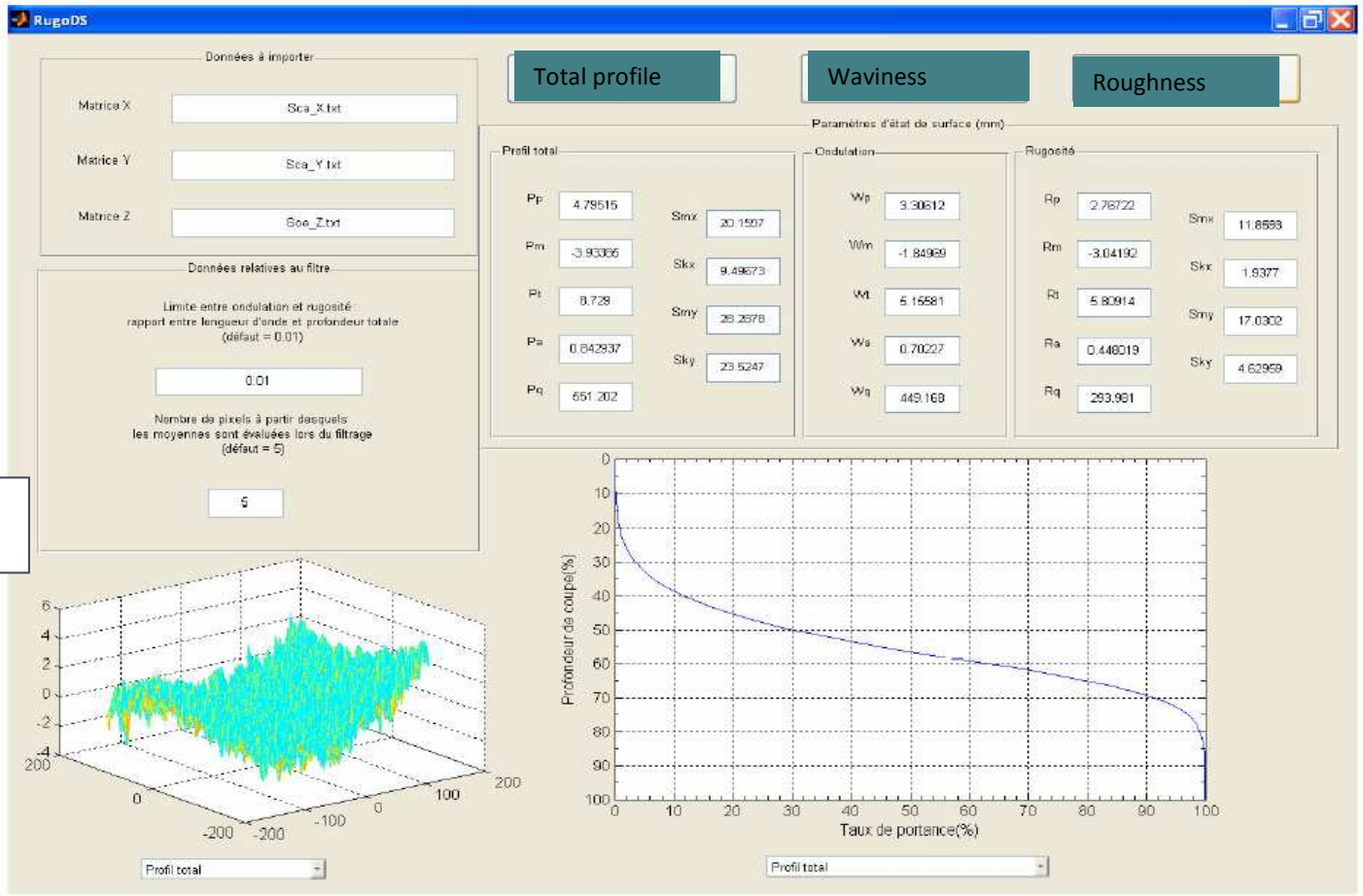




- Filtration process: 0.800 mm

Surfology: roughness

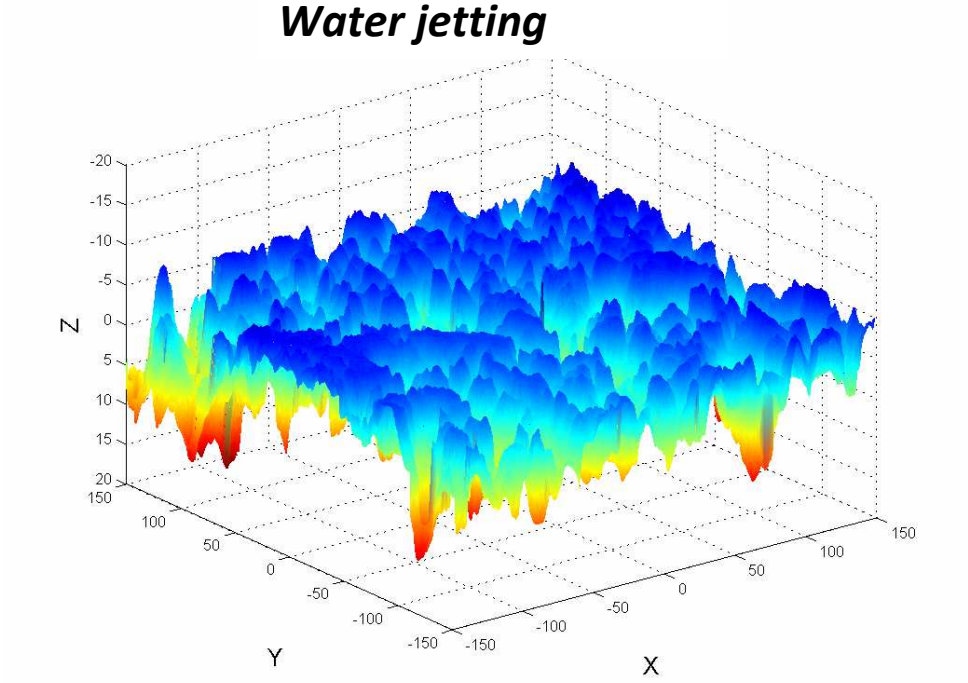
RugoDS



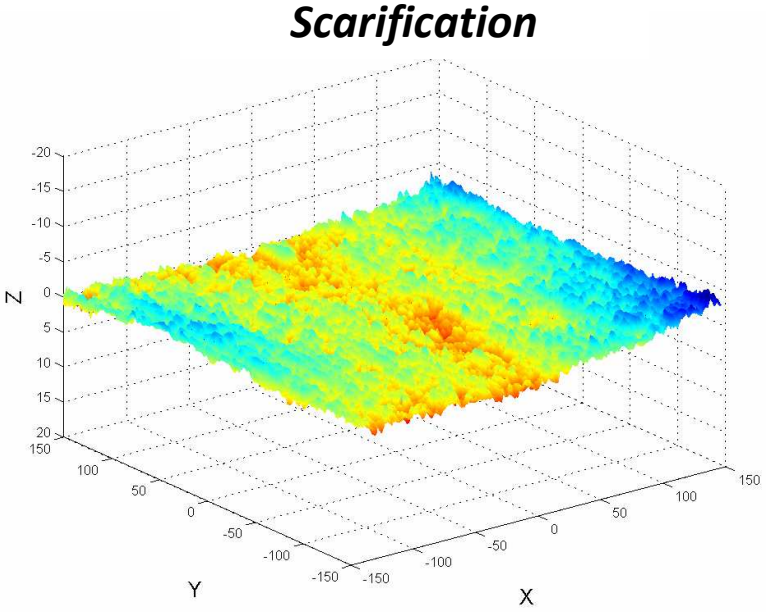
Automatic calculation of surface roughness parameters by signal treatment (D. Schwall)

Surfology: roughness

Water jetting



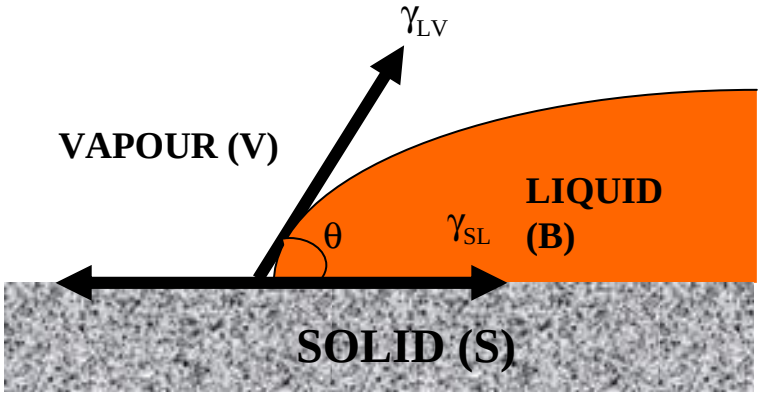
Scarification



Thermodynamic properties

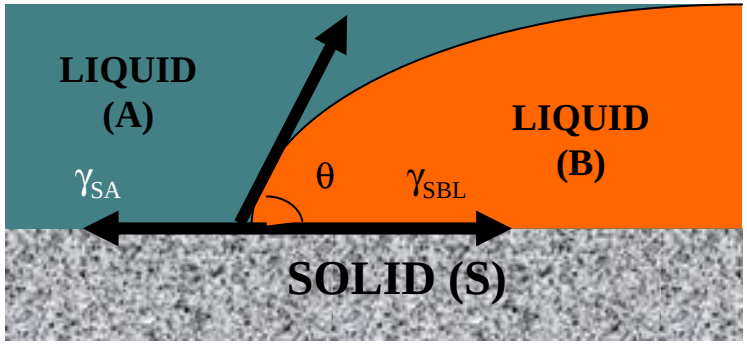
Surfology: thermodynamic properties

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



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

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



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

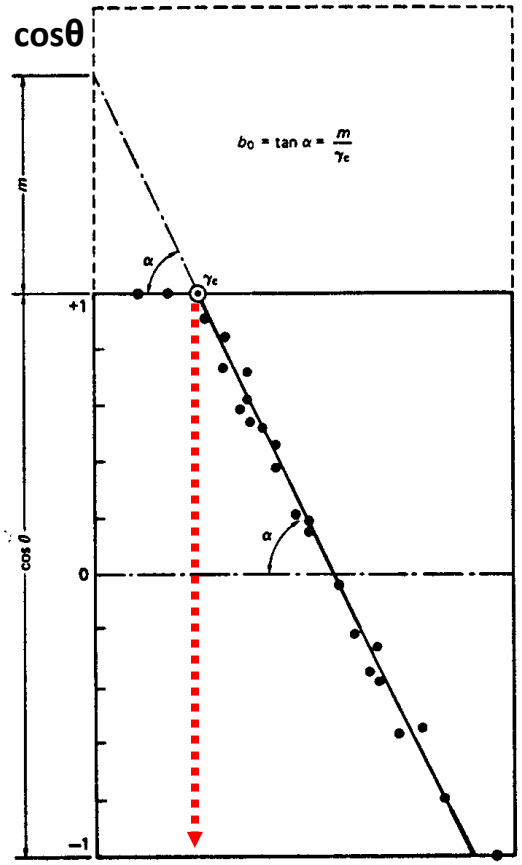
$$\gamma_B \cdot \cos\theta_B - \gamma_A \cdot \cos\theta_A > \gamma_{AB}$$

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

Surfology: thermodynamic properties

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 γ_L

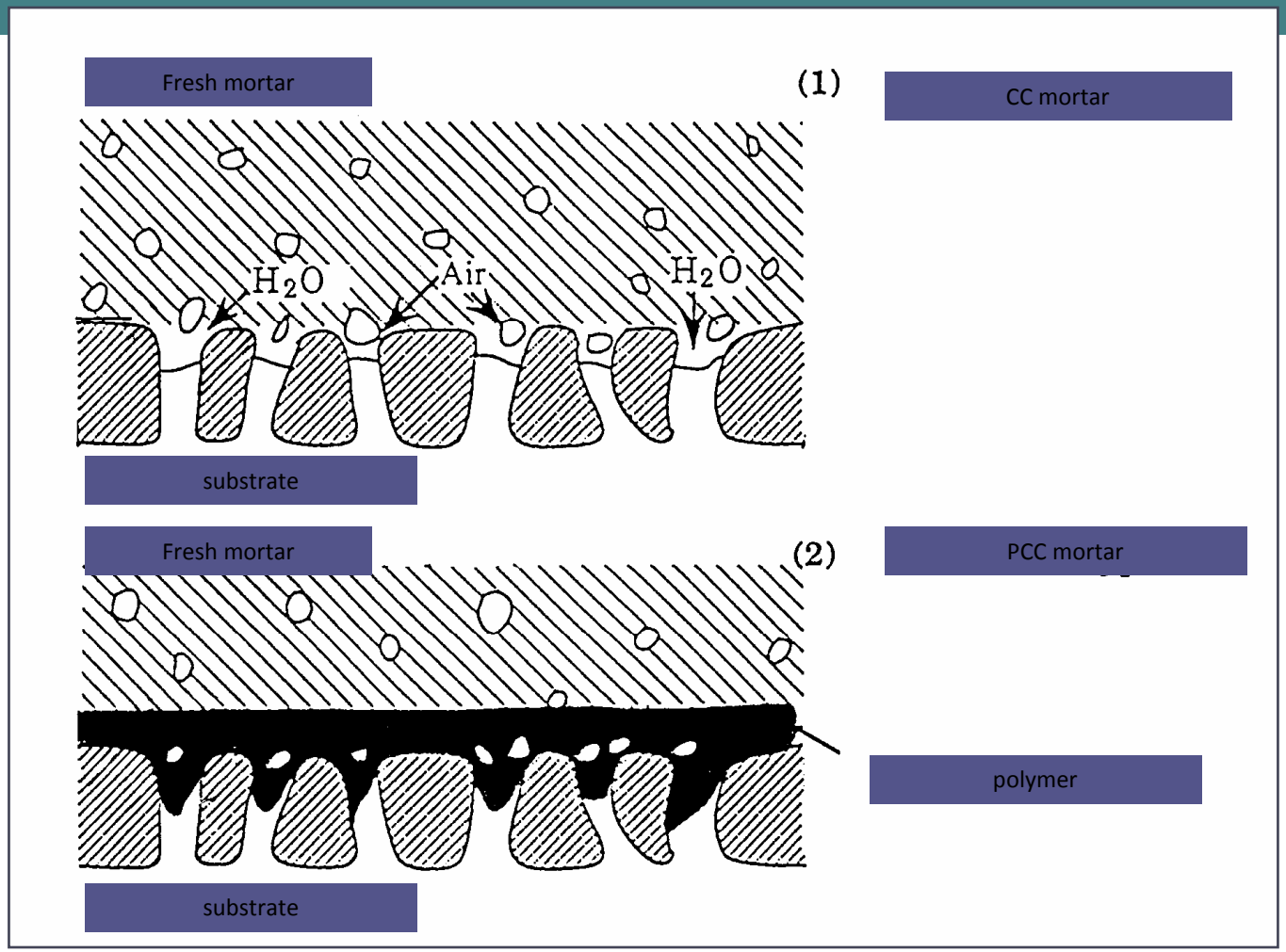
Surfology

Why to define surfology?

Surfology: adhesion

conditions and kinetics of contact

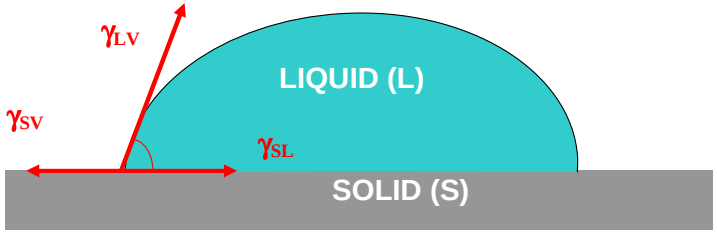
- **spreading on the surface, shear stress, viscosity**
- **penetration into the capillaries of the superficial concrete**
- **environmental conditions (temperature, relative humidity)**

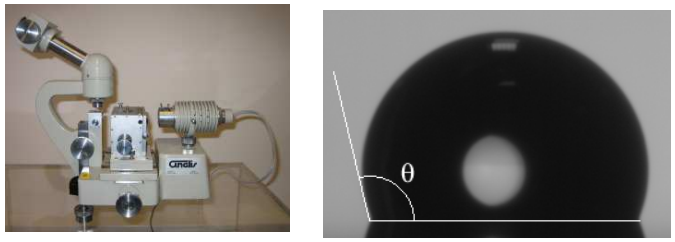


(Ohama, 1989 - Ohama and Pareek,1993)

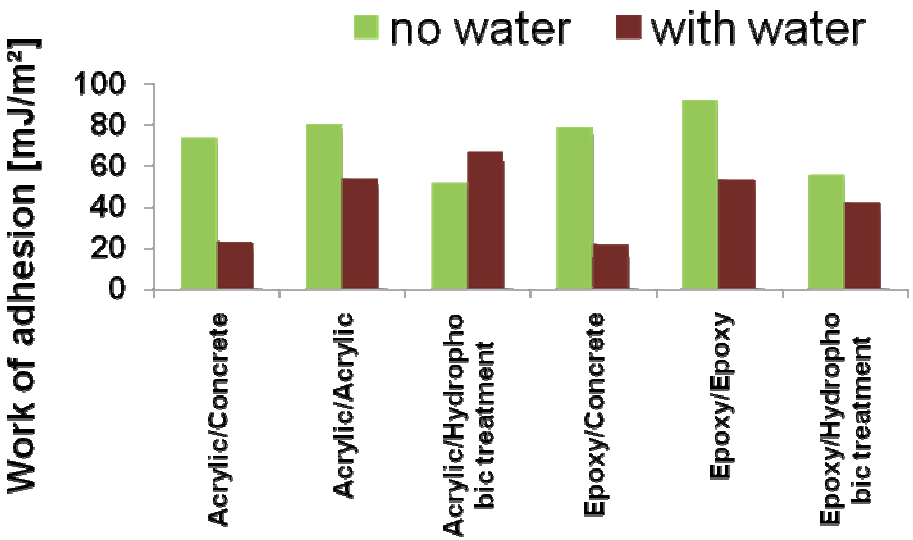
Effect of water

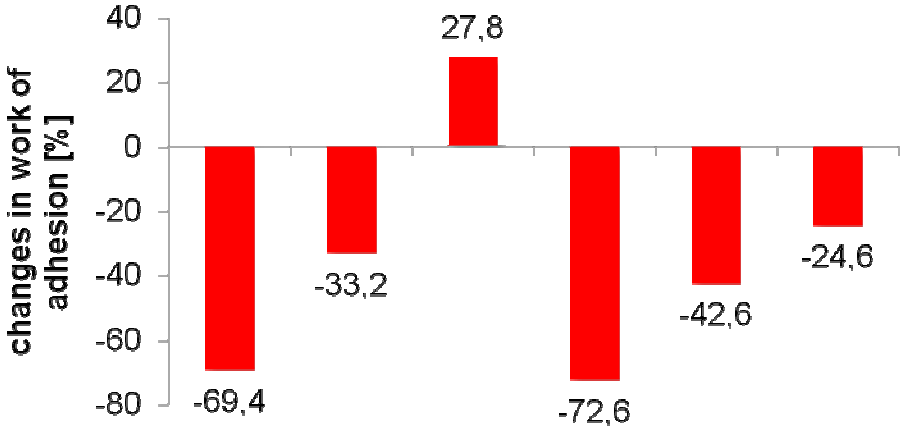
Surfology: effect of water



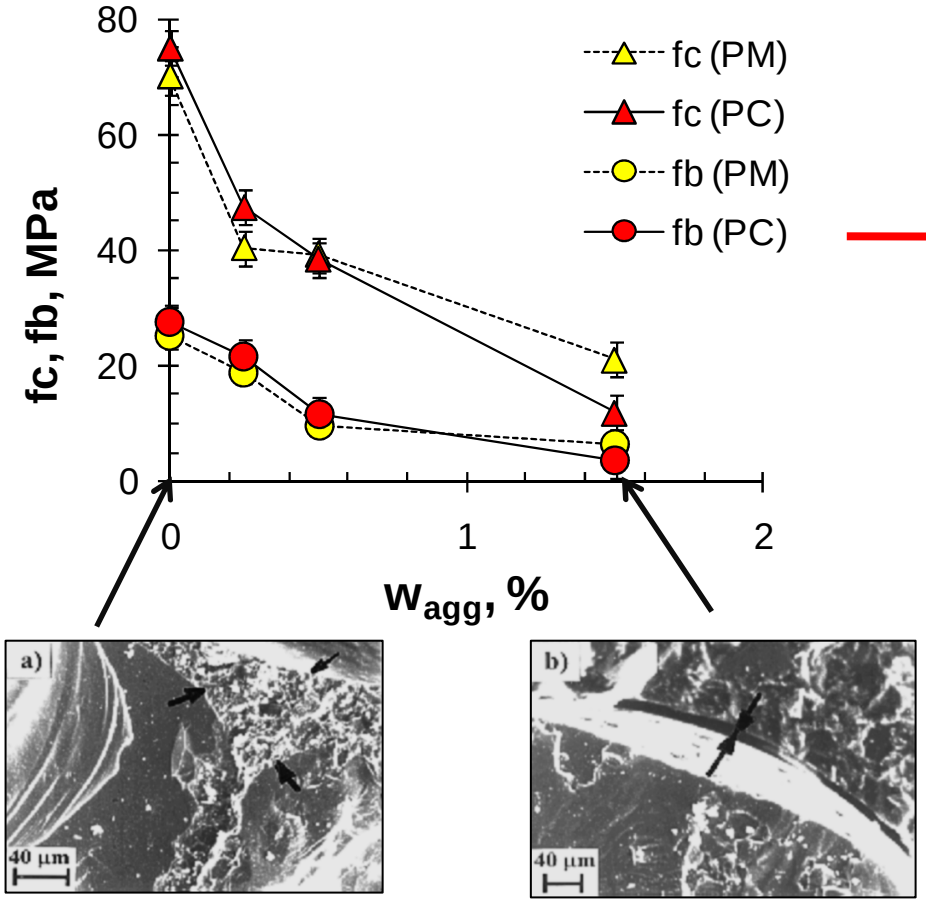


$$W_{a\ SL} = \gamma_{LV}(1+\cos\theta)$$





Surfology: effect of water



w_{agg} [%]	$(f_c^w - f_c^{dry})/f_c^{dry}$ [%]	$(f_b^w - f_b^{dry})/f_b^{dry}$ [%]
Polymer concrete		
0.25	-36.8	-22.5
0.50	-48.6	-58.7
1.50	-84.2	-87.5
Polymer mortar		
0.25	-42.2	-24.4
0.50	-43.8	-61.2
1.50	-69.9	-74.5

$(W_{AL} - W_A) / W_A$ [%] for epoxy/concrete -72.6 %

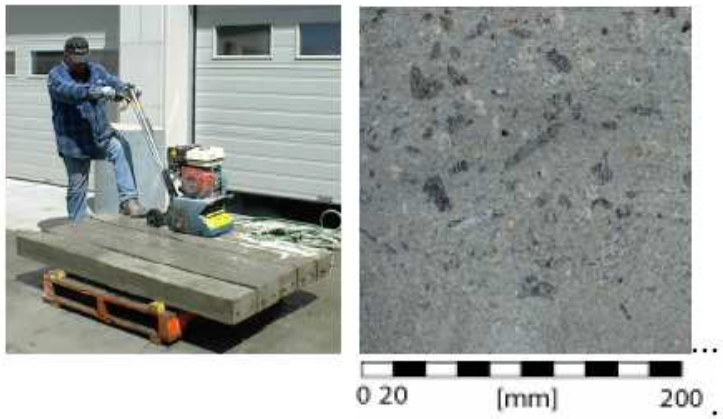
Surfology: effect of water

Adhesion (N/mm²)		
Saturation level	with dry slurry	with wet slurry
50	0.83	2.32
52	2.80	2.14
55	2.09	2.89
70	2.75	2.65
90	3.54	3.36
93	2.13	3.06
97	1.81	2.58
100	1.43	1.48

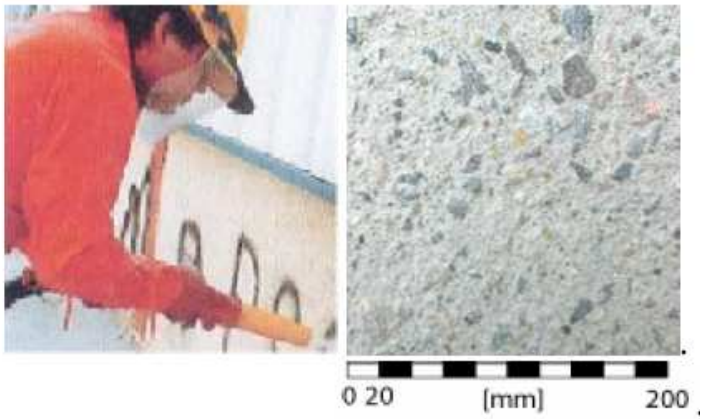
(Courard, Lenaers, Michel and Garbacz 2011)

Surface preparation techniques

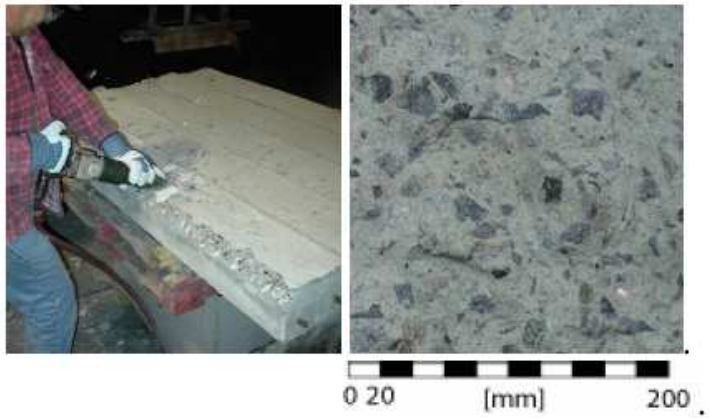
Surfology:
surface preparation techniques



a) Scarification(SCA)



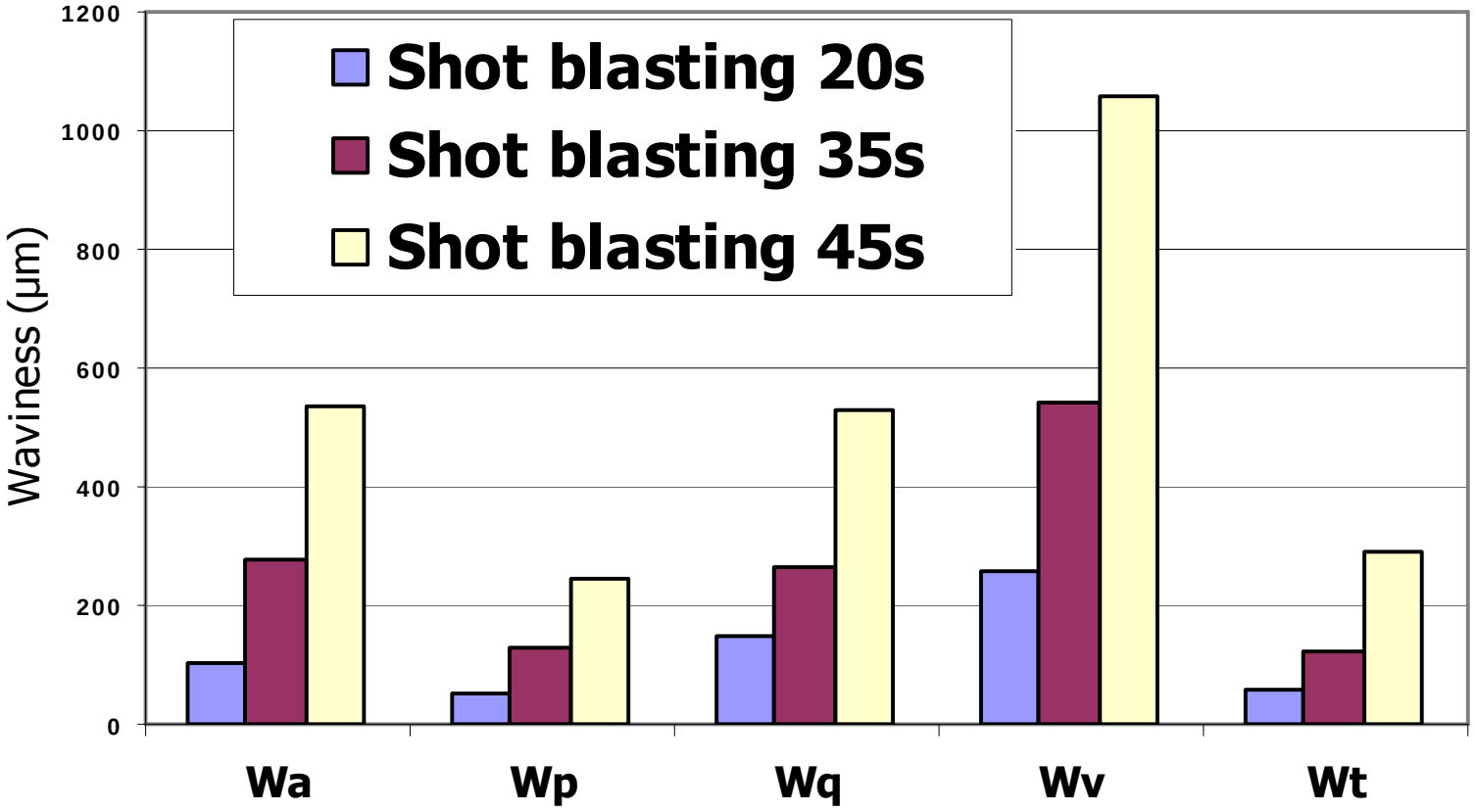
b) Sandblasting (SAB)



c) Pneumatic jackhammer(PJ7S)

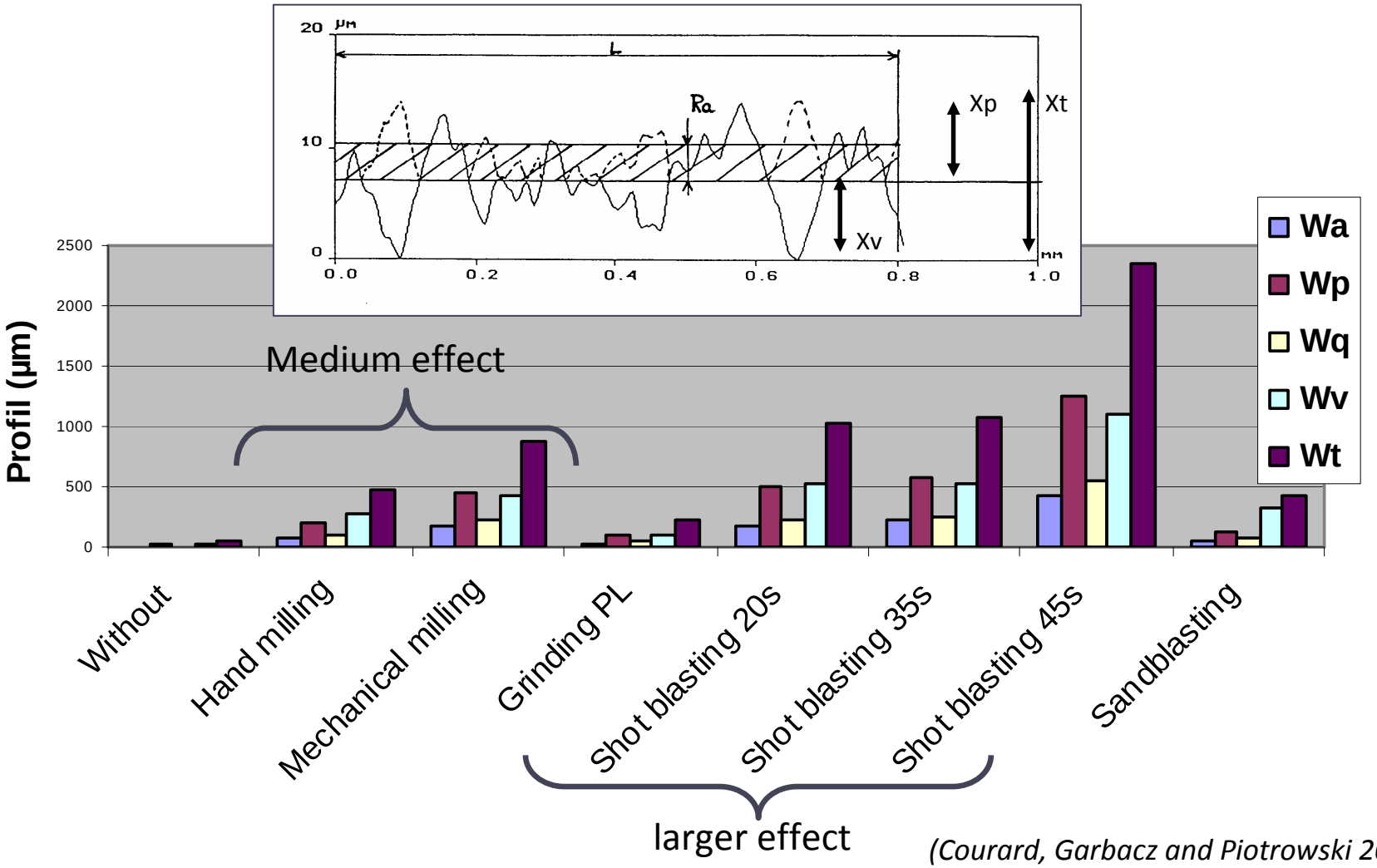
d) Water jetting (WJ)

Surfology:
surface preparation techniques



(Courard, Garbacz and Piotrowski 2008)

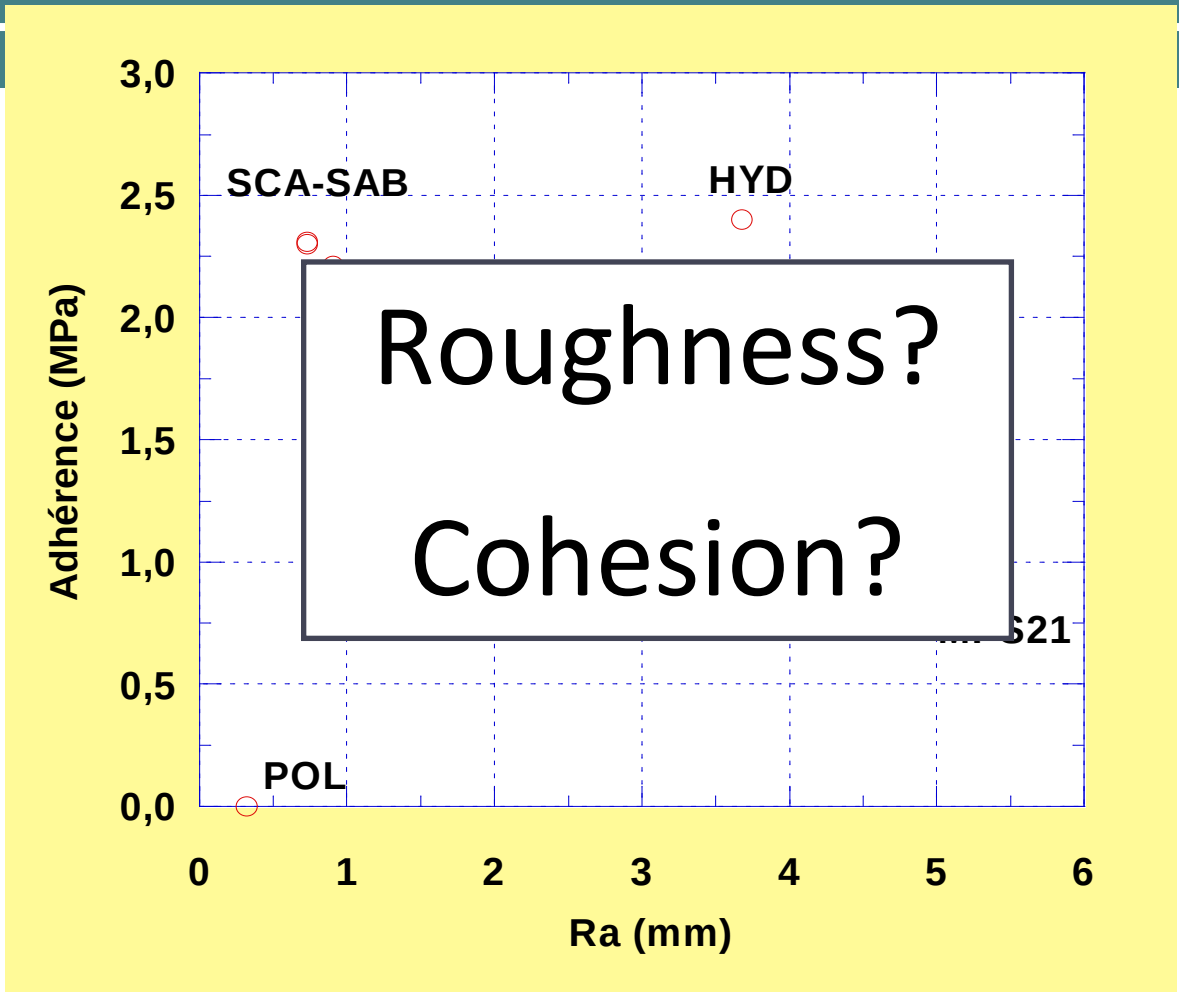
Surfology:
surface preparation techniques



(Courard, Garbacz and Piotrowski 2008)

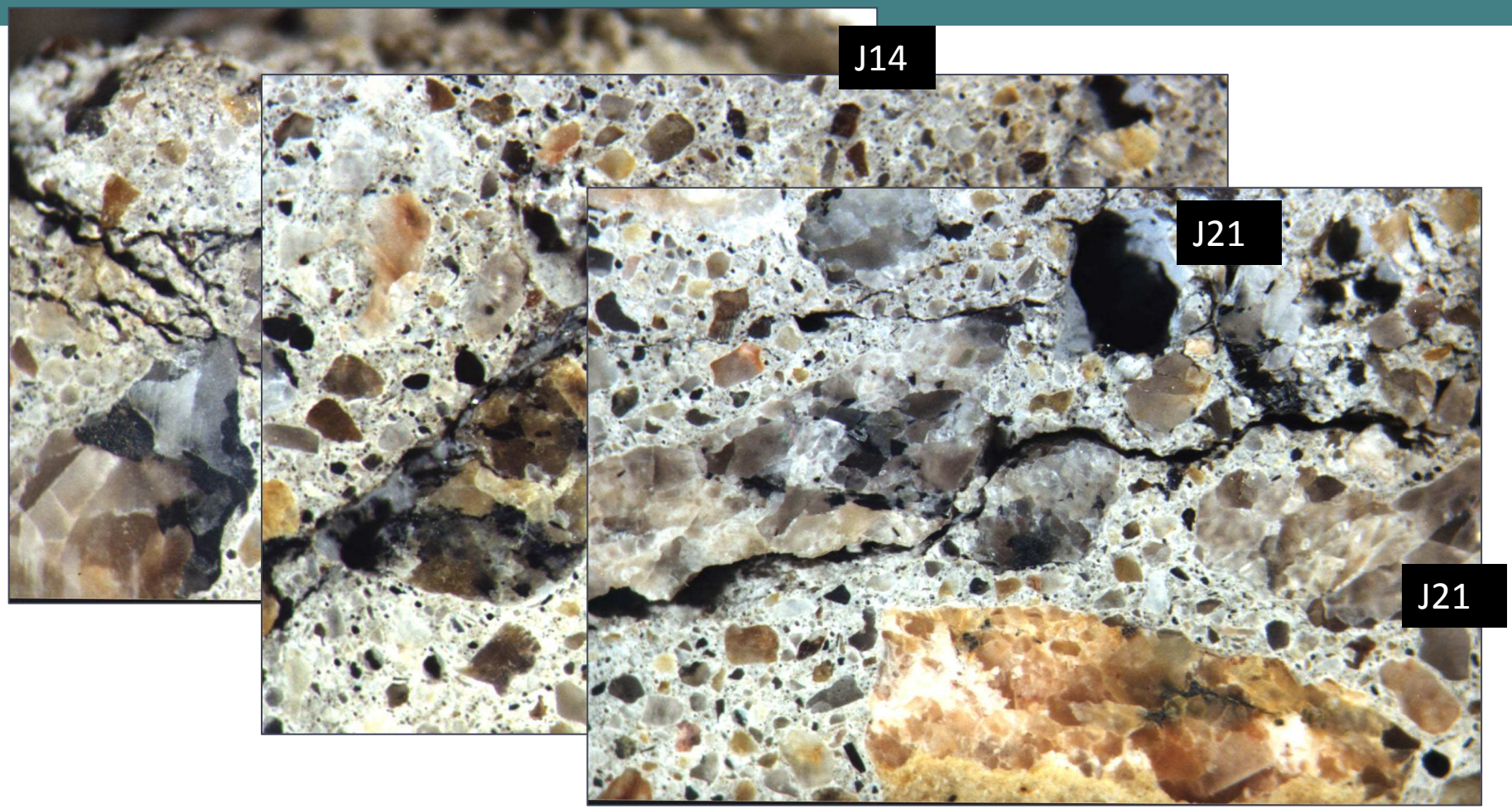
Roughness and adhesion

Surfology:
roughness and adhesion



(Vaysburd, Courard, Bissonnette and Bélair 2006)

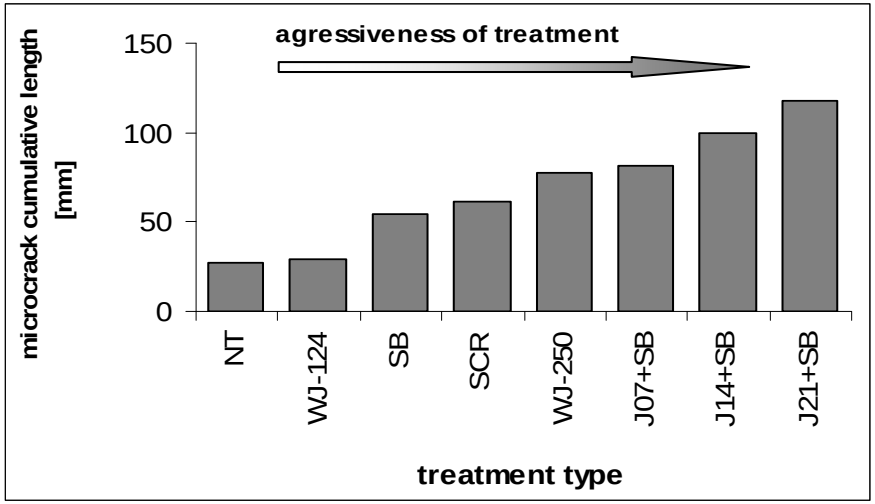
Surfology:
roughness and adhesion



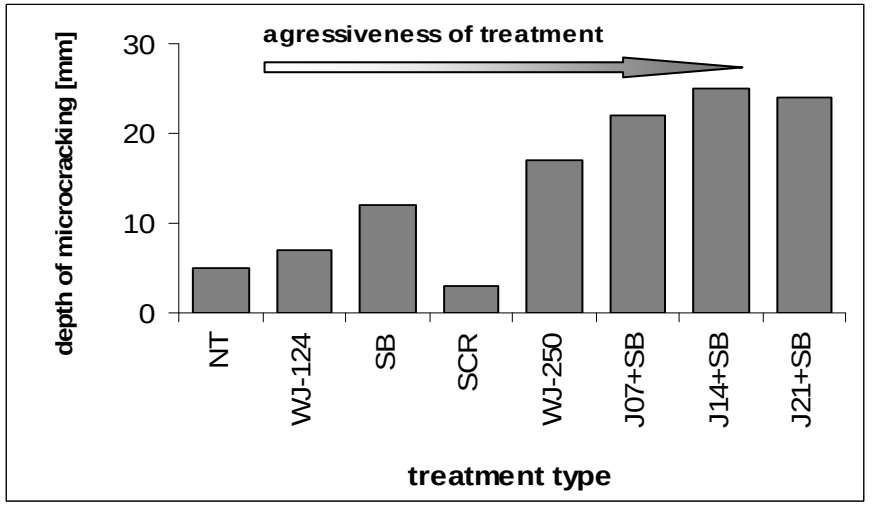
(Vaysburd, Courard, Bissonnette and Bélair 2006)

Surfology: roughness and adhesion

length (Li) of the cracks



depth of microcracking



NT – no treatment; **WJ** – water jetting – pressure 124 psi/250MPa; **SB** – sandblasting; **SCR** – scabbling; **J+SB** – jack hammering of weight 7,14,21 kg + sandblasting

Application of polymer primer or polymer modified cement bonding agents usually improves the interface quality due to strengthening of concrete substrate by gluing microcraks and lost concrete particles (Garbacz, Kostana and Courard 2006)

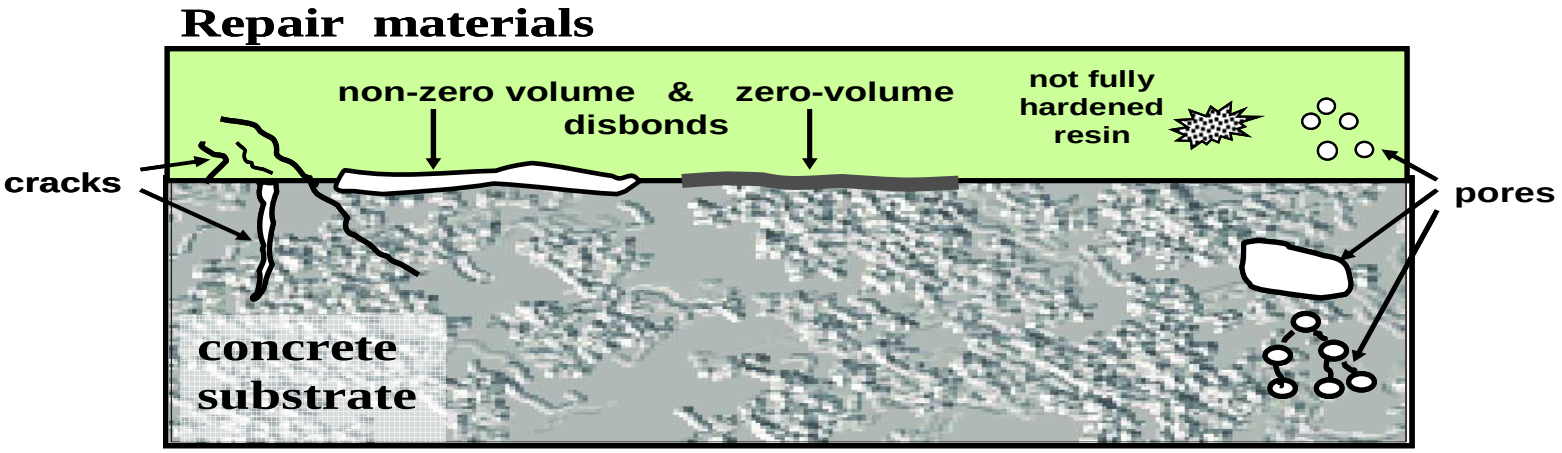
Surfology: roughness and adhesion

Treatment type	Mean value [MPa] (coefficient of variation in %)	
	Repair mortar with bond coat	Repair mortar without bond coat
NT	1.92 (23.4)	2.28 (17.1)
GR	1.82 (15.9)	1.16 (50.9)
SB	1.93 (11.4)	1.82 (32.4)
SHB20	1.68 (18.5)	0.78 (39.7)
SHB35	1.94 (11.3)	1.25 (28.8)
SHB45	1.96 (32.7)	0.83 (25.3)
HMIL	1.42 (12.7)	1.01 (40.6)
MMIL	1.60 (24.4)	0.49 (57.1)

(Garbacz, Courard and Kostana 2006)

Research and investigations

Surfology:
repair system as an object of NDT testing



Selection of NDT method

- Defect size & depth
- Repair material thickness
- Repair material type (R coeff.)
- **Substrate quality?**

Surfology: influence on bond strength

***b* – relative influence on f_h prediction**

$\beta(SRI) = 0.67$	$\beta(f_{hs}) = 0.63$	$\beta(L_A) = 0.12$	$\beta(f_{ck}) = -0.08$

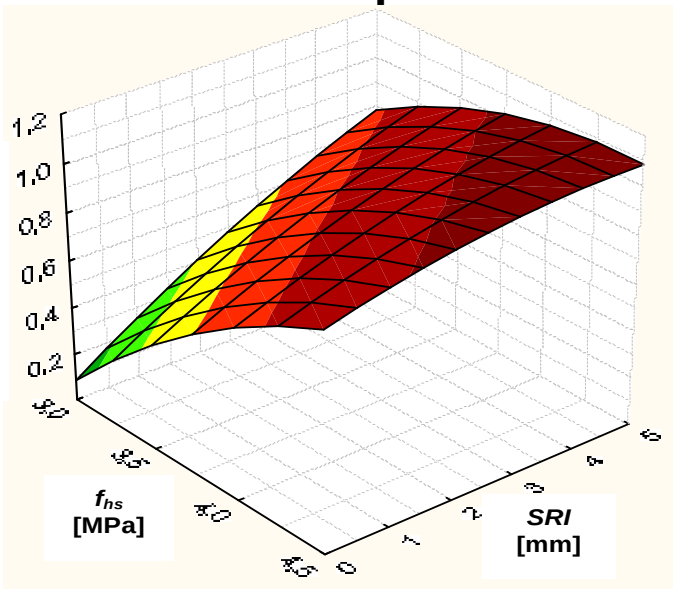
***U*(f_h) – usability function**

***U*(f_h)=1.0 for $f_h \geq 2.5$ MPa**

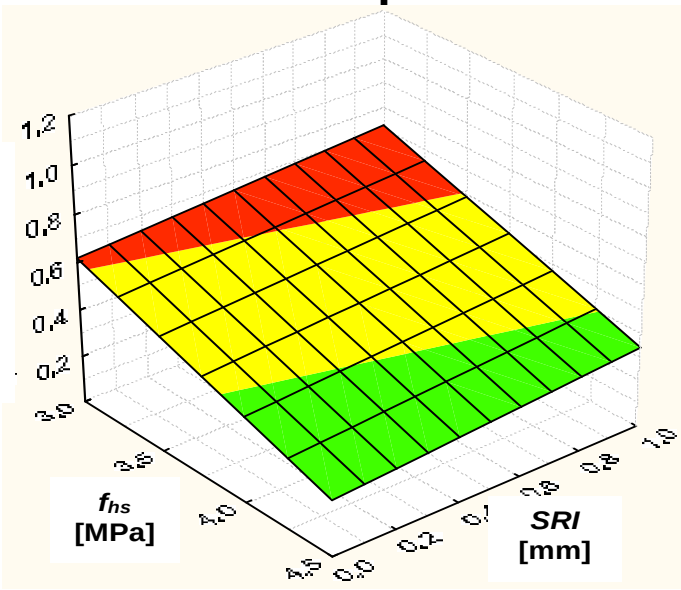
***U*(f_h)=0.5 for $f_h = 1.5$ MPa**

***U*(f_h)=0.0 for $f_h \leq 0.5$ MPa**

Group A

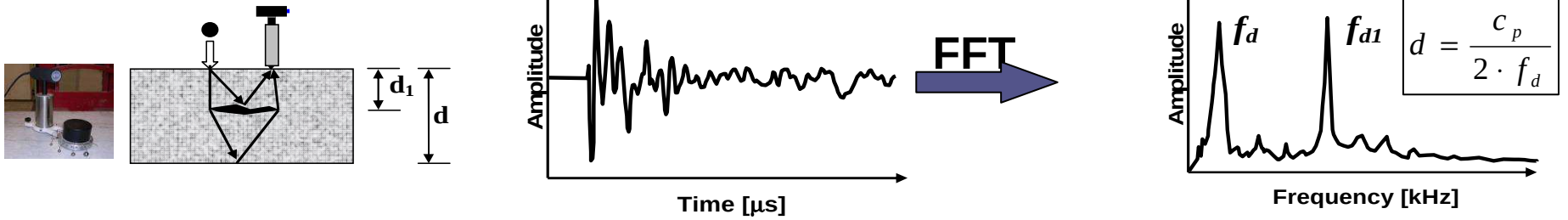


Group B



T.Piotrowski et al., 2010

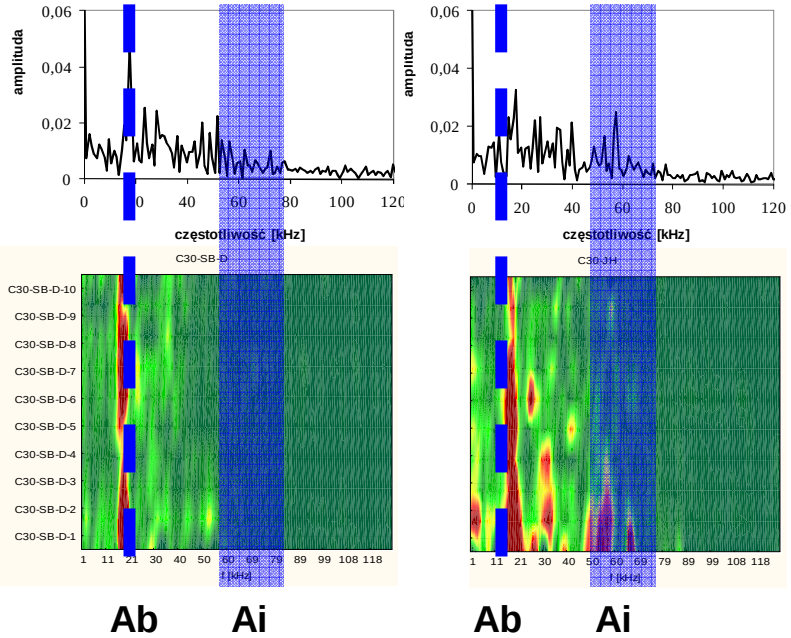
Surfology:
NDT testing with Impact-echo method



Group A

C30-SB-D
f_h = 2.04 MPa

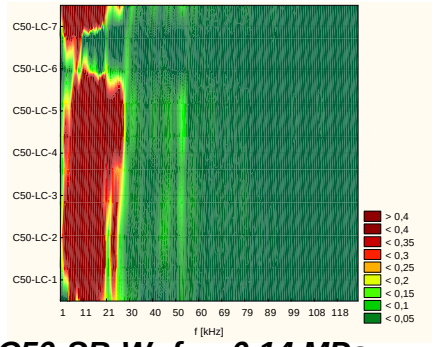
C30-JH
f_h = 1.02 MPa



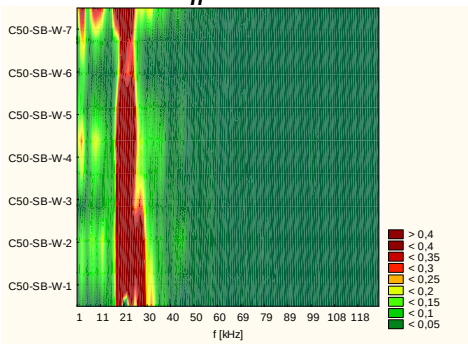
R = 0.29

Group B

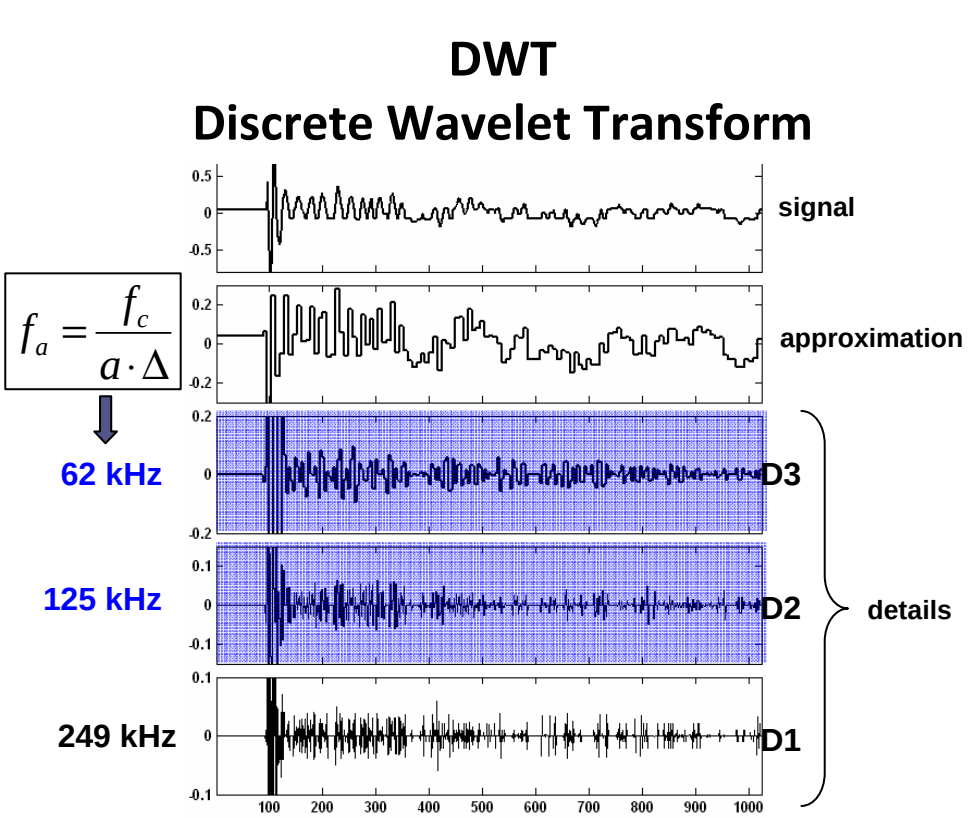
C50-LC: f_h = 0.00 MPa



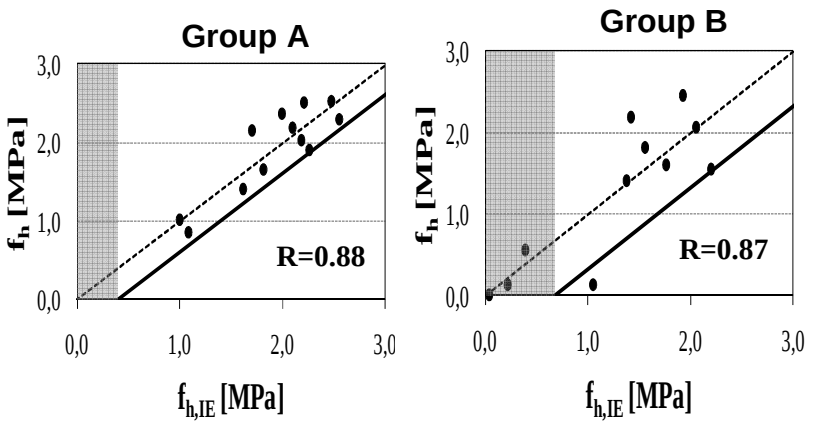
C50-SB-W: f_h = 0.14 MPa

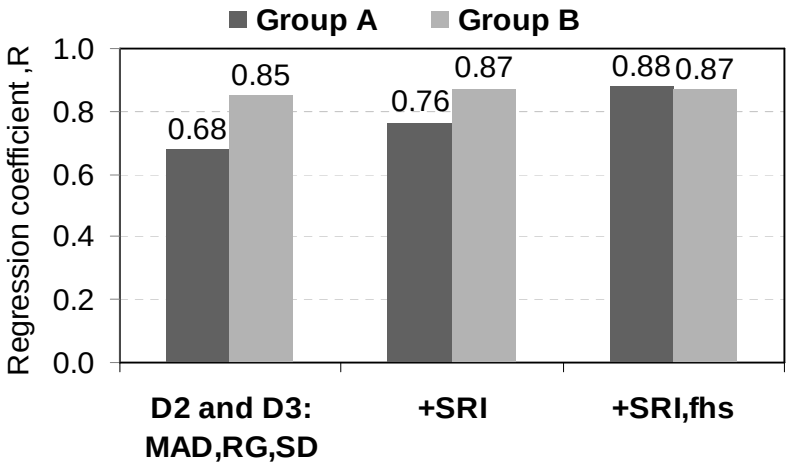


Surfology: wavelet approach

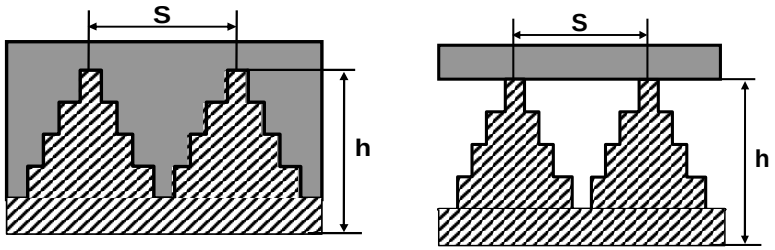


T.Piotrowski et al., 2010



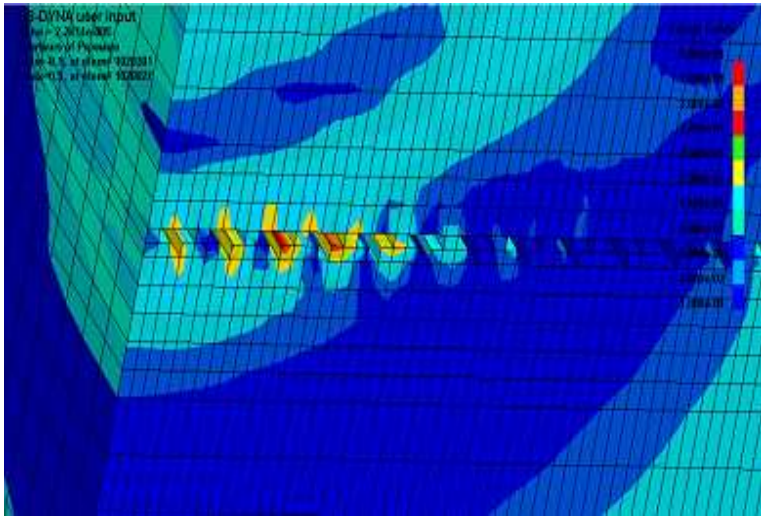


Surfology:
FEM model of repair system (LS-Dyna)

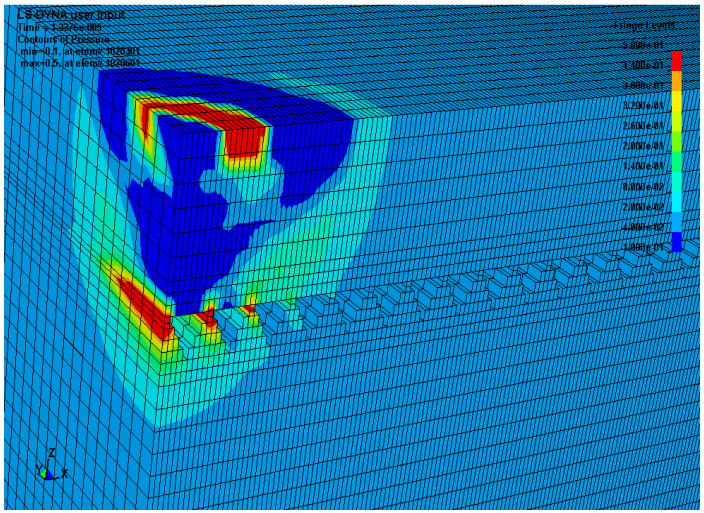


	S [mm]	h [mm]
SB	4	2
HD	8	8

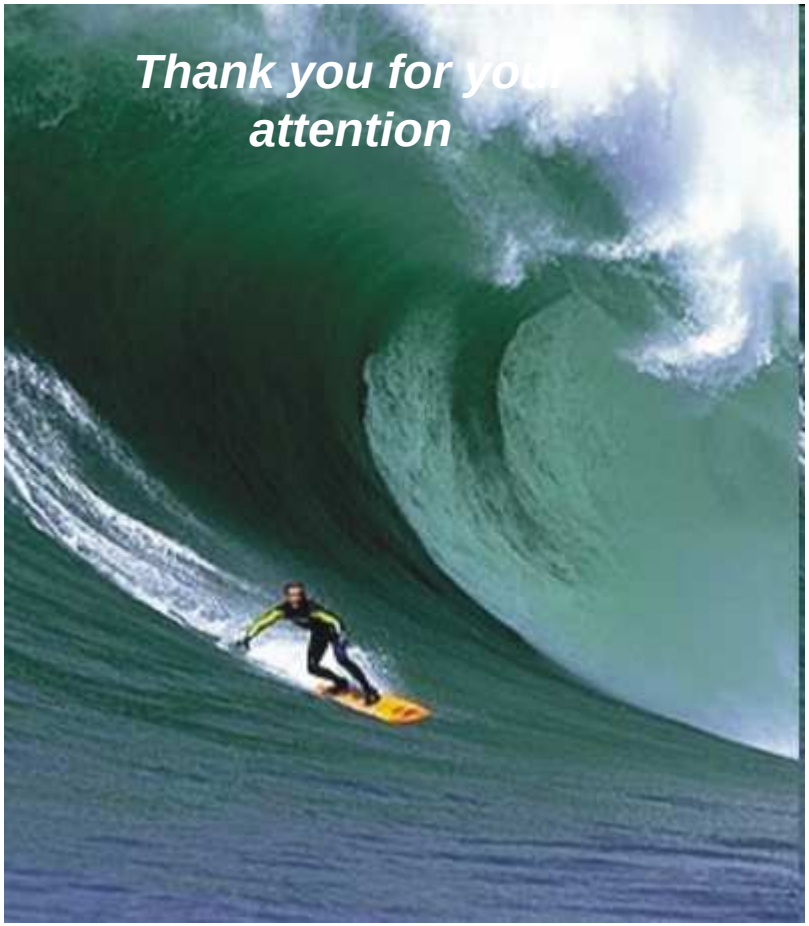
SB



HD



Conclusions



http://floconsdebonheur.wordpress.com/2008/08/21/le-king

Surfology, as a scientific concept including all surface properties of materials and their influence on adhesion, contributes to understand what will make the contact effective or not, and allow interactions of variable intensities between the materials at different scales of observation.

Acknowledgements